

National Aeronautics and Space Administration



2015

spinoff

# SPINOFF

## 2015

### Technology Transfer Program

NASA Headquarters

Daniel Lockney, *Technology Transfer Program Executive*

Spinoff Program Office

Goddard Space Flight Center

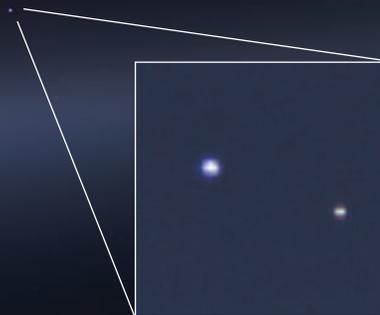
Daniel Coleman, *Editor-in-chief*

Samson Reiny, *Senior Science Writer*

Mike DiCicco, *Science Writer*

John Jones, *Senior Graphics Designer*

Lisa Rademakers, *Contributing Writer*



**On the cover:** This depiction of the Earth-moon system against a backdrop of the Milky Way uses an image of North and South America assembled from data acquired by the Suomi NPP satellite in April and October of 2012. The resulting composite was mapped over existing imagery of Earth to simulate a realistic view of the planet on its dark side, when artificial lights from cities are easily visible from space.

**Title page background:** This unique photograph, taken by NASA's Cassini probe, provides not only a stunning look at Saturn but also a rare peek at the Earth-moon system from very far away. Earth is clearly visible as a bright dot near the center of the page and just below Saturn's rings. When the original image was magnified five times, the two bodies could easily be seen (inset).

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## Industrial Productivity



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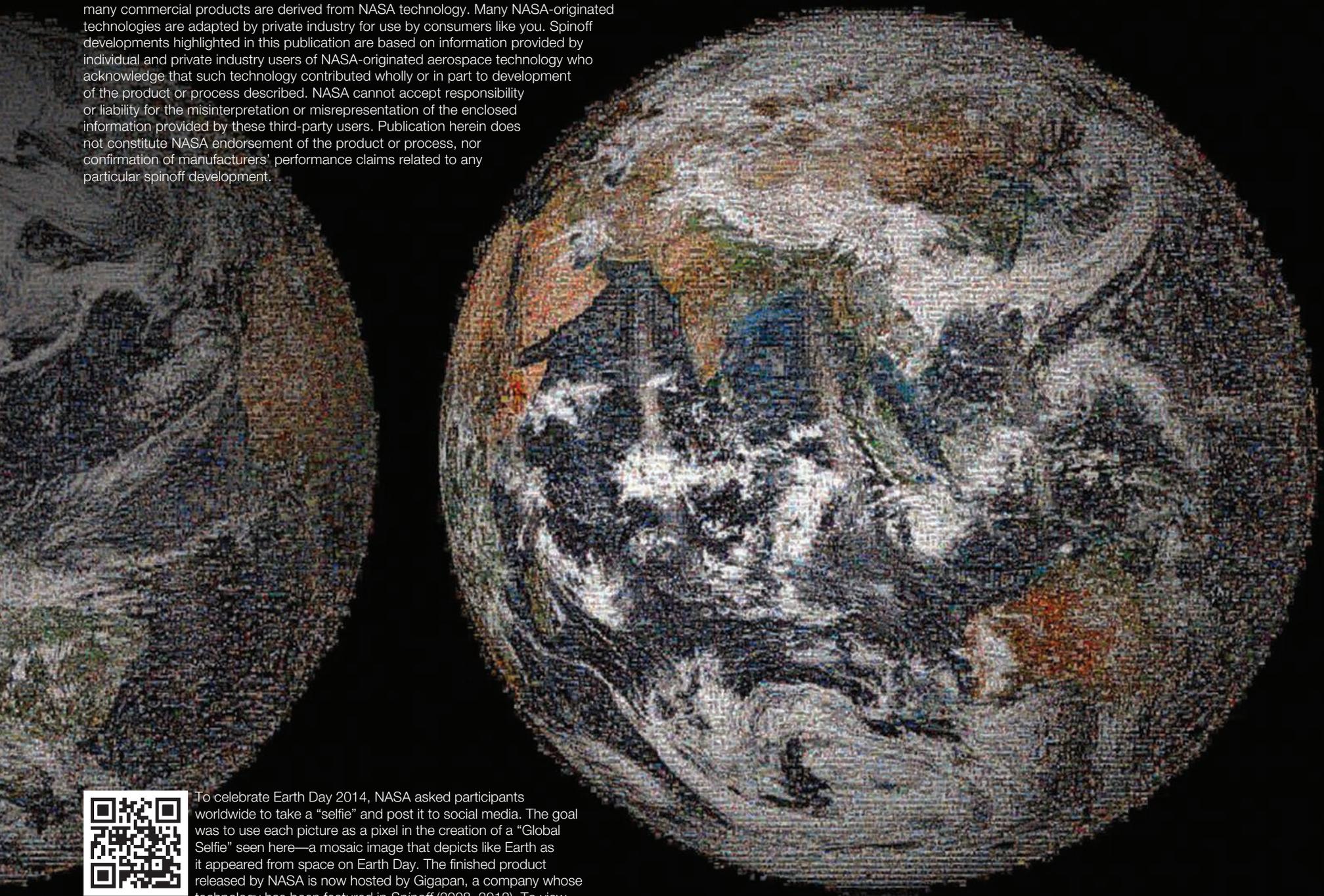
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**DISCLAIMER:** While NASA does not manufacture, market, or sell commercial products, many commercial products are derived from NASA technology. Many NASA-originated technologies are adapted by private industry for use by consumers like you. Spinoff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



To celebrate Earth Day 2014, NASA asked participants worldwide to take a “selfie” and post it to social media. The goal was to use each picture as a pixel in the creation of a “Global Selfie” seen here—a mosaic image that depicts like Earth as it appeared from space on Earth Day. The finished product released by NASA is now hosted by Gigapan, a company whose technology has been featured in *Spinoff* (2008, 2012). To view and navigate the full image, scan this code.



Charles F. Bolden, Jr.  
*Administrator*

National Aeronautics and  
Space Administration

This year's *Spinoff* publication celebrates the important and fast-growing commercial space industry, focusing on how this sector is drawing on decades of NASA technology and experience to grow our economy and improve life on Earth. We applaud the efforts of the companies who are helping advance NASA's mission and finding new uses for exploration technologies. In this year's publication you can read about a number of NASA spinoffs already benefitting commercial space, and I am confident we will see many more in the future.

While NASA continues to work with our industry partners to bring launches of astronauts to the International Space Station (ISS) back to American soil, we're also pioneering the next frontier of human space exploration. Our path to Mars builds on our work aboard the ISS, the success of commercial space, and the demonstration of new technologies in deep space. This stepping-stone approach takes advantage of more than a decade of living and working aboard the station to achieve scientific breakthroughs not possible here on Earth and the continued strong progress on the Space Launch System heavy-lift rocket and the Orion spacecraft that will carry astronauts to new destinations such as an asteroid and Mars.

NASA will continue working with commercial partners to develop tools that will advance our space and aeronautics missions and bring our nation new capabilities. I am particularly proud of the many small businesses that have played a critical role in every major NASA undertaking. We all know that small businesses form the backbone of our nation's economy, but they are also essential to the space program, accounting for 21 percent of our prime contract awards in fiscal year 2013—that's more than \$2.7 billion in revenue.

Small businesses also play a crucial role in transferring NASA technology to commercial and public uses. Among the 44 spinoffs in this publication, you'll find that many

prominently involve small businesses. Here are a few examples:

- Under a series of NASA Small Business Innovation Research (SBIR) contracts, a company developed a 3D printer capable of micro-precision in zero-gravity, which will soon be in operation aboard the ISS. This technology will allow customers, including NASA, to essentially email items into space, and it will revolutionize the space supply chain. This will be the first instance of supplies being manufactured in space, rather than taking up room on jarring and infrequent rides from Earth. (page 134)
- Under the Commercial Crew Development Program, NASA has been working with companies to develop privately operated spacecraft and supporting technologies. One firm is now using an air purification system that it matured under the program to design a pressurized capsule attached to a helium balloon that will send customers to the stratosphere for amazing views of Earth. (page 76)
- In order to assess the thousands of possible technologies that could be used for a human mission to Mars, the agency awarded grants to MIT to develop algorithm-based software that could highlight the most efficient, cost-effective options. A start-up company is now using the software to help home builders choose low-cost and energy-efficient design plans. (page 122)

NASA prides itself on tackling the most ambitious program of exploration the world has ever seen, and that effort is driven by technology. We are doubly pleased when our technology also drives progress among small businesses and strengthens our economy.

I hope you enjoy the many stories in this book about how technology drives exploration at the same time as it brings benefits to each of us on Earth.

## Spinoff (spin'ôf) -noun.

1. A commercialized product incorporating NASA technology or expertise that benefits the public. These include products or processes that:
  - were designed for NASA use, to NASA specifications, and then commercialized;
  - are developed as a result of a NASA-funded agreement or know-how gained during collaboration with NASA;
  - incorporate NASA technology in their manufacturing process;
  - receive significant contributions in design or testing from NASA laboratory personnel or facilities;
  - are successful entrepreneurial endeavors by ex-NASA employees whose technical expertise was developed while employed by the agency;
  - are commercialized as a result of a NASA patent license or waiver;
  - are developed using data or software made available by NASA.
2. NASA's premier annual publication, featuring successfully commercialized NASA technologies.



Shown here is a full-scale test NASA conducted on the tail from a 757 commercial aircraft that was modified with tiny jets called "sweeping jet actuators" to blow air across the rudder surfaces. This innovative Active Flow Control system might one day allow airplane builders to design smaller tails, which would reduce weight and drag and help improve fuel efficiency. This image was taken inside the National Full-Scale Aerodynamic Complex, a massive wind tunnel located at NASA's Ames Research Center. In the image, an engineer braces himself against the strong winds in the tunnel as he holds a wand emitting a stream of smoke that's used to visualize in-flight air flow across the tail. For a deeper look at the operation, scan this code.





Daniel Lockney

*Technology Transfer  
Program Executive*

National Aeronautics and  
Space Administration

The space agency enjoys a wide and varied technology portfolio that is unlike any other in existence. Here at the Technology Transfer Program at NASA Headquarters, our task is to make sure these innovations get into the hands of companies and organizations that need them, bringing NASA technology down to Earth so that the public can benefit from its investment in space exploration.

To that end, the Technology Transfer Program took an unprecedented step in 2014, compiling more than 1,000 pieces of agency software in one place and making them publicly available at no cost. Software now comprises more than one-third of NASA's technology portfolio, and the agency is dedicated to ensuring that these tools expand beyond their space and aeronautics applications to solve commercial challenges. At the same time, we have been increasing the rate of technology transfer to private organizations from our large patent portfolio, and we've made the process of acquiring NASA intellectual property faster than ever. You can learn more about these accomplishments in the "Spinoffs of Tomorrow" section (page 186).

NASA's range of successful technology transfer is as diverse as our many missions. In this year's *Spinoff*, you will find 44 examples of NASA technology at work in everything from medical devices and consumer goods to the latest advances in manufacturing and transportation. Some of my favorites are:

- In the 1960s and '70s, a NASA aeronautics engineer almost single-handedly developed an airplane wing that operated more efficiently around the speed of sound than any existing wing design. The "supercritical" airfoil turned out to also be more efficient at subsonic speeds and has since become ubiquitous, saving airlines billions of dollars every year in fuel costs while also reducing engine emissions. That was just one of three major contributions the eccentric but brilliant Richard Whitcomb made to the world of aviation. (page 42)

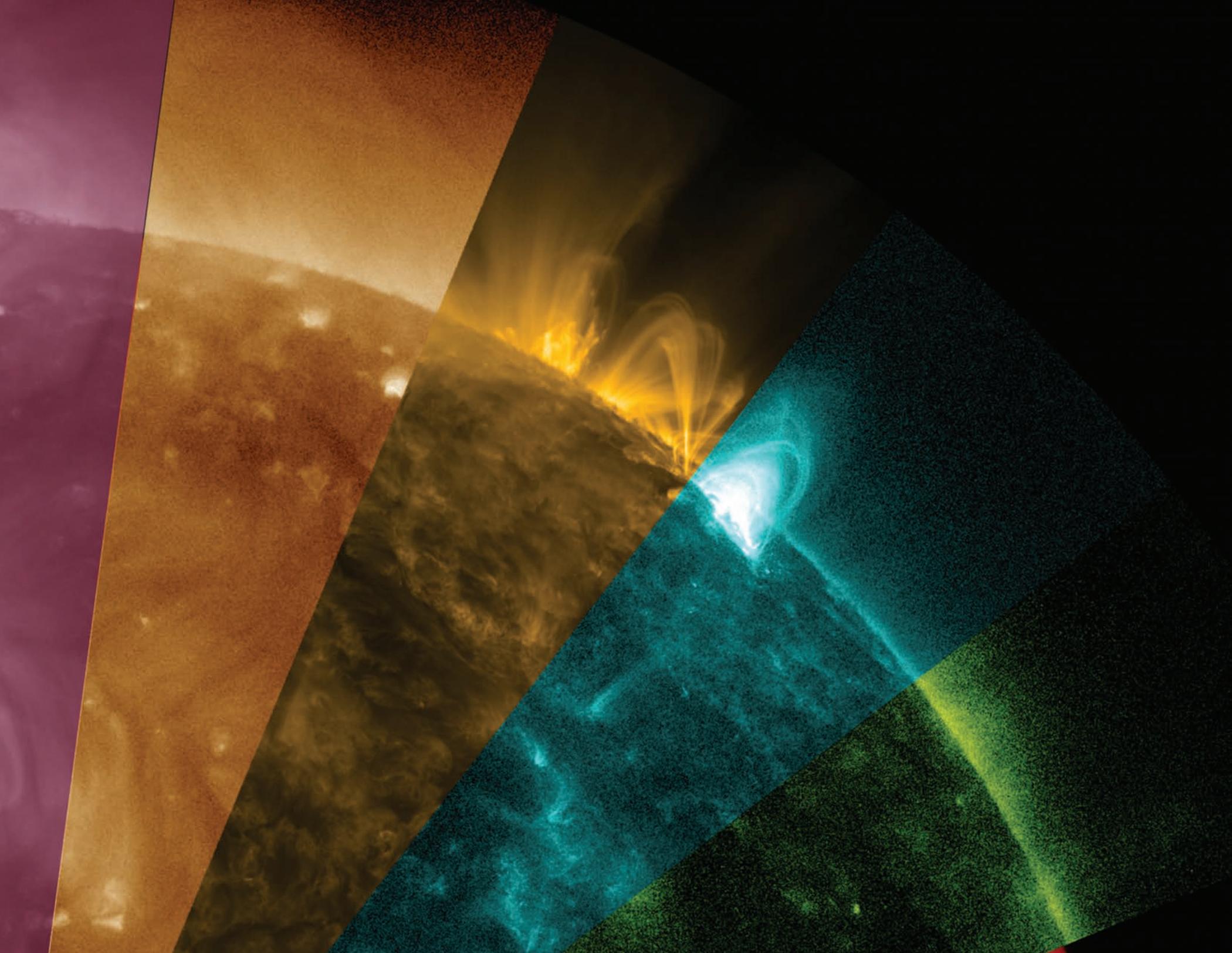
- Collaboration between NASA researchers and a brain surgeon resulted in the first endoscope suitable for brain surgery that is capable of producing 3D video images, giving the operator a better understanding of his or her tight working space. It's also the first device of its kind to be able to steer its lens back and forth, further enhancing visibility. This technology will likely find broad application across all kinds of surgery, improving safety, speeding patient recovery, and ultimately reducing medical costs. (page 24)
- Using NASA Landsat satellite and other remote sensing topographical data, a company developed an algorithm-based software program that can locate underground water sources. Working with NGOs and governments, the firm is helping to provide water for refugees and other people in drought-stricken regions such as Kenya, Sudan, and Afghanistan. (page 56)
- NASA aeronautics has been working for years with industry to improve aircraft fuel efficiency. Through collaboration with the agency, one company has developed a turbofan engine that is up to 16 percent more fuel-efficient than other models and up to 75 percent quieter. The technology is helping to reduce carbon dioxide emissions while saving airlines millions of dollars in fuel costs every year. (page 40)

Each technology featured in *Spinoff* is a reminder that the vibrant culture of innovation and progress at NASA results in tangible benefits for the nation and world. Over the course of decades, this has meant thousands of new and improved products, tens of thousands of new jobs, billions of dollars in generated revenue, billions more in saved costs, and even thousands of lives saved. As we continue moving forward in an era when it's easier than ever to share our knowledge, I am confident that there is much more to come.

# Executive Summary

Each year, *Spinoff* features dozens of NASA technologies improving everything from medical devices and software tools to the food you eat. The companies featured in this year's publication span a broad range of industries and geographic locations, showing the diverse benefits our nation enjoys from its investment in aeronautics and space missions.





# Executive Summary



## 24 3D Endoscope to Boost Safety, Cut Cost of Surgery

Researchers at the Jet Propulsion Laboratory worked with the brain surgeon who directs the Skull Base Institute in Los Angeles to create the first endoscope fit for brain surgery and capable of producing 3D video images. It is also the first to be able to steer its lens back and forth. These improvements to visibility are expected to improve safety, speeding patient recovery and reducing medical costs.



## 26 Audio App Brings a Better Night's Sleep

Neuroscientist Seth Horowitz was part of a NASA-funded team at State University of New York Stony Brook demonstrating that low-amplitude vestibular stimulation could induce sleep. After recognizing the same stimulation could be applied through sound, Horowitz founded Sleep Genius, located in Park City, Utah, and released a mobile app of the same name that helps people to get a more restful sleep.



## 30 Liquid Cooling Technology Increases Exercise Efficiency

To keep astronauts' airtight spacesuits from becoming hot and humid, Ames Research Center developed liquid cooling garments that were integrated into each suit's long underwear. Vasper Systems, in San Jose, California, is using the technology in its liquid-cooled compression cuffs, which help people exercise more efficiently by concentrating lactic acid in their muscles.



## 32 Algae-Derived Dietary Ingredients Nourish Animals

In the 1980s, Columbia, Maryland-based Martek Biosciences Corporation worked with Ames Research Center to pioneer the use of microalgae as a source of essential omega-3 fatty acids, work that led the company to develop its highly successful Formulaid product. Now the Nutritional Products Division of Royal DSM, the company also manufactures DHAgold, a nutritional supplement for pets, livestock and farm-raised fish that uses algae to deliver docosahexaenoic acid (DHA).



## 34 Space Grant Research Launches Rehabilitation Chair

Working with funding from the National Space Grant College and Fellowship Program—which was implemented by NASA headquarters to fund research, education, and public service projects—a biomedical engineering student created a vibration-based system that could combat bone loss from prolonged trips to space. A rehabilitation chair incorporating the technology is now sold by Sheboygan, Wisconsin-based VibeTech Inc. and is helping people recover more quickly from injuries and surgery.



## 36 Vision Trainer Teaches Focusing Techniques at Home

Based on work Stanford Research Institute did for Ames Research Center, Joseph Trachtman developed a vision trainer to treat visual focusing problems in the 1980s. In 2014, Trachtman, operating out of Seattle, released a home version of the device called the Zone-Trac. The inventor has found the biofeedback process used by the technology induces an alpha-wave brain state, causing increased hand-eye coordination and reaction times, among other effects.



## 40 Aircraft Geared Architecture Reduces Fuel Cost and Noise

In an effort to increase fuel efficiency and reduce noise in commercial airplanes, NASA aeronautics teamed up with East Hartford, Connecticut-based Pratt & Whitney through a Space Act Agreement to help the company increase the efficiency of its turbofan engine. The company's new PurePower line of engines is 15 percent more fuel-efficient and up to 75 percent quieter than its competitors.



## 42 Ubiquitous Supercritical Wing Design Cuts Billions in Fuel Costs

A Langley Research Center engineer's work in the 1960s and '70s to develop a wing with better performance near the speed of sound resulted in a significant increase in subsonic efficiency. The design was shared with industry. Today, Renton, Washington-based Boeing Commercial Airplanes,

as well as most other plane manufacturers, apply it to all their aircraft, saving the airline industry billions of dollars in fuel every year.



#### **46** Flight Controller Software Protects Lightweight Flexible Aircraft

Lightweight flexible aircraft may be the future of aviation, but a major problem is their susceptibility to flutter—uncontrollable vibrations that can destroy wings. Armstrong Flight Research Center awarded SBIR funding to Minneapolis, Minnesota-based MUSYN Inc. to develop software that helps program flight controllers to suppress flutter. The technology is now available for aircraft manufacturers and other industries that use equipment with automated controls.



#### **48** Cabin Pressure Monitors Notify Pilots to Save Lives

In 2013, San Diego-based Aviation Technology Inc. obtained an exclusive license for the technology behind the cabin pressure monitor invented at Kennedy Space Center and built its own version of the product. The Alt Alert is designed to save lives by alerting aircraft pilots and crews when cabin pressure becomes dangerously low.



#### **50** Ionospheric Mapping Software Ensures Accuracy of Pilots' GPS

IonoSTAGE and SuperTruth software are part of a suite created at the Jet Propulsion Laboratory to enable the Federal Aviation Administration's Wide Area Augmentation System, which provides pinpoint accuracy in aircraft GPS units. The system, used by more than 73,000 planes, facilitates landings under adverse conditions at small airports. In 2013, IonoSTAGE and SuperTruth found their first commercial license when NEC, based in Japan, with US headquarters in Irving, Texas, licensed the entire suite.



#### **56** Water Mapping Technology Rebuilds Lives in Arid Regions

Using NASA Landsat satellite and other remote sensing topographical data, Radar Technologies International developed an algorithm-based software program that can locate underground water sources. Working with international organizations and governments, the firm, which maintains an office in New Braunfels, Texas, is helping to provide water

for refugees and other people in drought-stricken regions such as Kenya, Sudan, and Afghanistan.



#### **60** Shock Absorbers Save Structures and Lives during Earthquakes

With NASA funding, North Tonawanda, New York-based Taylor Devices Inc. developed fluidic shock absorbers to safely remove the fuel and electrical connectors from the space shuttles during launch. The company is now employing the technology as seismic dampers to protect structures from earthquakes. To date, 550 buildings and bridges have the dampers, and not a single one has suffered damage in the wake of an earthquake.



#### **64** Software Facilitates Sharing of Water Quality Data Worldwide

John Freighery was an environmental engineer at Johnson Space Center when a new, simplified version of the coliform bacteria test was developed for astronaut use on the International Space Station. Through his New York City-based mWater Foundation, Freighery is using the test to help rural communities monitor their water supplies for contamination. The organization has also developed

a mobile phone app to make the information publicly available.



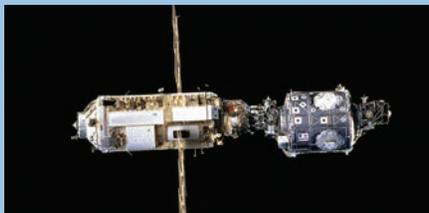
#### **66** Underwater Adhesives Retrofit Pipelines with Advanced Sensors

Houston-based Astro Technology Inc. used a partnership with Johnson Space Center to pioneer an advanced fiber-optic monitoring system for offshore oil pipelines. The company's underwater adhesives allow it to retrofit older deepwater systems in order to measure pressure, temperature, strain, and flow properties, giving energy companies crucial data in real time and significantly decreasing the risk of a catastrophe.



#### **68** Laser Imaging Video Camera Sees through Fire, Fog, Smoke

Under a series of SBIR contracts with Langley Research Center, inventor Richard Billmers refined a prototype for a laser imaging camera capable of seeing through fire, fog, smoke, and other obscurants. Now, Canton, Ohio-based Laser Imaging through Obscurants (LITO) Technologies Inc. is demonstrating the technology as a perimeter security system at Glenn Research Center and planning its future use in aviation, shipping, emergency response, and other fields.



**72**  
**3D Lasers Increase Efficiency, Safety of Moving Machines**

Canadian company Neptec Design Group Ltd. developed its Laser Camera System, used by shuttles to render 3D maps of their hulls for assessing potential damage. Using NASA funding, the firm incorporated LiDAR technology and created the TriDAR 3D sensor. Its commercial arm, Neptec Technologies Corp., has sold the technology to Orbital Sciences, which uses it to guide its Cygnus spacecraft during rendezvous and dock operations at the International Space Station.



**76**  
**Air Revitalization System Enables Excursions to the Stratosphere**

Paragon Space Development Corporation, based in Tucson, Arizona has had a long history of collaboration with NASA, including developing a modular air purification system under the Commercial Crew

Development Program, designed to support the commercial space sector. Using that device and other NASA technology, startup company World View is now gearing up to take customers on helium balloon rides to the stratosphere.



**80**  
**Magnetic Fluids Deliver Better Speaker Sound Quality**

In the 1960s, Glenn Research Center developed a magnetized fluid to draw rocket fuel into spacecraft engines while in space. Sony has incorporated the technology into its line of slim speakers by using the fluid as a liquid stand-in for the speaker's dampers, which prevent the speaker from blowing out while adding stability. The fluid helps to deliver more volume and hi-fidelity sound while reducing distortion.



**82**  
**Bioreactor Yields Extracts for Skin Cream**

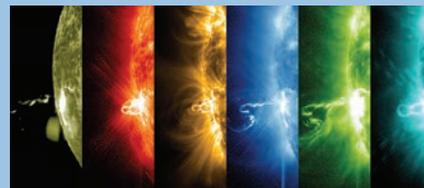
Johnson Space Flight Center researchers created a unique rotating-wall bioreactor that simulates microgravity conditions, spurring innovations in drug development and medical research. Renuell Int'l Inc., based in Aventura, Florida, licensed the technology and used it to produce a healing skin care product, RE'JUVEL. In a Food and Drug Administration test, RE'JUVEL substantially

increased skin moisture and elasticity while reducing dark blotches and wrinkles.



**84**  
**Private Astronaut Training Prepares Commercial Crews of Tomorrow**

A new company that includes a handful of former NASA personnel is already taking applications for the first comprehensive commercial astronaut training approved by the Federal Aviation Administration. Waypoint 2 Space, located at Johnson Space Center, hopes to draw space tourists and enthusiasts and future commercial crewmembers with first-hand NASA know-how, as well as agency training technology.



**86**  
**Activity Monitors Help Users Get Optimum Sun Exposure**

Goddard scientist Shahid Aslam was investigating alternative methods for measuring extreme ultraviolet radiation on the Solar Dynamics Observatory when he hit upon semiconductors that measured wavelengths pertinent to human health. As a result, he and a partner established College Park, Maryland-based Sensor Sensor LLC and developed UVA+B SunFriend, a wrist monitor that lets people know when they've received their optimal amounts of sunlight for the day.



**88**  
**LEDs Illuminate Bulbs for Better Sleep, Wake Cycles**

Life on the International Space Station (ISS) wreaks havoc on an astronaut's biological rhythms, and one way NASA mitigates the problem is through the use of LED lighting to alternately stimulate energy and focus and induce relaxation. Satellite Beach, Florida-based Lighting Science partnered with Kennedy Space Center to commercialize an LED system designed for the ISS, resulting in its DefinityDigital product line of light bulbs now used in numerous homes, hotel chains, and resorts.



**92**  
**Charged Particles Kill Pathogens and Round Up Dust**

To keep plants fresh longer in space, Marshall Space Flight Center awarded funding to the University of Wisconsin-Madison to develop a titanium oxide-based device that reduced the amount of decay-inducing ethylene gas in the air. Electrolux (now Dallas-based Aerus Holdings) furthered the technology by developing an air purification product that kills pathogens both in the atmosphere and on surfaces.



## 94 Balance Devices Train Golfers for a Consistent Swing

As part of the effort to understand the effects of spaceflight on astronauts, NASA funded research that resulted in a commercial product to treat balance disorders. West Palm Beach, Florida-based Sports Therapy Inc. worked with the inventor to modify the technology, creating the Dynamic Balance System (DBS) for sports applications. DBS is now used by Professional Golfers' Association-owned facilities and golf academies to help players achieve an effective, balanced swing.



## 98 Landsat Imagery Enables Global Studies of Surface Trends

Landsat 8 is the latest in the NASA-developed series of satellites that have provided a continuous picture of Earth for more than 40 years. Mountain View, California-based Google has incorporated Landsat data into several products, most recently generating

a cloud-free view of Earth. Google has also teamed up with researchers at the University of Maryland and Goddard Space Flight Center to create a global survey showing changes in forest cover over many years—the first of its kind.



## 102 Ruggedized Spectrometers Are Built for Tough Jobs

The Mars Curiosity Chemistry and Camera instrument, or ChemCam, analyzes the elemental composition of materials on the Red Planet by using a spectrometer to measure the wavelengths of light they emit. Principal investigator Roger Wiens worked with Ocean Optics, out of Dunedin, Florida, to rework the company's spectrometer to operate in cold and rowdy conditions and also during the stresses of liftoff. Those improvements have been incorporated into the firm's commercial product line.



## 104 Gas Conversion Systems Reclaim Fuel for Industry

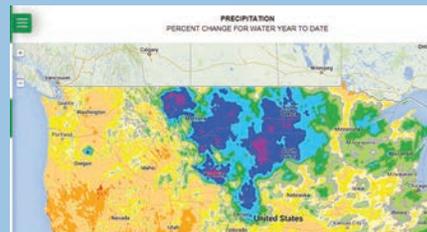
A human trip to Mars will require astronauts to utilize resources on the Red Planet to generate oxygen and fuel for the ride home, among other things. Lakewood, Colorado-based Pioneer Energy has worked under SBIR agreements with Johnson

Space Center to develop technology for those purposes, and now uses a commercialized version of the technology to recover oil and gas that would otherwise be wasted at drilling sites.



## 108 Remote Sensing Technologies Mitigate Drought

Ames Research Center has partnered with the California Department of Water Resources to develop satellite-based technologies to mitigate drought conditions. One project aims to help water managers adjust their irrigation to match the biological needs of each crop, and another involves monitoring areas where land is fallow so emergency relief can more quickly aid affected communities.



## 112 Satellite Data Inform Forecasts of Crop Growth

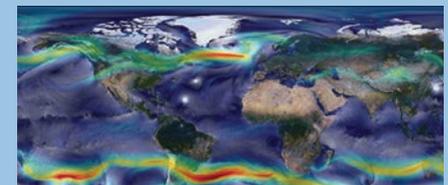
During a Stennis Space Center-led program called Ag 20/20, an engineering contractor developed models for using NASA satellite data to predict crop yield. The model was eventually sold to Genscape Inc., based in Louisville, Kentucky, which has commercialized it as LandViewer. Sold under a subscription model, LandViewer software provides

predictions of corn production to ethanol plants and grain traders.



## 114 Probes Measure Gases for Environmental Research

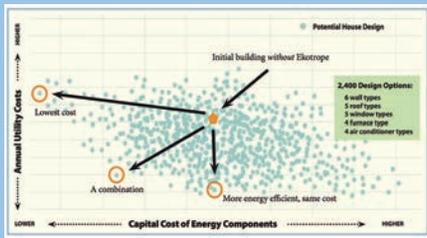
NASA's Orbiting Carbon Observatory-2 satellite will make the first space-based measurements of carbon dioxide in Earth's atmosphere. In support of the mission, Goddard Space Flight Center will fly air missions from Wallops Flight Facility to gather finer-grained data in areas of interest. Goddard started working with Blacksburg, Virginia-based Aeropro Corporation through the SBIR program in 2008 to develop sensors for such flights, and the company has since commercialized the resulting product.



## 118 Cloud Computing Technologies Facilitate Earth Research

Under a Space Act Agreement, NASA partnered with Seattle-based Amazon Web Services to make the agency's climate and Earth science satellite data publicly available on the company's servers. Users

can access the data for free, but they can also pay to use Amazon's computing services to analyze and visualize information using the same software available to NASA researchers.



**122**  
Software Cuts Homebuilding Costs, Increases Energy Efficiency

To sort out the best combinations of technologies for a crewed mission to Mars, NASA Headquarters awarded grants to MIT's Department of Aeronautics and Astronautics to develop an algorithm-based software tool that highlights the most reliable and cost-effective options. Utilizing the software, Professor Edward Crawley founded Cambridge, Massachusetts-based Ekotrope, which helps homebuilders choose cost- and energy-efficient floor plans and materials.



**124**  
Portable Planetariums Teach Science

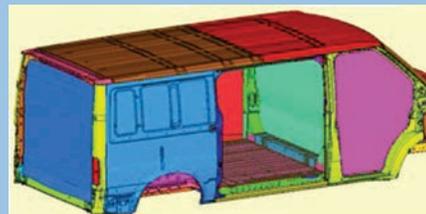
With the Internet proving to be the wave of the future, in the 1990s Johnson Space Center awarded grants to Rice University in Houston for developing the world's first Internet-accessible museum kiosk.

Further grants were awarded to the school for creating educational software for use in homes and schools, leading to the creation of Museums Teaching Planet Earth Inc. The company has gone on to develop and sell portable planetariums and accompanying educational shows.



**128**  
Schedule Analysis Software Saves Time for Project Planners

Since the early 2000s, a resource management team at Marshall Space Flight Center has developed and improved the Schedule Test and Assessment Tool, a software add-on capable of analyzing, summarizing, and finding logic gaps in project schedules. Companies like Lanham, Maryland-based Vantage Systems Inc. use the tool to manage NASA projects, but it has also been released for free to more than 200 US companies, agencies, and other entities.



**130**  
Sound Modeling Simplifies Vehicle Noise Management

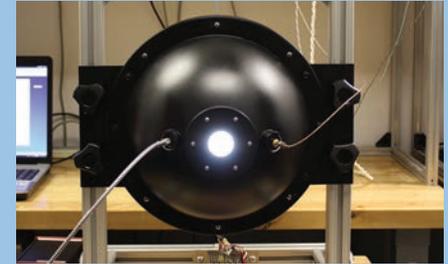
Under two SBIR contracts with Langley Research Center, Ann Arbor, Michigan-based Comet

Technology Corporation developed Comet EnFlow, a software program capable of predicting both high- and low-frequency noise and vibration behavior in plane fuselages and other structures. The company now markets the software to airplane, automobile, and ship manufacturers, and Langley has found an unexpected use for it in leak detection on the International Space Station.



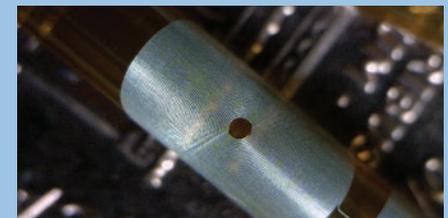
**134**  
Custom 3D Printers Revolutionize Space Supply Chain

Under a series of SBIR contracts with Marshall Space Flight Center, start-up company Made In Space, located on the center's campus, developed a high-precision 3D printer capable of manufacturing items in microgravity. The company will soon have a printer installed on the International Space Station, altering the space supply chain. It will print supplies and tools for NASA, as well as nanosatellite shells and other items for public and private entities.



**138**  
Improved Calibration Shows Images' True Colors

Innovative Imaging and Research, located at Stennis Space Center, used a single SBIR contract with the center to build a large-scale integrating sphere, capable of calibrating a whole array of cameras simultaneously, at a fraction of the usual cost for such a device. Through the use of LEDs, the company also made the sphere far more efficient than existing products and able to mimic sunlight.



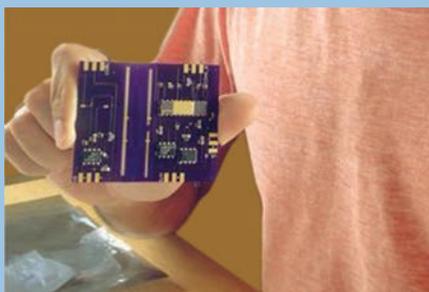
**142**  
Micromachined Parts Advance Medicine, Astrophysics, and More

In the mid-1990s, Marshall Space Flight Center awarded two SBIR contracts to Potomac Photonics, now based in Baltimore, for the development of computerized workstations capable of mass-producing tiny, intricate, diffractive optical elements. While the company has since discontinued the workstations, those contracts set the stage for Potomac Photonics to be a leader in the micromachining industry, where NASA remains one of its clients.



### 146 Metalworking Techniques Unlock a Unique Alloy

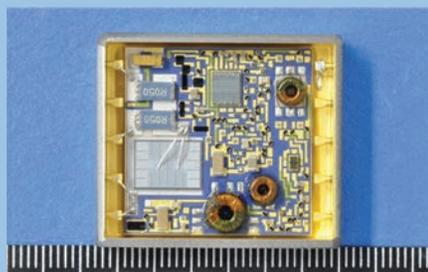
Approached by West Hartford, Connecticut-based Abbot Ball Company, Glenn Research Center agreed to test an intriguing alloy called Nitinol 60 that had been largely unused for a half century. Using powdered metallurgy, the partners developed a method for manufacturing and working with the material, which Abbott Ball has now commercialized. Nitinol 60 provides a unique combination of qualities that make it an excellent material for ball bearings, among other applications.



### 148 Low-Cost Sensors Deliver Nanometer-Accurate Measurements

As part of a unique partnership program, Kennedy Space Center collaborated with a nearby business school to allow MBA students to examine and analyze the market potential for a selection of NASA-patented technologies. Following the

semester, a group of students decided to form Winter Park, Florida-based Juntura Group Inc. to license and sell a technology they had worked with: a sensor capable of detecting position changes as small as 10 nanometers—approximately the thickness of a cell wall.



### 150 Electrical Monitoring Devices Save on Time and Cost

In order to protect the Solar Dynamics Observatory's instruments from blowing their fuses and being rendered unusable, Goddard Space Flight Center worked with Micropac Industries Inc., based in Garland, Texas, to develop solid-state power controllers, which can depower and then resupply power to an instrument in the event of an electric surge. The company is now selling the technology for use in industrial plants.



### 154 Dry Lubricant Smooths the Way for Space Travel, Industry

Reviving industry standards for coating parts in tungsten disulfide, a dry lubricant developed for

the Mariner space probes managed by the Jet Propulsion Laboratory in the 1960s and '70s, Applied Tungstenite, a relatively new Temecula, California-based company, has found a client base in the mushrooming commercial space industry, as well as other manufacturers.



### 156 Compact Vapor Chamber Cools Critical Components

Advancements in the production of proton exchange membrane fuel cells have NASA considering their use as a power source for spacecraft and robots in future space missions. With SBIR funding from Glenn Research Center, Lancaster, Pennsylvania-based Thermacore Inc. developed strong, lightweight titanium vapor chambers to keep the fuel cells operating at optimum temperatures. The company is now selling the technology for cooling electronic components.

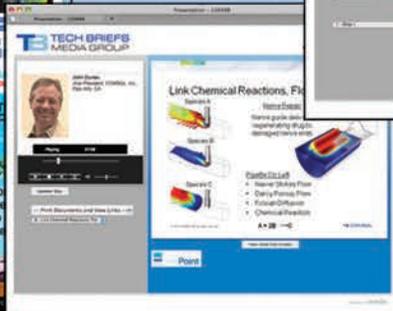


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# NASA Spinoffs: By the Numbers



## Tangible benefits comparison



Lives saved = Population  
449,850 = Atlanta, Georgia



Jobs created = Crowd capacity  
18,888 = Madison Square Garden



Revenue generated = Total revenue  
\$5.2 billion = North American concerts  
2013



Costs reduced = Total revenue  
\$18.6 billion = global airline industry  
2014



While reaching for new heights in space, NASA is always working to make sure its advancements are brought back to Earth. In addition to the stories of successful technology transfer you'll find in this book, NASA spinoffs spanning the gamut of industry yield quantifiable benefits in the form of lives saved, jobs created, revenue generated, and costs reduced.

These totals could populate a city, fill an arena, or replace a year's income for an entire industry. And as America's space agency continues to develop the technologies needed to explore ever deeper into space, these numbers will only continue to grow.

Source: Quantifiable benefit totals are approximate and based on responses to a survey sent to companies featured in *Spinoff* since 2000. For more information on collecting these numbers, visit <http://spinoff.nasa.gov/resources.html>.

# NASA Spinoff Technology across the Nation

## Health and Medicine

1. 3D Endoscope to Boost Safety, Cut Cost of Surgery (CA)
2. Audio App Brings a Better Night's Sleep (UT)
3. Liquid Cooling Technology Increases Exercise Efficiency (CA)
4. Algae-Derived Dietary Ingredients Nourish Animals (MD)
5. Space Grant Research Launches Rehabilitation Chair (WI)
6. Vision Trainer Teaches Focusing Techniques at Home (WA)

## Transportation

7. Aircraft Geared Architecture Reduces Fuel Cost and Noise (CT)
8. Ubiquitous Supercritical Wing Design Cuts Billions in Fuel Costs (WA)
9. Flight Controller Software Protects Lightweight Flexible Aircraft (MN)
10. Cabin Pressure Monitors Notify Pilots to Save Lives (CA)
11. Ionospheric Mapping Software Ensures Accuracy of Pilots' GPS (TX)

## Public Safety

12. Water Mapping Technology Rebuilds Lives in Arid Regions (TX)
13. Shock Absorbers Save Structures and Lives during Earthquakes (NY)
14. Software Facilitates Sharing of Water Quality Data Worldwide (NY)
15. Underwater Adhesives Retrofit Pipelines with Advanced Sensors (TX)
16. Laser Imaging Video Camera Sees through Fire, Fog, Smoke (OH)
17. 3D Lasers Increase Efficiency, Safety of Moving Machines (TX)

## Consumer Goods

18. Air Revitalization System Enables Excursions to the Stratosphere (AZ)
19. Magnetic Fluids Deliver Better Speaker Sound Quality (NY)
20. Bioreactor Yields Extracts for Skin Cream (FL)
21. Private Astronaut Training Prepares Commercial Crews of Tomorrow (TX)
22. Activity Monitors Help Users Get Optimum Sun Exposure (MD)
23. LEDs Illuminate Bulbs for Better Sleep, Wake Cycles (FL)
24. Charged Particles Kill Pathogens and Round Up Dust (TX)
25. Balance Devices Train Golfers for a Consistent Swing (FL)

## Energy and Environment

26. Landsat Imagery Enables Global Studies of Surface Trends (CA)
27. Ruggedized Spectrometers Are Built for Tough Jobs (FL)
28. Gas Conversion Systems Reclaim Fuel for Industry (CO)
29. Remote Sensing Technologies Mitigate Drought (CA)
30. Satellite Data Inform Forecasts of Crop Growth (KY)
31. Probes Measure Gases for Environmental Research (VA)

## Information Technology

32. Cloud Computing Technologies Facilitate Earth Research (WA)
33. Software Cuts Homebuilding Costs, Increases Energy Efficiency (MA)
34. Portable Planetariums Teach Science (TX)
35. Schedule Analysis Software Saves Time for Project Planners (MD)
36. Sound Modeling Simplifies Vehicle Noise Management (MI)

## Industrial Productivity

37. Custom 3D Printers Revolutionize Space Supply Chain (CA)
38. Improved Calibration Shows Images' True Colors (MS)
39. Micromachined Parts Advance Medicine, Astrophysics, and More (MD)
40. Metalworking Techniques Unlock a Unique Alloy (CT)
41. Low-Cost Sensors Deliver Nanometer-Accurate Measurements (FL)
42. Electrical Monitoring Devices Save on Time and Cost (TX)
43. Dry Lubricant Smooths the Way for Space Travel, Industry (CA)
44. Compact Vapor Chamber Cools Critical Components (PA)



# NASA Technologies Benefiting Society

There's more space in your life than you think: NASA research and development has tangible benefits that go beyond supporting mission needs. Spinoffs create jobs, generate revenue, and save costs for businesses. They even save lives. Through next-generation jet engines, tools for brain surgery, 3D printers, and more, NASA technology works for the benefit of the nation and world.

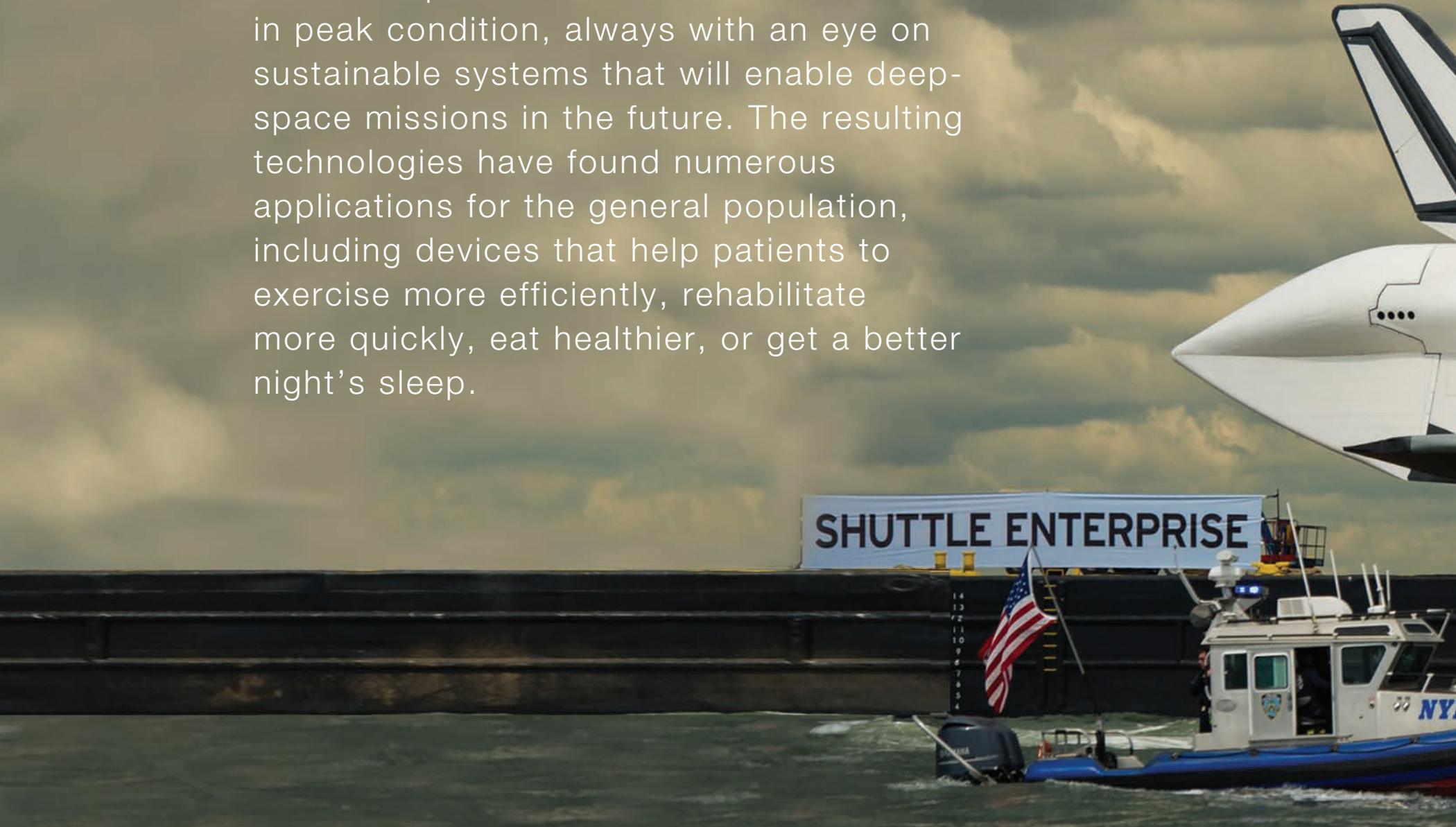






# Health and Medicine

**N**ASA is continually developing new ways to keep its astronauts comfortable and in peak condition, always with an eye on sustainable systems that will enable deep-space missions in the future. The resulting technologies have found numerous applications for the general population, including devices that help patients to exercise more efficiently, rehabilitate more quickly, eat healthier, or get a better night's sleep.





NASA

Enterprise

United States 

TO INTREPRET  
WEEKS

# 3D Endoscope to Boost Safety, Cut Cost of Surgery

## NASA Technology

“A lot of things are not easy to solve when you’re trying to break through a new technology right from the get-go,” says Harish Manohara, supervisor of the Nano and Micro Systems Group and principal member of the technical staff at NASA’s Jet Propulsion Laboratory (JPL).

Trust a supergroup of rocket scientists and a brain surgeon to make it happen, though.

In 2007, Dr. Hrayr Shahinian was looking for an engineering team to help him develop an endoscopic device suitable for brain surgery and capable of both steering its lens and producing a three-dimensional video image, when he discovered that the person he happened to be seated next to at a social function was Charles Elachi, director of JPL. Their discussion was the spark that eventually put Shahinian in touch with the JPL team.

Director of the Skull Base Institute in Los Angeles, Shahinian helped to pioneer minimally invasive, endoscopic brain surgery in the mid-1990s. As the industry shifted away from open-skull operations to endoscopic techniques, in which a tiny camera and tools are inserted through a small hole, the risk of complications for most surgeries plummeted, as did the length of hospital stays and rehabilitation time. The change was not, however, without its drawbacks.

“It became obvious to me, even 15 years ago when I was converting to endoscopic, that we were losing depth perception,” Shahinian says, noting that no matter how high-definition the image an endoscope may produce, it’s still flat, making it difficult for the surgeon to see how close the tumor is to potentially critical nerves or tissue behind it, for example. “I realized that 3D endoscopy is the future.”

The problem, though, was that this sort of brain surgery is carried out in exceedingly close quarters, so that the device couldn’t be more than four millimeters in diameter. This ultimately ruled out the possibility of using

dual lenses to create a 3D image, although Manohara says his team explored the idea.

NASA, too, often wants to get high-quality images, he says. “Whenever there are optics and 3D imaging involved, it can be adapted for planetary exploration.” For example, Manohara says, on a rover, such a camera could peer into the opening left by a rock core extraction. “There is lots of interest in terms of assessing geological features, and 3D is often better than 2D.”

On a shuttle or space station, he adds, the instrument could be used to look for a fault or fracture in machinery that’s hidden from view. In this case, a 3D image would make it easier to assess the nature of the damage.

Seeing this common interest, NASA entered into a Space Act Agreement with Shahinian, and he obtained a license for the technology. “He had a very specific need and knew exactly what he wanted,” Manohara says. “The problem was well-defined, but the solution was not there.”

After the dual-lens model was scrapped due to poor image quality at such a small lens size, the team hit on another idea: two apertures with complementary color filters, incorporated into a single lens.

Just as humans and other animals process two images from the slightly different viewpoints of their eyes to perceive depth, 3D imaging requires two viewpoints.

“If it’s a single-lens system, we still have to somehow create two viewpoints of the same image,” Manohara explains. “It was a question of brainstorming.”

To create a fully lit image that can be viewed with standard 3D glasses, the team relied on color filters. Each aperture filters specific wavelengths of each of the red, green, and blue spectrums that are not filtered by the other aperture. These together comprise white light. The light source, a xenon cold lamp, cycles rapidly through these six specific color wavelengths in sequence, with only half of the reflected light passing through each aperture.

“You’re creating two separate, fully colored images,” Manohara says. These are then run through the standard





A joint effort between NASA's Jet Propulsion Lab and the Skull Base Institute in Los Angeles produced the Multi-Angle Rear-Viewing Endoscopic Tool (MARVEL), the first endoscope suitable for brain surgery that is capable of producing three dimensional imagery.

software used to create and display images suitable for viewing with the same polarized 3D glasses used in movie theaters.

The other challenge to overcome was Shahinian's specification that the end of the camera be able to steer side to side. To date, the endoscopes available to brain surgeons are all either straight-looking or fixed-angle.

Manohara says the tight restriction on diameter made it difficult to install an automated joint in the device. "You have to have illumination in there, and you have to have data and power cables in there," he says. "You have a lot of wires inside, and the room available is very small."

However, the team succeeded in enabling the camera, which is controlled with a joystick, to turn 60 degrees in each direction. Manohara credits Sam Bae, also of the Nano and Micro Systems Group at JPL, with much of the system design and integration, and he says optical engineer Ronald Korniski made the lens work.

### Technology Transfer

In December of 2013, Shahinian had the first prototype of the Multi-Angle Rear-Viewing Endoscopic Tool (MARVEL) in his hand. Two more stereocamera prototypes have since been built, and the technology is being prepared for submission to the Food and Drug Administration for approval for medical use. Shahinian says he expects to have the device in use by early 2015.

He says he wants to be the first surgeon to use the MARVEL in his practice but expects that this advancement will soon find widespread application. "This technology with MARVEL will apply to all types of endoscopy," he says. "Brain surgery is a very small niche."

### Benefits

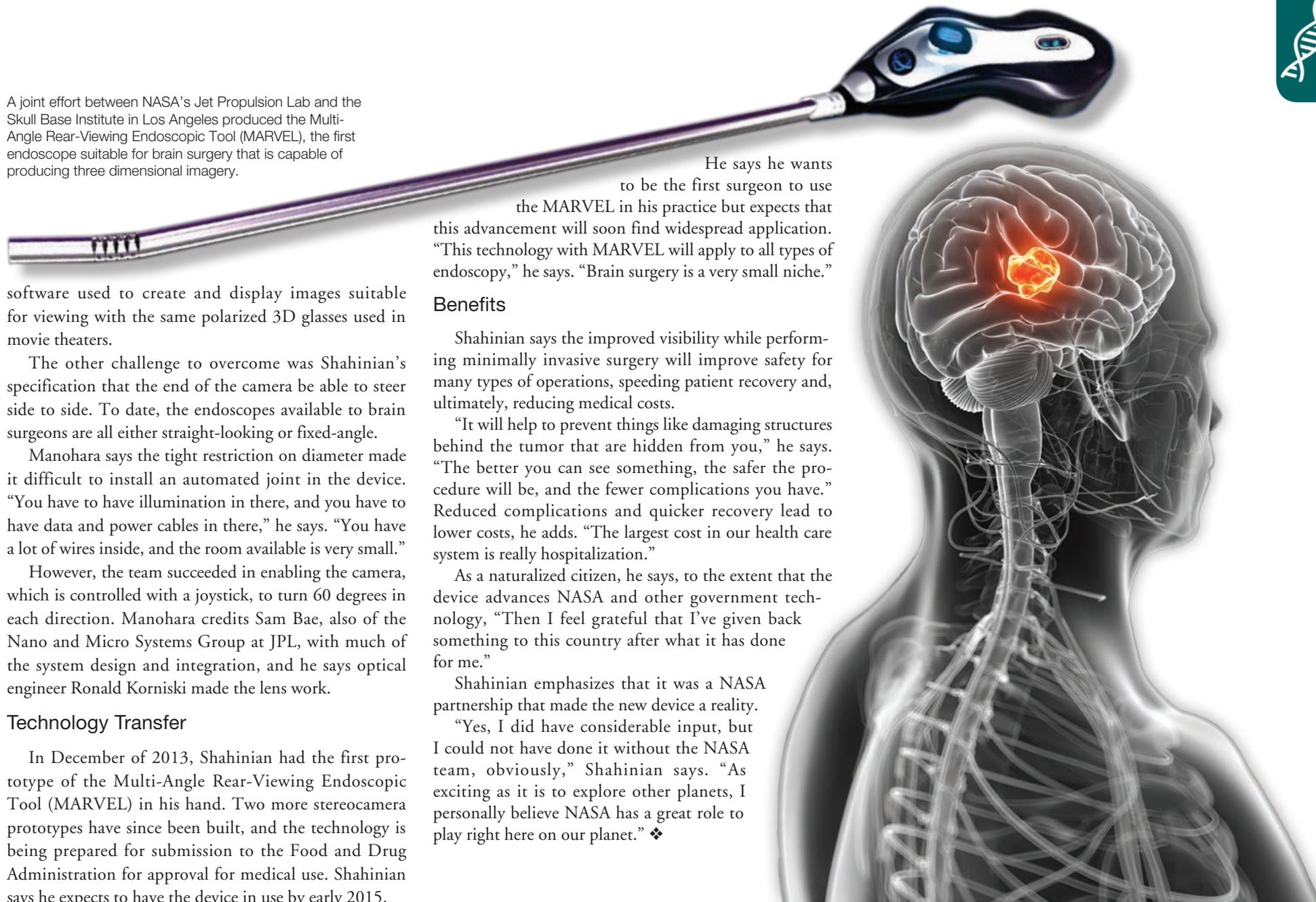
Shahinian says the improved visibility while performing minimally invasive surgery will improve safety for many types of operations, speeding patient recovery and, ultimately, reducing medical costs.

"It will help to prevent things like damaging structures behind the tumor that are hidden from you," he says. "The better you can see something, the safer the procedure will be, and the fewer complications you have." Reduced complications and quicker recovery lead to lower costs, he adds. "The largest cost in our health care system is really hospitalization."

As a naturalized citizen, he says, to the extent that the device advances NASA and other government technology, "Then I feel grateful that I've given back something to this country after what it has done for me."

Shahinian emphasizes that it was a NASA partnership that made the new device a reality.

"Yes, I did have considerable input, but I could not have done it without the NASA team, obviously," Shahinian says. "As exciting as it is to explore other planets, I personally believe NASA has a great role to play right here on our planet." ❖



# Audio App Brings a Better Night's Sleep

## NASA Technology

With demanding schedules, a sunrise or sunset every 45 minutes, and extremely noisy surroundings, it's understandable why many astronauts onboard the International Space Station suffer from insomnia in the early stages of a mission. To help combat what can be a dangerous condition, over the years NASA has funded research not only to investigate the underlying physiological phenomena that contribute to sleep deprivation but also to find methods for treating it.

With those objectives in mind, in 2001 the agency's medical research arm, the National Space Biomedical Research Institute, provided funding for State University of New York at Stony Brook neuroscience professors to examine the impacts of the body's vestibular system on sleep, the ultimate goal being to help astronauts adjust their sleep schedules more effectively.

The vestibular system, says Seth Horowitz, one of the neuroscientists involved in the study, is known primarily for contributing to our sense of balance. Three connected, semicircular canals and two small otolith organs located in each of our inner ears work in constant unison with other physiology to act as rotational and linear accelerometers, sensing movements and communicating them through neural signals that travel to the brainstem's vestibular nuclei. From there, the nuclei trigger neural structures throughout our brains and bodies that enable us to walk and run and do everything else without falling.

But research in the 1960s and '70s on a common medical condition called Sopsite syndrome hinted at the vestibular system's involvement in sleep regulation as well. Sopsite syndrome is, in short, a form of motion sickness, but "it doesn't make you want to lose your lunch and your tequila," explains Horowitz. "What it does is make you sleepy." The reason? Scientists hypothesized that the afflicted are especially susceptible to a running vehicle's constant low-amplitude vibration, which, similar to



Astronauts Mike Massimino (left) and Michael Good, STS-125 mission specialists, are pictured in their sleeping bags, which are attached to lockers on the middeck of the Earth-orbiting Space Shuttle Atlantis at the end of flight day eight on May 18, 2009. Astronauts' busy schedules combined with a host of biological factors make getting adequate rest in space a challenge. As a result, NASA has funded research to investigate and treat sleep deprivation.

rocking a baby to sleep, triggers something in the vestibular system that reduces arousal, or general wakefulness.

At Stony Brook, Horowitz and his colleagues tested that theory by performing experiments on hamsters, animals with very stable sleep habits and comparable vestibular systems. To induce a similar vibration to riding comfortably in the backseat of a sedan, they simply spent time handling the hamsters in various ways—lightly shaking them, rolling them, and spinning them in place. The results were clear: low-amplitude vestibular stimulation shifted hamster—and therefore human—sleep cycles.

"On one end, high-amplitude, sudden vibration wakes you up," says Horowitz, "but these low-amplitude,

periodic vibrations put you to sleep. You've got a psychophysical curve that covers all states of arousal and sleep."

Further research would reveal that, in fact, the vestibular system is tied into nearly every aspect of the sleep network, including the suprachiasmatic nucleus, the master clock in charge of regulating our circadian rhythms, and a region in the hypothalamus that's host to a stimulation-inducing neuropeptide called orexin. As the hamster experiment demonstrated, vestibular modulation can affect these arousal centers, causing either an excited or sleepy state.

After the NASA funding ended in 2005, at which point Horowitz left the university, he got to thinking:



How he could utilize what he learned to help people, himself included, get a better night's rest? He would come up with a breakthrough idea by recognizing that sleep-inducing vestibular vibration could also be brought about through sound.

### Technology Transfer

To understand how sound induces various states of arousal or wakefulness, Horowitz says, imagine you're

in a nightclub, and you hear this steady 4/4 rhythm carried by a deep bass. "It's a dance-or-die kind of rhythm," he says. "It turns out that very low frequencies at very high amplitudes can trigger certain cells in the vestibular system that make you tap your feet or move your body back and forth to the rhythm."

This "crosstalk" phenomenon, as Horowitz calls it, between the auditory and vestibular system formed the basis for an audio program that incorporates the science

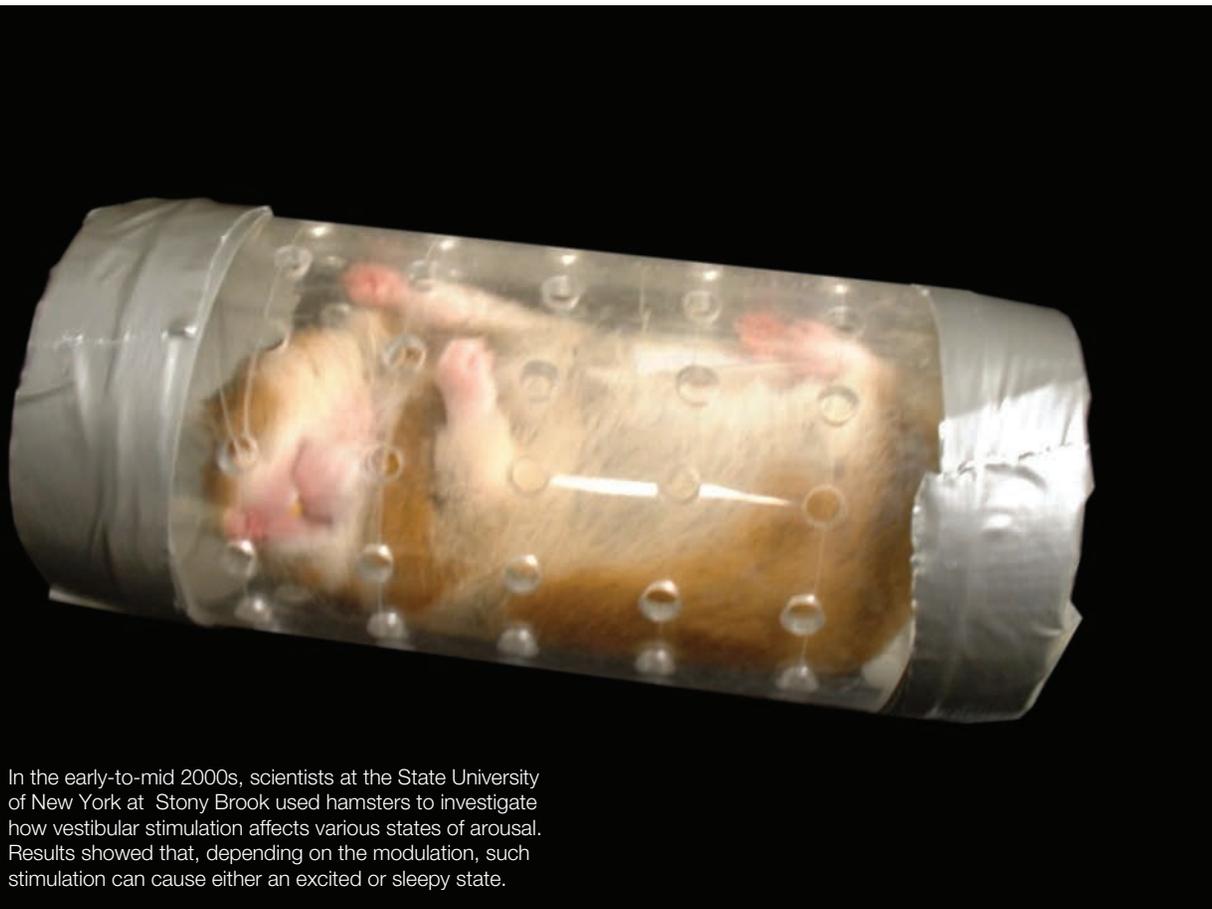
from Horowitz's NASA-funded research along with other tools to help people get a better night's rest. Using sound makes sense, he says, because "your auditory system is the only sensory system that's still working full-bore while you're asleep."

In creating the program, Horowitz first developed algorithms that produced a low-frequency, semi-periodic, moderate-amplitude rumbling sound; in other words, a sound simulating the vestibular stimulation in a vehicle that causes a person with Sopite syndrome to fall asleep, only slightly louder. He describes the resulting sound as akin to "a recording of a microphone being held in the back of a car."

Next, Horowitz mixed in what are known as binaural beats: stereo-beating pulses of sound that synchronize the cortex of the brain. He arranged the beats to match the brain's rhythm changes during different stages of sleep, helping to keep a person in slumber throughout the night. Third, he added auditory-facilitated relaxation, which means using calming sounds to lower heart and breathing rates to levels that promote sleep. Horowitz worked with composer Lance Massey—creator of the T-Mobile ring tone—to weave the three technologies into a number of classical music tracks.

Their invention would be put to the test when a friend of Massey's challenged them to help his two energetic young boys fall asleep at night. Putting them to bed every night was a struggle many parents can relate to. The inventors handed him a CD containing the classical music tracks. The first night, he played the boys a variation of Pachelbel's Canon, but because they were fans of a thrash metal version of that particular piece, says Horowitz, they became energized by it, which had the opposite effect. The second night, their father instead played an unfamiliar track, which triggered a different response.

"He said that it worked like a charm," Horowitz recalls. "He said it just knocked them out."



In the early-to-mid 2000s, scientists at the State University of New York at Stony Brook used hamsters to investigate how vestibular stimulation affects various states of arousal. Results showed that, depending on the modulation, such stimulation can cause either an excited or sleepy state.

The result encouraged Horowitz and Massey to test the technology on a larger group, so they set up an experiment with a therapist in Los Angeles who worked with people suffering from severe sleep problems. She handed two-thirds of her patients CDs containing music that carried the algorithms and other sleep-inducing stimuli, and the rest—the control group—were given CDs without them. The results were telling: 77–80 percent of those who used the audio program were sleeping better at night, while the control group was not reporting a better night’s rest with any significance.

The successful study spurred the pair to commercialize the technology, resulting in the formation of Park City, Utah-based Sleep Genius, which in 2013 began selling the audio program of the same name as a downloadable smartphone app for the iOS and Android platforms.

## Benefits

Using the Sleep Genius app, Horowitz says, requires only a stereo system or sleep-safe headphones. Next is simply choosing one of three music selections—Renewed Universe, Dreamscapes, or Tranquility—setting the alarm (or the timer, if you only need help falling asleep), and then turning out the lights.

The program is configured in ways that can benefit people of all ages. Horowitz says older adults generally are able to fall asleep but wake up a lot during the night; young adults tend to have the exact opposite problem. Adults older than 40 years of age start to lose their ability to hear high frequencies; babies tend to respond positively to high-pitched white noise. “We’ve found a balance of frequencies that seems to address most of those factors for a wide group of people,” he says.

Horowitz notes that chronic sleep sufferers usually need to use the app for several consecutive nights before the benefits start to kick in, and he gives extra encouragement to those who use sleep medications. “We’re not anti-pharmaceutical,” he says. “If you’ve got meds and you need them, take them. But if a non-medical alterna-

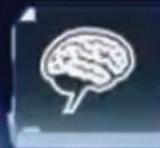
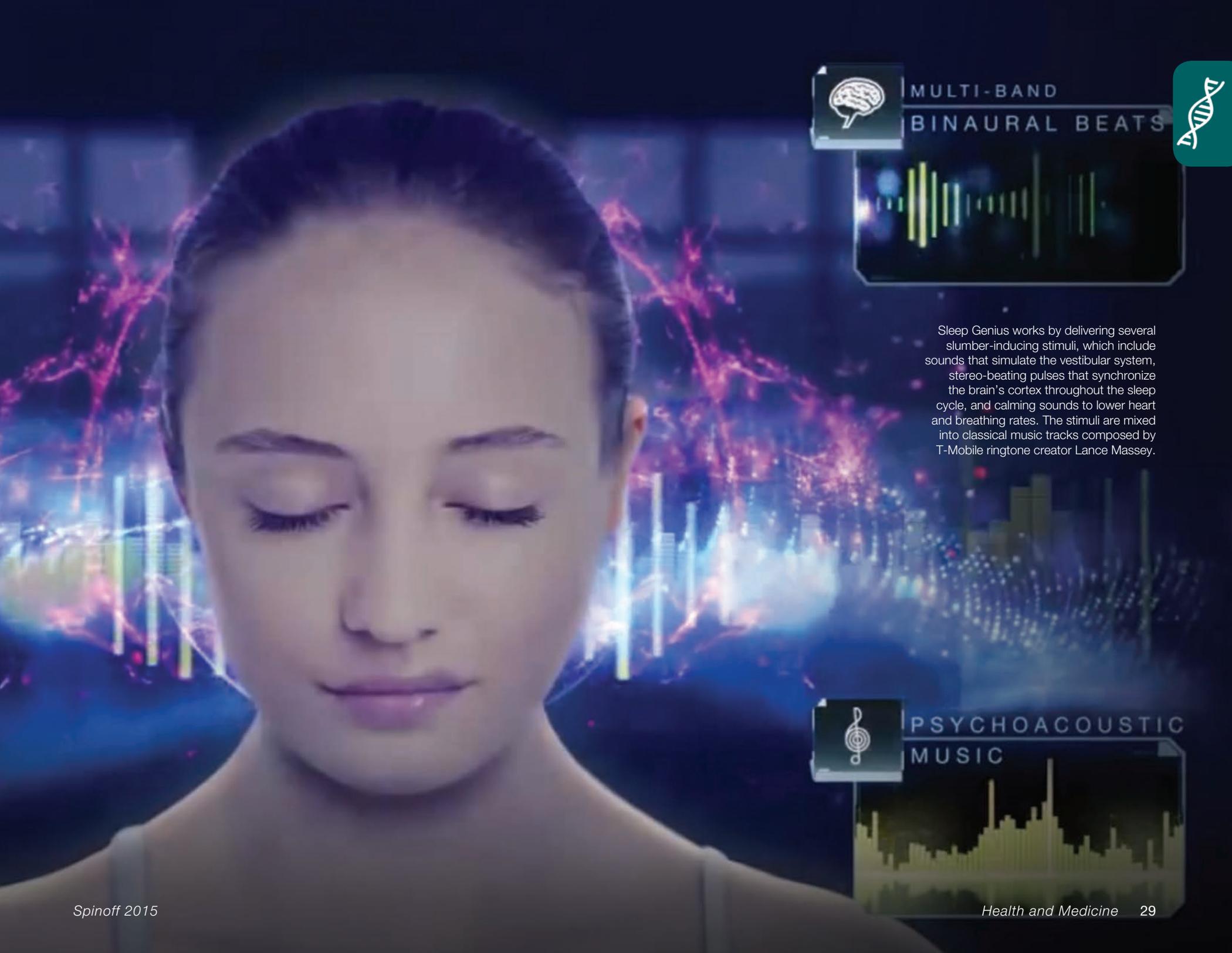
Neuroscientist Seth Horowitz used the results of his research on vestibular stimulation to develop Sleep Genius, a mobile app that can help people who have trouble sleeping get a better night’s rest. The app also helps those who take power naps during the day.

tive such as this works, pursue it, because drugs can present all sorts of unwanted side effects.”

In the short time the app has been on the market, more than 400,000 customers who suffer from chronic sleep ailments have downloaded it. In addition to evaluating customer questionnaires, Horowitz plans to conduct further research on the technology’s efficacy by having test subjects wear watches that monitor for movement throughout the night. Because muscles become paralyzed during deep sleep, less movement is indicative of a better night’s rest.

“The whole venture started with NASA research using hamsters and studying a common problem,” Horowitz says. “The end result is, this app is doing people a lot of good.” ♦





## MULTI-BAND BINAURAL BEATS



Sleep Genius works by delivering several slumber-inducing stimuli, which include sounds that simulate the vestibular system, stereo-beating pulses that synchronize the brain's cortex throughout the sleep cycle, and calming sounds to lower heart and breathing rates. The stimuli are mixed into classical music tracks composed by T-Mobile ringtone creator Lance Massey.



## PSYCHOACOUSTIC MUSIC



# Liquid Cooling Technology Increases Exercise Efficiency

## NASA Technology

The human body in space is as vulnerable as a fish out of water. Beyond a spacecraft's protective environment, there is no oxygen to breathe and nothing to shield you from the sun's searing heat and radiation. And just as disturbing, the lack of air pressure means your body suffers from rapid decompression symptoms and eventual death.

Enter all that stands between an astronaut and such a bleak prognosis: the spacesuit. Also called an Extravehicular Mobility Unit, or EMU, the spacesuit is a convergence of technologies designed to provide a breathable and otherwise livable temporary microclimate. Because of the sometimes hours-long projects undertaken outside the spacecraft, there's even a "drink bag" for when thirst calls, and an extra-absorbent undergarment for when nature does.

Another critical requirement for a spacesuit is controlling the heat and humidity generated by the human inside the airtight outfit. In the mid-1960s, NASA adopted for the Apollo lunar suits a concept originally developed by the British Royal Air Force to provide cooling for aircraft pilots in hot environments. It utilized a battery-operated miniature pump that cycled chilled water through a series of tubes lining the garment, which pressed against the skin, absorbing heat. An iteration of this liquid cooling technology is still used by astronauts today.

Starting in the late 1960s, a team of scientists and engineers at NASA Ames Research Center investigated the physiological effects of a wide variety of artificial cooling concepts. Many of these were subsequently commercially developed and applied to solve various industrial, military, and medical problems on Earth. One

such application now helps athletes and active people recuperate from injuries.

## Technology Transfer

When someone sprains his or her knee or ankle, the RICE (rest, ice, compression, and elevation) method is standard protocol for treating such an injury. Icing plays a critical role in reducing pain and swelling, but applying ice for too long or with too cold a compress can cause more tissue damage.

In 1997 William Elkins, an engineer who had worked with the NASA Ames team, and Peter Wasowski, a veteran in the medical device industry, co-founded CoolSystems (now Game Ready) to bring to market a device—consisting of ergonomic wraps connected to a control unit—that delivers optimal amounts of pressure and cold to speed up recovery (*Spinoff* 2004). Professional athletes, therapy centers, and athletic trainers around the world now use the technology.

While Elkins used the NASA-derived liquid cooling garment to help heal injuries, Wasowski utilized the concept of cooling the body and combined it with another innovation that helps people perform anaerobic exercise.

The benefits of anaerobic exercise are many, as it builds muscles and strength, burns fat, increases anabolic hormones (human growth hormone, testosterone), continues the burning of calories after exercise through excess post-oxygen consumption, and enhances endurance by increasing lactate threshold and maximal oxygen consumption, or  $VO_2$  max. According to Wasowski, these benefits are superior to those offered by aerobic exercise.

The problem, however, is that many people cannot reap the benefits afforded by anaerobic activity because the exercise traditionally requires heavy weightlifting or high-intensity interval training, such as hard sprinting. "This is especially true for the elderly, injured clients going through physical therapy, and the inactive people who either can't or won't exercise," he adds.



NASA astronaut Mike Hopkins works to change out a faulty water pump outside the International Space Station in December 2013. To dissipate body heat that accumulates in his spacesuit, an undergarment circulates chilled water through tubes pressed against his entire body.



Wasowski has developed a system he says helps people overcome those barriers, and it started in the late 1990s when he discovered a technique called vascular compression. The basic idea is that adding compression to arm and leg muscles during exercise accelerates the activation of the body's fast-twitch muscles and hastens the buildup of lactic acid, thereby placing the muscles in an anaerobic exercise state.

Utilizing that theory, Wasowski developed his own compression cuffs that also incorporate the NASA-derived liquid cooling technology, which, in addition to increasing one's exercise efficiency, also helps to reduce sweat and post-workout aches and tiredness. After integrating the device into a specialized workout routine, in 2009 Wasowski founded San Jose, California-based Vasper Systems California LLC to deliver the technology,

### Benefits

A Vasper session takes only 30 minutes to complete, which reflects, Wasowski says, the efficiency of the technologies built into it. Once the liquid-cooled compression cuffs are on the arms and thighs, along with a cooling vest strapped to the chest, the workout commences on a recumbent elliptical specially set according to ability. The program follows

principles of interval training: a warm-up period followed by short sprints interspersed with short recovery periods. In total, the session demands only 20 minutes of actual exercise. Following the regimen are 10 minutes of decompression, accomplished by lying face-up on a cooling mat.

Despite its brevity, Wasowski says, thanks to the cooling cuffs, the program can produce results similar to other exercises that take longer than an hour to complete. The low-impact nature of the Vasper exercise protocol also leads to decreased wear and tear on the body compared to more physically strenuous routines. That also means the typical delayed muscled soreness that frequently comes after exercise is avoided. This makes the Vasper program

highly accessible to those recovering from injury or vulnerable due to age or disease.

Vasper currently has locations in San Jose and Honolulu, and Wasowski says the reception has been very positive from people of all backgrounds and abilities, from Olympic athletes and Ironman triathlon competitors to exercise physiologists and senior citizens. The cool compression technology's effects on other health outcomes are also being explored, for instance, on those who suffer from Parkinson's disease and multiple sclerosis, and for patients undergoing cardiac rehabilitation. Other research is being done to see if people suffering from post-traumatic stress disorder, traumatic brain injuries, and concussions would benefit from Vasper, the idea being that the benefits of anaerobic exercise may restore balances in the brain's chemistry.

And it all began with regulating an astronaut's body temperature in space. "The idea of cooling the human body has made quite a journey," Wasowski says. "It's wonderful how it's found a critical use back on Earth in helping people lead healthier lives while helping others compete at the highest levels in sports." ❖

Patrick Marleau, a Canadian professional hockey player and two-time Olympic gold medalist, completes a Vasper session. The exercise regimen uses NASA-derived liquid cooling technology to concentrate both lactic acid and oxygenated blood in the muscles, which is said to improve workout efficiency and reduce recovery time.



# Algae-Derived Dietary Ingredients Nourish Animals

## NASA Technology

Algae-based food ingredients pioneered by NASA-sponsored research in the early 1980s revolutionized the infant formula industry a decade later and have subsequently appeared in a host of dietary supplements for humans of all ages, but these products have also, more quietly, found their way into animal food products over the years.

Columbia, Maryland-based Martek Biosciences Corporation, the same company that in the mid-1990s introduced the world to Formulaid—a NASA spinoff that is now included in nearly all US infant formulas and those in more than 75 other countries (*Spinoff* 1996, 2008)—began offering a similar product a few years later called DHAgold, intended as an ingredient in farm animal and aquaculture feed. DHAgold has since been marketed to pet food companies as well.

Long-chain omega-3 fatty acids are found in high concentrations in many microalgae, which have been around the bottom of the food chain since the early days of life on Earth. One of these, docosahexaenoic acid, commonly known as DHA, is essential for proper neuron functioning and makes up most of the fat in the brain and retina. This became one of the two omega-3 fatty acids in Formulaid and is the active ingredient in DHAgold.

Martek pioneered the application of algae as a source of omega-3 fatty acids as a result of a partnership with NASA. The company's founders worked with Ames Research Center in the early 1980s to study the possible use of single-celled algae for food supply, oxygen generation, and waste disposal in the agency's Closed Environment Life Support System (CELSS), a self-sustaining domicile intended to support crews in space for extended periods of time. As it does in nature, microalgae, which also produces about half the atmospheric oxygen on earth, would complete the food-waste loop.



DHAgold is made from dried algae cells, which contain docosahexaenoic acid, commonly known as DHA, a long-chain omega-3 fatty acid essential for proper neuron functioning. The product is intended to be incorporated into animal food. Chickens fed on a diet of DHAgold produce DHA-rich eggs for human consumption.

## Technology Transfer

After the program, Martek scientists continued to build on the research they'd done for NASA and hit on a species, *cryptocodium cohnii*, that produces high levels of DHA. To create Formulaid, the company extracted the oil from the algae cells and combined it with another fatty acid, arachidonic acid, taken from a species of fungus. Both are found in human breast milk but were not in most baby formulas at the time. Martek then discovered, developed, and commercialized a different strain of algae, *Schizochytrium*, to make DHA-rich oils for human nutritional supplement and food and beverage applications. DHA omega-3 oil from this algae is now used in more than 500 human products, and *Schizochytrium* algae is also used to produce DHAgold for animal feed applications. To make DHAgold, the algae cells are dried intact and formulated into the product, which makes it less expensive to produce. When the animal digests it, the lipids in the cells are released and become bioavailable.

By the time it was inducted into the Space Foundation's Space Technology Hall of Fame in 2009, Martek had more than 500 employees and annual revenues of more than \$270 million. In 2011 Dutch-based Royal DSM spent more than \$1 billion to purchase Martek, which, as the DSM Nutritional

Products Division, continues to manufacture many of the same products. It has retained its offices in Maryland, and one of the founders and former CELSS researchers is still with the company as director of physiology.

## Benefits

Martek's omega-3 fatty acid-delivery products proved popular because a growing body of research has confirmed their health benefits. The long-chain fatty acids are what Christian Martin, global category manager for aquaculture at DSM, calls "functionally conserved nutrients," meaning they serve similar purposes across species.

DHA, for example, is essential to brain and eye development in babies and contributes to brain, eye, and heart health over the entire lifespan. In humans, DHA has been credited with positive effects on maladies from hypertension and arthritis to cancer and adult-onset diabetes, in addition to more neuron-related





DHAgold can replace fish oil in aquaculture feed. A goal of fish farming is to slow the depletion of the seas' fish populations, but using fish oil in the feed undermines that aim.

complications, such as Alzheimer's disease, attention deficit disorder, and depression.

When DHAgold is incorporated into chicken feed, Martin says, the nutrient is delivered to humans indirectly, via DHA-enriched eggs. When it's fed to pigs or fish, it accumulates in the animals' flesh, which is then eaten by consumers. At the same time, he says, it also has positive health effects such as increased piglet viability.

Growing concerns about overfishing, together with Americans' changing attitudes toward their pets and increasing awareness of DHA health benefits, have contributed to the product's growing popularity, says Martin.

Fish have long been considered a source of DHA, as well as the omega-3 fatty acid eicosapentaenoic acid, but this is because fish either feed off of algae directly or feed on organisms that have an algae-based diet. "We're going directly to the source of DHA—algae—instead of having to follow this important fatty acid through bioaccumula-

tion and successive biomagnification events in our oceans," Martin says. As concerns about overfishing increase, this distinction becomes more important.

He notes that fish oil, the product frequently found in nutritional supplements and aquaculture feeds, is typically high in DHA and is extracted from wild fish caught in the world's oceans. "Right now, there is a static world supply of fish oil," he says, pegging that supply at about 1 million metric tons. Meanwhile, he says, demand for the omega-3 fatty acids contained in fish oil, for human, animal, and aquaculture consumption, continues to rise. "There's a need for an alternate supply for the animal nutrition industry, and that's where DHAgold and DSM's algal production technology comes in."

Aquaculture, the practice of farming fish, is supposed to be a solution to overfishing, but this industry, too, relies on fish meal and fish oil in its feeds. Nonetheless, aquaculture remains the most efficient way to convert feed into

edible protein. For these reasons, in 2007 the National Oceanic and Atmospheric Administration (NOAA), together with the US Department of Agriculture (USDA), launched the NOAA-USDA Alternative Feeds Initiative, aimed at reducing the use of fish products in aquaculture feeds. One alternative way to provide feed rich in omega-3 fatty acids that the initiative is exploring is the use of algae.

The algae for DHAgold and other DSM products are raised in a closed, controlled environment and fed on a few basic nutrients without disrupting the larger ecosystem, "so it doesn't draw from or negatively impact the food supplies of humans or other species," Martin says.

Meanwhile, as businesses like dog spas and pet health insurance proliferate, Martek started marketing the DHAgold supplement to pet food producers in the mid-2000s.

"Pets are now much more part of the family compared to a few decades ago," Martin says. "People often want the same for their pets as they would want for themselves." He says studies have proven that DHA consumption boosts puppy trainability and memory and visual performance in older dogs.

The product has been incorporated into a number of pet foods and supplements, and even a pet food seasoning.

While a few other companies have begun marketing DHA and other omega-3 fatty acids as animal supplements, Martin says, "One area we are very proud of is, we invented this algal omega-3 production technology. It's exciting to continue development of our algal production platforms and explore new applications of this technology, while adding to DSM's global reach and larger research base. The core pioneering technologies established at Martek and further advanced by DSM may be looked to in the future to address some of the world's omega-3 supply needs." ❖



# Space Grant Research Launches Rehabilitation Chair

## NASA Technology

Stay on the International Space Station is no vacation. During a visit to the orbiting National Laboratory, astronauts divide their time among a variety of tasks. For one, they look after a multitude of space-based science experiments. For another, they clean and check the station's equipment—inside and out. They also spend a significant amount of time doing something you might not expect: exercising.

In microgravity, astronauts' bodies do not have to work like they do on Earth to move and accomplish normal daily tasks. Without the force of gravity acting on their bodies every moment of the day, astronauts' bones lose density in space at a rate 10 times faster than those who suffer from osteoporosis. To stay healthy and keep their bones strong, astronauts spend a considerable amount of time working out while in orbit.

## Technology Transfer

In 2000, a biomedical engineering student at Michigan Technological University, Jeff Leismer, became particularly interested in this issue of bone loss in microgravity. He was taking a class called Aerospace Physiology and Bone Remodeling, taught by Dr. William Harold Cooke.

"The skeleton loses about 1 percent of bone mass per month in space," says Cooke, now in the Department of Health and Kinesiology at the University of Texas at San Antonio. "At Michigan Tech, we had an idea to develop something to simulate impact to the body so the bone wouldn't decrease as much in space."

Leismer says he began looking closely at mechanical vibration as a possible solution. At the time, a study had found that vibration could stimulate bone growth in animals. The researchers suggested that vibration fooled the bones into thinking they were working hard, resulting in the retention and growth of bone.



Japan Aerospace Exploration Agency astronaut Koichi Wakata, Expedition 38 flight engineer, gets a workout on the advanced Resistive Exercise Device in the Tranquility node of the International Space Station. Intense exercise regimens are a necessary part of life in microgravity to maintain bone and muscle mass.

"How then, do we apply vibration to the weight-bearing components of the human body, which are the ones most affected by bone disuse atrophy?" asked Leismer.

To begin answering his question, Leismer began his graduate thesis research, with Cooke serving as advisor. Cooke had received funding from the Michigan Space

Grant Consortium, part of the National Space Grant College and Fellowship Program, which was implemented by NASA in 1989 to fund research, education, and public service projects through a network of university-based Space Grant consortia.

Working with Space Grant funding under Cooke's purview, Leismer built a prototype vibration-based system that could apply compressive loads from the heel to knee, heel to the waist, and heel to the shoulders to strengthen bone, just like a weight-bearing exercise would.

When it came time to test the system, Leismer decided to try it out. After about 10 minutes on the device, he attempted to stand, but nearly fell down. "It felt like I did about 1,000 leg presses. I realized then that it wasn't just affecting bone; it was affecting muscle as well. That was my 'Ah-ha' moment, and I knew I'd better apply for a patent," he says. "The technology was something much bigger than I'd thought it was going to be."

From Michigan Tech, Leismer went to the University of Florida to work with other bone researchers and to make sure his treatment device wasn't going to create any safety concerns. After completing his doctoral work, he received funding from the National Institutes of Health and, three years later, started selling the device.

"The work under Cooke was the inspiration for this product," says Leismer, now the founder and chief technology officer of Sheboygan, Wisconsin-based VibeTech. "I started this over 10 years ago, and now we are making it a commercial product."

## Benefits

Named VibeTech One, Leismer's rehabilitation chair uses a biomimetic approach to therapy, meaning it uses human-made means to mimic something that happens naturally. In this case, the chair uses vibration to simulate load-bearing exercise, which elicits muscle contractions in the body. The body then responds in a manner similar to the way it would respond to weight-bearing physical activity, and the bones and muscles are strengthened.

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“ Exercise is the number-one thing you should do, but patients don’t do it because of barriers including exertion, pain, and flexibility. I am hoping this will help people lead a much higher quality of life—and hopefully live longer as well.”

— Jeff Leismer, VibeTech

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According to the company, the treatment has two parts: partial bodyweight loading and muscle vibration. The adjustable partial bodyweight loading simulates forces acting on the legs during standing and walking while also preparing the legs for the muscle vibration, which is recommended for up to 10 minutes at a time, three to five times a week.

One of the main advantages of the VibeTech One is that it does not require any physical exertion. As a rehabilitation chair, it can be used by people who have little or no physical strength or function from their heels to their lower back. They can simply sit and relax as the therapy takes place.

“We are providing treatment to put the mechanical signals into the body that it needs to stay strong—even during a period of inactivity. It’s for anyone suffering from disuse atrophy and functional decline due to age, disability, illness, injury, or surgery,” says Leismer. “In a rehabilitation environment, our goal is to get people up and out of wheelchairs and walking independently.”

After a patient becomes strong enough, a setting on the device can be adjusted to require more effort from the patient. “You can choose anywhere from 0 to 100 percent effort from the user. They can do leg presses against the machine if they want, or the device itself can provide all of the work,” says Leismer.

The first commercial application of the technology will be in the rehabilitation department of a skilled nursing facility. Another place where the product will likely find beneficial applications, however, is sports

medicine, where the chair can be used to reduce muscle atrophy while keeping the joints limber after an injury or surgery. Already, a prototype in a hospital has shown success in treating patients with ankle sprains, hamstring sprains, and pelvic fractures. Anecdotal evidence reports that the technology has provided the added benefit of reducing pain for these patients as well.

Currently designed for the lower extremities, the device could potentially be used on any part of the body, explains Leismer. “Our treatment provides dynamic motion in a form that replicates natural biomechanical

signaling in the body. Although we haven’t tested all of these areas yet, we fully anticipate that they will be positively influenced by treatment.”

With high hopes for the future, Leismer suggests the technology could be a new solution for getting people to exercise. “Exercise is the number-one thing you should do, but patients don’t do it because of barriers including exertion, pain, and flexibility,” he says. “I am hoping this will help people lead a much higher quality of life—and hopefully live longer as well.” ❖



The VibeTech One rehabilitation chair can be used by people who have little or no physical strength or function in their lower body. Users can sit and relax as the therapy progresses.



# Vision Trainer Teaches Focusing Techniques at Home

## NASA Technology

Inventions often find unintended uses. The first mechanical clocks in Europe were intended to track the motions of celestial bodies and found their original market among monks who kept a strict prayer schedule. A mixture invented by ancient Chinese alchemists was used to fumigate insects and treat skin diseases before it became gunpowder.

When NASA's Ames Research Center contracted Stanford Research Institute in the 1960s to develop a means of objectively measuring pilots' ability to adapt their vision to different distances, known as visual accommodation, the agency was not considering a biofeedback device that could teach users to control their eye focus—much less a system that could improve sensory and motor processes, as well as attention, creativity, and learning, by inducing an “alpha brain-wave state.”

To be fair, unlike gunpowder skin treatment, the highly accurate eye position tracker that Stanford investigators Hewitt Crane and Thomas Cornsweet built in 1968—the world's first automatic, objective optometer—was inarguably valuable in its intended capacity. An objective optometer, more commonly called an autorefractor, determines the power and range of your vision every time you watch the little barn at the end of the road go in and out of focus in the machine at the optometrist's office.

However, as Robert Randle, human factors engineer and NASA's technical monitor of the Stanford Research Institute contract, ran experiments on pilots using the optometer, he discovered that his subjects were often able to control their normally involuntary eye focus. To help them gain focal control, he incorporated auditory biofeedback, whereby the machine produced different tones depending on the contraction or relaxation of the

ciliary muscle, the eye's focusing mechanism, and carried out experiments in which many subjects succeeded in gaining control of the muscle. He considered the device a potential means to overcome “empty-field myopia,” the tendency for a pilot's focus, in empty skies, to rest at a distance of half a meter to a meter away, rather than scanning the sky ahead.

Randle presented his first papers on the subject in 1970, and Crane and Cornsweet soon published a study confirming NASA's results, using a different type of biofeedback.

Although NASA didn't develop the device any further as a treatment for empty-field myopia and has done little research on the subject since the 1980s, the Ames project inspired a recent invention that brings a modern biofeedback device into the homes of individual consumers.

## Technology Transfer

Having earned multiple optometry and vision degrees, Joseph Trachtman was doing doctoral studies in experimental psychology when he heard of the NASA and Stanford research. After studying Randle's papers and the reports by Crane and Cornsweet, he decided that the same biofeedback technique might be used as a way to treat nearsightedness without resorting to corrective lenses.

Following his doctoral dissertation on the subject, Trachtman built an optometer that included an audio biofeedback function, based on the Stanford scientists' invention and the studies conducted at Ames. After seven more years of research and development to refine the device, Trachtman released the NASA-inspired Accommotrac Vision Trainer in 1984 (*Spinoff* 1990).

The device has not been shown to correct nearsightedness, but it has won acclaim as a way to gain control over visual focus, with many users also reporting some unexpected additional benefits.

The optometer that Stanford researchers created for Ames Research Center in 1968, and which Joseph Trachtman has based his inventions on, was originally intended to objectively measure pilots' visual accommodation as NASA tried to combat “empty-field myopia”—the tendency for a pilot's focus to rest on a spot a meter or two away when confronted with an empty sky.



Trachtman sold about 200 of the machines in the United States and 200 more abroad, he says.

He wanted to build a more affordable version for individual consumers, but he says he first had to wait for the technology to get sufficiently advanced, small, and inexpensive. For example, the original device replaced the NASA model's infrared sensor with a charged coupled device, which alone ran \$700 in the 1980s. Now, electro-optical technology costing \$20 can serve the same function, and new light-emitting diodes in the low-infrared range eliminate the need for laser-quality lenses.

With this new technology, Trachtman, whose practice is in Seattle, was finally able to build an affordable home version of the device. The Zone-Trac was released in February 2014.

## Benefits

For the most part, the original Accommotrac Vision Trainer units went to the offices of optometrists like Dr. Sanford Cohen, who purchased one for his Silver Spring, Maryland office in the mid-1980s, shortly after it was released.

"The instrument is very effective for the purpose of improving focal control," Cohen says, noting that he was able to teach most of the patients who used the device to gain control over their visual focus. He said he also found the device to be valuable in the treatment of nystagmus—rapid, uncontrollable movements of the eyes, which can affect vision. "I can very easily teach someone, if they can learn biofeedback, to slow the oscillation."

Trachtman claims about a 90 percent success rate for his invention in correcting, improving or stopping focusing problems.

"The trick is, you have to be able to gain control over a mechanism that you've never been able to control, so not everybody can get biofeedback," Cohen says. "You really have to tap into something. It's just tapping into a different thinking pattern. I've never really been able to tell a person how to do it."

He notes that this challenge is common to any biofeedback training.

That "tapping into something" has become one of Trachtman's selling points for the new Zone-Trac.

Thirty years after the release of his Accommotrac Vision Trainer, Joseph Trachtman, pictured here, released a home version of the device, called the Zone-Trac. Advances in technology made it possible for Trachtman to build a much smaller, wearable, and more affordable device.



Over the years, Trachtman and others who have used the machine in their practices say they have had patients, especially athletes and military service members, report unexpected side effects, such as a widening of the field of vision, seeing in slow motion, intensified color perception, and increased hand-eye coordination and reaction times, which lingered after the treatment.

Trachtman says Navy pilots at the Naval Branch Health Clinic in Pensacola, where he had one of his vision trainers, referred to "streaming, which is parallel processing, so they can see everything on the control panel and the aircraft carrier at the same time."

He began measuring quantifiable data, such as reaction time, hand-eye coordination, color perception, visual acuity, muscle relaxation, and finger warmth, which also indicates relaxation, and found that all were heightened by use of the machine. He also measured brain waves.

"When you take control of the focusing muscle of the eye, there's a dramatic change in brain waves, particularly one wave, called the alpha brain wave," Trachtman says, noting that these are the same waves emitted by practitioners of meditation. "It was not what I had in mind when I built it, but it explains all the changes we see."

He says he's also found the devices helpful for students who have difficulty concentrating and is now using them to treat military veterans with post-traumatic stress disorder, whom he offers free sessions. After they slip into a relaxed state, they are asked to revisit a traumatic incident and associate it with the tranquility they're experiencing.

Cohen says he believes Trachtman's new home system will prove beneficial, as the training he offered his patients with the original device included practicing at home, imagining the tone of the machine and recalling the sensation that came with controlling it.

Trachtman began selling the Zone-Trac for \$1,750, and after the first month and a half, he had sold most of the first batch of 10.

"What we're hoping to do is get enough sales to have the credibility to go to investors so we could make it even smaller, so we could mass produce it, and that would get the technology down to about \$300–\$500 per unit," says Trachtman. ❖





# Transportation

NASA is best known for its audacious forays into the void beyond Earth's atmosphere, but "aeronautics" comes before "space" in the agency's name, and from its inception NASA has worked continuously to advance air travel for all Americans. Its endeavors have contributed directly to aircraft fuel efficiency, noise reduction, and safety and have also improved air traffic control.



# Aircraft Geared Architecture Reduces Fuel Cost and Noise

## NASA Technology

Just 12 years after the Wright brothers became the first to take to the skies in a powered airplane, in 1915 Congress established the National Advisory Committee for Aeronautics to advance aviation. In 1958 the agency was dissolved in order to transfer aeronautics research to NASA, where space exploration would steal much of the limelight, beginning with the space race with the Soviet Union throughout the 1960s and '70s, followed by the Space Shuttle Program's ascendance in the 1980s.

Yet throughout all those years the agency has never wavered in its commitment to also advance air travel. NASA has worked hand-in-hand with industry to better commercial flight safety and efficiency, from advancing aircraft body components that increase fuel efficiency to developing software that helps air traffic controllers better monitor and direct airspace.

In the mid-2000s, as the nation grappled with spiking gas prices, NASA established the Subsonic Fixed Wing Project, aimed at helping the private sector advance fuel efficiency and noise-reduction technologies. To do so, the agency would partner with an aerospace company to finish its years-long work on a single, game-changing technology that would accomplish both goals. Collaborating with the agency would provide the extra lift needed to propel the device onto the commercial market.

## Technology Transfer

Pratt & Whitney, a company within United Technologies Corporation, has long been a leading aircraft engine manufacturer. Founded by Frederick Rentschler in 1925, the East Hartford, Connecticut-based firm first came to prominence by developing the Wasp family of piston-powered engines, which were cooled by air rather than water. The result was a significant increase in efficiency and reliability during flight. In the 1950s Pratt & Whitney helped to usher in the age of the

modern jet engine with its revolutionary J57 Turbojet, which was the first to achieve 10,000 pounds of thrust.

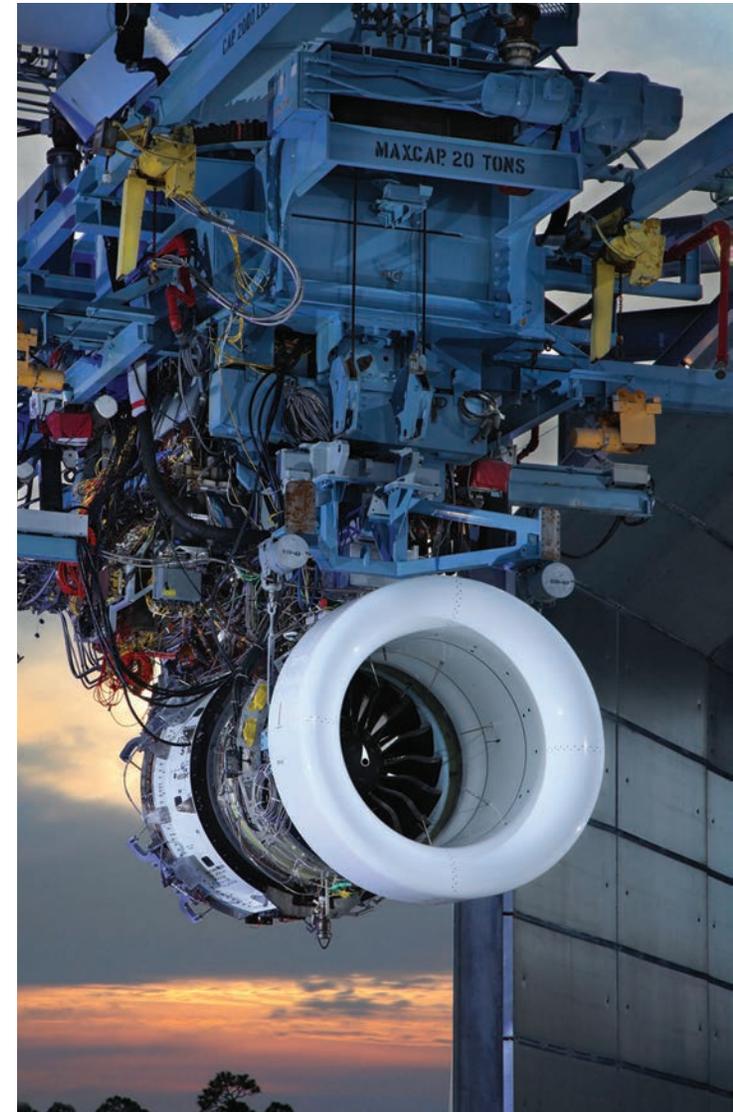
In keeping with its record of innovation, in the late 1990s the company started investing considerable time and money into finding a solution to a long-known inefficiency in turbofan engines.

Powering virtually all commercial aircraft today, turbofans generate thrust by drawing in air at the front with a fan. While most of the air goes around the engine, some passes through it, drawn in by a compressor comprising many blades attached to a shaft. The compressor pressurizes the air, greatly increasing its temperature. The hot air is then forced into a combustion chamber where it's sprayed with fuel and ignited, resulting in hot, high-pressure gas that, as it expands, spins a turbine before blasting out of the nozzle at the rear of the engine, thrusting the aircraft forward. Because all the engine's components are connected through a central shaft, a rotating turbine not only drives the low-pressure compressor but also spins the fan, providing additional thrust.

Now for what Pratt & Whitney chief engineer Michael Winter calls "the paradox" of modern turbofan engine design: fans are more efficient the slower they spin, whereas turbines become more efficient as they spin faster. "And the problem was that the two components have always been attached to the same shaft, so they have to spin at the same speed," Winter says. "We wanted to introduce a gearbox that would allow the fan and turbine to spin at their optimum speeds, the effect being greater fuel efficiency and noise reduction."

NASA and Pratt & Whitney had worked together on numerous projects throughout the years, including the development of fuel-efficient, low-pressure-ratio fans through the agency's Advanced Subsonic Technology program in the 1990s. (NASA was the first to develop such fans under its Quiet, Clean, Short-Haul Experimental Engine program in the 1970s.)

The gearbox presented yet another opportunity for collaboration. In 2005 the two entered into a Space Act



In collaboration with NASA, Pratt & Whitney developed its PurePower family of turbofan engines, which are more fuel-efficient and quieter than other commercial models. Here, the PurePower 1217G engine, developed for Mitsubishi Regional Jet aircraft, undergoes ground testing in West Palm Beach, Florida.



Pratt & Whitney's PurePower PW1217G engine on its first test flight over Montreal, Canada. Engines in the PurePower family release 3,000 fewer tons of carbon dioxide into the atmosphere each year while saving airlines roughly \$1.5 million in annual fuel costs.

Agreement, which allowed the company access to the agency's aeronautical experts as well as to NASA facilities, including the use of Glenn Research Center's 9-by-15-foot Low-Speed Wind Tunnel, ice tunnels, and combustion facilities. In 2010 another NASA program, the Environmentally Responsible Aviation (ERA) Project, which also has goals of improving fuel efficiency through noise and emissions reduction, provided additional funding and engine testing.

After several years spent refining and testing the gearbox's lubrication system, alignment, and overall efficiency to withstand more than 30,000 horsepower, in 2010 the full engine was ready for testing. Transport Canada certified the engine in February 2013, and Pratt & Whitney brought to market the PurePower Geared Turbofan (GTF) family of engines, designed for use in regional and single-aisle aircraft, and to date has more than 5,500 PurePower engine orders and commitments, including options, from more than 50 global customers.

## Benefits

Over the 60 years that jet engines have been used on commercial flights, fuel-burn efficiency has improved at 1 to 1.5 percent every year, says Pratt & Whitney's Winter. "The GTF engine, in one fell swoop, improves efficiency by over 15 percent." The drastic increase is made possible by the engine's turbine and fan spinning at more optimal speeds, and by increasing the bypass ratio. In other words, incoming air is being routed around rather than through the engine, which adds thrust to the aircraft without burning extra fuel.

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“ The GTF engine, in one fell swoop, improves efficiency by over 15 percent.”

— Michael Winter, Pratt & Whitney

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The reduction in fuel consumption per aircraft each year, Winter notes, translates to 3,000 fewer tons of carbon dioxide (CO<sub>2</sub>) released into the atmosphere, "comparable to the amount of CO<sub>2</sub> displaced by 900,000 trees in the same amount of time." Nitrogen oxide, a major greenhouse gas and air pollutant, is also reduced to 50 percent below the most rigorous standard set by the United Nations' International Civil Aviation Organization.

Decreased fuel consumption benefits not only the environment but also commercial airlines' pocketbooks. "Fuel savings with this technology comes to about \$1.5 million per aircraft every year," Winter says. "It's a key reason for why we've already sold over 5,500 GTF engines to major and regional airline companies all over the world."

Another main benefit is noise reduction. The annoying whine and piercing roar from current engines during takeoff have been reduced by slowing the velocity of the exhaust gases exiting the engine and reducing the fan rotation speed. Fan blades typically run at supersonic

tip speeds, creating loud tones. The company has slowed the fan blades in its GTF to where the noise footprint has been reduced by up to 75 percent. Not only will the decreased noise pollution benefit communities situated near airports and flight routes; air travel could become more flexible and efficient. Airports will be able to consider longer operational hours, and flight routes designed for noise abatement around intercity airports can be replaced with more direct routes.

In the coming years, other GTF engine models will offer even greater fuel-burn efficiency and noise reduction, thanks to the ongoing ERA project collaboration between the company and NASA. A third partner, the Federal Aviation Administration, is also providing funding and guidance through its Continuous Lower Energy, Emissions, and Noise program. "We're working together to improve all elements of the engine, from the fan and compressor to the combustor and turbine, and even some of the external flow around the nacelle," Winter says, referring to the housing that holds the engine's components.

Fay Collier, project manager for the ERA program, believes the joint effort has been—and will continue to be—a success. "I've been working with the company for 10 years, and it's been a very reliable and productive partnership," he says. "I'm looking forward to helping the company push the envelope in the aviation sector even further."

Winter says the agency's role in advancing commercial air transport cannot be underestimated. "The first A in NASA stands for aeronautics, and the agency brings world-class researchers and facilities to the table. It's a tremendous resource for the industry and the nation." ♦



# Ubiquitous Supercritical Wing Design Cuts Billions in Fuel Costs

## NASA Technology

By the time he was visiting what is now known as Armstrong Flight Research Center to witness the first tests of his latest creation, Richard T. Whitcomb was already something of a star in the aviation world. Sixteen years earlier, this Langley Research Center aeronautics engineer had received the 1954 National Aeronautic Association's Collier Trophy, considered the most prestigious honor in aviation, for doing more than any other single person to overcome the aviation challenge of the day—the so-called sound barrier. He'd been 34 at the time.

However, he was still working to improve flight efficiency at speeds approaching that barrier, now with a seemingly counterintuitive wing design, almost the inverse of what were then conventional wings. He called it the “supercritical” airfoil.

Later dubbed “the man who could see air” by the Smithsonian's *Air and Space Magazine*, Whitcomb took an unconventional approach to aerodynamics, eschewing calculations in preference of visualization and intuition.

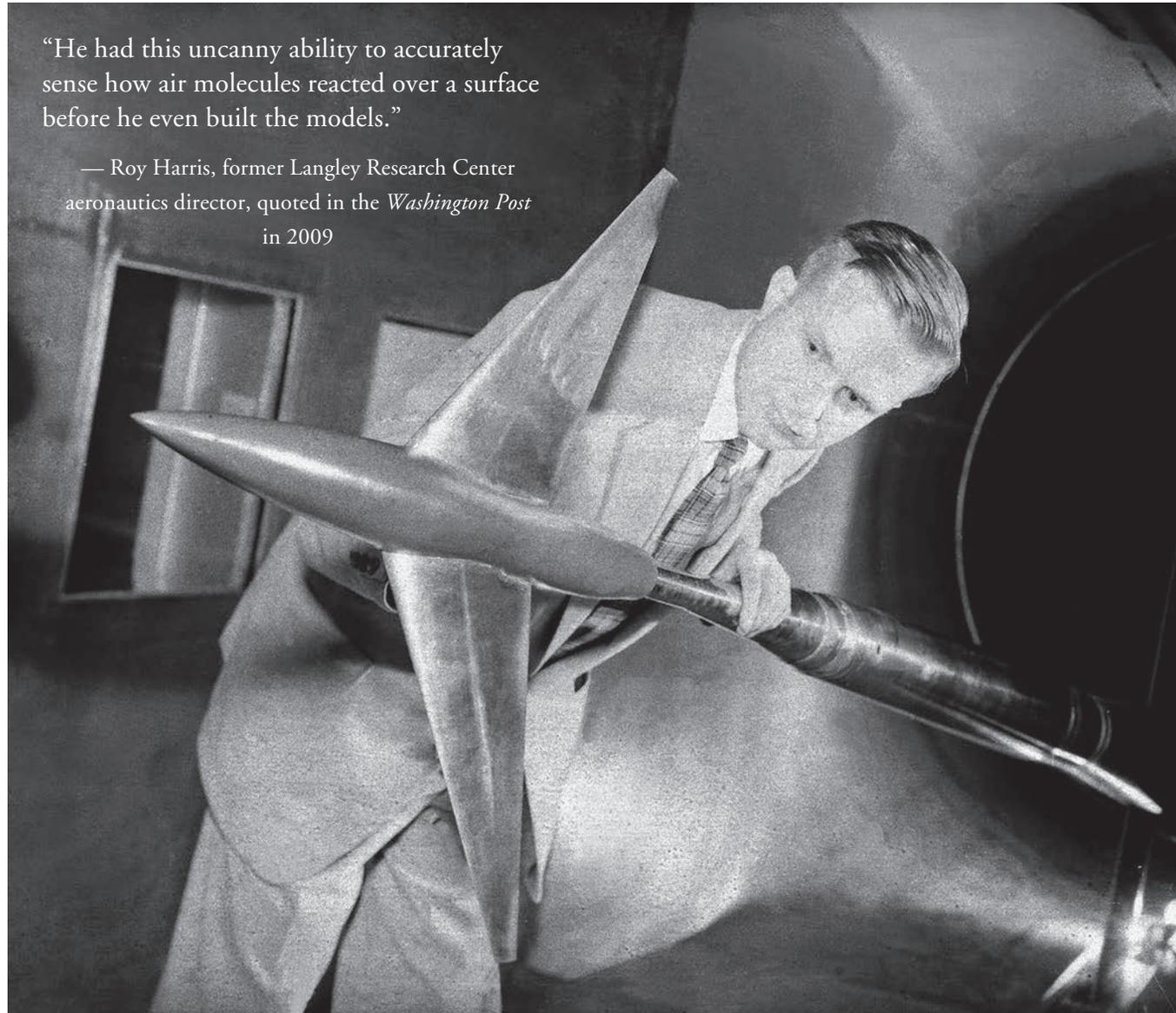
“Most people have to see through testing how air moves on a model,” Roy Harris, former aeronautics director at Langley, told the *Washington Post* in Whitcomb's 2009 obituary. “But he had this uncanny ability to accurately sense how air molecules reacted over a surface before he even built the models.”

Indeed, he hadn't been calculating or even observing wind tunnel tests when he had the insight that earned him the Collier Trophy. Now known as the “area rule,” this is the idea that a fuselage that tapers where the wings are attached can pass the speed of sound more easily than the traditional bullet shape. By his own accounts, he'd been sitting at his desk, chain smoking and imagining wind as pipelines sweeping over the surface of his model when the idea hit him.

In the early 1960s, after several years of work on designing a Mach 2-rated jet—that is, one that could fly

“He had this uncanny ability to accurately sense how air molecules reacted over a surface before he even built the models.”

— Roy Harris, former Langley Research Center aeronautics director, quoted in the *Washington Post* in 2009



The supercritical wing was one of three major contributions Langley Research Center engineer Richard Whitcomb made to aeronautics. An eccentric who seemed most at home in the center's wind tunnel facilities, where he was known to sometimes sleep between double shifts, Whitcomb tended to prefer intuition to calculation when working out designs.



The first aircraft used to test supercritical wing designs was a modified Vought F-8 Crusader provided by the US Navy.

at double the speed of sound—he became frustrated and returned to the more familiar field of transonics, speeds at or around the speed of sound. His supervisor suggested he research wing characteristics for an aircraft design being studied by the Ling-Temco-Vought Company.

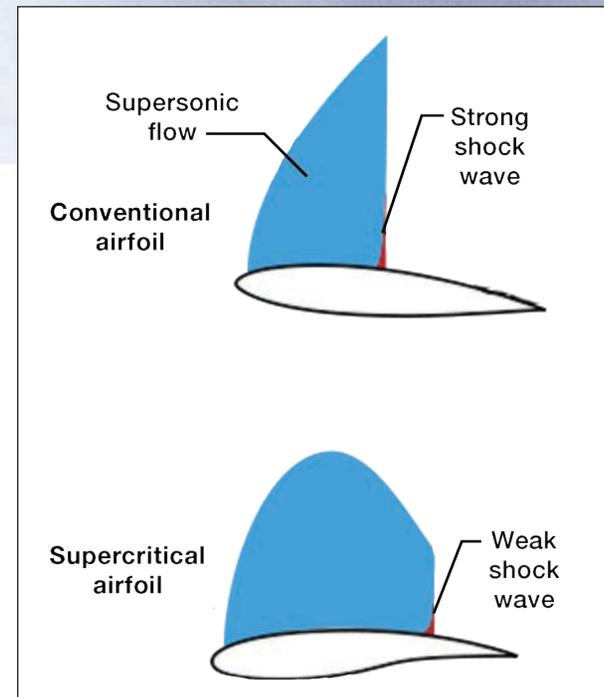
“Though he had a conservative, shy personality, he was a radical in the laboratory,” NASA historian James Hansen wrote of Whitcomb in his history of Langley. “In some respects, management did not know exactly how to deal with him. The best idea any of his supervisors came up with was to leave him alone except to help him through those administrative duties distracting him from what he really wanted to be doing.”

Whitcomb was well aware of the problem the wings needed to overcome to ease flight approaching the speed of sound.

“As an object moves through air, it collides with the air molecules, creating a disturbance that propagates away from the object by means of weak pressure waves—

essentially sound waves,” explains Robert Gregg, chief aerodynamicist for Boeing Commercial Airplanes, headquartered in Renton, Washington. “As the object moves faster, approaching the speed of sound, these disturbances that travel at the speed of sound cannot work their way forward and instead coalesce to form a shock wave.”

That shock wave tends to stand on the aircraft’s wing, creating drag, as the air has to flow over it. This is the sound barrier that aeronautical engineers had struggled to breach. The sound barrier had been broken in 1947, eliminating fears as to what might happen when that difficult threshold was crossed, and Whitcomb’s area rule had made it easier for larger, less powerful aircraft to reach supersonic speeds. However, flying near the speed of sound—around 660 mph at cruising altitudes, depending on air pressure and humidity—remained highly inefficient because of the drag caused by these standing shock waves.



The supercritical wing design is almost the inverse of what was the conventional design when it was invented. Around the speed of sound, the flatter top side minimized the effect of the standing shock wave that formed on the wing, while a downward-curving underside compensated with additional lift.



Because a wing creates lift by accelerating the air moving over it and slowing the air passing under, the air on top of the wing reaches the speed of sound before the aircraft itself does, Gregg explains.

Whitcomb's first insight into a possible supercritical wing design came unexpectedly, when observing an airfoil meant for a vertical-takeoff jet. Air passages between the wing and its flaps appeared to delay the formation of the troublesome shock wave, but Whitcomb decided this slotted design ultimately wouldn't work. With this curtailed shock wave in mind, he returned to the wind tunnel.

Again, instead of running calculations, he started with a conventional wing design and, relying on intuition, used auto body putty to add bulk to some areas while filing away others, testing and re-testing his models in Langley's high-speed wind tunnel.

Obsessed with the aerodynamics of flight since his childhood, Whitcomb had made his parents' basement a workshop for improving the performance of model airplanes throughout his teenage years, and he worked no less obsessively now. He never married, and during the years when he was working on what would become his supercritical wing, he often worked two shifts per day, sleeping on a cot at the high-speed wind tunnel facility, according to coworkers, who said aerodynamics dominated his mind at work and at home.

His nephew, David Whitcomb, told the *New York Times* that NASA accountants scolded his uncle more than once for letting his paychecks expire while he used them as bookmarks.

The initial design for a supercritical wing was produced in 1964, and Whitcomb and his colleagues spent the next five years working through different models and concepts.

What they ended up with almost looked upside-down compared with standard wings of the day, because it was nearly flat on top and rounded on the bottom. It was also thicker than the norm, especially on its blunt leading edge.



NASA-developed supercritical wings save the airline industry billions of dollars' worth of fuel every year, which also means significant reductions to greenhouse gas emissions.

“The low upper-surface curvature weakens the shock wave and, in many cases, moves the location of the shock wave farther aft,” Gregg explains. To compensate for lift lost by flattening the top of the wing, the trailing edge curves downward, especially on the bottom side.

While wind-tunnel testing showed the wing worked more efficiently than standard models, NASA lacked an explanation as to why this was so, since Whitcomb hadn’t arrived at the design by any analytical method. The agency had to contract outside help, in this case mathematician Paul Garabedian and aerodynamicist Anthony Jameson, both from the Courant Institute at New York University, to work with Whitcomb to develop a computational method for designing the wings.

Flight testing at what was then called the NASA Flight Research Center, later renamed Dryden Flight Research Center and now known as Armstrong Flight Research Center, was carried out between 1971 and ’73. The first plane used was a Vought F-8 Crusader provided by the US Navy, outfitted with wings commissioned from Rockwell International’s North American Aircraft Division. The tests showed the supercritical wing increased the F-8’s efficiency near the speed of sound by as much as 15 percent.

Whitcomb’s supercritical wings were a success, and aircraft manufacturers and airlines were paying attention.

## Technology Transfer

NASA presented its test data at a 1972 conference. As industry designers evaluated the data, most commercial companies decided that, rather than use the new wing design to achieve transonic cruising speeds, they would use it to save fuel while continuing to cruise at around Mach 0.8. The Boeing 787, for example, was originally planned to cruise at Mach 0.9, but the company decided to drop that to Mach .85 and take a 20 percent fuel savings over its other two dominant twin-engine models.

It had turned out that the wings were more efficient at subsonic speeds as well.

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““ NASA’s work on managing the sound barrier provided the fundamental understanding of transonic and supersonic aerodynamics, which allowed the development of the aircraft we fly around in today.”

— Robert Gregg, Boeing Commercial Airplanes

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The US Air Force joined NASA for a joint program to test the supercritical wing on the highly maneuverable F-111, with test flights continuing into 1975. Results showed the test wing created up to 30 percent more lift than the conventional wing. This data was made available to the aviation industry at a time when fuel prices were hitting the business hard.

Some of the first commercial firms to incorporate supercritical wing technology into their airliners in the US were Rockwell, Canadair, and Lear. Dassault did likewise in Europe. Today, supercritical wings are used in commercial, business and military aircraft all over the world.

Gregg says all Boeing commercial and military transports use the technology.

## Benefits

“The ability to have a thicker wing as a result of incorporating supercritical wings generally results in a lighter wing,” Gregg says. Because a thicker wing forms a sturdier attachment to the fuselage, it requires less reinforcing structure. The resulting weight savings allows more weight to be spent on either widening wing span or reducing wing sweep, and a wider span brings greater fuel efficiency.

“Because supercritical airfoils enable less-swept, wider wing spans, low-speed maximum lift and low-speed lift-to-drag ratio has improved,” Gregg says. “Improved

maximum lift reduces the speed required to lift off or land, so takeoff and landing field lengths can be reduced. A better lift-to-drag ratio reduces the thrust required to fly at a given speed. These principles apply to any aircraft.”

In 1974, NASA calculated that air carriers worldwide could save a total of about half a billion dollars in fuel by incorporating the technology. That’s almost \$2.4 billion in today’s dollars, but then, there were only around 4,500 airliners flying in the world at that time, according to the Canadian Department of Transport, while Boeing estimated the industry’s global fleet by the end of 2012 at more than 20,000.

“NASA’s work on managing the sound barrier provided the fundamental understanding of transonic and supersonic aerodynamics, which allowed the development of the aircraft we fly around in today,” Gregg says. He notes that 734 million passengers traveled on US carriers in 2012, and \$1.6 trillion worth of freight were transported by air in 2008, adding, “Without the work led by NASA, this would not have been possible.”

And, he adds, whatever is saved in fuel is also saved in carbon dioxide and other greenhouse gas emissions.

Later, in the 1970s, Whitcomb was inspired by an article on birds to refine what he called “winglets”—the small, vertical wings that are now seen on the ends of nearly all airliner wings (*Spinoff* 2010). This innovation saves airlines another 4 to 6 percent in fuel, with comparable reductions in emissions, according to Aviation Partners Boeing.

“Dick Whitcomb’s three biggest innovations have been judged to be some 30 percent of the most significant innovations produced by NASA Langley through its entire history,” Langley chief scientist Dennis Bushnell said in a NASA press release upon Whitcomb’s death. “That’s from its founding in 1917 to the present. He is without a doubt the most distinguished alumnus of the Langley Research Center.” ❖



# Flight Controller Software Protects Lightweight Flexible Aircraft

## NASA Technology

Since its founding in 1958, NASA has made profound contributions to aviation, including advancing our understanding of flight mechanics—the study of forces that affect aircraft in flight—and devising ways to improve aircraft performance.

In keeping with that tradition, in the late 1980s the agency participated in the development of what's known as Robust Control theory. Put simply, the theory aims to provide automated stability to a structure in response to various external forces. An important resulting application is called gain scheduling,

whereby electronic controllers are programmed to apply those split-second changes.

Gain scheduling has proven very important for airplanes, which are susceptible to conditions such as turbulence and other gust disturbances that can damage wings and other critical components. In response to data picked up by onboard sensors, automated controllers are able to direct ailerons (hinged control surfaces attached to wings), rudders, and elevators to shift the plane's

trajectory and prevent structural damage and otherwise improve flight quality for passengers.

In the early 2000s a new type of airliner was drawn up called a lightweight flexible aircraft. True to its name, the plane's body and wings would be made of lighter materials—carbon fiber instead of metal, for example—resulting in drastic reductions of fuel needed for transport and longer flight distances. But reducing a wing's heft also increased susceptibility to a dangerous condition called flutter: uncontrollable vibrations that can cause a wing to break apart.

For lightweight flexible aircraft technology to become viable, NASA advanced what's called Linear Parameter-Varying Control (LPV) theory to account for the aeroelastic conditions that bring about flutter. Now the agency needed new gain scheduling tools capable of applying the theory so that controllers could be programmed to prevent the dangerous occurrence.

In the short term, researchers at Armstrong Flight Research Center would use the technology to synthesize flight control algorithms for an unmanned, lightweight flexible aircraft called the X-56A Multi-Use Technology Testbed (MUTT). Developed by Lockheed Martin initially for the Air Force Research Laboratory, the X-56A MUTT's successful deployment of flutter suppression algorithms would be an important step toward making lightweight flexible aircraft technically feasible.

## Technology Transfer

Founded in the early 1990s, MUSYN Inc. was among the first companies to build on NASA's Robust Control theory research and develop a software program, aptly named the Robust Control Toolbox (distributed by MathWorks), to help manufacturers design controllers



Using MUSYN's LPVTools software toolkit, NASA is synthesizing flight control algorithms for an unmanned, lightweight flexible aircraft called the X-56A Multi-Use Technology Testbed (MUTT). The agency's work with MUTT is an important step toward making such aircraft, which are prone to flutter, technically feasible.

for their aircraft at specific flight conditions. In the late 1990s, when NASA's new theories on flutter suppression arrived on the scene, the firm once again began working on a complementary set of software tools. Development languished until 2010, when the agency put out a call for such a software program to be created.

The company's proposal was met with approval, and later that year NASA and the Minneapolis, Minnesota-based company entered into a Small Business Innovation Research (SBIR) Phase I contract, followed by Phase II funding the following year. "It was an opportunity to finish what we had started," says MUSYN CEO Gary Balas.

Much of MUSYN's work over that two-year period centered on building on the software and theory developed for the Robust Control Toolbox, and overcoming its limitation: It can analyze the flight conditions of speed, altitude, and angle of attack only one point at a time. "That means you'd have to look separately at conditions during takeoff, landing, and cruise altitude, and everything in between," Balas says. "It makes it difficult for flight control engineers to both analyze and synthesize controllers for an aircraft that flutters at different places and times during flight."

By 2013 MUSYN had overcome that roadblock with its LPVTools software toolkit. The application is able to synthesize flight control algorithms and set a controller's gain schedule for not just a single point in time, but the entire duration of an airplane's flight.

## Benefits

With lightweight flexible aircraft on the horizon, it's hard to underestimate the importance of having the LPVTools software toolkit, says Armstrong engineer Marty Brenner, who played a key role in developing both the Robust Control and LPV theories. "Flutter and instability can happen very quickly with this type of aircraft, so it's critical that we have an advanced tool to deal with the problem adequately."



Two pilots operate the X-56A MUTT from a ground control station.

Brenner is one of the researchers who will be using LPVTools to experiment with flutter suppression algorithms in the X-56A MUTT's flight controller. Having overseen MUSYN's work during the SBIR contract, he's confident the technology will perform well. "The company has really improved on the original algorithms while also developing a solid software infrastructure to handle complex models," he says. "It's topnotch."

The software was made commercially available in 2014, and aircraft manufacturers designing similar lightweight flexible aircraft will want to use the software, says MUSYN's Balas. But the application is more than just a flutter prevention tool. Farming equipment companies, for example, can utilize the software to set controls for engines and active suspensions. "Even a bulldozer's blades can be programmed for precision grading and digging work," he says. "Farming today is

incredibly automated. You don't get out there with just an ox and a tiller anymore."

Industrial plants that employ robots and companies that develop unmanned aerial vehicles such as drones can also benefit from the programming technology. In agriculture, drones are employed to measure water, growth density, and other variables in crop fields. "Like aircraft, they need cues to handle air disturbances and other threats," Balas explains.

The sky's literally the limit with the technology, and Balas gives credit to NASA for helping make it possible.

"The agency's hand in applying the Robust Control theory helped guide the software development in the first place," he says. "Also, the SBIR funding was invaluable for a small company like ours. The project otherwise might have sat on the shelf for years, but now it's here and available to the commercial community. NASA has been invaluable." ❖



# Cabin Pressure Monitors Notify Pilots to Save Lives

## NASA Technology

Typical cruising altitudes for business and commercial aircraft are up to 50,000 feet or more. At such altitudes, the oxygen concentrations in the air are much lower than on the ground. Occupants could not survive in this environment without pressure inside the aircraft being controlled to maintain oxygen concentrations consistent with those at lower altitudes.

One startling tragedy that illustrated the importance of cabin-pressure regulation took place in 1999 when a Learjet was flying golf champion Payne Stewart from Orlando to Dallas. Six minutes after the Learjet pilots reported that all was well, the aircraft ceased communication with the air traffic controllers. Military aircraft in the vicinity were able to view the aircraft but reported that frost or condensation obscured most of the windshield and no movement could be seen inside the jet. Eventually, the plane ran out of fuel and crashed. There were no survivors.

When the National Transportation Safety Board investigated the accident, it found that the plane had experienced a loss of cabin pressure, and all onboard were incapacitated due to hypoxia, an insufficient supply of oxygen to the body's tissues and organs.

If sudden cabin depressurization occurs in an aircraft like a Learjet flying at 40,000 feet, the pilots and passengers may initially experience a brief euphoria and then have as little as 5 to 12 seconds of useful consciousness to don their oxygen masks. Following this brief period, without supplemental oxygen, their cognitive and motor skills diminish, leading to incapacitation, often with fatal consequences.

However, Stacy Pappas, founder and owner of Aviation Technology Inc. (AV Tech), based in San Diego, says an instance of depressurization is rarely so sudden or dramatic, making it all the more dangerous.

"Assuming that the cabin-pressure warning system installed on the aircraft is working properly, a warning

light, and in some cases a warning tone, in the cockpit alerts crewmembers that their cabin pressurization is approaching a dangerous level," Pappas says.

Usually, the pressurization system either has failed or was not turned on in the first place.

"When you combine a subtle malfunction with a failure of the aircraft warning system, which was likely the case in the Stewart accident, the crew becomes slowly incapacitated without any awareness of the situation," says Pappas.

"To me, it's a needless accident," she says. "In such cases, a simple, redundant warning system is all that is needed to protect the crew and passengers from a slow, insidious onset of hypoxia. Even if the pressurization system fails, all the pilot would need is a backup notifier that could tell him or her to reduce the aircraft's altitude for safe oxygen levels."

In addition to having value for pilots, such a monitor could alert NASA astronauts to a loss of pressure when training in a vacuum chamber used by NASA to simulate lunar and Martian environments. The device could also assist in alerting the crew on the International Space Station if a depressurization event occurs.

Not long after the Payne Stewart accident, Jan Zysko, an engineer at NASA's Kennedy Space Center, invented a cabin pressure monitor (CPM) to provide early warning of hypoxic conditions. Zysko displayed the device at the Oshkosh Air Show in Wisconsin, where several pilots told him of their brushes with hypoxia-related symptoms, and how fortunate they felt to have lived through them. After the show, Zysko investigated the number of similar cabin-pressure failure incidents and found it to be surprisingly high.



Aviation Technology Inc.'s Alt Alert cabin pressure monitor uses a flashing, red light combined with either advisory chirps or sustained alarms, depending on the seriousness of the situation, to alert pilots and crewmembers to a loss of cabin pressure. The device can be secured to a visor with a clip, but it can also use a suction cup to attach to a window, or Velcro for mounting on an instrument panel.

## Technology Transfer

Over the course of only six months, the NASA CPM went from prototype to a fully functioning unit, and in 2002, a company licensed the technology from NASA and started selling it (*Spinoff* 2003). In 2003, the CPM won both NASA's government and commercial Invention of the Year awards in recognition of its value, not only on planes and in space, but potentially for skydivers, balloonists, mountain climbers, meteorologists, and people working in altitude chambers and underwater habitats, among others.

A decade later, the company that originally licensed the technology went out of business, and the license returned to Kennedy Space Center. That was when Pappas learned about the pressure monitor from a colleague of her father's and felt an immediate, personal connection to the technology.

"My father had a love of aviation from the time he was a child," she says, adding that he worked as an airline pilot and opened a jet-flying school. "By the time that I could walk and talk, my dad had immersed me in aviation."

When she heard about the CPM, she called NASA and did the work to obtain an exclusive license for the technology.

Working with her team of engineers and designers, Pappas built a new product from start to finish, based on the original NASA concept. She addressed everything from the battery-powered circuit board to testing devices for the technology to the aesthetic design of the product. In about a year, she produced an all-new CPM based on the size, feel, and look of a smart phone.

## Benefits

Launched in 2014, AV Tech's Alt Alert is a personal altitude pressurization monitor that is smaller and lighter than most cell phones. It comes with three different mounting options, including a backing with suction cups

for window mounting, a backing with Velcro for mounting against the instrument panel, and a clip to attach it to a visor.

As an aftermarket product, the Alt Alert is an option for pilots of pressurized aircraft—jets or airliners that fly above 15,000 feet—to take with them in their professional pilot's flight bag. It is currently available for all pilots of pressurized aircraft in the United States, a market that could mean tens of thousands of customers. In the future, Pappas plans to offer the technology to international markets as well.

Alt Alert features an alarm and LED light that alert pilots when the cabin pressure is compromised. Typically, aircraft maintain cabin pressures that are consistent with an altitude of 8,000 feet or so.

"If you are at 35,000 feet, the cabin should have pressurization measuring anywhere from 8,500 to a maximum of 10,000 feet," Pappas says. If the pressure

inside the cabin falls below the equivalent of 10,000 feet, the device makes an advisory chirp and the LED flashes. If the pressure-altitude exceeds 12,500 feet, a 30-minute timer starts, and if it stays above 12,500 feet but below 15,000 feet for longer than 30 minutes, an un-mutable, sustained alarm will sound and the LED will flash. "This same alarm mode will be in effect if the aircraft cabin pressure exceeds 15,000 feet for any period of time," Pappas says.

These alarms are designed to go off well before the advanced onset of hypoxia. Once alerted, the pilot can identify and correct the pressurization issue or immediately reduce altitude and use supplemental oxygen.

"Oftentimes, pilots don't realize their pressurization system has failed. If it does fail, or simply was not turned on prior to flight, and the pilots have adequate notification, they will have ample time to take action," says Pappas. "It could save lives." ❖

Once the Alt Alert warns a pilot of a dangerous drop in cabin pressure, which also means low concentrations of oxygen, the pilot can don an oxygen mask and either correct the malfunction that led to pressure loss or simply descend to a lower altitude.



# Ionospheric Mapping Software Ensures Accuracy of Pilots' GPS

## NASA Technology

To permit safe and reliable aircraft navigation over North America using the Global Positioning System (GPS), the Federal Aviation Administration (FAA) has developed the Wide Area Augmentation System (WAAS), which improves the accuracy, availability, continuity, and integrity of GPS positioning enough to ensure its safe use by pilots to determine their locations. The early development of WAAS relied on software developed at NASA's Jet Propulsion Laboratory (JPL), particularly the GPS-Inferred Positioning System (GIPSY) and the Global Ionospheric Mapping (GIM) software packages. The former has been licensed by hundreds of commercial and noncommercial organizations (*Spinoff* 1999 and 2010).

More recently the continued development of WAAS has relied on companion software also developed at JPL. The SuperTruth and IonoSTAGE packages allow the system to address the threat to accurate positioning posed by code delays and phase advances due to refraction in Earth's ionosphere.

More than about 50 miles above the planet's surface, electrons can be separated from atoms, resulting in positive ions and free electrons. Ionization of the upper atmosphere is much more active in the daytime since it's largely driven by the sun's ultraviolet radiation and the solar wind, which rip electrons off of neutral particles. Earth wind patterns and electrodynamics in the atmosphere help make the electron distribution irregular and patchy, resulting in "space weather" that can interfere with signals.

GPS signal delays caused by activity in the ionosphere are measured in meters, with large delays being on the order of 40 meters, says Lawrence Sparks, senior technologist with the Ionospheric and Atmospheric Remote Sensing Group at JPL. While it doesn't take long for signals traveling at the speed of light to cover

40 meters, he says, even a delay of a small fraction of a second can make a significant difference in determining the position of a fast-moving plane. "It is crucial to bound the positioning errors accurately for landing an aircraft safely in fog, for example."

GIM allows Raytheon Corporation, the prime contractor of the system, to map ionospheric disruption in real time by processing the delays between GPS satellites and the 38 WAAS reference stations around North America. Each signal includes a sort of time stamp, making it possible to determine how long it took to travel from the satellite to the receiver, Sparks says. WAAS broadcasts vertical ionospheric grid delays for regularly spaced points across the coverage area.

The observations are also used to calculate and broadcast the grid ionospheric vertical error (GIVE) for those same points. The GIVEs bound the range of possible error in pilot positions derived from GPS—that is, they let users know how reliable the information provided by WAAS really is.

"Only part of the ionosphere is sampled by WAAS at any given time," Sparks explains. "A disturbance can be overlooked because its location hasn't been sampled. To protect the user from such errors, WAAS relies on an ionospheric threat model."

The threat model—one factor in calculating GIVE—is constructed from a sort of worst-case scenario based on historical data generated by SuperTruth, including records of severe ionospheric storms. "We try to quantify what kinds of ionospheric disturbances the system could have possibly missed," Sparks says. "For every possible satellite configuration, we determine the worst-case errors we've ever seen." These are usually caused by coronal mass ejections—huge bursts of solar wind and magnetic fields on the surface of the sun that can cause dramatic increases in the number of ions in Earth's upper atmosphere.

Sparks designed and wrote the computer code comprising the Ionospheric Slant TEC Analysis Using GNSS-Based Estimation (IonoSTAGE) software package,



**“It** was only at **larger airports** that an **aircraft** had the **capability to land** under **extremely** adverse **conditions. Smaller airports** were simply **not available.”**

— Larry Sparks, Jet Propulsion Laboratory

The sun emits a constant stream of charged particles, ultraviolet radiation, and x-rays, which generate activity in Earth's ionosphere by ripping electrons away from molecules to create more charged particles, or ions. Solar flares or coronal mass ejections such as the one seen here cause the most dramatic “space weather,” which interferes with radio signals and electrical systems.

Smaller aircraft and smaller airports especially benefit from the Federal Aviation Administration's Wide Area Augmentation System, which operates on software pioneered by NASA. For example, most small airports don't accommodate enough traffic to justify the cost of more than \$1 million to install an instrumented landing system, but the cost to inspect and commission an approach procedure that can be navigated with the help of GPS is about 90 percent less.



wherein TEC signifies total electron content between a GPS receiver and satellite, and GNSS stands for global navigation satellite systems. JPL uses the program to compute the ionospheric threat model and corroborate Raytheon's calculations of ionospheric delay and the maximum possible error in those calculations.

To generate the threat model, IonoSTAGE calculates electron density in the ionosphere between any given satellite and reference station—a figure known as total electron content—and the signal delay it's causing. The software's computation of the ionospheric threat model has proven to be a critical contribution to WAAS, Sparks says, noting that Raytheon and JPL have relied on completely independent code packages to arrive at the same model, allowing IonoSTAGE to validate Raytheon's results.

SuperTruth plays a critical role in providing high-precision measurements for generating the ionospheric threat model by IonoSTAGE. The new and improved SuperTruth algorithm provides a fast and more advanced approach to processing ionospheric measurements under

adverse solar and geomagnetic conditions, explains JPL's Attila Komjathy, chief architect of the SuperTruth software. "After transferring the code base, Raytheon personnel reported to us an average of about 30 percent improvement in data volume over the early version of the processing algorithm comprising GIPSY and GIM alone."

### Technology Transfer

Since WAAS was commissioned in 2003, FAA spokesman Paul Takemoto says, more than 73,000 planes have been outfitted with the capability to use the system for navigation and landing assistance. Because big airliners generally have other onboard navigation systems that can serve the same functions, and because these planes tend to travel exclusively between major airports outfitted with instrument landing systems, he says, WAAS finds most of its users among individual aircraft owners, business jets, emergency transporters, and an increasing number of regional airlines across North America. These often land at airports that don't have enough traffic to justify purchasing an instrument landing system.



Global Positioning System (GPS) satellites, such as this one from the Block IIR series, not only transmit data to and from GPS units on earth, but they are also used to determine the extent to which those signals are being delayed by activity in Earth's ionosphere.

With WAAS, no navigational equipment is required at the airport, although infrastructure requirements such as runway markings or lighting, for example, may still need to be met to gain the full benefit of WAAS for landing. Furthermore, no consideration needs to be given to the placement of a navigation facility, maintenance of clear zones around the facility, or access to the facility for maintenance.

Since the advent of WAAS, the FAA has created almost 4,000 "localizer performance" approach procedures, each enabling the use of the system for landing on a specific runway end, Takemoto says, adding that the agency has a goal of writing procedures for every airport that qualifies for them.

In late 2013, the first commercial licenses for SuperTruth and IonoSTAGE were issued when NEC, an international company based in Japan, with US headquarters in Irving, Texas, licensed the entire suite of WAAS-enabling software for use in Japan. The company says it plans to use the technology to provide its clients with more reliable calculations of ionospheric delays.

## Benefits

WAAS is especially useful for landing in low visibility, and Sparks says this is a critical function.

Before WAAS, he says, small planes required an airport with an instrument landing system to land under low-visibility conditions. “It was only at larger airports that an aircraft had the capability to land under extremely adverse conditions. Smaller airports were simply not available.”

Using GPS with no augmentation to land at airports without an instrument landing system, aircraft may have no vertical guidance for approach, says Jason Burns, space segment lead for WAAS at the FAA. “WAAS provides additional safety by providing vertical guidance where there otherwise would be none.”

With WAAS providing greater assurance as to the aircraft’s actual position, the same plane can now drop to altitudes as low as 200 or 250 feet without runway visibility.

In addition to assisting with landing, Burns says, WAAS also is beneficial when flying point to point. Before satellite navigation, a plane would fly from one ground radio beacon to the next when visibility was limited. This did not always result in a straight path to the desired destination. With WAAS, aircraft can fly the most direct path. This can also be accomplished with GPS, but only if appropriate procedures are followed to ensure GPS will be reliable for the entire length of the flight. WAAS provides this integrity.

Sparks says the system seeks to strike a balance between providing ranges of possible errors that are wide enough to guarantee that they bound the actual error but narrow enough that the information is useful for positioning.

If a signal error were ever greater than the bound calculated by WAAS, Sparks says, that would constitute what NASA and the FAA call HMI, or hazardously misleading information. WAAS specifications require that this not happen more than once in 10 million landings. “That’s the spec we’re all trying to meet, and so far, we have,” he says. “In 11 years, we’ve never had a single instance of HMI recorded.” ♦

“**WAAS** provides **additional safety** by providing **vertical guidance** where there **otherwise** would be **none.**”

— Jason Burns, Federal Aviation Administration



The most visible ionospheric activity comes in the form of aurorae, such as the aurora borealis, pictured here. These occur when Earth’s magnetic field pulls electrons in the ionosphere down toward the poles, where they collide with atoms lower in the atmosphere, releasing energy. Ions in the solar wind can also contribute to aurorae.

Image courtesy of the US Air Force



# Public Safety

From technologies meant to safeguard astronauts to crucial Earth-observation data, much of what NASA does has applications in keeping the general public safe and in helping people find or monitor resources such as drinking water, agricultural products, and forest cover. The agency also partners with industry to pioneer safety solutions, from preventing oil spills to assessing potential structural damages or increasing visibility under hazy conditions.





# Water Mapping Technology Rebuilds Lives in Arid Regions

## NASA Technology

**T**urkana County in northwest Kenya has been reeling from several years of crippling drought. As a consequence, the nomadic peoples in the region have suffered. Livestock such as goats and cattle, the sole source of income for these pastoralists, have perished by the droves from starvation, and the resulting economic hardship has left many children malnourished. Many have also died from violent clashes over increasingly scarce resources.

But a new story was written over this hardened landscape in September 2013, following the announcement of an incredible find: at least 66 trillion gallons of water deep beneath the surface of Turkana in the Lotikipi and Lodwar basins. Combined with the 898 billion gallons of rainfall diverted into the basin annually, the previously untapped catchment system has the potential to improve Kenyans' lives for generations.

The discovery was made possible by international exploration company Radar Technologies International (RTI), which employs a battery of technologies, including troves of NASA data, to probe Earth in search of one of nature's most valuable resources.

## Technology Transfer

The story of RTI began some 20 years ago when its CEO, Alain Gachet, had been working as an exploration geologist and geophysicist discovering major oil fields for companies. In 1996 he decided to start his own business, which focused on not only oil but also mineral exploration. His first undertaking in that arena took him to the rainforests of central Congo, where a mining company's employees had discovered gold nuggets shimmering in rivers. The firm wanted to locate their source.

It was a challenging request because the region was poorly mapped due to dense rainforest cover. To work around the issue, for weeks Gachet followed the pygmies, who were randomly panning gold flakes in the



The largest of the African Great Lakes, Victoria is situated across Tanzania, Uganda, and Kenya. Radar Technologies International's (RTI) WATEX System uses Landsat data, which contains information on surface topography and rock chemistry, to help locate underground water.

rivers, and used a GPS unit to plot the points where the precious metals were being found. He then flew from Brazzaville to Washington, D.C. where he could access images taken with a new remote sensing technology called the Spaceborne Imaging Radar (SIR), which was flown onboard the Space Shuttle Endeavour in 1994.

By superimposing the GPS points over the imagery, he was able to locate the mother lode deposit within the general outline of the land's topography. What he was able to accomplish was a real shock, he said, and the experience opened new avenues for exploration in hostile and remote environments.

NASA's SIR is an example of a synthetic-aperture radar (SAR), a powerful tool that uses radio waves to map Earth's topography. In addition to having high-resolution capabilities, it's superior to optical instruments because it can function seamlessly in total darkness, isn't hampered by cloud cover and dense forests, and can even penetrate under the canopy to reveal geological features beneath the surface of the ground.

NASA pursued the SIR mission because the agency understood that topographical maps would prove invaluable tools for studying any of a number of environmental issues, from deforestation in the Amazon to soil moisture retention in the American Midwest. While Gachet and RTI initially used the data from the mission to locate gold, diamonds, and

other prized commodities, it also eventually led him to what he considers his most important finds.

In 2002 Gachet was working as an oil exploration consultant for Shell. While combing through the Libyan desert using SAR-gathered imagery, he noticed something peculiar: evidence of heavy moisture underground. The moisture turned out to be leaks from the Great Man-Made River—a massive subsurface pipeline that carries water from a Saharan aquifer to the country's coastal towns. After reporting the faulty pipe to the Libyan government, he realized again that he was onto something new and important.

"The experience gave me the idea that I could use radar frequencies to find underground water that could be used to help people," he says, "because people don't drink oil—they drink water."

Gachet spent the next few years developing the WATEX System, RTI's water exploration and discovery technology. WATEX combines several inputs to achieve its unique capabilities. At the core of the technology is



RTI founder Alain Gachet celebrates the discovery of water in the Lotikipi basin, an area that has suffered from severe drought in recent years.



The Turkana women come with containers to gather newly discovered water from a drilled well in the Lotikipi basin.

Gachet with the Turkana women as they rejoice in the water's discovery. The Kenyan government says the 66 trillion gallons estimated to be in the Lotikipi and Lodwar basins can sustain the country for 70 years.



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“ Discovering a little water brings war, but discovering a lot of water can bring peace, because everyone can share it.”

—Alain Gachet, Radar Technologies International

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a proprietary process Gachet developed that removes surface obstacles from NASA SAR data and SIR data without harming the soil wetness signal. In other words, the WATEX processes NASA SAR imagery so that information about groundwater can be inferred without the interference of surface features such as infrastructure, rocks, or vegetation. This process is combined with several other inputs, such as geophysical and geological data.

Then there's NASA Landsat satellite data, which is added as a critical input to the WATEX System. Started in 1972, the Landsat program, administered by both NASA and the US Geological Survey, is the longest continuous satellite-based record of the Earth's surface through not only visual imagery but also the near-infrared, short-wave, and thermal infrared bands of the electromagnetic spectrum. By analyzing the time-lapsed imagery, scientists are able to monitor numerous environmental conditions, from deforestation to agricultural land use and rates of erosion. For WATEX, Gachet utilized Landsat data to note the chemical signatures of rocks and also discern surface landscapes, which give clues to where water might accumulate by looking at slopes, flood plains and ditches.

All that data is used in conjunction with various other disciplines—physics, chemistry, geophysics, seismology, and a complex algorithm developed by Gachet—to render a 3D map of water occurrence probability in a given area that shows where groundwater is likely to be located and how deep. RTI's WATEX maps are used by companies to plan drilling and avoid costly mistakes. But determining the exact location where water flows under-

ground wouldn't be possible without another NASA technology: the Shuttle Radar Topography Mission, or SRTM. In February 2000 the Space Shuttle Endeavour flew in low-Earth orbit for 11 days, gathering the first high-resolution, near-global data set of land elevations. Gachet says the data is accurate up to 12 meters, which is enough to obviate the need of going into the field to calibrate the maps and plot coordinates manually.

Thanks in part to SRTM, in order to find the water in the field, drillers now need only use RTI's WATEX maps and a special GPS-based device called Groundwater Exploration Navigation System, which guides them to their drilling locations. “There's life before SRTM, and life after it,” says Gachet. “Before we started using it, we had to travel into some very dangerous territories marked by civil war and terrorism. I was threatened several times while in the field and had to escape very quickly because an attack was going to be launched at me. That's why this technology is so important—it saves time and lives.”

### Benefits

It was 2004, and the Darfur crisis—a major armed conflict in western Sudan—had displaced 250,000 people in Chad, forcing them into refugee camps. The United Nations High Commissioner for Refugees contacted Gachet requesting that he use WATEX, which had just been developed to its full capacity, to uncover areas of Eastern Chad that contained enough subsurface water to sustain the evacuees. In four months he managed to find enough of it to sustain all of the refugees. The feat caught the attention of the United States Agency for International Development, which funded RTI to continue working in Sudan, on the other side of the Chad border, where 2 million others had been displaced. As a result, Gachet and his team spent another six months mapping 200,000 square kilometers of land in Darfur. Enough water was discovered to support 3 million people and prevent further spending of millions of US dollars to truck water to the camps.

Since his work in Sudan, Gachet has utilized his high-tech divining rod to find much-needed water all over the world. He's helped refugees in war-torn countries such as Afghanistan, aided in post-war reconstruction efforts in Angola, and assisted the Kurdish government during a major drought. He's even working to find reservoirs in Texas, where RTI has an office, in New Braunfels near San Antonio.

While the discovery in Kenya—made possible through UN funding—is the most recent in a string of successes over the last several years, every find gives him the satisfaction of knowing he's done something of value for the world. He is especially proud of his work in Turkana County, the most desolate area of northern Kenya.

“There's not a single village on the land for 5,000 square kilometers,” he says of the place. “No trees, no villages, nothing. And people are struggling for life, having to walk 80 kilometers to get to the nearest water hole for their cattle. Sometimes they are forced to intrude into Uganda or South Sudan where they are killed by other tribes. They kill each other because there is no water and lots of weapons.”

But the estimated 66 trillion gallons of potable water detected by RTI, which the government says can sustain the country for 70 years, could bring long-lasting stability, economic and otherwise, to the region. Gachet revels in how profound that is. “As I like to say, discovering a little water brings war, but discovering a lot of water can bring peace, because everyone can share it.”

And a lot of credit, he says, should also go to the space agency, whose technologies helped make all this possible. “NASA's Landsat and SRTM are my eyes on the ground. Without them I am totally blind. They are great gifts to humanity.” ❖



# Shock Absorbers Save Structures and Lives during Earthquakes

## NASA Technology

In the early 1960s NASA tackled one of its greatest challenges: sending a man to the moon. The physical embodiment of that effort, the Apollo spacecraft, stood as a testament to human ingenuity. At 363 feet tall, the structure would dwarf the Statue of Liberty by nearly 60 feet; fully fueled, it weighed more than 6.2 million pounds.

Delivering all that liquid hydrogen fuel to the spacecraft, along with electrical signals and gases, were the umbilicals: bundles of cords and tubes that extended from ground sources up to the service tower, or gantry, where they were tied onto large swing arms that connected them to different parts of the rocket. The umbilicals remained fastened to the spacecraft up until just a few moments before launch; in the case of an emergency on-pad abort,

they would de-tank fluid from the rocket to prevent an explosion.

To get the swing arms out of the way quickly during a launch, the umbilicals were attached to the rocket with pyro bolts—fasteners that immediately break apart after receiving an electrical charge. Once liftoff was underway, the pyro bolts would sever, detaching the swing arms from the rocket. A built-in spring would then pull the arm



An illustration of the fuel- and electricity-carrying umbilicals that extended from the gantry to the Apollo spacecraft. In the 1960s Taylor Devices developed shock absorbers to help safely dislodge the umbilicals from the spacecraft during launches.



back into its cradle near the gantry. But the challenge, given the scenario, was controlling that sudden, powerful thrust so the swing arm didn't break from overexertion or collide with the vehicle.

That's where shock isolation systems come into play. Also known as dampers, these devices control spring and suspension movement, which in this case meant guiding the swing arms gently into their cradles during launch.

Dampers are basically oil pumps. Inside, hydraulic fluids flow through orifices designed to slow the liquid's movement according to how much resistance is needed at any given point in an object's stroke, or its movement from one point to another. All that kinetic energy is diverted into the fluid by way of heat, which eventually dissipates into the air.

Helping to develop these dampers for NASA was North Tonawanda, New York-based Taylor Devices Inc. It was founded in 1955 by Paul Taylor, a former lead engineer with Curtiss-Wright Corporation, which



Space Shuttle Columbia just before its inaugural launch on April 12, 1981. Taylor Devices developed fluidics-based shock absorbers (above left), derived from NASA funding for advancing computers, to safely remove the shuttle's umbilicals during launch. Depending on their positions, the shock absorbers ranged from two to eight feet long and five to eight inches in diameter.

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“ It’s a simple device that lasts a really long time with no maintenance.”

— Doug Taylor, Taylor Devices

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manufactured the famous P-40 Warhawk fighter planes (known for their painted shark’s mouth logos) during World War II. The company had previously developed dampers for the Navy’s fighter jet aircraft programs, and it’s collaboration with NASA in the early 1960s marked the beginning of a long engagement with the space industry.

### Technology Transfer

In working with NASA on the swing-arm dampers, Taylor Devices experimented with a gas-driven type of shock isolation system. Paul’s son, Doug, who is now CEO of the company, explains its complexity. “You had a scuba tank attached to the side of a hydraulic cylinder, with all kinds of external plumbing, hoses, and valves,” he says. “There were a gazillion parts involved. It was a mechanic’s and plumber’s nightmare.”

The technology worked, but to guarantee maximum reliability NASA asked the company to apply conventional shock absorption technology, and even that request was a challenge. Shock absorbers can be highly intricate machines that require numerous sets of orifices to control for different stages of a stroke. For example, a swing arm moved by a spring needs more resistance at the initial stage, when there’s more kinetic energy to absorb, than at the end of the stroke as the arm approaches its cradle.

Extreme differences in resistance mean the damper must vary mechanically from one end to the other. “The shock absorber designs we created were pretty much stretched to their limits because of the impact speeds we were dealing with,” says Taylor.



One of Taylor Devices’ chevron brace dampers is embedded in a building’s frame at the Portland, Oregon Galleria shopping mall. The company is using its NASA-derived dampers to secure structures during earthquakes.

The experience with Apollo inspired Taylor Devices to work on another kind of shock absorber that the space agency was investigating—not for rockets, but for computers.

In the 1960s, Taylor explains, scientists enabled computers to run on transistors rather than vacuum tubes, but the initial transistor prototypes were found to be too expensive, complex, and cumbersome. NASA funded Honeywell to investigate utilizing oil-based hydraulics to run a high-speed analog computer instead, and Taylor Devices was hired as a sub-contractor to work on some of the engineering elements.

The company's research in the science of fluidics enabled it not only to aid in building a hydraulics-based computer, but also to develop its successful line of innovative dampers.

The science behind fluidics is based on the principle that, in a converging-diverging duct, a compressible liquid's density and pressure change depending on its flow speed through the subsonic, transonic, and supersonic velocity ranges. Taylor Devices developed a damper using a compressible fluid capable of operating at transonic and supersonic fluid velocities. Intricate and precisely machined passageways provided the ability to have fluid flow properties change as the fluid accelerated past sonic velocity.

The end result was a fluidic damper that can easily exceed the performance of conventional variable orifice designs over a much wider range of system impact velocities. The fluidic damper also operates at higher pressures than conventional designs, which allows for a more compact but exceedingly powerful damper package as compared to previous technology.

"Ultimately, the fluidic dampers' internal pistons are just pieces of steel or bronze machined with very specific and complex passageways to affect the flow of liquid the way you want," he says. "It's a simple device that lasts a really long time with no maintenance."

By the time the agency officially instituted the Space Shuttle Program in 1972, the fluidics-based dampers were ready for the offering. "We said to NASA, 'Here, this is an improvement on Apollo. What do you think?'" Taylor recalls. "They loved it."

The technology would be used to control the gantry's swing arms and the umbilical withdrawal arms inside the launch platform's tail service masts during shuttle launches until the program's end in 2011, and it is still used by the agency to protect sensitive electronic equipment during launches to the International Space Station.

But the technology hasn't been limited to protecting swing arms or computers. Taylor Devices' fluidic shock absorbers are now being used as seismic dampers to stabilize buildings in the event of an earthquake.

## Benefits

Of all the natural disasters on Earth, earthquakes are capable of unleashing the most energy. For example, an 8.0-magnitude earthquake releases the equivalent of over 6 million tons of TNT, enough to destroy everything at its epicenter. To protect buildings and bridges from collapsing from such powerful tremors, in the 1990s Taylor Devices began selling and installing fluidics-based seismic dampers. By absorbing destructive energy, the same technology that kept the Apollo and space shuttle swing arms safe keeps structures—and the people in and around them—safe during an earthquake.

The rule of thumb, says Taylor, is the larger the diameter of the damper, the more energy it can absorb. The company's smallest damper is five inches in diameter and three feet in length and absorbs up to 25 tons of force. The largest damper the firm has manufactured is more than three feet in diameter and 22 feet in length, with a force rating of 1,100 tons. Because dampers can be made to virtually any size and level of resistance, they can be customized to meet every building's specific needs.

"I've got one 55-story building in Mexico City that has only 12 dampers on each side of the building's frame,

because they're giant dampers that span six floors each," he says. The relatively small number of dampers makes possible the skyscraper's giant glass windows and large open spaces in the interior. "But then you go to another building, and you might have 300 or 400 smaller dampers put into individual bays."

Older buildings that are more structurally vulnerable may also require rubber bearings placed under their foundations, as was the case with Los Angeles City Hall, an 80-year-old concrete and steel edifice that had sustained a number of cracks caused by prior earthquakes in the tremor-prone region. "The entire building was jacked out of the ground and all the columns were cut," Taylor recalls, "then the building was lowered back down onto rubber bearings so it could move plus or minus two feet horizontally in either direction. Then we put 54 large dampers alongside the rubber bearings. The dampers absorb the energy, and the rubber bearings allow the whole building to float."

Taylor estimates that, to date, more than 550 buildings and bridges are now protected by the company's fluidic seismic dampers, many of them located in the world's most seismically active areas such as San Francisco, Tokyo, and Taiwan, among others. "Not a single building outfitted with our dampers has fallen or had even minor damage after a quake," he says, "and because of that a substantial number of human lives have been saved."

Today those seismic dampers account for roughly 60 percent of company sales. Much of that success, Taylor notes, is tied to the firm's longstanding relationship with the space agency. "We're a small business," he says. "We didn't have the money to finance a total revamp of our technology, but with some NASA funding we were able to bring fluidics-based dampers into the market. That was a big advantage for us." ❖



# Software Facilitates Sharing of Water Quality Data Worldwide

## NASA Technology

Onboard the International Space Station, or ISS, very little goes to waste. One of the more glaring examples is the spacecraft's water supply, which is reclaimed by recycling astronaut urine, sweat, and even exhaled humidity. Thanks to the technology, former ISS crewmember Don Pettit once said, "Yesterday's coffee becomes today's coffee."

But water is precious only when it's safe for drinking, which means being free of contamination. One test that's required by the Environmental Protection Agency and performed by municipalities across the country checks



Canadian astronaut Robert Thirsk shows the coliform bacteria test kit that is used onboard the International Space Station. The test is designed to be lightweight and simple yet accurate.

for the presence of coliform bacteria such as *E. coli*. The existence of such bacteria is an indication of fecal contamination, which can lead to a host of diseases.

Throughout the late 1990s and early 2000s, astronauts on the ISS only had access to technology that could count the number of bacteria in a sample; there was no way of knowing what kinds of bacteria were present without having samples flown back to Earth. But the Space Shuttle Columbia disaster in 2003 temporarily discontinued US flights to and from the station, which hampered the agency's ability to transport water samples along with supplies. As a result, NASA scientists worked to simplify the coliform bacteria test so that it could be performed in a restricted space environment without compromising its accuracy.

## Technology Transfer

The standard procedure for the coliform bacteria test kit is designed for a laboratory. It requires pouring the water sample into a container filled with a growth indicator powder, screwing the lid on, and then placing it into an incubator that's set to the temperature of the human gut, where coliform bacteria thrive. Within 24 hours, if the bacteria is present, its enzymes will cleave the powder's reagent molecules into pieces, which in turn changes the water color from yellow to purple.

Given the limited number of flights available to the ISS via Russian spacecraft, it wasn't feasible to transport all that equipment. "We needed to supply the space station with just a fraction of the uplift capability that we had before," says John Feighery, who at the time was an environmental engineer at Johnson Space Center charged with overseeing air- and water-monitoring hardware. That meant incubators, and even containers, were too bulky to bring up into space. So a critical question had to be answered: Could an accurate coliform bacteria test be performed without containers and without an incubator to warm the sample to an ideal temperature?

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“ I realized that NASA's way of thinking in terms of making things simple, low-cost, and reliable could be really powerfully applied back on Earth.”

— John Feighery, mWater

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The answer was yes. When Feighery realized that the Johnson Microbiology Lab had designed an alternative procedure that functioned nearly as well as the standard one, he worked across organizational lines to get the system certified for flight. "We did a lot of testing to show you could do these tests at lower temperatures and without containers and still make them work," says Feighery. To put it simply, a water sample, mixed with the growth indicator powder, is stored in a plastic bag and left out at room temperature for approximately 44 hours, at which time a dependable reading can be made.

While the new procedure was a boon for astronauts onboard the ISS, Feighery, who cofounded the Johnson chapter of Engineers Without Borders, an organization that helps with international development work, would come to recognize its potential use on Earth.

In 2007 Feighery enrolled in a PhD program in Earth and Environmental Engineering at Columbia University, and a major project involved traveling to Bangladesh to test tube wells—shallow, hand-dug wells common in the country—for fecal contamination. What made the work a challenge, he says, was having to haul a bulky set of equipment that required a high level of skill to operate. "We want communities to perform tests on their own," he says, "but there's no way. The equipment's too expensive and it's too hard to understand how to use it unless you're an expert."

That's when he recalled the space agency's simplified coliform bacteria test, performed with a simple



Maurice Kanzala collects a water sample from a shallow dug well for The Water Trust, one of mWater's clients working to provide safe water in rural Uganda. The mWater app allows field workers to record and share water quality or other data on how the water source is functioning over time.

bag kept at room temperature for 44 hours. "I realized that NASA's way of thinking in terms of making things simple, low-cost, and reliable could be really powerfully applied back on Earth," he says. But it was a two-pronged problem. Apart from needing access to the technology, people needed an easy way to access those test results. "A lot of the time, data from projects that are done in countries just die in reports and spreadsheets that nobody ever translates or sends around to anybody else," he says. "There had to be a way to share data that anybody could use in real time."

Feighery's solution to these problems would first manifest when he and his wife Annie, who works in the international health sector, participated in the World Bank's Water Hackathon in October 2011. The two-day

Montreal event brought together software developers to brainstorm ways to address water-related challenges facing developing countries. The couple worked with software engineer Clayton Grassick and others in developing a working prototype for a smart phone application that instructs users on how to perform, among other simple tests, a coliform bacteria test inspired by NASA's research. The app could then be used to share the results with the public through the program's mapping software. In August 2012 a fully functional Android-based application called mWater was released to the public.

### Benefits

Water contamination is a major problem in many countries around the world, and many die from water-

borne diseases every day. Feighery says the application can be used to help families in rural areas and developing countries choose the appropriate tests for analyzing their local water sources for impurities ranging from *E. coli* to arsenic, fluoride, and nitrate. And to keep the software current, Feighery is continually investigating the latest methods. "In this respect we're like a guide to testing," Feighery says. "What we try to do is locate, identify, and test promising technologies for our users."

Feighery and his wife Annie, along with fellow cofounder Clayton Grassick, are also working through their mWater Foundation to integrate the technology on a larger scale. For example, in 2013 the US Agency for International Development awarded the organization funding to work with the Tanzanian government. The goal is to integrate the mobile phone technology for use by public employees. Water utility workers, public health workers, and community health workers are currently using the app on a regular basis.

"All we've done is supply the initial test kits and the mobile phones," Feighery says. "We're learning what can be done by these different groups in terms of water quality monitoring, what are the obstacles, and what are the opportunities to make it better before it's scaled up to a nationwide system." That outcome figures into mWater's loftier plans: to work with other organizations to map the quality of the entire world's water supply.

In the meantime, mWater continues to improve on its technologies by, for example, facilitating group collaboration on projects and implementing more user-friendly features on its app. Feighery's former NASA colleagues have also been inspired by mWater's work. Mark Ott, a researcher in the Biomedical Research and Environmental Sciences Division at Johnson, is looking into the feasibility of transferring to mWater other water-monitoring technologies that have been developed at NASA.

"Being a microbiologist, you become aware of things like diarrheal disease, and so much of that is due to a lack of good-quality water, which is a major problem," Ott says. "I love what John's doing out there and am happy to help in any way that I can." ❖



# Underwater Adhesives Retrofit Pipelines with Advanced Sensors

## NASA Technology

By the time the gas you fill your car with hits the engine, it's been through quite a journey. Even apart from its transformation from organic matter into fossil fuel over millions of years, the process of bringing petroleum to Earth's surface, where it can be processed and distributed, is no easy task. Many of the world's oil reserves are buried not just deep beneath ground but also under an ocean.

An oil platform in the Gulf of Mexico, for example, might need to be built over water with a depth of 10,000 feet. Extending from the platform, which floats on the sea, are specialized pipelines stretching nearly two miles to connect the operation to the sea bed. Then comes the drilling, which in some cases might need to go another 35,000 feet beneath the ocean floor before hitting its target.

"That oil is traveling a long distance under extreme conditions," says David Brower, president of Astro Technology Inc. (ATI), a Houston-based company that provides instrumentation and monitoring services to the oil and gas industry. "Temperatures range from very cold to very hot. The pressures can be extreme. And the distance that you have to flow the crude oil can sometimes reach 50–60 miles—that's a really long pipeline."

Long pipelines under high pressures face a multitude of dangers. Some are structural, such as natural vibrations generated by ocean currents and waves that bend the pipes back and forth—a phenomenon known as vortex-induced vibration, which Brower compares to the sway of a car antenna wire when driving the highway. Other risks lie inside the pipe, where the right combination of pressure and temperature causes the hydrates in the oil to

precipitate, forming a dirty, snowball-like mass that quickly grows. "That can build up to the point where the pipe is plugged and the oil flow stops, which is a nightmare to fix. You're looking at a month of work and a cost of a hundred million dollars," he says.

Given the extremes of temperature, pressure, distances, and risk faced by his industry, for Brower it made perfect sense to reach out to NASA's Johnson Space Center when he needed help developing new safety and monitoring technologies. "NASA knows how to utilize sensors and take measurements in extreme environments. They've got a whole host of technical expertise that's relevant, even though they aren't experts in the oil and gas industry per se," he says, noting that NASA's outsider perspective actually offers advantages. "They can be a second set of eyes that look over your processes without prejudging them. That means they see things that oil folks might typically overlook, which is simply invaluable."

Johnson engineer Calvin Seaman, who has spent years specializing in extravehicular activity (EVA) tools and engineering, agrees. "A lot of the work ATI was interested in exploring is analogous to what we do in space: the tools, the equipment, the environment, and a lot of what I did with EVAs for Hubble Space Telescope and the International Space Station actually applies to underwater projects, which I've enjoyed learning about. This ended up being a match made in heaven."





Pictured here are two tests of ATI's clamps in a NASA lab at Johnson Space Center. On the left, a proprietary coating uses friction to keep the clamp in place. On the right, a special adhesive works even underwater to bind clamps to pipes.

## Technology Transfer

Partnering under a Space Act Agreement in 2010, ATI provided funding for NASA engineers to design and test new sensors and adhesion methods that would allow the company to equip pipelines and tension legs that hold the offshore platform upright for safety monitoring. Knowing how much stress the lines are experiencing is essential to safe operation, and when sensors gathering that data on tension legs fail, drilling operations must cease (“costing the company a million dollars a day,” says Brower). ATI has long provided fiber optic sensors for tension leg monitoring, but now Brower wanted to embed them in clamps that could be brought underwater and be easily installed by a diver or, in deep waters, a robot.

That’s where NASA’s expertise and facilities proved helpful. They worked with ATI to select an adhesive that could bond underwater and provide a solid grip for the clamp’s sensors, and then they tested it in fresh- and salt-water environments. They also developed a method for embedding fiber optic cables in the polyurethane substrate used to create the clamps, providing them protection from the environment where they would operate.

Once Brower felt confident that the design was effective, he took 16 of the clamps to oil platforms off the coast of West Africa, where an oil company had requested

his help fitting older pipes and tension legs with new sensors. Divers first had to grind off years of contamination and marine growth from the pipes, but once a clean surface was established, installation took just 15 minutes.

“So far, they’re working like a champ,” says Seaman. “And even if one were to fail, they can just send a diver out to install a new one. Meanwhile, Dave sits in his office in downtown Houston and can monitor all these clamps in West Africa on his computer in real time. It’s a remarkable system.”

## Benefits

Brower says that the trial in West Africa showed that ATI’s new sensors are unlike any before them. While calibrating them, ATI was able to detect and precisely measure nearly everything happening on the platform, from tides, waves, and wind to the gentle pressure exerted by a boat docking. “We got it all and measured it very accurately. The operators on the platform were just dazzled; they were amazed that we were able to get that data,” he says.

Now commercially available under the Trident Subsea Systems product line, ATI’s sensors are the first of their kind: hyper-sensitive safety monitors that can be retrofitted on older subsea pipelines. The clamps include models with and without adhesives—the non-adhesive

clamps relying on a proprietary, rough industrial coating that digs into the pipe and uses friction to stay in place.

The sensors are new to the market, but Brower sees potential for them to be as ubiquitous one day as seatbelts and airbags are in cars. “He’s working to market the technology through a noncompetitive mechanism,” notes Seaman. “It’s an elegant solution, everyone needs it, and he wants to see it shared among companies.”

For NASA’s part, the agency plans on using its experience designing these tools for future applications in space exploration. Seaman says that he and his colleagues have added these experiences to their “bag of tricks,” and that other centers have already been in contact with him to inquire about the applicability of this project to current NASA missions.

NASA never stops obsessing over improving safety in its extreme environments, and that is a passion Brower understands well. “Even if you can prevent just one incident like BP had with the *Deepwater Horizon* spill—which has run up about an \$80 billion price tag—the value in this technology is obvious,” says Brower.

“This has truly been a mutually beneficial partnership. It’s not just win-win; it’s win-win-win. We win, NASA wins, and the oil industry wins. Society wins, Congress is happy—there is no one who is grumpy about it.” ❖



# Laser Imaging Video Camera Sees through Fire, Fog, Smoke

## NASA Technology

In November 2012, Bob Foraker was strolling through the NASA Technology Days expo in Cleveland, Ohio. He was there to look for technology that might apply to the line of retrofitted hybrid electric vans he helped to pioneer, but he stumbled on something he'd never seen before: a video camera capable of seeing through flames, fog, dust, and virtually any other obscurant, even at night.

Owner of an international business incubator, entrepreneur, and merchant banker with interests in real estate, software and technology development, energy, consulting, and a variety of other areas, Foraker happened to have once worked on a perimeter security project in Saudi Arabia. "I thought, wow," he recalls, "this could

really be put together for a perimeter security system on the border, at a factory or a nuclear power plant, or on a military installation."

He made a proposition to enter into a collaborative agreement with the inventor, Richard Billmers, whereby Foraker would round up investors, find a chief financial officer, and help to develop a business model for what would become Canton Ohio-based Laser Imaging through Obscurants (LITO) Technologies Inc.

Security wasn't the original intent of the technology, which ultimately could find use in a number of fields. Billmers had conceived of it a decade prior as a tool that would allow firefighters and other first responders to see through smoke and flames, and he had developed the capability working with the Navy. However, funding ran

out long before the device was feasible or affordable for use in firefighting, so Billmers applied for a NASA Small Business Innovation Research (SBIR) contract through Langley Research Center in 2006 and was awarded Phase I and II contracts.

"When we saw it, we became very excited about it for our applications," says Ivan Clark, senior research scientist at Langley's Electromagnetics and Sensors branch and lead for the Lidar and Electro-Optics element of NASA's Aviation Safety Program. Billmers had approached NASA with a working "fire lidar," as he called it at the time (lidar being a common portmanteau of "light" and "radar"), capable of seeing through a blaze. Since it was also capable of penetrating almost any other obscurant, Clark saw potential for the device to increase visibility for aircraft under adverse conditions.

Much of NASA's aviation efforts over the last decade have been in support of the Federal Aviation Administration's (FAA) endeavor to update air traffic control, accommodating more flights while also increasing safety, Clark says. The FAA refers to this technological push as the Next Generation Air Transportation System, or NextGen.

An example of the need for this update can be found at San Francisco International Airport, where frequent fog causes backups that can mean planes end up grounded all over the country, waiting to fly into San Francisco, Clark says. "If you can see the other aircraft, you can get more aircraft in and out of an airport in a given time."

This is the kind of issue Clark has been working on, as his job in support of NextGen has been to address atmospheric hazards to aviation. It's also just the sort of problem Billmers' invention could solve, along with other visibility issues pilots face.

The device works by sending out fast pulses of near-infrared laser light and then opening the aperture, or gate, just in time to catch them after they've reflected off the target object, Billmers explains.



Perimeter security for facilities such as nuclear power plants, which are often located on foggy lakes, is one possible application for Laser Imaging through Obscurants (LITO) technology. The prototype is currently being demonstrated for perimeter security at NASA's Glenn Research Center.

Light travels at one foot per nanosecond, so the camera might send out a 10-nanosecond pulse of light and then wait about 50 nanoseconds to open the gate. In the interval, the light has passed through the obscurant, which reflects and dissipates some of it, then bounced off of whatever happens to be around 25 feet away, and returned to the camera.

“When I turn the camera on, all that near-term reflected light is gone,” Billmers says. “I can get rid of the near-term scattering, so I’m not blinded.” The laser light also scatters less than normal white light.

By adjusting the time that the gate waits to open, Billmers can train the camera on objects at different distances, and it is capable of reaching up to a couple of miles.

A closer object’s shadow can also make it identifiable, he explains. Something near the camera would show up as a silhouette against light reflected from objects farther away.

The camera can see through fire because it only catches a few nanoseconds’ worth of light from the blaze,

which isn’t much compared to the concentrated laser light reflected from the object behind it. “I’ve time-gated out the fire, because there’s almost no light from it in that short window,” Billmers says.

Billmers concedes that there are other ways to look through obscurants. A thermal imager, for example, can see through smoke if it’s cold, but it doesn’t do well with fog because heat is absorbed by water. A thermal imager also cannot penetrate glass.

“There is no other system out there that can see through a flame sheet,” he says.

“Basically, this is a strobe video camera,” Clark says. Not only did the device Billmers had built with the Navy present an elegant solution to a difficult problem, but it had already been demonstrated to be effective, he says.

### Technology Transfer

However, while the idea was relatively simple, the hardware to make it work was a technological challenge. Under the first two SBIRs with Langley, Billmers developed and refined his current prototype. “A lot of it has

just been developing the hardware, making sure everything works, getting all the timings right,” he says, adding that he’s also run extensive tests to see what surfaces reflect better under various conditions. A third SBIR with Langley funded further testing into 2012. Billmers now holds several patents on the technology.

As the fledgling company came together, Foraker suggested commercializing the device for a ground application and using the income to continue developing the technology until it could be made small enough for use on airplanes. Billmers had already hit on the possibility of perimeter security after he was able to spot workers through dense fog while testing the camera on an Army base.

Foraker also had an idea for a proving ground for the technology—NASA’s Glenn Research Center, which is not far from his home, and with whom he had worked on a Space Act Agreement 10 years prior. “It also ended up at Glenn because there was a location there that they could not securitize, and we were able to solve it,” Foraker says.

NASA’s Langley Research Center entered into three SBIR agreements with LITO Technologies, recognizing the technology’s potential to enhance visibility for pilots under adverse conditions. The company hopes to market the technology for ground applications and use revenues to advance it enough for use on aircraft.

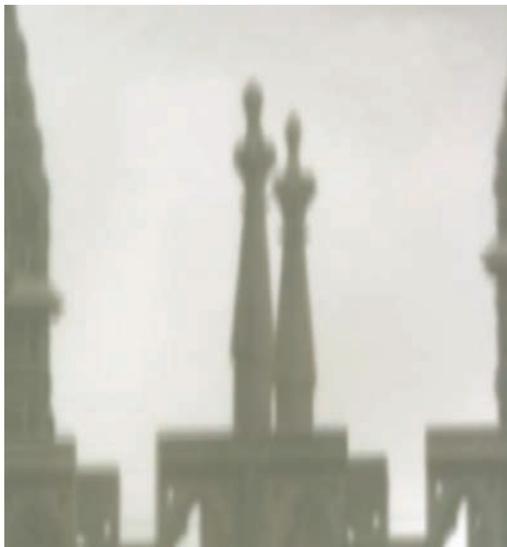




**“There** is no **other system** out there **that** can **see through** a **flame sheet.**”

— Richard Billmers, LITO Technologies

The LITO technology was originally conceived of as a “fire lidar” capable of seeing through flames. The technology was proven effective early on, and the company still envisions a device that would prevent firefighters and other first responders from being blinded by smoke and flames.



Starting from the left, three pictures of a pair of church towers, all taken at 500 meters, demonstrate the LITO technology. Image 1 is a pair of church towers, as seen with regular, visible light. Image 2 is those same towers barely discernible through rain and drizzle by a regular camera. Image three is of the towers as seen with the LITO device through the same rain and drizzle.



In late 2013, less than a year after the encounter at NASA Technology Days, LITO Technologies had a Space Act Agreement with Glenn and another with Langley allowing the company to use the hardware—which still belongs to Langley—and incorporate it into the center’s security system.

The camera at Glenn is triggered by a tripwire-like laser and automatically turns to the place where the perimeter was breached, Foraker says, adding that another option would be to put it on a track for added mobility. Neither the triggering laser nor the laser light from the camera is visible to the human eye.

Joe Shaw, director of venture and partnerships at Glenn, who helped set up the expo where Billmers and Foraker met and who also guided the Space Act Agreement with Glenn, said he was pleased that the partnership was proving fruitful. “Based on our interactions with LITO and some of their early technology demonstrations through the SBIR, we are very excited about the possibilities for this,” Shaw says.

“We’re taking an aviation-needs SBIR with NASA Langley and turning it to a ground application at NASA Glenn,” Foraker says, adding that he still intends to eventually refine the technology for use in aviation, as well as a host of other applications.

Even as the company demonstrates the invention at Glenn, Foraker says LITO Technologies has already received some interest from potential clients and is ready to take orders. Each system will have to be customized depending on the distance to the perimeter and other factors.

### Benefits

Billmers still looks to the day when the technology will help firefighters blinded by smoke and flames in the Santa Ana winds, and he doesn’t think that time will be far off. “We think we used the SBIR for exactly what it’s intended for, which is getting this thing commercially ready,” he says. “We now know how to build a system we can sell for perimeter security or for first responders.”

Foraker sees the perimeter security systems being useful in sandstorms at desert outposts, at nuclear power plants that are often on foggy lakes, on the US border, and at other facilities. LITO technology could also find an application in accident prevention on police and emergency vehicles, he says.

Jared Sullivan, who Foraker brought on as LITO’s chief financial officer, says the company is also partnering with an acoustics company to incorporate “localized acoustics” into the system, capable of pinpointing a sound between a person’s ears, in this case at distances of up to

600 meters. “Then it can say, ‘Please stop what you’re doing,’ or, ‘We can see you,’ or whatever,” he says.

Because low visibility is not always an issue, he says, LITO has to be considered a supplement to a system that includes other infrared and regular cameras.

Since he was first introduced to Billmers’ early “fire lidar,” Clark says, he has envisioned applications not only in perimeter security and enhancing safety and efficiency in aviation but also in shipping, where vessels have to make their way in and out of foggy harbors, and trucking, where it could prevent accidents and pileups in storms and fog.

“I think there’s a lot of commercial capability, and I think they’re right on the hairy edge of being able to do it,” he says, adding that he thinks the demonstration at Glenn is putting the company over the top and into the realm of commercial viability. “It’s the kind of thing that can do NASA proud.” ♦

# 3D Lasers Increase Efficiency, Safety of Moving Machines

## NASA Technology

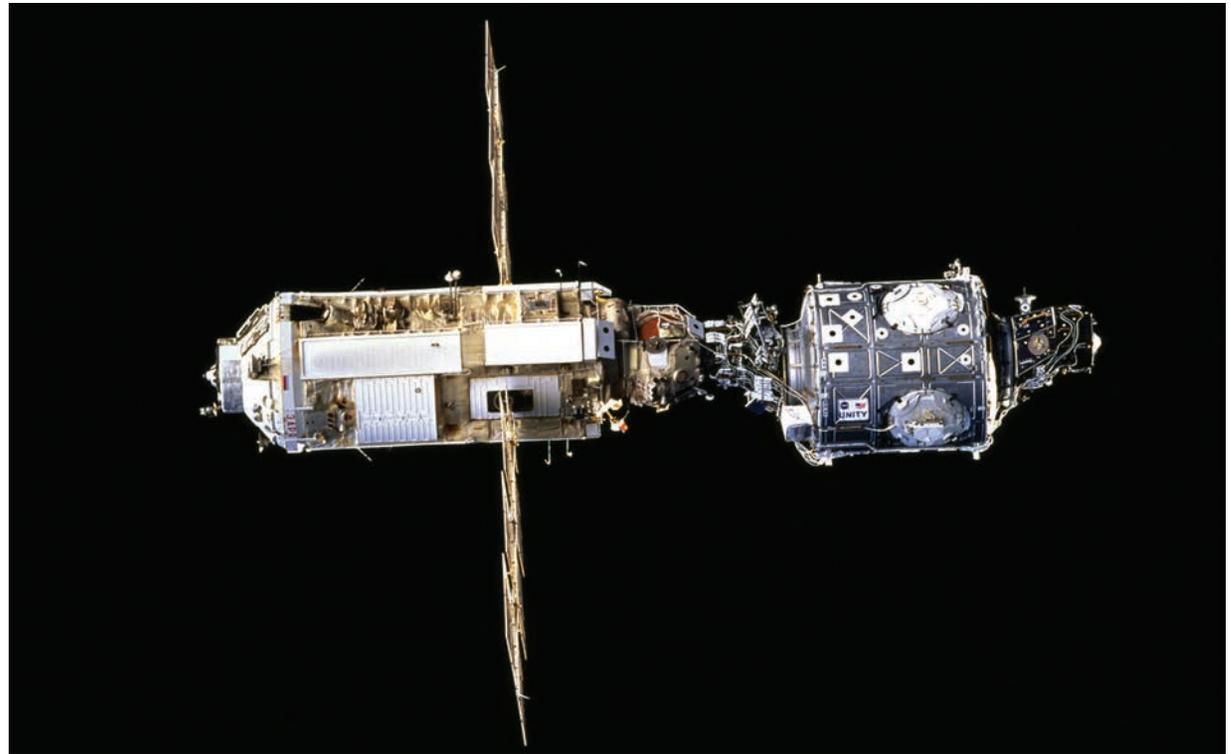
As NASA planned the logistics for a proposed space station, called Space Station Freedom, in the early 1990s, one of the agency's concerns was ensuring that the modules— individual station compartments to be constructed on Earth and flown piecemeal by space shuttles into low-Earth orbit—would be properly attached to each another. A critical part of the assembly process involved crewmembers leveraging the shuttle's Canadian-made robotic arm, Canadarm, for the heavy moving, and engineers wanted astronauts to receive positioning cues sufficient for setting objects within an inch and a degree of one another.

A solution was found in a technology called the Space Vision System (SVS), developed by Ottawa, Canada-based Neptec Design Group, a contractor for the Canadian Space Agency. Using standard cameras to track black and white dots placed on the space station modules, the SVS processing system would display their location and orientation at 15 frames per second, giving astronauts the necessary realtime visual cues for successfully connecting these large and costly research and habitation components.

Although the Space Station Freedom project was eventually discontinued, the SVS went on to be used in the construction of the International Space Station (ISS). For Neptec it was also the start of a long engagement in the US aerospace industry, serving as a Houston-based NASA prime contractor tasked with developing 3D sensor applications to help spacecraft safely navigate the dark, formidable backdrop of the cosmos.

## Technology Transfer

One of Neptec's important succeeding contributions came as a result of the Columbia Space Shuttle disaster in 2003. The tragic accident was the result of foam insulation breaking off the external tank during launch and striking the left wing, causing damage that ultimately led



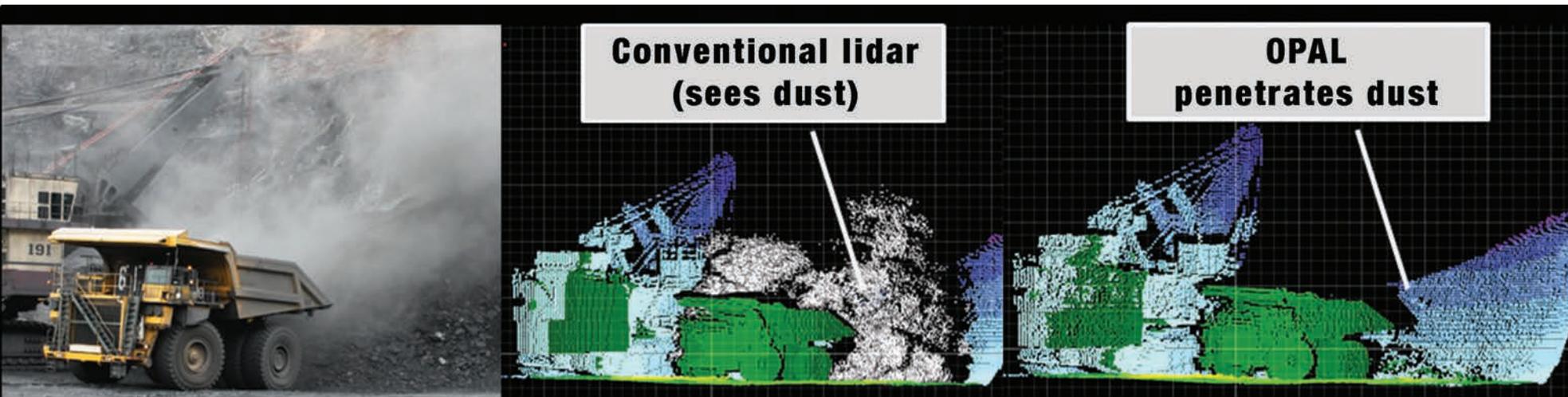
On December 4, 1998, Space Shuttle Endeavor launched Unity, the first US-built module of the International Space Station, into low-Earth orbit. Once in space, the shuttle performed rendezvous and docking maneuvers to attach Unity to Russia's Zarya module. Neptec Design Group's Space Vision System was used to provide the necessary visual cues.

to the spacecraft breaking apart upon reentry. Aside from assisting in analyzing video imagery of the accident—expertise they gleaned from working with the SVS—the company also helped fulfill one of the agency's mandates that resulted from the investigation: more detailed safety inspections of the space shuttle before reentry through Earth's atmosphere.

Neptec helped accomplish this by installing its Laser Camera System, or LCS, onto a 50-foot boom, which was grappled by the shuttle's Canadarm to capture images of the spacecraft's thermal protection system. What made the LCS particularly effective was that it was

able, using triangulation, to render a three-dimensional map of the shuttle's hull. That data was relayed back to Johnson Space Center, where engineers could use a 3D printer to produce a physical model. "We didn't have to do this every flight," says NASA's David Moyer, who helped ensure shuttle safety, "but it was nice to have those models because when we did have those cases where there was some damage, we were able to give those high-definition maps to the project's damage assessment team." Fortunately, shuttle repairs were never needed.

Neptec has gone on to further develop its 3D sensor capabilities. Funded by NASA and the Canadian Space



Neptec Technologies' Obscurant Penetrating Auto-Synchronous Lidar, or OPAL, family of 3D laser sensors, unlike conventional lidar technology, is able to penetrate dust, operate in total darkness, and withstand considerable vibration and shock.

Agency, the company's TriDAR 3D sensor combines the company's LCS technology with a long-range Lidar system in allowing spacecraft to rendezvous and dock with each other. The technology automatically acquires and tracks the target spacecraft without the use of any markers and can operate in total darkness. Originally developed in part to prepare for an unmanned mission to repair the Hubble Space Telescope, TriDAR was successfully tested on three space shuttle missions, including the program's final flight in July 2011.

The space shuttle program's closure heralded the end of an era for Neptec, but it also signaled new beginnings for the company, which in the same year founded a separate firm, Neptec Technologies Corporation, to commercialize its made-for-space products for the terrestrial market. For example, not only is TriDAR being used by Orbital Sciences Corporation to dock its Cygnus cargo transport spacecraft to the ISS; a slightly modified version of the technology has found its way onto helicopters to help pilots see through dust during landings.

But Neptec's main commercial entrée is the Obscurant Penetrating Auto-Synchronous Lidar, or OPAL, family of 3D laser scanners, which is derived from, among various other projects, its TriDAR and LCS contracts. Working in unison with its corresponding 3DRi software development toolkit, OPAL is designed to help machines operate

in challenging environments where safety and efficiency is key.

### Benefits

Much like how Neptec's contributions have allowed NASA spacecraft to navigate their missions in the dark expanse of space, OPAL, which uses a Risley prism pair for laser beam deflection, is designed to help businesses, such as mining and offshore gas and oil companies, more efficiently operate machinery in similarly dark and dangerous surroundings.

Neptec Technologies CEO Mike Sekerka says there are other 3D laser scanners on the market, but they lack several of OPAL's capabilities, the first being its real-time video feed. "Most laser scanners that are out there are used for survey-type applications," he says, "so they're usually too slow for navigation." It's also the only device that, because of its lineage to space-approved technologies, can penetrate dust, operate in total darkness and withstand a high degree of vibration and shock. "We really designed this for environments that no other laser scanner has been able to operate in," he says.

The company has already started collaborating with two global mining companies by installing OPAL scanners on their excavators and haul trucks. The size

of these machines, combined with the often limited light and space in which they operate, makes it difficult for operators to maneuver to desired locations on the first attempt. OPAL will help by allowing operators clear visual access to their targets, saving precious time as a result. Because equipment and other industry costs are high, increasing efficiency pays dividends. "If this technology shaves one or two seconds off the average spot time, that translates to millions of dollars a year in increased revenues," Sekerka says.

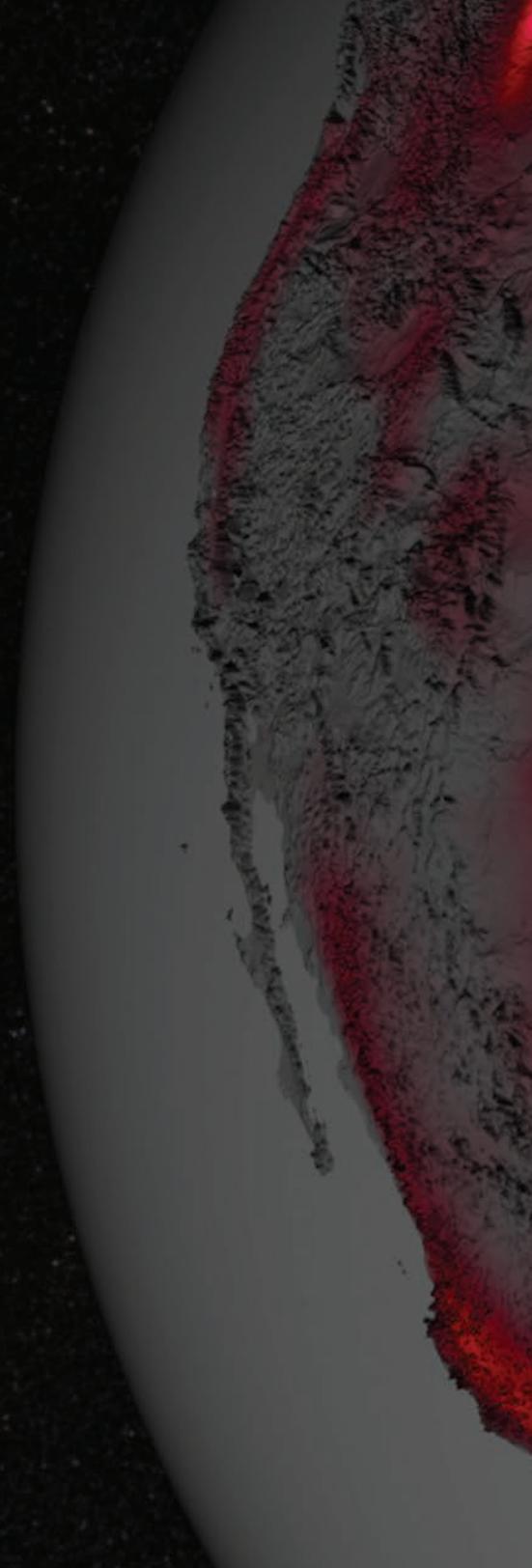
With recent investments being made by industry in driverless haul trucks operated by remote control, Sekerka notes that 3D intelligence technologies such as OPAL are generating even greater interest. The scanner's ability to operate in murky water also makes it an appealing tool for companies extracting oil from deep underwater fields. "There are lots of opportunities to take this technology to a number of applications and markets," he says.

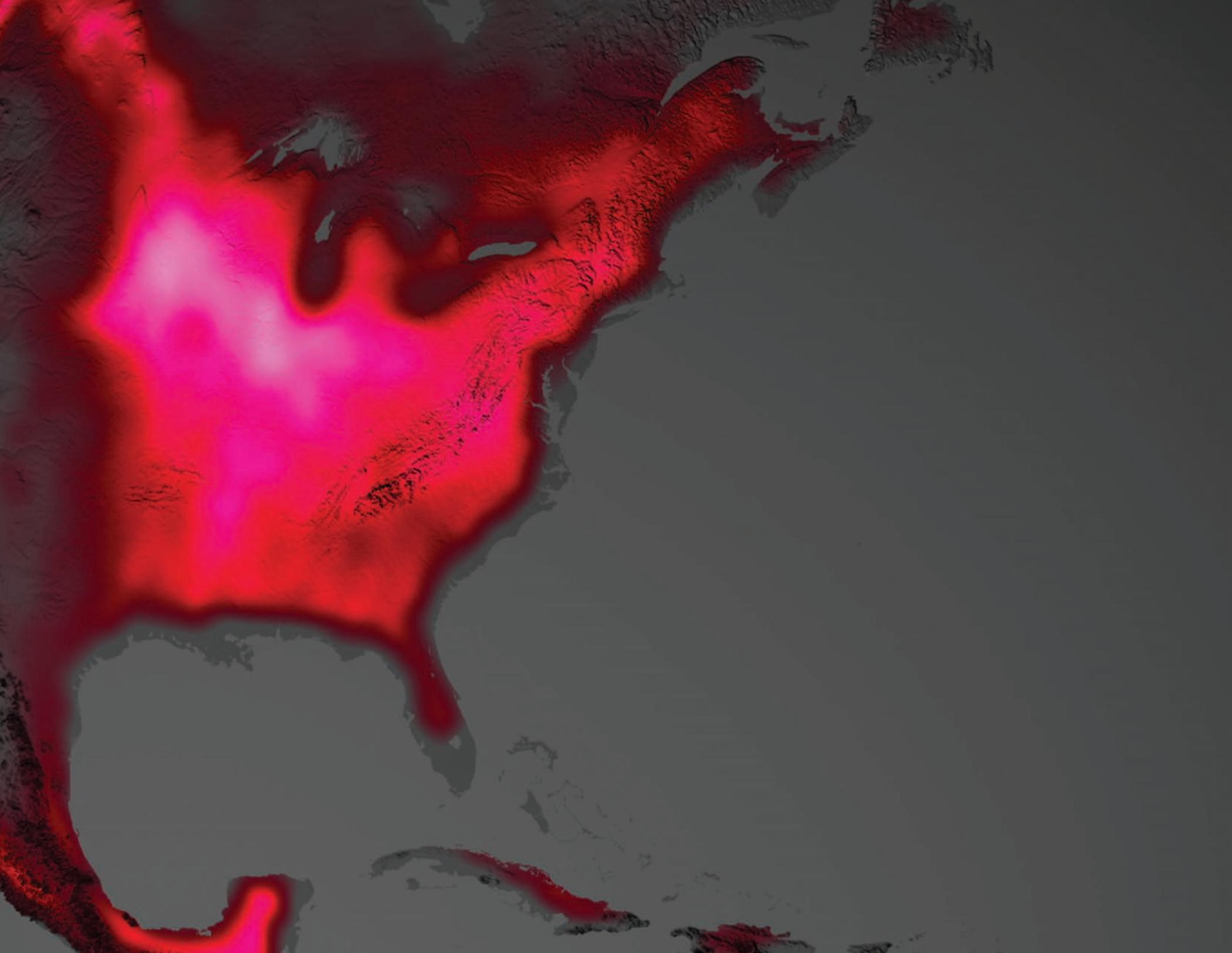
And it all began with Neptec's initial involvement in space exploration over 20 years ago. "To look at space investment as purely for space is too narrow," Sekerka says. "Support from NASA and the Canadian Space Agency laid the foundation for our commercial products, which helps drive jobs and exports and other economic benefits." ♦



## Consumer Goods

**N**ASA's innovations and partnerships have steadily found their way into the commercial market in countless consumer products, ranging from the obvious—such as technology and training that will one day enable civilian trips to space—to the unexpected, such as inventions that turn up in speakers, skin cream, lighting systems, and air purifiers. They even include devices to monitor personal ultraviolet exposure or to improve your golf swing.





# Air Revitalization System Enables Excursions to the Stratosphere

## NASA Technology

In order to test a parachute system for surviving high-altitude bailouts, from 1959 to 1960 the US Air Force commenced Project Excelsior. It required Captain Joseph Kittinger to complete a series of jumps from a gondola tethered to a helium balloon that had carried him into the stratosphere. On August 16, 1960, Kittinger completed his most audacious leap from a height of 102,800 feet—until recently the highest altitude reached by man in an unpowered aircraft. After achieving a freefall velocity of 714 miles per hour, he landed safely back on New Mexico soil.

Kittinger's risky skydive proved useful for not only pilots but also NASA astronauts. Besides the parachute, Kittinger also wore a pressurized suit to withstand being above what's known as the Armstrong limit. At approximately 62,000 feet, or roughly 12 miles above Earth's surface, atmospheric pressure drops so low that water boils at temperatures as low as the human body's. The pressurized suit prevented Kittinger's bodily fluids from doing the same, and its design also helped inform NASA's early space suits, which protect astronauts from the same dangers in space.

Another of Kittinger's contributions to space exploration was his participation in Project Manhigh, an Air Force program carried out just before Project Excelsior that studied the impacts that high altitudes have on helium balloons, aircraft, and human health. The research was an early inquiry into space exploration; the resulting findings laid the groundwork for NASA's missions in the 1960s and beyond.

Lifting the World View capsule into the stratosphere is a helium-filled, high-altitude balloon that has its roots in NASA technology. The agency developed standardized testing and launching methods and contributed research to understanding the aerodynamics of how objects descend to Earth from the edge of space.



Now there's a new story in the works that builds on the nation's history with high-flying balloons and space travel, and it involves allowing others the opportunity to see the world from a view that only a select few, such as Kittinger, have ever been allowed to see.

The first chapter began as one of NASA's iconic missions, the Space Shuttle Program, was coming to an end. The agency had set its sights on new horizons, such as sending humans to Mars and designing other spacecraft to explore the deeper reaches of the solar system. Instead of using the shuttle to get to the International Space Station (ISS), astronauts would hitch rides with the Russian Soyuz spacecraft. But the space agency recognized an opportunity for the private sector to eventually fill that transport role, and as a result, in 2009 NASA began accepting proposals under its Commercial Crew Development (CCDev) program.

Under CCDev, the agency paid companies to develop privately operated space vehicles and supporting technologies that would be used for low-Earth orbit missions such as trips to the ISS. One such supporting technology critical to astronaut survival in space is an air revitalization system. The air onboard a spacecraft must constantly be scrubbed of impurities and excess metabolic substances, so the shuttles were equipped with several components—housed in separate compartments—that removed carbon dioxide, carbon monoxide, and even humidity buildup from human sweat. Other technologies

were used to control the room temperature and cycle air around to prevent it from stagnating.

To improve the safety, reliability, and affordability of privately operated space vehicles while simplifying the integration process, Tucson-based Paragon Space Development Corporation, which was already working with NASA to develop next-generation space suits, proposed combining all of those discrete functions into a single, dependable module that could be installed onto any commercial spacecraft. The agency accepted the proposal, and in 2010 the two entities entered into a Space Act agreement.

Ten months later, the company announced completion of the preliminary design of the Commercial Crew Transport-Air Revitalization System, or CCT-ARS. The CCT-ARS is an all-purpose unit containing seven life-sustaining modules: carbon dioxide removal, trace contaminant removal, air filtration, post-fire atmospheric recovery, cabin air circulation, a dehumidifier, and air temperature control. The key innovation lies in the fact that, with the use of patent-pending technology, only one moving part is involved—a fan that circulates the air through all the modules.

### Technology Transfer

While the CCT-ARS was made for future manned flights into space, the air purification system's modular design and cost-effectiveness has been successfully transferred to other industries, for instance, as a life support component for refuge chambers that sustain miners in the event of an underground disaster (*Spinoff* 2013). For its part, the leadership at Paragon, through the creation of a separate company, Tucson-based World View Enterprises



The Commercial Crew Transport-Air Revitalization System was originally developed for future use on manned missions to the International Space Station (ISS), but World View is using the technology in its capsule to keep crew and passengers safe and comfortable throughout the unique experience.

Inc. is taking advantage of that technology, a favorable regulatory environment, and a rise in adventure tourism to send passengers, literally, into rarified air.

The concept is simple. At a launch site, likely in Page, Arizona, customers will board a pressurized capsule fitted with the CCT-ARS and attached to a large polyethylene balloon filled with helium. Two crewmembers onboard will guide the craft to heights of about 100,000 feet, at which point passengers will experience the same kinds of views Kittinger once beheld. After a few hours, the capsule will descend gently back to Earth. The experience takes an entire day.

Not only does World View use the CCT-ARS, which provides clean air throughout the duration of the flight,

the firm also uses another technology that Paragon developed through NASA's Small Business Innovation Research (SBIR) program: a single-loop radiator. "The advantage is that you have all of your pumps and valves and control systems inside the pressure vessel, so they're accessible by the crew," says Taber MacCallum, who is both chief executive officer at Paragon and chief technology officer at World View. "It's simpler and also takes less energy to operate than standard radiators."

MacCallum says NASA's fingerprints can also be found throughout the rest of the vehicle. "Virtually every aspect of the World View spacecraft can be traced to NASA, from radiation-tolerant computers to the micro-meteoroid impact-tolerant design of the pressure vessel."





The cabin is a pressure vessel similar in design to the modules that form the living and working quarters of the ISS. Inspired by the space station's cupola, the expansive windows allow for maximum viewing.

What's more, the agency has also contributed heavily to the ballooning technology that makes physically getting to that altitude possible. "NASA has been flying high-altitude balloons with payloads in the 8,000- to 10,000-pound range to very high altitudes for a long time," MacCallum says, "and really helped develop some of the testing and launching methods, as well as the aerodynamics of how a vehicle flies back from the edge of space."

### Benefits

What does Earth look like from 100,000 feet up? According to the World View website, as one ascends,

everything on the ground—the trees, buildings, even the mountains—blends into a beautiful collage. Through the capsule's dramatic windows, the roundness of Earth is also clear to see, as well as its position within a vast universe. To enhance the experience, the journey begins before dawn so the passengers can observe the night sky as well as the sunrise.

Apparently, the latter has even gotten astronauts excited. "Some of them I've spoken to really think it would be a nice experience to watch the sunrise occur from this frontier of space," MacCallum says, noting that astronauts in orbit circle Earth every 90 minutes. They're only allowed a glimpse of places before they zoom by.





The plan is for the capsule to launch and return to Page, Arizona, where winds are calm. Passengers will also be treated to breathtaking views of the Grand Canyon during descent.



Passengers will ascend 100,000 feet above the ground, high enough to see the curvature of Earth and picture its existence in a vast universe.

Because the capsule will take off in the early morning, passengers will also be able to take in views of both the nighttime sky and the sunrise.

“They think it would be a different experience to watch the sun and see the clouds forming from one location.”

In addition to these once-in-a-lifetime experiences, there are also science research opportunities to be had onboard the capsule. For example, microbiology and celestial observing applications could benefit from an environment nearly devoid of atmosphere.

“Certainly, we could carry payloads outside,” MacCallum says, “and maybe we’ll end up doing dedicated science flights that have a lot of instrumentation inside or outside facing the window or attached to the outside of the capsule. We’re starting at 100,000 feet, but certainly other altitudes are also possible.”

World View is pushing to take its inaugural commercial flight by the end of 2016, and a number of tickets have already sold. The introductory price is steep at \$75,000, but it compares favorably to similar services: Virgin Galactic, for example, is offering a suborbital spaceflight experience for \$250,000.

“A big part of the timing is that the demographics are good in terms of the number of people having the financial wherewithal to take a trip like this,” MacCallum says. “And when you consider the aeronautics and space community’s history with Kittinger’s jump and the Manhigh program, it’s like we’re returning to our roots.” ❖

# Magnetic Fluids Deliver Better Speaker Sound Quality

## NASA Technology

In the early 1960s NASA scientists were trying to work around a major problem for orbiting spacecraft: how to move fuel into an engine without the benefit of gravity. A scientist at Lewis Research Center (now Glenn Research Center) came up with a possible solution, which was to magnetize the liquid with extremely fine particles of iron oxide. That way, fuel could be drawn into the engine using magnetic force.

The quick advancement of solid rocket propulsion technology soon afterward precluded the need for

what would be called ferrofluid technology, but it was considered again in the mid-1960s as a means to control a spacecraft's temperature, which is very hot on the side facing the sun and very cold in its shadow. Scientists at Avco Space Sciences Division added their own expertise to the original NASA technology, developing a magnetic field that would draw the ferrofluid through a pipe ring around the spacecraft, stabilizing temperatures. Once again, an alternative solution was discovered and used instead.

But two scientists at Avco who were involved in the research, Ronald Moskowitz and Ronald Rosensweig,

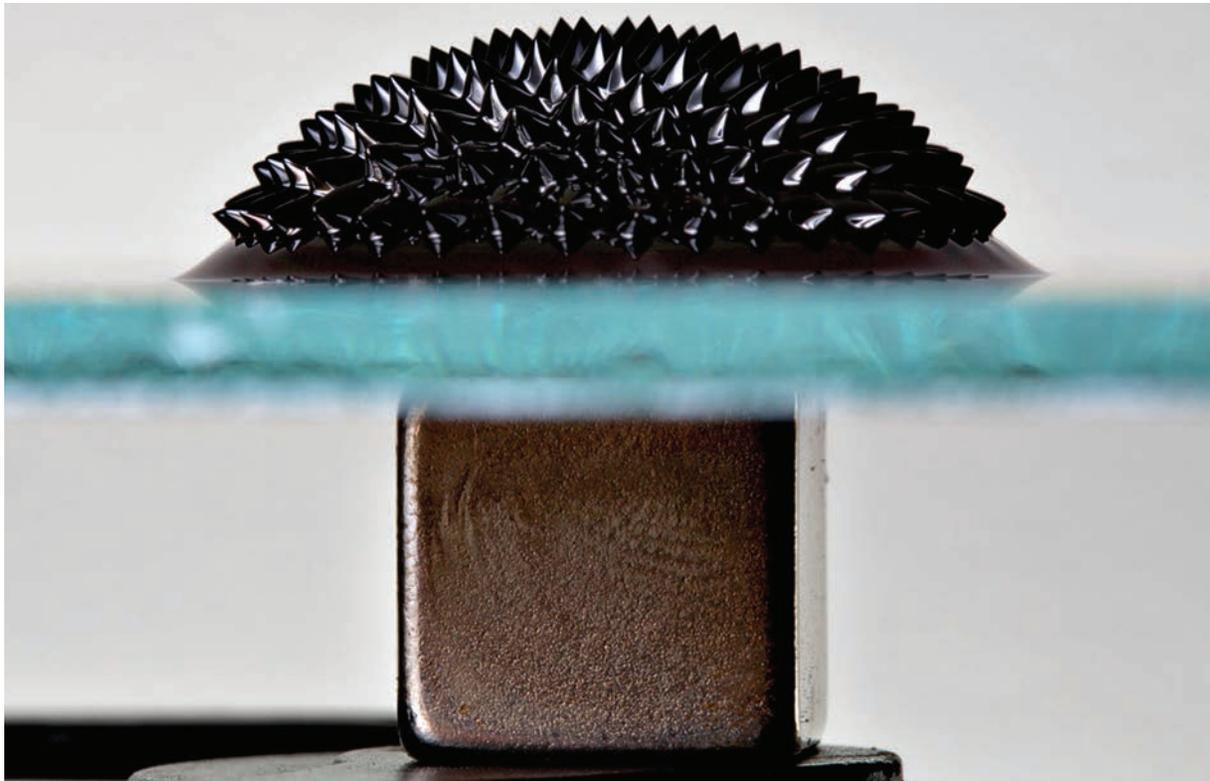
recognized the fluid's potential and licensed the technology from the space agency. They formed Nashua, New Hampshire-based Ferrofluidics Corporation (later Ferrotec Corporation) in 1969, and began applying ferrofluids in a variety of applications (*Spinoff* 1980, 1981, 1993).

## Technology Transfer

One of Ferrofluidics Corporation's first uses for the technology was in the development of seals used in fabricating semiconductor chips for electronics. In production, aluminum is deposited on silicon wafers within a vacuum chamber, but in order to ensure an even distribution, the wafers are rotated by a shaft. Because contamination (such as air, mist, vapor, lubricant, or dirt) can ruin a chip, all the involved components in the process are sealed. Nonetheless, frequent leakages caused by the rotation resulted in revenue losses due to replacement material costs.

To fix the problem, the company manufactured a magnetic seal composed of ferrofluid and a magnetic circuit. The magnetic field traps the ferrofluid in a manner that seals in the spaces between the moving shaft and static components, eliminating leaks and saving on costly materials. From there, Ferrofluidics Corporation went on to develop many more applications, from thermal solutions and quartz fabrication to advanced ceramics, vacuum coating, and even loudspeakers.

In 2012, Sony Corporation, through in-house research, also integrated ferrofluid technology, this time into a commercial line of slim speakers, which the company says produces a louder, cleaner sound than others of comparable size. A key component is the micron-deep



A magnet shapes ferrofluid from underneath glass. In the 1960s NASA developed the magnetic liquid technology as a way to move a spacecraft's fuel to its engines.

Image courtesy of Gregory Maxwell



pool of ferrofluid that serves as a damper.

Speakers produce sound by sending alternating currents through a coil, which moves rapidly back and forth in relation to a permanent magnet. The coil's movement vibrates the diaphragm, producing sound. A damper is typically a ring of any manner of materials, perhaps cardboard, paper, or silk, that fits around the coil to prevent it from wobbling and also to inhibit the diaphragm from blowing out. The downside of the damper, however, is that it can cause extraneous vibrations that can distort

sound and lower overall volume capability.

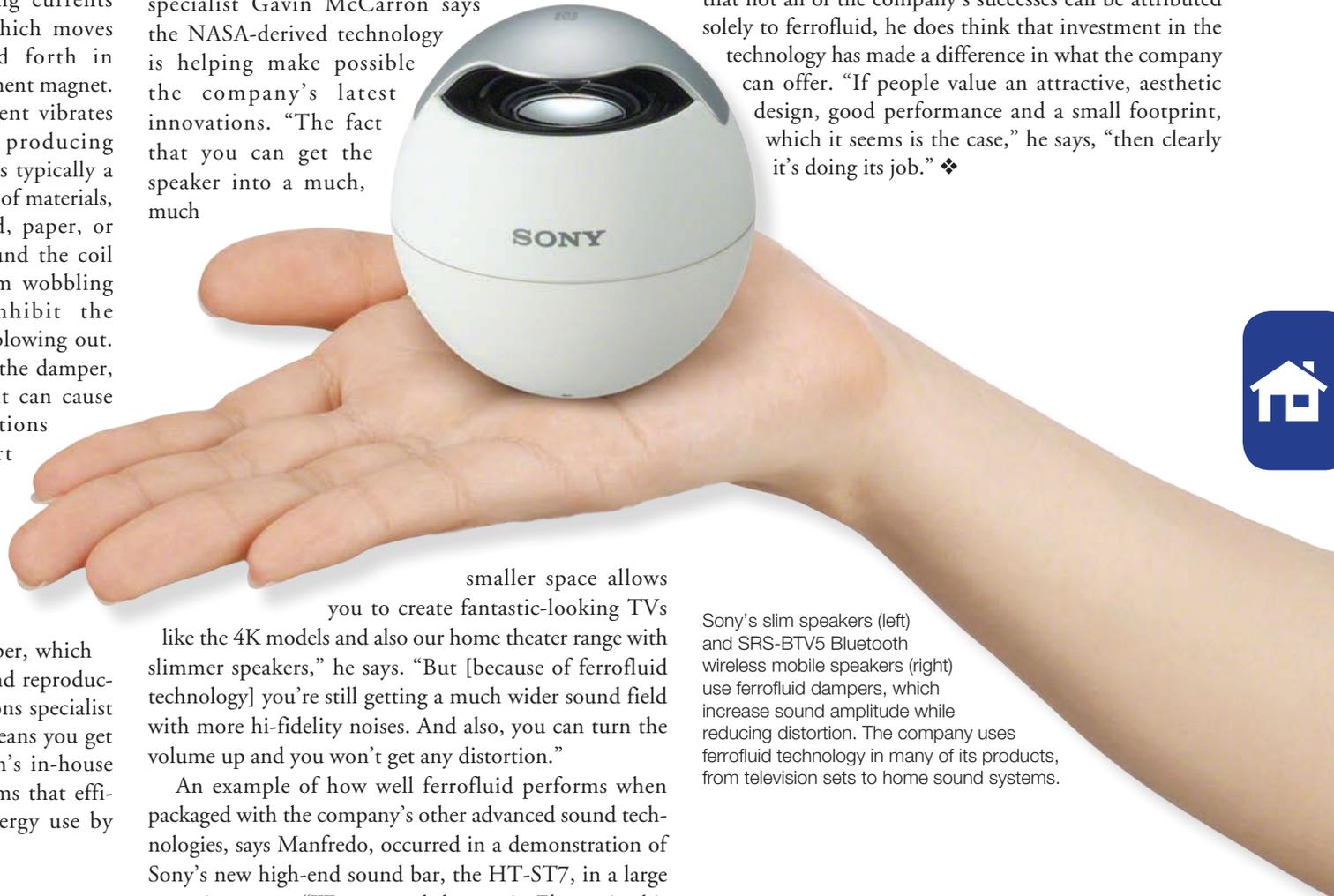
Sony's solution was to replace a solid damper with ferrofluid. The result, according to the company, is a better speaker. "The ferrofluid provides a free-flowing movement for the speaker to deliver sound without the vibration of a traditional damper, which minimizes some of the accuracy of the sound reproduction," says Rob Manfredi, a communications specialist with Sony. "The lack of dampening also means you get three decibels more in volume." The firm's in-house research and development group also claims that efficiencies created by the fluid decrease energy use by 35 percent.

### Benefits

In addition to professional installations in movie theaters, concert sound stages, and recording studios, Sony is also using ferrofluids for slim speakers in various

television models, sound bar attachments, and home sound systems.

In a promotional video released by Sony, product specialist Gavin McCarron says the NASA-derived technology is helping make possible the company's latest innovations. "The fact that you can get the speaker into a much, much



smaller space allows you to create fantastic-looking TVs like the 4K models and also our home theater range with slimmer speakers," he says. "But [because of ferrofluid technology] you're still getting a much wider sound field with more hi-fidelity noises. And also, you can turn the volume up and you won't get any distortion."

An example of how well ferrofluid performs when packaged with the company's other advanced sound technologies, says Manfredi, occurred in a demonstration of Sony's new high-end sound bar, the HT-ST7, in a large screening room. "We screened the movie *Elysium* in this 60-seat room, and we only used the HT-ST7," he says. "It just filled the room with sound. That's just seven small speakers using this technology."

In 2013, Sony, with US headquarters in New York City, was rated one of the top home audio retailers by sales in the country, says Manfredi. While he notes that not all of the company's successes can be attributed solely to ferrofluid, he does think that investment in the technology has made a difference in what the company can offer. "If people value an attractive, aesthetic design, good performance and a small footprint, which it seems is the case," he says, "then clearly it's doing its job." ❖

Sony's slim speakers (left) and SRS-BTV5 Bluetooth wireless mobile speakers (right) use ferrofluid dampers, which increase sound amplitude while reducing distortion. The company uses ferrofluid technology in many of its products, from television sets to home sound systems.



# Bioreactor Yields Extracts for Skin Cream

NASA Technology

Most scientists do not question whether the force of gravity will affect their experiments. On Earth, gravity is a constant. For NASA scientists studying the effects of microgravity on the human body, however, it's a different story.

"The force of gravity is a major variable in our research because we research human physiology in microgravity," explains Dr. Thomas J. Goodwin, a scientist and inventor at Johnson Space Center. "There are no other researchers in the world—except space scientists—that consider the force of gravity an experimental variable. Negating external forces such as gravity can lead to significant new discoveries in human biology for the benefit of humankind."

One such example is the bioreactor that came from experimentation by NASA researchers who wanted to replicate microgravity conditions in the laboratory. They invented a rotating wall vessel (RWV) bioreactor that kept the growth medium and cells suspended in the chamber of the device, simulating a constant free fall similar to the conditions found in microgravity. Unlike the way cells typically grow in a laboratory—two-dimensionally on a flat surface—the cells in the RWV bioreactor grew in a three-dimensional fashion, similar to how they naturally grow in the human body. NASA used the RWV bioreactor to perform tissue-growth experiments both on the ground and in space.

"Not only is the cell-to-cell architecture and interaction in the RWV bioreactor better than a two-dimensional medium," says Goodwin, "but the molecules that the cells produce are very similar to native molecules produced in the human body."

In addition to producing cells and tissues similar to those produced in the human body, another advantage of the RWV bioreactor is that biomolecules

A photograph of an astronaut in a white spacesuit working on the Columbus module of the International Space Station (ISS) during the STS-122 mission. The astronaut is positioned in the center-right of the frame, floating in space. The ISS structure, including large solar panel arrays, is visible in the background against the blackness of space and the blue curve of the Earth. The Columbus module is a large, cylindrical structure with various panels and equipment attached to its exterior.

European Space Agency astronaut Hans Schlegel works on the Columbus module of the International Space Station (ISS) during STS-122. Columbus is a science laboratory that has housed many experiments on the ISS, including research into how micro-organisms react to and grow in the microgravity environment.

Image courtesy of ESA

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“ Negating external forces such as gravity can lead to significant new discoveries in human biology for the benefit of humankind.”

— Thomas Goodwin, Johnson Space Center

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can be made in very large volumes at high purity. “By using the NASA RWV bioreactor, gallons of molecular fluid can be generated in a shorter time than existing methods using other bioreactors or the two-dimensional methods,” says Goodwin.

NASA scientists have continued using the technology to research biological markers indicative of viral infections, oxidative damage, and toxic responses to the microgravity environment. Goodwin hypothesized that oxidative, toxic products could begin to build up in astronauts’ bodies during long space missions and that the toxic effects tend to worsen as a mission continues for months or years. His team grew human kidney tissue in the RWV bioreactor to investigate tissue response and then looked at the kinds of molecules produced in the tissue based on the microgravity environment and specific toxins. The final goal of the investigation, says Goodwin, was, “Can we do anything to protect the cells and tissues from these oxidative, toxic products?”

While examining this question, the researchers found that molecules produced by the cells will vary after exposure to certain toxins in their cellular environment. Based on that discovery, they started wondering what other kinds of tissues would grow in the RWV bioreactor, as well as what molecules those tissues would produce. During their investigation of adult human kidney, lung, and epithelial stem cells, Goodwin’s group produced a range of biomolecules that had regenerative qualities, including fibroblasts—adhesive molecules that help to hold cells together.

“The spectrum of different molecules that were produced was a surprise to us,” Goodwin says. “We found things there that were really very useful that we had not thought about when we first started the experimentation.”



When used as directed, RE'JUVEL has been shown to significantly increase skin moisture and reduce darkness and wrinkles.

### Technology Transfer

The patent for the process to produce a regenerative fibroblast extract using the NASA bioreactor was licensed from NASA by a company in 2013. That business, Technology Applications International Corporation, formed a subsidiary company, Renuèll Int’l Inc., based in North Miami Beach, Florida, to market and sell cosmetic skin care products infused with the NASA bioreactor-produced fibroblast extract to promote skin healing and skin rejuvenation.

### Benefits

Renuèll’s skin care product, RE’JUVEL, is a facial repair cream that yields benefits for both men and

women. According to Renuèll, the product stimulates the body’s cellular activity and rebuilds and tightens skin for a firm, healthy, youthful appearance. The company claims that benefits include reduced wrinkles, increased skin moisture, and reduced skin discoloration due to age spots and dark circles. In addition, the company finds that RE’JUVEL stimulates the growth of new collagen and has acne-fighting capabilities.

The key ingredient is a composition that includes agents from human fibroblasts grown using the RWV bioreactor. Fibroblast skin cells exist naturally in the skin and play a critical role in healing. As people age, the body generates fewer fibroblast cells; replenishing those cells allows the skin to repair itself more quickly.

According to John Stickler, vice president of Renuèll, “As we age, elasticity decreases and blotching and wrinkles appear. Our skin shows uneven skin tones and discoloration. When RE’JUVEL is applied, your skin absorbs the compound and stimulates the repair of your skin naturally using your body’s own healing abilities.”

Stickler says that when used properly, and depending on a person’s skin type, results may be seen as quickly as in several hours or days. According to efficacy results from a Food and Drug Administration (FDA)-approved laboratory, on average, RE’JUVEL increased skin moisture content by 76 percent, reduced darkness by 61 percent, reduced wrinkles by 54 percent, reduced dark circles by 57 percent, and increased biological elasticity by 43 percent.

The product is currently available on the company’s website, in salons, and in doctors’ offices and will soon be available in retail outlets.

“One never really knows what kind of applications will come from a discovery process,” Goodwin says. “This was truly a discovery process that had one intention and goal for NASA but has led to something completely different that can benefit people on the ground.” ❖



# Private Astronaut Training Prepares Commercial Crews of Tomorrow

## NASA Technology

In addition to teaching crewmembers to perform crucial tasks like using their spacecraft's technical devices, piloting a vehicle back into Earth's atmosphere, and landing a shuttle or capsule, major portions of NASA's astronaut training simply teach how to survive and carry out basic tasks in an environment where the dangers and basic physics are completely altered from those of terrestrial life. These lessons are based primarily on the collective experience of everyone who has gone before.

Jack James, who spent 15 years involved in astronaut training at Johnson Space Center (JSC) and is now in the center's Technology Transfer Office, tells a piece of

astronaut lore from the early days of space travel: because pens don't work without gravity to pull the ink down, a pressurized pen has to be used. The Russians avoided the problem by using pencils. The pencil shavings, however, posed a potential hazard, in that an escaped shaving could be inhaled or get in someone's eye.

"You've got to understand, you can't just do whatever you do down on Earth," James says. "When you fly somebody, you want to prepare crew members and eliminate unexpected situations as much as possible."

At JSC, where the bulk of NASA astronaut training happens, trainers specialize in every aspect of operations and daily life in space, and all returning crewmembers debrief with each of them, sharing the ways their experience departed from their training. Those interviews are

used to refine future training, teaching astronauts how to carry out even the most ordinary activities, such as eating, bathing, and using the bathroom, James says.

A number of sophisticated systems are used to simulate the experience of space travel. Parabolic airplane flights to simulate weightlessness, centrifuges to replicate the g-forces of takeoff and reentry, and underwater "neutral buoyancy" operations have long been training mainstays.

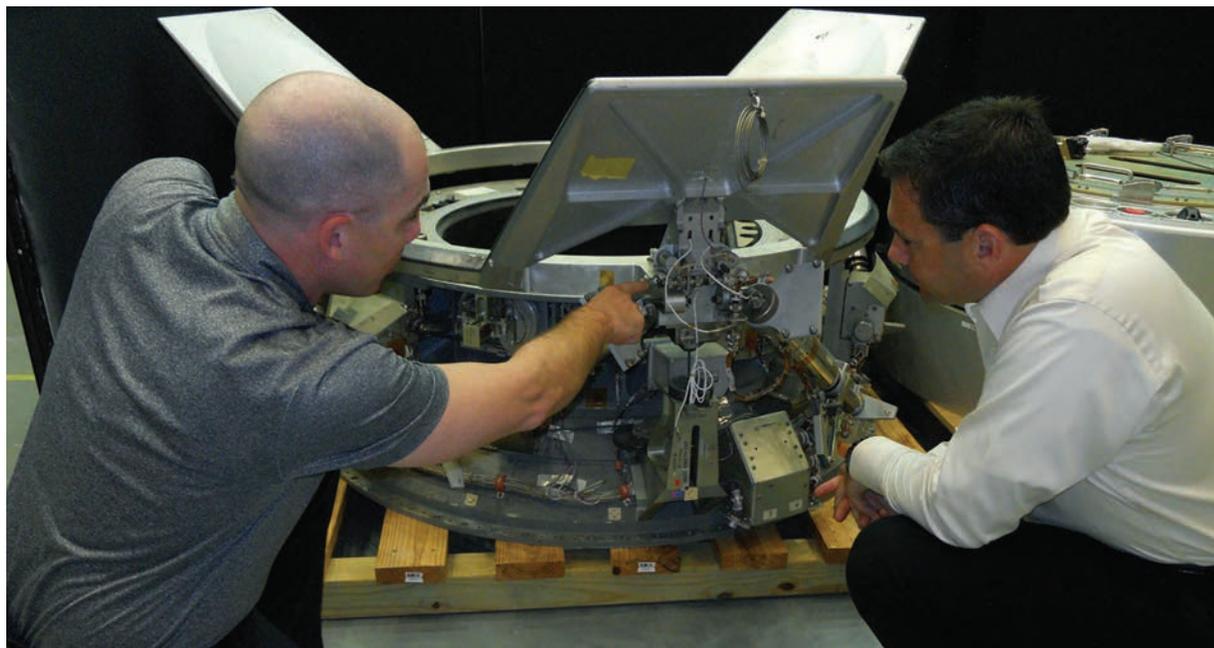
The curriculum includes courses in life support systems, orbital mechanics, payload deployment, Earth observations, space physiology and medicine, flight and safety operations, and Russian, among many other subjects.

## Technology Transfer

Virtual reality software is now a common tool in NASA's training regimen, and NASA software developers have developed and built on a variety of simulation programs. Two of those programs—*Trick Simulation Environment 07* and *Engineering DOUG Graphics for Exploration*, wherein DOUG stands for dynamic onboard ubiquitous graphics—were recently acquired from NASA through a General Public Release Software Usage Agreement by a new company that plans to open up astronaut training to the general public. Waypoint 2 Space, which is setting up a 15,000-square-foot training facility near JSC, plans to offer its seven-day, level-one training to 300 people in groups of 4 to 12 in its first year. The company hopes to open its doors in spring of 2015.

The company is one of the first to receive a safety approval from the Federal Aviation Administration's (FAA) Office of Commercial Space Transportation to offer commercial astronaut training. The approval, granted in early 2014, was based on Air Force, NASA, and FAA criteria and includes approval to train instructors, according to a release on the Federal Register.

The training was developed from firsthand knowledge of spaceflight operations and training, as the staff includes a handful of former NASA personnel and contractors.



A Waypoint 2 Space payload specialist trains a researcher on how to package and prepare a payload. The company offers payload services, from instruction on how to meet Federal Aviation Administration requirements to accompanying payloads and carrying out experimentation in orbit.

Among them is Kelly Soich, director of programs and chief payload specialist for Waypoint 2 Space, who is in charge of the company's training curriculum. Soich supported Extravehicular Activity training and evaluation of astronauts for NASA and was also a flight lead in the mission evaluation room for more than 60 spacewalks.

"It's really a collective of commercial and NASA people blending together to get something that's effective," Soich says.

Those who attend this first level-one training—"the Elite 300," as Waypoint calls them—won't be trained in the Russian language, but they will learn about everything from how to prevent fainting due to accelerated g-forces to how to don and carry out operations in a pressurized space suit and how to negotiate Martian or lunar terrain using analog simulations. Other subjects include conflict and stress management, oxygen deprivation symptoms and recovery, flight dynamics, orbital mechanics, and how to maneuver in microgravity, to name a few. The course uses vehicle mockups, software, and other technology in its simulations.

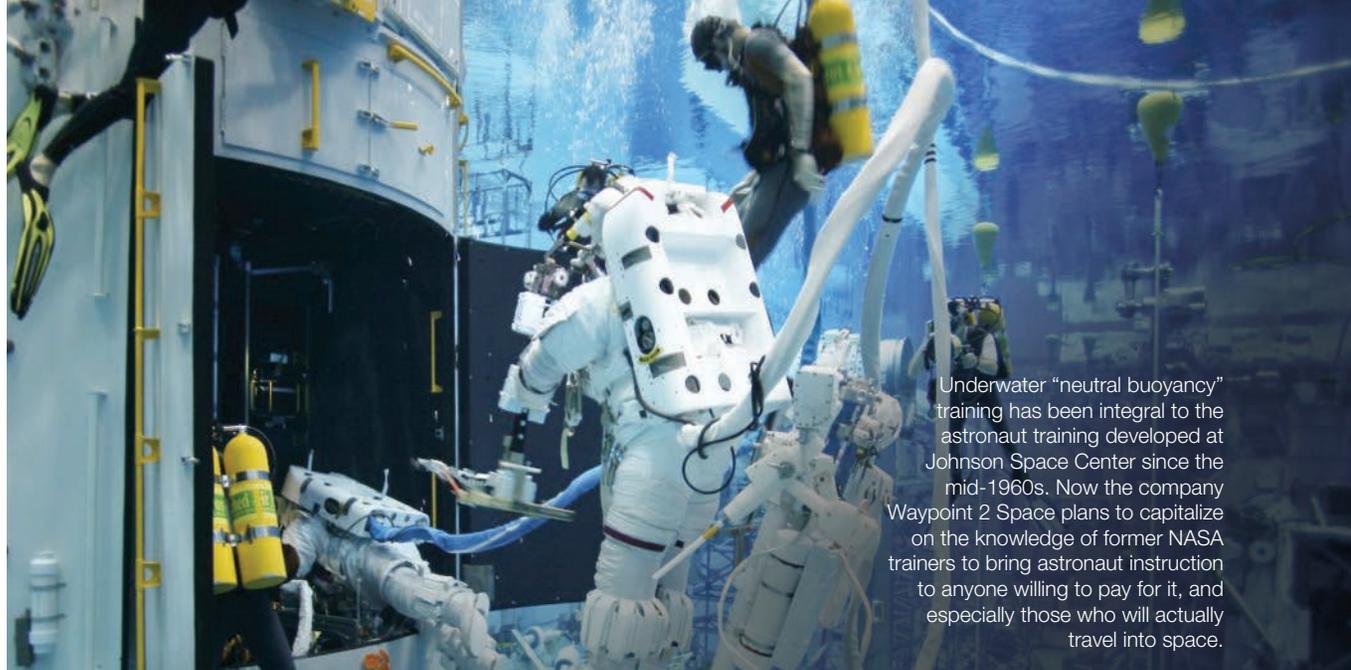
"Our level-one is open to anybody," Soich says. "If you have an interest in space, we'd love you to go through it."

The price tag? Forty-five thousand dollars.

The three-day, level-two sub-orbital course and the 8- to 12-week, level-three orbital course haven't been priced yet, but those are planned to be reserved for clients who already have a ticket to go into space. The wait list for the third level is expected to open in 2015.

Waypoint 2 Space also offers its services to anyone sending a payload up on a commercial flight. These services can range from consultations on how to meet FAA requirements and ensure the success of experiments in space to accompanying a payload and carrying out experimentation in orbit.

Soich notes that putting a payload in space can cost hundreds of thousands of dollars. "Three to four minutes in suborbital gravity is a pretty expensive investment to come home with no results," he says.



Underwater "neutral buoyancy" training has been integral to the astronaut training developed at Johnson Space Center since the mid-1960s. Now the company Waypoint 2 Space plans to capitalize on the knowledge of former NASA trainers to bring astronaut instruction to anyone willing to pay for it, and especially those who will actually travel into space.

## Benefits

Not all 300 of Waypoint's first trainees are likely to go into space, and, as people continued to enroll in the spring of 2014, Soich said many were simply buying the experience.

"We have folks who are just intrigued and want to be part of the space legacy," he says. Others, however, are considering a trip into space.

Anyone traveling to the ISS would have to train with NASA, just as a payload sent on a NASA mission would have to meet the agency's requirements, but Soich expects the commercial presence in Earth's orbit to grow considerably in the coming years. He's not alone. As a couple of companies have started launching rockets to carry payloads to the ISS, dozens more are gearing up for space operations, including tourism and mining. Bigelow Aerospace has designed what it plans to be the first commercial space habitats. Anyone going on these missions would require training to meet FAA requirements.

"We would be the pathway for training somebody to go up on Bigelow and operate, for example," Soich says. Thanks to FAA approval, anyone certified by Waypoint wouldn't have to have their training vetted.

That's where Waypoint 2 Space sees its future.

"I think we're probably a decade out from a continued commercial presence in orbit," Soich says, adding that, at that point, the industry could take over the sort of operations NASA carries out on the ISS, while the agency could focus on its campaign to push its work beyond Earth orbit and toward Mars. He compares this transition to the commercialization of mail delivery or passenger flight.

As it sets about developing training for the pilots, flight attendants, and vacationers of tomorrow's aerospace industry, Waypoint 2 Space has about a dozen full-time workers and 20 or so others that it reaches out to as regular consultants. In the spring of 2014, the company was vetting customers, working to transfer technology from NASA, and trying out hardware and training programs on about six "test case" trainees.

"It's really a fun project because the excitement is there, and every day you come in to work and it's something new," Soich says. "It's really like the Wild West in a lot of ways." ❖



# Activity Monitors Help Users Get Optimum Sun Exposure

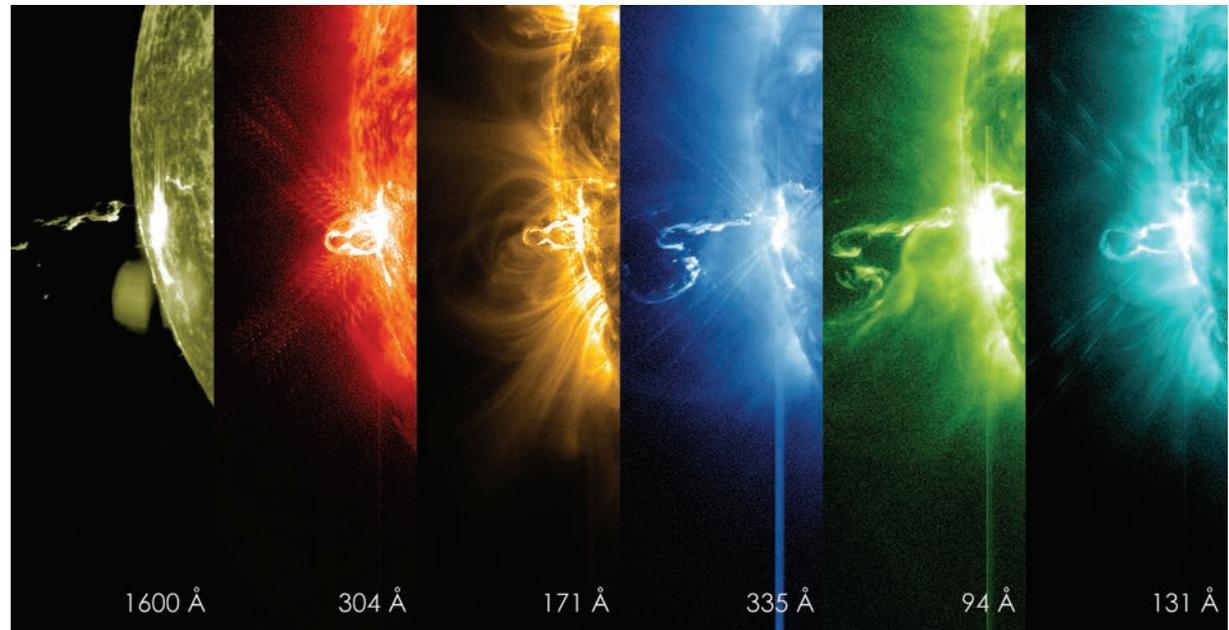
## NASA Technology

To the casual observer, the sun appears as a steady, static, glowing ball of heat. But closer inspection reveals our closest star can be rambunctious, capable of emitting powerful, sudden bursts of energy and radiation that can impact life on Earth. Coronal mass ejections (CME), for example, are bubbles of gas and magnetic fields that explode outward at rates of several million miles per hour. If directed at Earth, a CME can cause geomagnetic storms that interfere with high-frequency radio communications and disrupt electric power grids.

In order to further understand the sun's impacts on Earth, in 2001 NASA initiated the Living with a Star program and soon after began developing a key research satellite: the Solar Dynamics Observatory (SDO). The SDO would be outfitted with a suite of onboard instruments that could provide both real-time, high-definition images of the sun's atmosphere and measurements of both its magnetic field and its output of varying radiation. The data gleaned from the satellite would go toward developing forecasting methods that could help prevent disruptions.

One of the instruments created for the SDO was the Extreme Ultraviolet Variability Experiment (EVE), tasked with measuring extreme ultraviolet (UV) radiation, which plays a key role in atmospheric heating and satellite drag. If left unchecked, such radiation can send spacecraft plummeting toward Earth. In 2005 Goddard Space Flight Center scientist Shahid Aslam joined other researchers, headed by Tom Woods of the University of Colorado Boulder's Laboratory for Atmospheric Space Physics, in developing EVE.

A focus of Aslam's work was experimenting with different ways of measuring extreme UV radiation. Silicon semiconductors have been used traditionally as detectors, but a drawback is they take in both UV and visible light. Filters are used to isolate the ultraviolet signal, but the



On February 24, 2014, NASA's Solar Dynamics Observatory (SDO) captured an X-class solar flare in different wavelengths of light, including ultraviolet (UV). One of the SDO's instruments is the Extreme Ultraviolet Variability Experiment (EVE), tasked with measuring extreme UV radiation, which plays a key role in atmospheric heating and satellite drag.

results aren't ideal, he says. "Every time you apply a filter, you get transmission losses, so it becomes tricky."

To sidestep the filtration process, the team looked into what are called wideband gap semiconductors: chemical compounds that detect a narrower range of wavelengths on the electromagnetic spectrum. In particular, the team worked with compounds that detect only UV light. "We were no longer contaminating our signal with radiation we were not interested in," Aslam says.

The team made great strides with the novel semiconductor technology, and although it wasn't integrated into the SDO, the team's findings were published in peer-reviewed journals, and the agency filed a few patents. For his part, Aslam would take the knowledge he gained from working on wideband gap semiconductors and apply it to an entirely different industry.

## Technology Transfer

It was early on in the project while experimenting with different compounds that Aslam noticed that a few of them detected bands of wavelength in the UV spectrum that held special significance for human health. "I was thinking, wow, we're detecting radiation between 280 all the way to 400 nanometers in wavelength," he says. "This is exactly where you have biological effects due to sun exposure."

Of the many types of UV light, UVA, which ranges from 400 to 320 nanometers, and UVB, present in the 320- to 280-nanometer territory, play important roles in health since their rays can pass through the atmosphere and make contact with Earth's surface. Whether they're friend or foe depends on the amount of exposure: Our

bodies need UV light to produce vitamin D, critical to building bone density and supporting brain and immune system function, but too much sunlight can cause sunburn, premature aging, and skin cancer.

To gauge how much sunlight is too much, scientists have developed what's known as the erythemal UV index, which highlights the durations at which UV wavelengths, when set at certain power quotients, will likely cause erythema, or reddening of the skin due to inflammation. Wouldn't it be great, Aslam thought, to develop some kind of device that measures UV exposure in a way that allows people to manage their daily sun intake?

He brought the idea up with fellow squash player and marketing guru Karin Edgett, and the pair agreed to move forward with developing the product. In his spare time away from Goddard, Aslam began working on

the technical development, which included formulating algorithms and homing in on a proficient detector compound; Edgett tackled marketing and branding. Their resulting concept—a UV light-detecting activity monitor—received recognition in 2011 when it won first place in the consumer products category in NASA Tech Briefs magazine's Create the Future Design Contest.

Buoyed by the initial reception, the pair formed Sensor Sensor LLC and moved forward with further development and crowd funding. In April 2014, after receiving positive reviews in trade shows the previous year, the UVA+B SunFriend was put on the market.

### Benefits

UVA+B SunFriend activity monitor comes at a time, Edgett says, when one in five people in the United States will get skin cancer in his or her lifetime, making it the most common form of cancer in the country. On the flip side, in some regions of the world—Scandinavia, for example—vitamin D deficiency is considered a pandemic. “This product provides a way to optimize the Vitamin D synthesizing process up to a maximum dose and before it starts causing cellular breakdown,” she says.

To use SunFriend, a user first selects his or her level of skin sensitivity on an 11-point scale, with 1 indicating the highest level of sensitivity and 11 the lowest, reserved for very dark or sun-tolerant skin types. The device is then worn face-up on the wrist and left uncovered.

Throughout the day, as UVA and UVB light hit the embedded semiconductor compound, it produces photocurrents indicative of how much radiation is coming in. A microchip processes that current, taking into account radiation strength, the ratio of UVA to UVB light, and the selected level of skin sensitivity. When the maximum recommended daily dose of UV light is reached, the LEDs on the face of the device will



Inspired by his work on EVE, Goddard scientist Shahid Aslam conjured up the idea for what is now UVA+B SunFriend, a UV light-detecting activity monitor that informs people when they've reached their maximum recommended daily dose of sunlight.

flash. Aslam says, “At that point you apply sunscreen, go indoors, or put on clothing.”

When first using SunFriend, it may take a few tries to settle on the right skin sensitivity number, Aslam says. “If your skin is already red when the SunFriend flashes, you need to lower the number.” However, once it's set to the right number, it can be used without fuss year-round.

While the benefits of using the technology to prevent overexposure are apparent in the summer, during winter people can run the risk of not getting enough sun, which can lead to vitamin D deficiency, followed by depression, according to Aslam. “This is one of the phenomena we're facing in northern-latitude countries like Finland and Sweden, where there are very high suicide rates. All the research shows that lack of sunlight plays a key role.”

While SunFriend is still very new to the market, the company is already working on increasing its functionality, such as implementing Bluetooth technology so that information can be communicated to users' smartphones for record-keeping and statistics.

Aslam says such an add-on would be a clear step in the right direction. “People are now taking control of their vital statistics,” he notes. “Everyone wants to track how many calories they've burned, their heart rate, blood pressure, blood sugar levels. The same should be true about the amount of sunlight they're getting. It's just as important.” ❖



# LEDs Illuminate Bulbs for Better Sleep, Wake Cycles



The newest plant-growing experiment on the International Space Station (ISS), Veggie, went live in May of 2014. Veggie uses LED lighting to stimulate plant growth and will provide fresh lettuce and produce to astronauts on the ISS.

## NASA Technology

Kennedy Space Center has been known as America's spaceport for more than 50 years. From Project Mercury to recent commercial-space missions, the nation has witnessed many amazing launches from the Space Coast to low-Earth orbit and beyond. But another, not-so-well-known area of Kennedy's expertise is in something not typically sent on its launches: plants.

Because NASA is planning for future visits to distant locations like Mars, however, the agency is researching how to grow plants in space. Live plants would be valuable on space missions because they provide a nutritious food source; offer astronauts a familiar feature from home; provide a pleasurable activity—gardening—while in space; and contribute to cleaning air in a spacecraft.

When looking at how to best grow plants on space missions, one must look at lighting for the plants. Kennedy engineer Daniel Shultz says, "In studying plants and growth chambers at Kennedy, we looked at high-intensity halogen lights, special UV bulbs, and then LEDs. As we were doing our research, LEDs were getting more and more robust."

LEDs, or light-emitting diodes, are semiconductors that produce different wavelengths of light depending on the material they are made from. By incorporating different LEDs on a single circuit board, the light can be changed and controlled to include or omit specific wavelengths of light, and at different times.

NASA is interested in using LEDs not only for plants but for general lighting needs in spacecraft. This is because LEDs require little power, last a long time, can

function in extreme temperatures, are lightweight and shatterproof, don't give off heat at the light source, and are able to produce specific colors of light.

"When you are going to Mars, you want a light bulb that can last six years even though it might be a three-year mission," says Shultz. "It means you can carry fewer spares, and the spares that you do stock need to be versatile—not one for the restroom and one for the cockpit. One bulb needs to fit many lights and have many different functions."

While the Kennedy team was investigating LEDs for plants, the National Space Biomedical Research Program (NSBRI), a NASA-funded group of institutions that seek solutions to health concerns facing astronauts on long space missions, had sponsored researchers to study how light affects the human body. The Kennedy team built a

prototype LED light for the NSBRI research, and “what they were finding,” says Shultz, “was that different colors of light help people stay awake and to go to sleep.”

The NSBRI researchers, including George Brainard, a professor of neurology at the Jefferson Medical College at Thomas Jefferson University, found that blue light at a particular spectrum could reduce melatonin production. Melatonin is a hormone that helps to maintain the body’s circadian rhythm, or natural body clock. More melatonin helps people sleep; less disturbs the circadian rhythm.

Based on the findings, Brainard and others suspected that the human eye must have photoreceptors, or areas sensitive to light, that don’t have anything to do with vision. Soon after the researchers theorized their idea, it was confirmed when other scientists were able to identify the receptor in the eye.

For NASA, this meant lighting could possibly assist in helping astronauts avoid sleep deprivation. Because astronauts see more than a dozen sunrises and sunsets every 24 hours from the International Space Station (ISS), their circadian rhythms are disturbed. On Earth, we are exposed to different wavelengths of light at certain times, and our circadian rhythms acclimate to this schedule. Sunlight, for example, signals that it is time to be awake. But when astronauts see the sun appear and disappear many times in a matter of 24 hours, it affects their ability to get to sleep.

In addition to building the LED lighting used in the NSBRI research, the Kennedy team also started developing the first prototype LED system for the ISS. They worked with a NASA contractor, Bionetics, and by 2008 the system was installed in the station, where it continues to function successfully.

## Technology Transfer

After the installation of the system on the ISS, Robert Soler, a lighting science expert with Bionetics at the time, started working with Satellite Beach, Florida-based Lighting Science to help bring the developments of LED



Commercial crew vessels, such as the mockup of Boeing’s CST-100 shown here, are all adopting LED lighting technology as a way to save electricity, extend the life of lighting sources, and potentially help crews manage their biological rhythms as they adjust to life in space.

lighting for space back down to Earth. Several other scientists and engineers involved with the LED work at Kennedy also brought their expertise to the Florida company; their aim was to develop and commercialize new LED products to benefit people, plants, animals, and the environment.

By late 2013, Lighting Science launched a new line of lighting called DefinityDigital. The family of products includes four LED lights: Awake & Alert, Goodnight, MyNature Grow, and MyNature Coastal.

“A lot of NASA’s learning, science, and research has led to these new products,” says Soler.

## Benefits

According to the company, Lighting Science is bringing not only the efficiency of LEDs to the market but their health and environmental benefits, too. “These lights go beyond illumination,” says Soler. “We are taking

what has been just a base illumination job of a light bulb and turning it into something far more powerful.”

The research under NSBRI funding—including the use of prototype LED lights developed by the Kennedy team—has directly influenced the development of the Awake & Alert and the Good Night lights. “These lights trigger a photoreceptor to send messages to the area of the brain where circadian rhythms are regulated,” says Soler. “When you do this, the body’s clock believes it is a certain time of day.”

Awake & Alert is programmed to produce wavelengths of blue light to suppress the production of melatonin. “It has daylight cues,” says Soler. He uses the example of how a person feels better after a walk outside during the day. “The reason is that we are blue-sky-seeking creatures. When the sky is blue, we are up. When it is dark, we go to sleep. The light you see while you walk has a tremendous number of alerting effects.”



“A lot of **NASA’s** learning, **science**, and **research** has **led to** these **new products.**”

— Robert Soler, Lighting Science



Background: One hotel chain replaced all of its bedside light bulbs with LED bulbs from Lighting Science. The new bulbs emit significantly less blue light, which would otherwise send signals to the body that it should be up and awake. Inset: NASA’s solid state lighting module, which was flown to and used on the ISS in place of traditional fluorescent lighting. The LED module could be controlled from the ground and uses different colors of light in an attempt to induce focus and alertness or rest and relaxation as needed.



According to the company, the Awake & Alert light promotes natural energy, alertness, focus, and overall performance. Some of the places where it could have the biggest benefits include gyms, schools, libraries, hospitals, in common spaces in senior centers, and in homes and offices. Recommended for everyday use, it can also be particularly beneficial during times of the year when people experience seasonal affective disorder, as well as for people who experience delayed sleep phase disorder.

The 9-watt bulb is meant to replace a 65-watt bulb, and it uses a patented spectrum filter with blue-enriched white light. “Even though these are white LEDs, they put out a blue peak,” says Soler.

“The hospitality industry is in the business of sleep. I think there is tremendous opportunity for them to replace their bedside bulbs.”

— Robert Soler, Lighting Science

In contrast, the Goodnight LED bulb from Lighting Science emits significantly less blue light than regular light bulbs, with the intention of supporting natural melatonin production. According to the company, the Goodnight light does not affect sleep as much as regular lights.

“When you go home at night and turn on the lights and TV, your body gets signals that it is daytime,” explains Soler. “If you have a regular light on next to your bed while you are reading and trying to prepare for sleep, it is suppressing the melatonin production in your body, and when you are ready to go to sleep, your body is not.”

The 12-watt LED Goodnight light is meant to replace 60-watt bulbs in private homes, university dorms, senior living centers, healthcare settings, spas, and throughout the hospitality industry. “The hospitality industry is in



the business of sleep,” says Soler. “I think there is tremendous opportunity for them to replace their bedside bulbs. One of our current customers is a premier spa and hotel chain that is switching all of their bedside lamps to DefinityDigital.”

The third DefinityDigital product—MyNature Grow—was designed by Lighting Science to deliver more blue and red light per watt than typical gardening lights. This LED can be used with any plant species, and because it does not radiate heat, the plant can be situated closer to the lighting source. According to the company, these LEDs last an average of 50,000 hours, resulting in energy

Lighting Science's MyNature Grow, part of its Definity Digital line of products, targets the key portions of the spectrum that deliver the right kind of light to encourage healthy plant growth.

and maintenance cost savings. Applications include urban farming, propagation research, indoor hobby gardening, agrotech research, hydroculture farming, and floriculture.

A similar DefinityDigital product, MyNature Coastal, was designed to deliver lighting that does not attract sea turtles. When sea turtle eggs hatch on the shore, the hatchlings are attracted inland by regular white lights, and instead of going to the ocean they move toward the buildings and roads. Lighting Science's MyNature Coastal LED is in the amber spectrum and does not attract turtles. During hatching season, regular light bulbs can be replaced with the MyNature Coastal light at resorts, residences, municipalities, parks, restaurants, and marinas.

In addition to developing new products for use on Earth, Lighting Science has also won a contract to work in partnership with Bionetics to develop the next generation of lighting fixtures for the ISS. These new lights will incorporate some of the same features found in their spinoff technology and will provide light for astronauts to help overcome sleep and circadian disruptions during spaceflight.

As Shultz says, “LEDs are going to be lighting every spacecraft from here on out.” In the meantime, they are beginning to light up buildings, homes, and coastal areas right here on Earth. ❖



# Charged Particles Kill Pathogens and Round Up Dust



A conceptual rendering of what a Martian garden could look like. Plants naturally produce ethylene gas, which hastens decay, especially if left to build up in enclosed spaces such as this. The Wisconsin Center for Space Automation and Robotics used NASA funding to develop a titanium dioxide-based scrubber that converts the gas into water and carbon dioxide, both of which are beneficial to plants.

## NASA Technology

**B**efore astronauts are able to undertake long-term missions into the solar system, they'll need technologies that allow them to grow their own fruits and vegetables. For years, NASA has been advancing technologies such as artificial lighting, plant monitoring devices, and growth chambers to advance that goal.

But it's one thing to grow plants; it's another to keep them from aging prematurely. The culprit is ethylene—a naturally occurring gas emitted from plants that hastens

ripening. Comprised of hydrogen and carbon, ethylene can induce decay when left to accumulate in enclosed spaces such as a spacecraft. To forestall that process, in the 1990s the Wisconsin Center for Space Automation and Robotics, a NASA Research Partnership Center located at the University of Wisconsin–Madison, developed an ethylene reduction device.

Also known as an ethylene “scrubber,” the device works by drawing in air through tubes coated with titanium dioxide. When a built-in ultraviolet light shines

onto the coat, the gas is converted into trace amounts of water and carbon dioxide, which are actually good for plants. The scrubber was first flown on Space Shuttle Columbia mission STS-73 in 1995 and proved successful in preserving a crop of potato seedlings. Subsequent missions used and improved the technology.

## Technology Transfer

In addition to converting ethylene into harmless byproducts, the scrubber was also found to kill pathogens.

As a result, a line of air purification systems utilizing the technology is now on the market that not only keeps food fresh in warehouses and markets but also helps decontaminate the air (*Spinoff* 2002, 2009). Consumer versions of the system for the home also followed (*Spinoff* 2013).

Another company, Electrolux (now Dallas-based Aerus Holdings), of vacuum cleaner fame, also furthered the technology but took it in a slightly different direction. Rather than cleaning passing air, the company's family of air purification products does something unique: it takes the circulated air generated by a building's heating and cooling ventilation (HVAC) system and produces molecules that disseminate into the environment, killing pathogens in the air and on surfaces.

Called ActivePure Technology, and commercially available since 2013 as the Air Scrubber Plus, the key to its function is a proprietary blend of reactive metals added to the original titanium dioxide coating. When exposed to ultraviolet light, these metals mix with the surrounding air and humidity to produce charged clusters of hydrogen and oxygen such as hydrogen peroxide, hydroxyls, and superoxide ions, which are antimicrobial agents also found in nature. "We call them friendly cleaners," says Air Scrubber Plus executive director Tom Lozano. "They go out and reduce contaminants throughout an entire home."

What's more, these "friendly cleaners" are also mostly negatively charged ions. The majority of particles around the house are positive, so these ions pull these particles from the air, greatly reducing loose dust and pollen. The Air Scrubber Plus is also available in models equipped with ozone, which greatly enhances the device's ability to combat strong odors from pets and cigarette smoke.

## Benefits

The benefits reaped by these two features—the antimicrobial agents and clumping capability—have been proven by peer-reviewed scientific studies, says Lozano. First, a Kansas State University study showed that

ActivePure Technology reduced an indoor environment's amount of methicillin-resistant *Staphylococcus aureus*, or MRSA, by 99.8 percent and *E. coli* by 98.1 percent. The study also demonstrated similar effectiveness in neutralizing black mold and other potentially dangerous pathogens.

In another study the University of Cincinnati validated the technology's ability to extract particulate matter. "These ions were dropping particles out of the air 100 times faster than relying on gravity alone," Lozano says. "That's a good thing because it means you're not breathing them in anymore."

While the company is careful not to make any medical claims, Lozano mentions some of the many positive responses he's received from customers. In one story, a woman was so allergic to cats that she wasn't able to stay at her daughter's house for longer than 30 minutes at a

“NASA is to thank for laying the foundation for a breakthrough product in indoor air quality.”

— Tom Lozano, Aerus Holdings

time. One day, her husband installed an Air Scrubber Plus without her knowing. "On Super Bowl Sunday, she's hanging out at her daughter's for four hours and says, 'Hey what's going on?'" he says. "She was surprised by how well she was feeling."



Aerus Holdings' Air Scrubber Plus incorporates NASA ethylene-scrubbing technology. The device is installed into home ventilation systems, which disseminate the product's "friendly cleaners" that kill pathogens in the air and on surfaces.



Besides making people feel better, Lozano says the technology also helps extend the life of a home's HVAC system. As particles clump around the charged clusters, or "friendly cleaners," they become too large to escape the system's filter, which means they're not able to go on and damage coils and blowers needed to help keep the system running effectively. "This translates to savings on your utility bills and reduces the chances of needing expensive repairs," Lozano says.

And it all started with the agency's need for keeping plants fresh in space. "NASA is to thank for laying the foundation for a breakthrough product in indoor air quality," Lozano says. "The Air Scrubber Plus is really improving people's lives." ❖

# Balance Devices Train Golfers for a Consistent Swing

## NASA Technology

After a stint in space, astronauts' minds and bodies take some time to readjust to life on Earth. While the human body adapts relatively quickly to a lack of gravity (it takes only a few days), readapting to the pull of Earth's gravity can take up to several weeks.

The adjustment starts before the astronauts ever land. In space, their blood pressure is equalized throughout their bodies. Their faces have more fluid and their legs

have less, causing their faces to look fuller and their legs slimmer. On the ride home, as the astronauts leave orbit and feel Earth's pull once again, blood rushes from their heads down to their feet, which makes them feel lightheaded.

NASA started studying the various effects of space flight on astronauts early in the space program. One example from the 1960s includes Massachusetts Institute of Technology doctoral candidate Lewis Nashner.

Interested in understanding how different sensory and motor systems contribute to balance, Nashner performed NASA-funded research that resulted in a technology that proved useful for assessing the balance of astronauts after coming home from space.

The technology incorporated a technique developed by Nashner called computerized dynamic posturography (CDP). His first device incorporating CDP was the EquiTest. This technology altered the surface that a



Following five months onboard the International Space Station, Expedition 35 astronauts Chris Hadfield, Roman Romanenko, and Tom Marshburn sit in chairs outside the Soyuz Capsule they used to return. Having landed just minutes before, their bodies require extra support as they begin to adjust once again to the full effects of Earth's gravity.

“ In my physical therapy practice, I work with a lot of orthopedic and sports injuries. I was unable to rehabilitate the balance deficits for these patients, so I obtained the NeuroCom technology.”

— Dan Goldstein, Sports Therapy Inc.

person stood on as well as the visual surroundings, and then measured the responses and provided assessments of the person’s postural alignment and stability. His second device used the same CDP technique, but incorporated a screen that provided feedback about balance to the person using the machine. Called the Balance Master, it could not only diagnose but also help to train individuals with balance disorders.

## Technology Transfer

After founding a company called NeuroCom (*Spinoff* 1996 and 2009), Nashner started offering the two systems for balance analysis and therapy to benefit individuals other than astronauts—including people suffering from vertigo, dizziness, the effects of a fall, or other balance problems.

In 1997, a physical therapist and athletic trainer named Dan Goldstein learned about the Balance Master and purchased one for his business. “In my physical therapy practice, I work with a lot of orthopedic and sports injuries,” says Goldstein. “I was unable to rehabilitate the balance deficits for these patients, so I obtained the NeuroCom technology.”

In addition to helping the patients in his physical therapy practice, Goldstein says he also realized he could help another group of people—golfers. “It is important for golfers to learn what proper balance feels like in order to achieve a consistent golf swing,” he says.

Goldstein soon started working with Nashner, and the partners co-patented a modified version of NeuroCom’s Balance Master to assist and train athletes, especially



The Dynamic Balance System from Sports Therapy helps golfers learn what proper balance feels like, not only improving their golf swing but helping them prevent injuries, too.

golfers. Now, Goldstein provides a product called the Dynamic Balance System (DBS) through his West Palm Beach, Florida-based business, Sports Therapy Inc.

## Benefits

The DBS from Sports Therapy has two main components: a shifting force platform that a person stands on and a computer connected to the platform that displays balance data. As a person tries to balance, the computer provides a real-time display of his or her balance and center-of-gravity movement. The technology monitors the heels, toes, weight transfer, and rotational movements while recording the motion of the center of gravity.

Along with specific screens for full swing, pitching, and chipping and putting, there is also audio feedback to help in training specific repetitive movements. A golfer can see their results on a monitor and after several seconds, repeat the swing routine and hit again, as if practicing at a driving range. Their progress is documented and saved on the computer for future comparisons. Individuals can use the technology to practice with a trainer or by themselves.

Based on immediate feedback related to balance, golfers are able to connect balance to certain movements and then repeat them. This way, Goldstein explains, golfers can learn what balance feels like. Instead of the old adage, “Practice makes perfect,” Goldstein likes to say, “Only perfect practice makes perfect.”

“We look for repetitive body movement within our defined ‘balance zone’ and repetitive position of the body’s center of gravity at ball contact,” says Goldstein. “These factors have been shown to improve consistency and also reduce the chance of injury. A balanced swing causes less physical strain, which helps to reduce the risk of injury.”

Goldstein says golfers with orthopedic problems, limited mobility, amputations, and neurological conditions can also benefit from the DBS. “The immediate feedback capabilities of the technology can assist anyone in learning the feel of a consistent, repetitive swing motion,” he says.

Currently, there are 128 units being used around the world for physical therapy and sports training in hospitals, medical clinics, country clubs, and golf schools. Some of the organizations that Goldstein has partnered with include the Professional Golfers’ Association’s (PGA) Center for Golf Performance and Learning, the PGA Tour Academies, the Leadbetter Golf Academy, and Keiser School of Golf.

Sports performance specialists, physical therapists, athletic trainers, exercise physiologists, strength and conditioning coaches, and personal trainers are using the DBS not only for golf but to help people practice and train for tennis, karate, bowling, and dance.

Goldstein says he looks forward to cultivating even more applications for the DBS in baseball and basketball and for people who have lost a limb. In a case study by Goldstein, the DBS was shown to help someone with an above-the-knee amputation improve his golf game as well as experience less pain. “The immediate feedback is exceptionally helpful for amputees,” says Goldstein.

The DBS has proven to be yet another valuable example of how NASA technology returns home from space to improve the lives of people on Earth. ❖





# Energy and Environment

**N**ASA has an obvious interest in energy efficiency, and its work in this area has been repeatedly commercialized, such as technology that reclaims oil and gas at drilling sites. But tools the agency builds to observe Earth, Mars, and the far reaches of the universe also help organizations monitor the environment and find a multitude of secondary environmental applications on our planet.



# Landsat Imagery Enables Global Studies of Surface Trends

## NASA Technology

When NASA launched the Earth Resources Technology Satellite, later known as Landsat, in July 1972, the first spacecraft dedicated to monitoring Earth's surface carried two imaging instruments—a camera and an experimental multispectral scanner (MSS) that recorded data in green and red spectral bands and two infrared bands. Expectations for the scanner, whose scan mirror buzzed distressingly during testing as it whirred back and forth at 13 times per second, were low.

Among the concerns voiced before launch were fears that its moving parts would not work properly in space, but it was also unknown whether a scanner could produce high-quality digital imagery while careening around the planet at a speed of 14 orbits per day. After launch, the engineers at NASA and the scientists at the US Geological Survey (USGS)—who would manage the project once the satellite was in orbit—were shocked at the high fidelity of the data the chattering imager sent back, and it almost immediately became the vehicle's primary imager.

The MSS sent back 300,000 images over its six-year lifespan and changed scientists' approach to remote sensing, adding the dimension of time to analyses of Earth's resources and surface covers. Now that researchers could access calibrated images of the same areas over the course of the seasons and years, attention moved away from merely building libraries of the spectral signatures of Earth's features and toward monitoring changes and patterns over time.

Landsat 1 data were used to monitor water levels of Lake Okeechobee and build a better understanding of Miami's local ecology and its water needs. Flood dynamics along the Mississippi River and Cooper's Creek in Australia were studied for disaster assessment. Images from the MSS were proven effective for improving crop predictions in Kansas and were used to monitor clear-

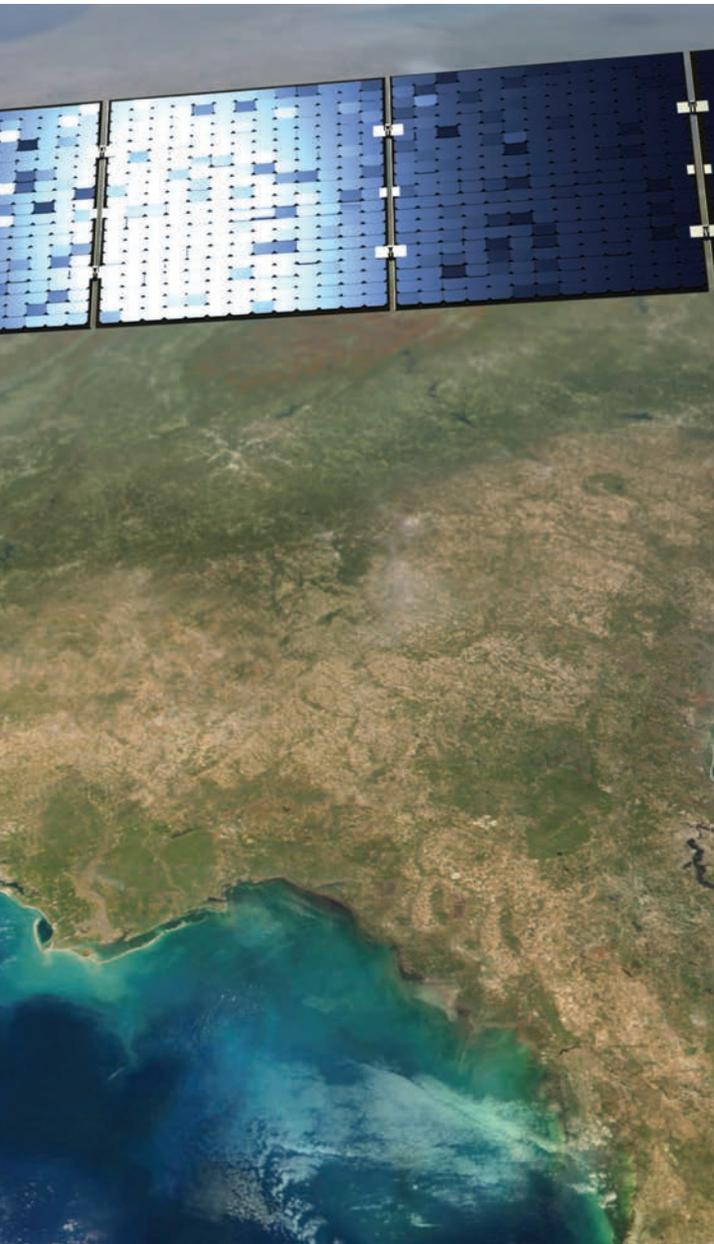
cutting of forests in Washington and evaluate compliance with timber harvest licenses.

However, as noted in the 1997 paper, "The Landsat Program: Its Origins, Evolution, and Impacts," none of the early attempts at using satellite data to address global issues like food security, desertification trends, resource sustainability, and deforestation impacts led to more profound, worldwide applications. Gaps in time data, coarse imagery, and the need for more input from other systems hampered any comprehensive results. But as the



Google used data from the NASA-built Landsat 7 satellite, right, to regenerate its image of the entire planet and also to cover the last dozen years or so of its time-lapse animation of the planet's recent history. Meanwhile, the company's fleet of cars and other vehicles outfitted with elaborate camera and laser mounts, above, continue to capture the street view of Earth.





paper's authors explain, "It was believed with certainty that the data and imagery would have commercial, as well as public value" if more of it could be collected.

Early attempts at public-private partnerships to facilitate commercialization may have further hampered broader results. Operations of the fourth and fifth Landsat satellites were turned over to the private sector, leading to dramatic price increases, with the cost of a single Landsat image rising to several thousand dollars. Even after the government resumed control of the program in 1999, the government still charged several hundred dollars for a single image, making global analyses cost-prohibitive.

By then, the Thematic Mapper aboard Landsat 5 and the Enhanced Thematic Mapper-Plus aboard Landsat 7 satellite had become the primary Earth imagers, replacing the MSS sensor aboard Landsat 5 and the prior Landsat satellites. These second-generation Landsat sensors collect grayscale data across the visible spectrum at a 15-meter spatial resolution, as opposed to the first MSS's 80-meter resolution, and also uses seven visible and infrared bandwidths for imaging and measuring temperature, at resolutions of 30 and 60 meters.

"Prior to 1999, when we launched Landsat 7, Landsat 4 and 5 had been operated by a private firm, and their cost per scene had gone up as high as \$4,400, which very few people could afford," says James Irons, Landsat Data Continuity Mission Project scientist at Goddard Space Flight Center, where the Landsat program has been housed since its inception. USGS agreed to reduce the cost to \$600, but, Irons says, that was still prohibitive to anyone who wanted global data. He and colleagues within USGS continued the push to make it all publicly available for free.

"In 2008, they made the decision—which I refer to as 'institutionally courageous'—to distribute those data at no cost to those requesting it," he says.

The data crunchers at Mountain View, California's Internet giant Google wasted little time in taking advantage of the new resource.

## Technology Transfer

At the end of 2010, Google unveiled its Google Earth Engine, a cloud computing platform for accessing and processing Landsat images of the planet going back about 40 years. With the digitization of a warehouse of information, scientific study of worldwide trends using Landsat data suddenly became possible.

"Now you can ask questions on a global scale, over time, that have never been possible before," says Rebecca Moore, engineering manager for the Google Earth Outreach program, a humanitarian arm of the Google Earth and Maps team.

Google is currently allowing total access to the mass of Landsat data, as well as its parallel processing platform for running algorithms on the mountain of information, to a limited group of science and research partners.

"We've got about a thousand scientists," Moore says, adding that many are analyzing forest and land cover or water resources. "Conservation biologists are doing nice modeling, and in this case, they're analyzing datasets like Landsat in combination with, for example, the [Jet Propulsion Laboratory's] Shuttle Radar Topography Mission elevation data."

In spring of 2013, in collaboration with *Time* magazine, Google Earth Engine released its Timelapse web feature, which uses Landsat imagery to allow users to watch a time-lapse animation of any land area on Earth—with the exception of those near the poles—running from 1984 to 2012.

To create this visual history of almost the entire planet, the company sifted through more than 2 million Landsat images to find the best representation of every individual pixel in the model, with each pixel representing an area of 900 square meters during one of 29 years. Under the pricing model set prior to 2008, the images Google used would have cost more than \$1.2 billion.

The following year, Google also completely regenerated its Google Maps and Google Earth imagery, using 2012





Image courtesy of Erik Patel, CC-BY-SA 3.0

Illegal logging, such as this rosewood harvesting operation in Madagascar, and slash-and-burn farming practices are among the threats to planet's most valuable rainforests. Troves of Landsat data are now allowing researchers to examine global trends in surface cover, such as gains and losses in forest cover.

data from the NASA-built Landsat 7 satellite and a similar pixel-picking technique in which the most common representation of each pixel was chosen from a set of many satellite images. "We ran it on 66,000 computers in parallel," Moore says. "It was more than one million hours of computation, but we were able to have the results in a couple of days." The resolution now used in those products is twice that of the Timelapse animation.

The company also partnered with a professor in the Department of Geographical Sciences at the University of Maryland to build a fine-grained model of global changes in forest cover between 2000 and 2012. Matthew Hansen is a leading scientist when it comes to analyzing Earth-observation data to classify forest cover and forest change, so the sudden availability of so much imaging data was a major boon to his work.

"We used to always say, 'We use the data we can afford, not the data we need.' But what kind of science is that?" he says. "Especially for NASA, which has a lot of Earth system science objectives related to global climate change, the carbon cycle—you name it. You have to have global observations to drive those models."

Hansen's work with monitoring deforestation began at the national level in central Africa, but he ran into problems over the Congo Basin, where cloud-free images are almost impossible to come by. That was when he hit on the pixel-by-pixel method Google used.

"That's how we work with [NASA's] Moderate-Resolution Imaging Spectroradiometer. It's always best-pixel-possible, so we started to do that with Landsat," he says. He went on to map forests in Europe, Russia, Indonesia, and Mexico.

"At some point, we felt comfortable that we could do the globe, and so that was the basis of the discussion with Google," says Hansen. "We have the Landsat archive here too, on campus, but I think if we tried to create full-bore, global imagery, it would take us six months to a year, whereas for Google it would take a week."

## Benefits

What Hansen and Google unveiled in late 2013, and what Google Earth Engine has posted on the front page of its website, is the first ever global study of forest cover: a map of the world accurate down to 30 meters, depicting current forests and gains and losses between 2000 and 2012, with layers of data for each year available for download.

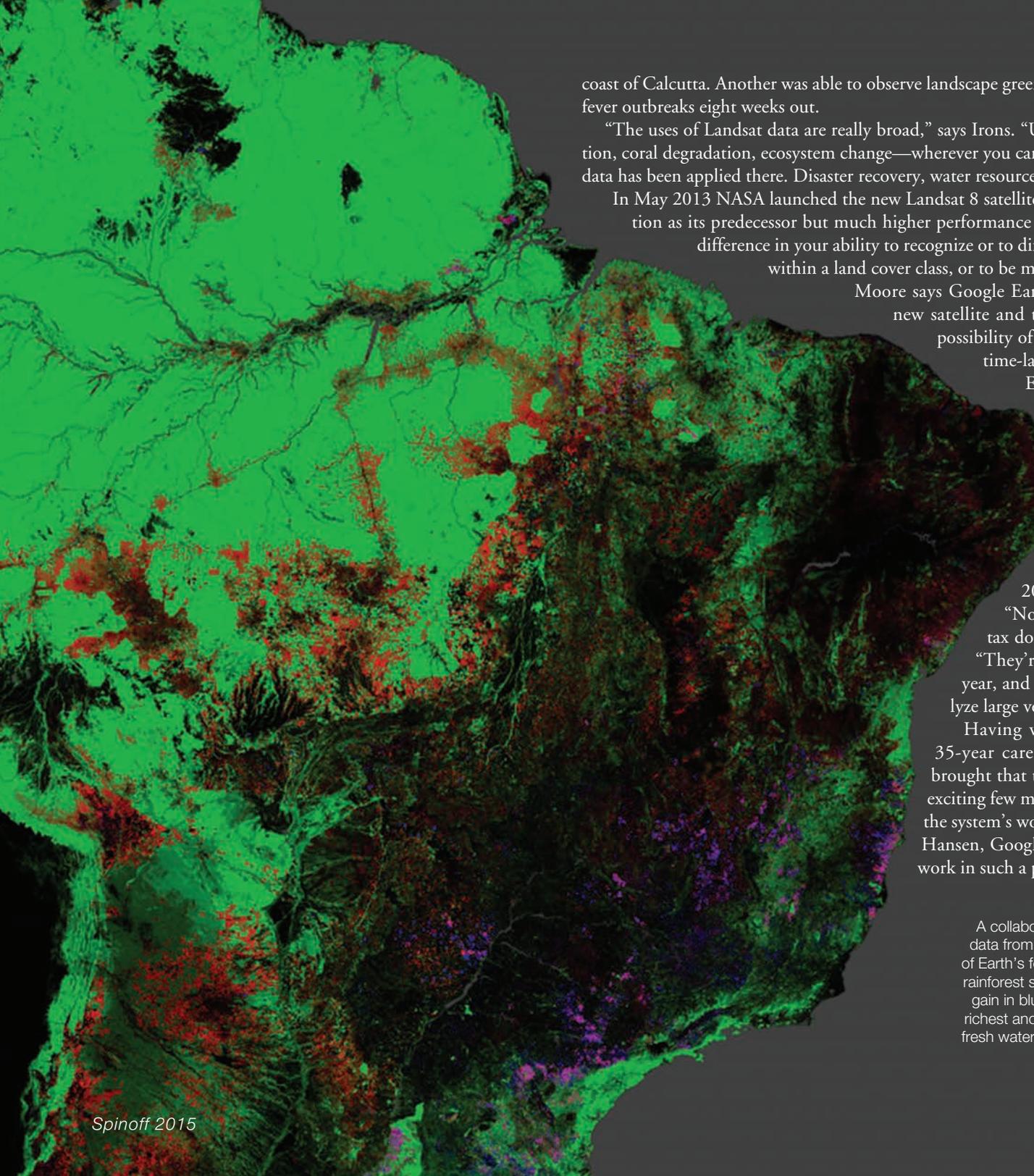
Meanwhile, Moore says Google's Timelapse feature has proven popular, with the animation drawing more than 3 million viewers in its first week alone.

"You can see amazing phenomena so clearly," she says. "You can see Las Vegas growing wildly while nearby Lake Mead is shrinking. You can see the deforestation of the Amazon, the artificial islands sprouting off the coast of Dubai, the Columbia Glacier receding in Alaska."

As users have explored the past and present world with the tool, online newspaper articles, blogs, and others have started posting links to different parts of the globe, Moore says. "And people have found interesting things that are not just gloom and doom," she adds, noting that these include meandering rivers, formations of oxbow lakes, and the shifting of the Cape Cod Harbor shoreline.

She says, however, that all this early work is only a beginning. "I think we're at the dawn of a new voyage of discovery, and it's a digital voyage," Moore says. "I think we're going to learn things that have been going on across the planet back to the '80s and '70s and discover things that were sitting there waiting to be discovered in this treasure trove of data."

She notes that the scientists Google is partnering with are also using current data to predict future events. Some found that they could predict an outbreak of cholera six weeks in advance by observing plankton blooms off the



coast of Calcutta. Another was able to observe landscape greening, rainfall, and temperatures to predict Rift Valley fever outbreaks eight weeks out.

“The uses of Landsat data are really broad,” says Irons. “Urban expansion, glacial retreat, agricultural production, coral degradation, ecosystem change—wherever you can think of land cover and land use changing, Landsat data has been applied there. Disaster recovery, water resources management—the list just keeps going on.”

In May 2013 NASA launched the new Landsat 8 satellite, which Irons says has about the same spatial resolution as its predecessor but much higher performance in terms of signal-to-noise ratio. “That makes a big difference in your ability to recognize or to differentiate different kinds of land cover and subtleties within a land cover class, or to be more sensitive to change over time.”

Moore says Google Earth Engine is receiving information daily from the new satellite and that the data quality is high enough that there’s a possibility of including seasonal images in future additions to the time-lapse animation. At some point, she says, Google Earth Engine hopes to be able to produce a near-real-time report on the health of the planet: “All the best data streaming in from NASA satellites, not just the optical instruments but all sorts of scientific instruments—have that data coming in and make it available for science and for practical use.”

Irons says NASA and USGS have formed a study team to develop a plan for a coordinated, sustained land-imaging program for at least the next 20 years to ensure that there are no gaps in coverage. “Now we’re getting a full return on the investment of tax dollars that were spent to launch the satellite,” he says. “They’re distributing something like 3 million scenes per year, and people are beginning to develop the capacity to analyze large volumes of Landsat data.”

Having worked on the Landsat program for much of his 35-year career, Irons says he feels recent developments have brought that time, effort, and energy to fruition. “It’s been a very exciting few months following the Landsat 8 launch and seeing that the system’s working really well—and then to have people like Matt Hansen, Google, and others coming along and putting the data to work in such a productive way, it’s extremely gratifying.” ♦

A collaboration between Google and the University of Maryland used data from NASA-built Landsat satellites to create the first global study of Earth’s forest cover over time. This 2012 map depicting the Amazon rainforest shows existing forest cover in green, forest loss in red, forest gain in blue, and replaced forest in purple. The Amazon is the world’s richest and most diverse biological reservoir, has 20 percent of Earth’s fresh water, and has been losing thousands of square miles to logging, farming, and illegal road construction every year.



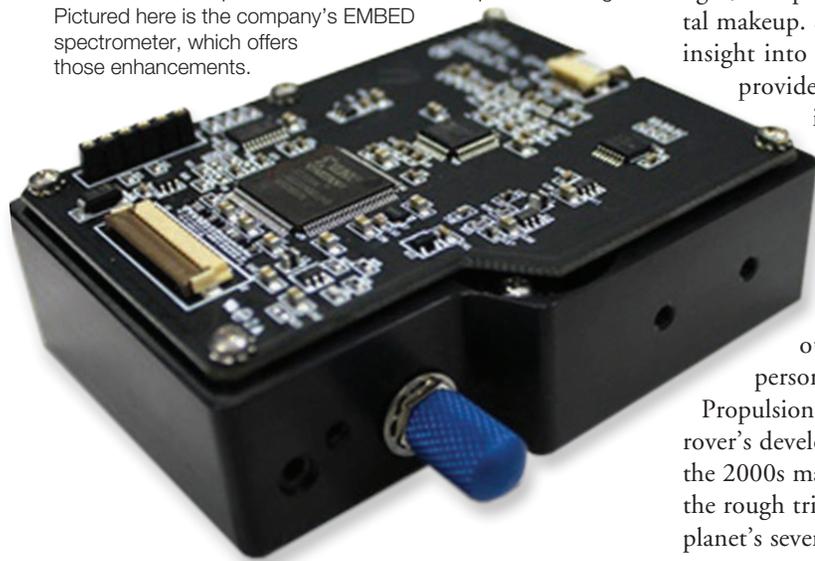
# Ruggedized Spectrometers Are Built for Tough Jobs

## NASA Technology

Curiosity is the undisputed hot rod of planetary rovers. Nine-and-a-half feet long, nearly 2,000 pounds, and powered by a thermo-nuclear power generator under its “hood,” Curiosity was built to travel far and handle extreme temperature fluctuations. What’s more, its instruments—radiation and gas detectors, imaging cameras, and mineral identifiers, to mention a few—are the most advanced that have ever scoured the Red Planet in hopes of answering that long-pondered question: Was Mars once capable of supporting life?

Another powerful instrument, and the one with perhaps the most visual flair, is the Chemistry and Camera system, otherwise known as ChemCam. It uses what’s called laser-induced breakdown spectroscopy (LIBS) to analyze the elemental composition of materials on the

Ocean Optics collaborated with NASA to redesign its miniaturized spectrometers for use in space and has since transferred those technologies to some of its commercial product lines, which are now more resistant to the effects of shock and vibration and are more protected from extreme temperature swings. Pictured here is the company’s EMBED spectrometer, which offers those enhancements.



Martian surface. What makes the instrument especially remarkable is its ability to take measurements from as far away as 23 feet and also remove dust from the sample before testing.

ChemCam works by first homing in on a visual target with its mast camera, which includes what’s called a Remote Micro Imager. Then, from its mast, a laser beam potent enough to outshine a million light bulbs (10 megawatts per square millimeter) is fired onto a pinhole-sized area. While the pulse lasts only about five-billionths of a second, it’s enough time for the affected material to reach about 25,000 °F and create plasma, emitting a very bright flash of light and generating a shock wave that ablates the surface part of the material, which enters the plasma. The light emitted by this material is collected by a telescope and travels through fiber-optic cables to the belly of the rover, where a series of dichroic mirrors separates the incoming photons into three wavelength bands to be processed by three different spectrometers, which measure their varying wavelengths and intensities.

Because each element emits specific wavelengths of light, the spectrometer can determine a sample’s elemental makeup. Such information can be used to gain more insight into the planet’s early development, and it also provides clues about which toxins to guard against in preparation for a future manned mission.

## Technology Transfer

Roger Wiens, a planetary scientist out of Los Alamos National Laboratory, serves as principal investigator for the ChemCam, which is a joint venture between various US and French organizations. As the person responsible for its final delivery to the Jet Propulsion Laboratory (JPL), the center overseeing the rover’s development, Wiens dedicated the better part of the 2000s making sure the instrument could first handle the rough trip to Mars and, afterward, operate amid the planet’s severe conditions. He wrote about the ordeal in

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The company’s high-resolution spectrometer was used as the inspiration and springboard design, but its evolution would ready it for some of the most challenging environments imaginable.

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his 2013 book, *Red Rover*. “Working on this Mars mission was a childhood dream come true,” he says.

But Wiens had some very adult decisions to make, and one of them was selecting a compact spectrometer—the device that measures the wavelengths and intensities of light emitted by a sample material—that was up to the task. It so happened that he had been working with such a device developed by Dunedin, Florida-based Ocean Optics. Founded in 1989, the company had developed the world’s first miniaturized spectrometer, revolutionizing the field. Its optical instruments were being used for a myriad of applications, from determining crop health through foliage color analysis to verifying nutritional content in food commodities.

In the early 2000s, while the ChemCam instrument was still in the proposal stage, Wiens came to an agreement with Ocean Optics to work with his team to make the spectrometer space-ready. In 2004, when the instrument was officially chosen for the mission, the collaboration continued. The company’s high-resolution spectrometer was used as the inspiration and springboard design, but its evolution would ready it for some of the most challenging environments imaginable.

Like most instruments used in space or on other planetary bodies, the spectrometer needed to be protected against the ravages of temperature, vibration, radiation, and shock. On Mars, electronics would need to be qualified for temperatures as low as -65 °F and as high as 155 °F. They also had to survive the intense vibration that would occur particularly during launch from Earth.



One of Ocean Optics' NASA-improved spectrometers is attached to an all-terrain vehicle, which is utilizing the instrument for analyzing upwelling and downwelling types of radiation in the desert. The temperature- and shock-resistant properties of the spectrometer prove vital in such a rugged environment.

“Imagine duct-taping yourself tightly to an unbalanced washing machine for eight minutes,” says Dave Landis, who at the time was a vice president for Ocean Optics and a key designer for the project. “It’s that intense.” Then, of course, there’s the radiation to contend with, as the instruments would see radiation exposure both during travel and on the surface of Mars.

The first step, explains Wiens, was putting the commercial spectrometer through an initial “shake and bake” test, referring to the experiments done in evaluating the unit’s temperature and vibration resistance. At the onset, the device’s aluminum casing was replaced with titanium, which, unlike the former, expands and contracts less with temperature fluctuations. But tests showed the optics also needed to be made less temperature-sensitive to avoid defocusing of the spectrometers. Landis, who worked on all aspects of the project, says, “You pick materials that can handle the temperature extremes of space—materials with well-matched thermal coefficients.” He adds that afterward, the reconfigured parts went through 2,000 temperature cycles, replicating the passage of 1,000 days

on Mars, to make sure everything worked continuously at a high level.

And following the shake test, it was discovered that some of the mounting systems for the optics, which direct the photons into the electronics for processing, needed redesigning. “If those pieces move during transit, you can corrupt the data from the instrument to the point where it’s not useful,” says Landis. “So you pick glues and epoxies that are going to survive the shock loads because you’ve got glass bonded to metal.”

Wiens also notes that the device’s optical throughput, its ability to receive light, was optimized. “We made specialized mirrors to optimize the slit configuration and changed the detector.”

All that work, which also included hardening various electronics against radiation, was completed over a span of several years at several locations, up until ChemCam was delivered to JPL in 2010. As the world witnessed, the LIBS spectrometer launched with the rover in November 2011, and since landing the following August, the instrument has identified more than 140,000 samples. Among its most important discoveries was the detection of cal-

cium, which led to the discovery of gypsum and bassanite, minerals formed as a byproduct of calcium sulfate and water: a key building block for life.

## Benefits

Ocean Optics’ spectrometers have helped uncover Mars’ secrets, but the work the company did with NASA to ready their devices for that otherworldly mission has also paid dividends here on Earth. That’s because some of the improvements made to ready the spectrometer for space have been incorporated into Ocean Optics’ newer spectrometer models.

One of the big changes they’ve made is to decouple the spectrometer detector from the electronics. Though not housed externally like in the ChemCam, just separating these two components within the spectrometer housing improves the long-term wavelength stability. “It’s incredible to think that we can achieve mere picometer-level drift over a period of hours of operation with our EMBED spectrometer,” says David Creasey, the firm’s vice president of sales and marketing. “That kind of performance is paramount for some of our OEM [original equipment manufacturer] customers.”

The measures the agency took to protect the spectrometers from extreme temperature swings have also inspired improvements in optics mounting methods, improving performance when exposed to a dramatic range of warm and cold environments. “We have spectrometers that are used in research applications from Antarctica to volcanic peaks and the Amazon,” Creasey says. “Our units need to be robust enough to make it there, and thermally stable enough to take high-quality measurements once in place.”

Having sold more than 250,000 spectrometers, the company is the most prolific manufacturer of such devices in the world. Its history of collaboration with the space agency, says Creasey, only adds to its appeal for organizations wanting a reliable device. “With each new spectrometer line we launch, we integrate our experience with scientific leaders like NASA and our OEM customers to push the boundaries of miniature spectroscopy further. We make each other better, and that is truly what science is all about.” ❖



# Gas Conversion Systems Reclaim Fuel for Industry

## NASA Technology

To understand the connection between the development of Martian power systems and technology that can pull oil from old wells or capture gases released during drilling, it helps to think of atoms—particularly carbon, oxygen, and hydrogen atoms—like Tinkertoys. Different configurations have sometimes drastically different properties, particularly when an element is added or removed, and rearranging them is just a matter of using the right chemical reactions.

Take this conversation with Robert Zubrin, founder and president of Pioneer Astronautics and Pioneer Energy, on the subject of making rocket propellant on Mars: “It can be done by combining hydrogen, perhaps from Earth, with Martian carbon dioxide—the atmosphere is 95 percent CO<sub>2</sub>—to produce methane and water. You can electrolyze the water and make oxygen, recycle the hydrogen off the electrolysis, and doing that will yield a lot of methane and oxygen, which is a good combination for rocket fuel. With that, you can return home to Earth,” he explains.

“Later on, we did some work where we would be able to make methanol and oxygen on Mars, and then we did a system where we decomposed methanol and water into hydrogen and carbon dioxide to produce lifting gas for research balloons,” he continues, speaking as if it were as simple as making a little windmill from sticks and spools.

Zubrin has what might be called a restless intellect. President of the Mars Society and a primary developer of an oft-referenced plan to put humans on Mars called Mars Direct, he has been championing colonization of the Red Planet—and working on the systems to make it happen—since the mid-1990s. Among the 10 books he’s published, though, are also a satirical science fiction novel lampooning the Israeli-Palestinian conflict and a five-act play portraying Benedict Arnold’s betrayal of the revolutionary army. He devised a three-player version of chess when he was 20 and patented it. And in 2010,

Zubrin appeared in a viral Symphony of Science music video along with Carl Sagan and other famous science popularizers.

In the course of its work, Pioneer Astronautics has won about 60 Small Business Innovation Research (SBIR) contracts, most of them with NASA. They have totaled more than \$12.5 million, which Zubrin has used for projects as diverse as a Mars hopper vehicle that uses carbon dioxide from the atmosphere as the engine propellant, a magnetic sail that would propel a spacecraft by using a magnetic field to deflect plasma winds, and a precision-landing parachute system designed for Mars’ thin atmosphere.

Some of the earliest contracts, dating to the mid- to late 1990s, were with Johnson Space Center and focused on creating rocket fuel on the surface of Mars through molecular mixing and matching. These followed work he had done as a NASA contractor with Lockheed Martin and Martin Marietta Astronautics Company, developing advanced space exploration strategies.

“He started with Lockheed Martin and helped build one of the first prototypes for how to collect carbon dioxide from the Mars atmosphere and turn it into oxygen and methane,” says Gerald Sanders, In-Situ Resource Utilization (ISRU) chief engineer with the Propulsion and Power Division at Johnson Space Center. He adds that Zubrin then went on to experiment with other chemical processes with Pioneer Astronautics, such as ways to make oxygen from carbon dioxide using a reverse water-gas shift process with water electrolysis—using electricity to separate water’s hydrogen and oxygen atoms.

“A lot of his work, like the name of his company, was very pioneering, trying different things out that may be interesting to NASA for exploration,” Sanders says.

He notes that much of this experimentation applies not just to his line of work—finding ways to collect and put to use the molecules available on Mars or the moon—but also to life support and power systems, the backbone of any space exploration mission.

Sanders’ group is still working out the logistics of tying all these systems together. Now that it’s known that there is water in the soil on Mars, he says, the best way forward appears to be processing that water to get hydrogen, which can be combined with carbon dioxide from the atmosphere to form methane for fuel, as well as oxygen, which is useful for both fuel and life support. All this would be powered by a small nuclear power plant and would require a soil processing plant and carrying rovers to excavate soil. The added equipment would total about 2,000 kilograms, which is significantly less than the 6,500 kilograms of methane that would be brought from Earth to get a rocket from Mars into space without processing soil.

“So there’s still a drastic increase in performance and return on investment,” Sanders says. “And if you go to the poles, where the ice concentration increases significantly, it just gets better.”

Zubrin’s work on this sort of molecular alchemy during his early work with NASA has more recently led him to two projects that are likely to have a dramatic effect on the oil industry back here on Earth.

“Some of these SBIRs made me realize that we could take a form of this technology, run it backwards, and

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“What we’re doing for Mars has a lot of applicability on Earth.”

— Gerald Sanders, Johnson Space Center

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Background: The Martian landscape, as imaged by Curiosity. Future spacecraft visiting Mars, including crewed missions, will likely use resources on the Red Planet to manufacture fuel for the trip home.

we would have something we could use on Earth for oil recovery,” Zubrin says.

In 2008, he created Pioneer Energy to put the theory to work.

## Technology Transfer

On Mars, carbon dioxide would be combined with hydrogen to make methane and water, and the water would be electrolyzed to make oxygen and hydrogen.

“On Earth, we’ve got methane in the form of natural gas, which right now is very cheap, and you can react it with water, which we also have a lot of, and produce carbon dioxide and hydrogen and then split them,” Zubrin explains. The hydrogen can be used to create carbon-free electricity, and the carbon dioxide can be used to pull oil out of defunct oil wells. “Basically, what we’re doing is running the Mars Direct field processing system in reverse.”

Depending on its geology, only about 30 percent of the oil in a well is captured by the initial pumping. In the early 1900s, a technique was developed to then flood the well with water, which the oil floats on, and this method yields another 20 percent of the original oil store. Still, half of the oil remains in the ground. The 1980s saw the advent of “enhanced oil recovery” (EOR), in which carbon dioxide is pumped into the well, where it mixes with the oil, making it less viscous and pressurizing it, which allows another 20 percent or so of the original amount to be removed. In the process, the carbon dioxide can be sequestered.

Only 4 percent of US oil is currently obtained this way, however. “The reason is that the only practical way to do this is with natural reservoirs of CO<sub>2</sub> that already exist,” Zubrin explains, adding that there aren’t many places where oil wells and natural stores of carbon dioxide coexist. While there has been much talk about using carbon dioxide expelled from power plants, he says, plant output is diluted, unpressurized, hard to separate, and probably produced far from any oil well. “It’s the wrong pressure, it’s the wrong mix, and it’s in the wrong place, and so it just doesn’t happen very much.”

Alternatively, carbon dioxide can be piped to the site, but this would only be done for a large operation, and



Pioneer Energy’s Mobile Alkane Gas Separator (MAGS) system separates flare gases that naturally occur at drilling sites into three streams: one can be captured in tanks and shipped off for sale, another powers generators that run the drilling operation, and a third powers MAGS itself. Pioneer sold its first MAGS unit in late 2014 to a company operating in North Dakota, where flare gases are most often simply burned onsite, the gases wasted.

furthermore, most companies don’t want to invest in a carbon dioxide pipeline if the EOR method hasn’t been tested at the site with a pilot operation. “Right now, the only way they do that is to truck it in, which is enormously expensive,” Zubrin says. “And because it’s so expensive, the pilot doesn’t happen, and because the pilot doesn’t happen, the pipeline doesn’t happen, and because the pipeline doesn’t happen, nothing happens.”

The Pioneer Portable Enhanced Recovery Technology (PERT) offers an attractive, inexpensive alternative capable of producing the carbon dioxide onsite from methane and water that are trucked in. “We’ve created a mobile system that can go right to the well, and you don’t need a pipeline,” Zubrin says. “That opens up CO<sub>2</sub> availability to the entire country—not just to west Texas and a couple other places—and to oil drillers of every size, including Farmer Brown’s strip well.”

The company started testing its first full-scale model of the PERT in spring of 2014. By then, though, the company was also testing the first field unit of another, related system.

While working on the carbon dioxide-producing system, Zubrin got another idea—a sort of spinoff of a spinoff. “Some of the subsystems involved in the research effort led us to an idea on how we could design a system that may seem unrelated but actually uses a lot of the same subsystems,” he says.

During the early stages of oil drilling, long before carbon dioxide is necessary, large amounts of natural gases may be released from the earth. In the industry, these are known as “flare gas” because, being byproducts released in isolated locations that lack plants and pipelines for processing them, they’re often simply burned onsite in what are called gas flares. This has become a contentious practice, particularly in North Dakota, where there is much more interest in extracting oil than in capturing gas, which has a significantly lower market value.

“They’re flaring it so much that North Dakota seen from space is now almost as bright as New York City,” Zubrin says. “It’s incredible. And it’s a massive waste of energy.”





Currently, natural gases released during oil drilling operations are often simply burned off in gas flares. Pioneer Energy's Mobile Alkane Gas Separator (MAGS) system would separate these gases into three streams, one to be captured in tanks and shipped off for sale, another to run a generator that would power the oil drilling rig, and one to power the MAGS system itself.

Pioneer Energy's Mobile Alkane Gas Separator (MAGS) system would separate these gases into three streams. One consists of propane, butane, and pentane, which can be captured in tanks and shipped off for sale. Methane can be used to run a generator that would replace the diesel generators powering the oil drilling rig. And ethane is used to power the MAGS system itself.

"So that came out of the Pioneer Energy company work, which in turn came out of my NASA work," Zubrin says.

The first MAGS field unit was tested in the spring of 2014, and units were sent to North Dakota later that fall.

### Benefits

The advantages of the MAGS system are manifold. "We greatly reduce the flaring and the need for diesel

fuel, and we produce liquid propane and butane for sale," Zubrin says, adding that the system is also self-sufficient.

Meanwhile, the PERT system can generate enough hydrogen for 1.3 megawatts of electricity while producing about 500,000 cubic feet of carbon dioxide per day. This is enough to run a small EOR operation, Zubrin says. For a large well, it's sufficient for the pilot operation that would justify a carbon dioxide pipeline.

"The United States has the oldest oil industry in the world," he says. "There are huge numbers—thousands—of defunct oil wells all over the country. But more than half of all the oil that was ever in US wells is still there."

While carbon dioxide-enhanced removal isn't feasible for all of them, Zubrin estimates the technology would allow access to an amount of oil equal to more than 10 percent of all the oil ever drilled in the country. "In

addition, of course, this technology could be used in other countries, so we're also talking about significantly expanding the world's oil resources."

"It's obviously a different application, but the type of chemical processing and the type of work he's doing, I could see a direct connection to the work he's done for Mars ISRU," says Sanders. "Those are the types of things we had been stating for years, that what we're doing for Mars has a lot of applicability on Earth."

It just took a restless mind—one that could be said to be highly reactive to ideas and theories—to make those connections and turn those Red Planet concepts into blue planet realities. ❖



So much gas is being flared off at oil drilling sites over the subterranean Bakken formation in North Dakota that at night the oil fields can be seen from space, shining nearly as brightly as any metropolis.



# Remote Sensing Technologies Mitigate Drought



Folsom Lake, located at the base of the Sierra foothills in California, provides hydroelectricity and drinking water for Folsom City as well as irrigation water for the Central Valley. The before-and-after image of the lake shows the severity of the state's current drought.

## NASA Technology

California is an agricultural powerhouse. In 2012, its 81,500 farms and ranches produced \$42.6 billion in cash receipts, the most by any state. But that abundance is threatened by what's been called one of the worst droughts in the state's history. For the last few years, "The Golden State" has been wilting under a dry spell that has left hundreds of thousands of acres idle and many contract farm workers jobless.

To save their most valuable crops, some growers have had to rely on pumping irrigation water from wells. In

certain regions, this pumped groundwater contains higher concentrations of various minerals that can lead to salt buildup, damaging soils over the long term. The heavy reliance on pumping water from wells has also led to rapid depletion of groundwater resources in numerous regions around the state.

NASA's satellites have captured the despair from up high. On January 18, 2014—the day after California governor Jerry Brown declared a state of emergency—NASA's Terra satellite snapped a striking image of the Sierra Nevada mountain range. Where thousands of

square miles of white snowpack should have been, there was only bare dirt and rock. In other words, the snowpack in the Sierra Nevada was far below average. That matters because melting snow from the range provides a critical source of water for both agricultural and urban regions of the state.

But NASA is doing more than just taking pictures. By accessing high spatial-resolution satellite data, the agency has been working in collaboration with the California Department of Water Resources (CDWR) to provide water managers with more tools to plan for, and mitigate,

the impacts of drought and also help the state better assist regions suffering from drought-related economic hardships.

Ever since NASA launched the first Landsat satellite in 1972, the agency (in partnership with the US Geological Survey (USGS), which currently operates the current Landsat 8 spacecraft and collects incoming data) has provided a continuous global record of Earth's surface. Gathered by sensors that can collect measurements in multiple spectral bands, data from the program has been used to analyze a wide range of environmental changes over time, from the recession of glaciers to coral reef health, to the impacts of natural disasters.

To complement Landsat, by 2002 NASA had launched the Terra and Aqua satellites, each of which carries an instrument known as the Moderate Resolution Imaging Spectroradiometer (MODIS). MODIS provides daily global coverage and has been used to detect and monitor fires, study multiple aspects of the carbon cycle, track harmful algae blooms in the ocean, and collect aerosol measurements, among other environmental monitoring applications carried out on a global scale.

Both of these Earth-observing satellites also figure prominently in vegetation research, as they are used to measure canopy density in rainforests and to track deforestation. The wealth of plant-related data they offer, combined with NASA's push to make both Landsat and MODIS data more utilized by the public, culminated in a partnership between the agency and the CDWR to develop new information products designed to assist farmers in calculating crop water requirements across millions of acres of irrigated farmland in California.

### Technology Transfer

Since the early 1980s, the CDWR, through its California Irrigation Management Information System (CIMIS), has utilized ground-based weather stations—and, more recently, satellite data—to estimate what's known as reference evapotranspiration (ET<sub>o</sub>): the total potential amount of water that can be transferred to the atmosphere in a given time through evaporation and plant transpiration (a plant's release of water vapor) for a reference crop, typically a short, well-watered grass or



NASA's Moderate Resolution Imaging Spectrometer (MODIS) provided the data that was used to draw up this map, which uses what's called a Normalized Difference Vegetation Index to assess California's crop health. Acquired on February 1, 2014, the map shows the drought's impact on California agriculture, as the shades of brown represent areas where plant growth is drier than normal.



alfalfa crop. The CDWR distributes ETo information through CIMIS as a reference to help farmers and irrigation managers determine how much water their crops need at any given period in the growing season.

As helpful as ETo data is, farmers and irrigators must still perform additional calculations to convert the ETo information into a number specific to their fields and crops. For example, the utility of ETo information is increased when paired with another piece of data called the crop coefficient. Specific to the crop type and its stage of growth, the number, when multiplied by ETo, results in a more refined measurement of evapotranspiration specific to a particular crop and field. As it turns out, in recent years NASA and the US Department of Agriculture (USDA) together were discovering that Landsat and MODIS data could be used to map vegetation conditions and, from that, derive crop coefficients.

What make that possible are the satellites' complementary strengths, explains Forrest Melton, who is a senior scientist both at Ames Research Center's Cooperative for Research in Earth Science and Technology and at the Division of Science and Environmental Policy at California State University, Monterey Bay. MODIS is able to provide daily observations at a resolution of about 15 to 16 acres. Landsat, while only gathering data once every eight days, is able to zoom in to a resolution as sharp as a quarter of an acre. "We found that by using them in tandem we could reliably map crop coefficients on a regular basis throughout the year," he says.

As a result of those findings, NASA and CDWR, with funding from the American Recovery and Reinvestment Act of 2009, initiated the Satellite Irrigation Management Support (SIMS) project, whose goal, Melton says, is "to deliver a consistent reference that can help growers adjust their irrigation to match each crop's biological demand for water."

## Benefits

In the years since the collaboration was formed, web and mobile prototypes of the technology have been developed, and growers across the state are now testing

them. The power of the technology, Melton says, is its ability to quantify the estimated amount of water required for specific crops at different phases of their growing cycles, and it can do this plot by plot in agricultural regions throughout the state.

"Ultimately, a grower will be able to specify a particular field or orchard, and the resulting information might include the latest satellite observation and information on the crop canopy development, crop condition, and its water requirements under well-watered conditions," he explains.

In conjunction with the particulars of the irrigation system, soil type, and production goals, growers can then use the information from SIMS to adjust for how much water is needed. "It allows growers to use water more efficiently if they choose to use irrigation-scheduling techniques," says Jeanine Jones, interstate resources manager and deputy drought manager for CDWR. For example, irrigation trials conducted on lettuce and broccoli crops in Salinas that were watered according to SIMS showed no reduction in yields while reducing the amount of water used by up to 33 percent relative to standard practice.

"It's important for us to validate elements of the satellite-based procedure in controlled commercial settings and understand any limitations of the approach," says NASA Ames and California State University, Monterey Bay senior research scientist Lee Johnson, who led the yield trials.

In addition to these water-saving technologies, the agency, in partnership with the USGS and the USDA, is also advancing tools to spot areas where water shortages have led to reductions in farmed acreage. This is being accomplished by utilizing Landsat's quarter-acre resolution capability to track crop development and uncultivated lands in "just about every field in the Central Valley," Melton says. "We can map the canopy conditions every eight days throughout each growing season and identify fields with bare soil or low vegetation cover, which is a very strong and clear signal, and use that to identify fields that are idle."

That information will be used by the state to help allocate resources to nearby farmworker communities that, because of the water shortages, are facing loss of income, resulting in economic hardship. "One potential application of this will be to support California agencies in identifying counties that are likely to need extra emergency relief to support food banks for workers and their families," Melton says.

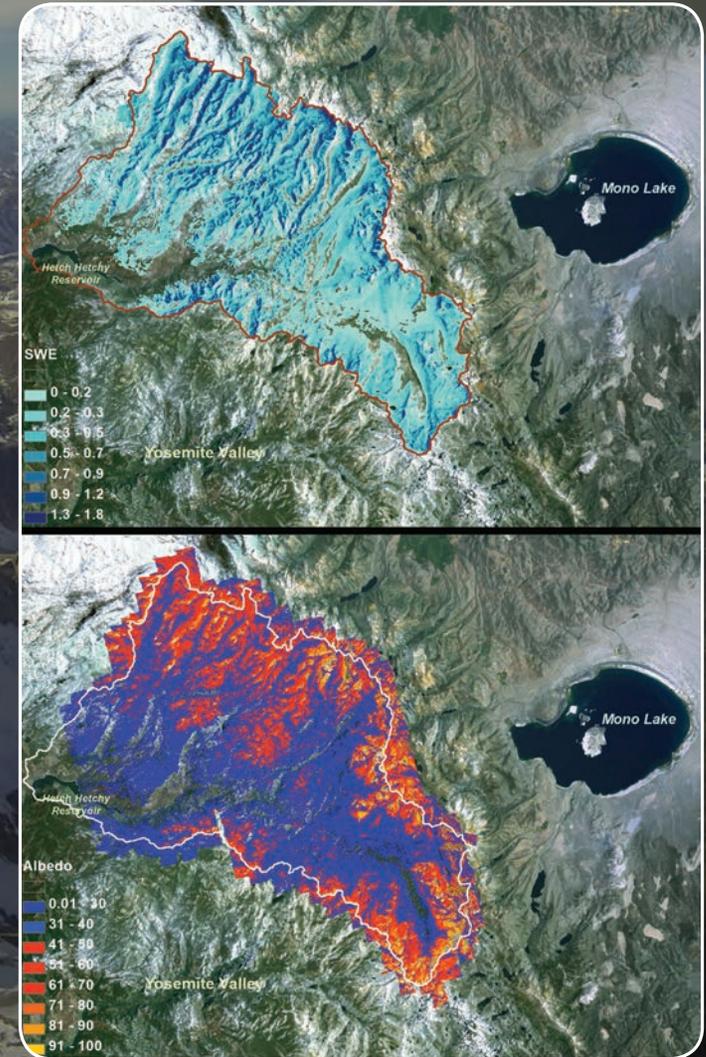
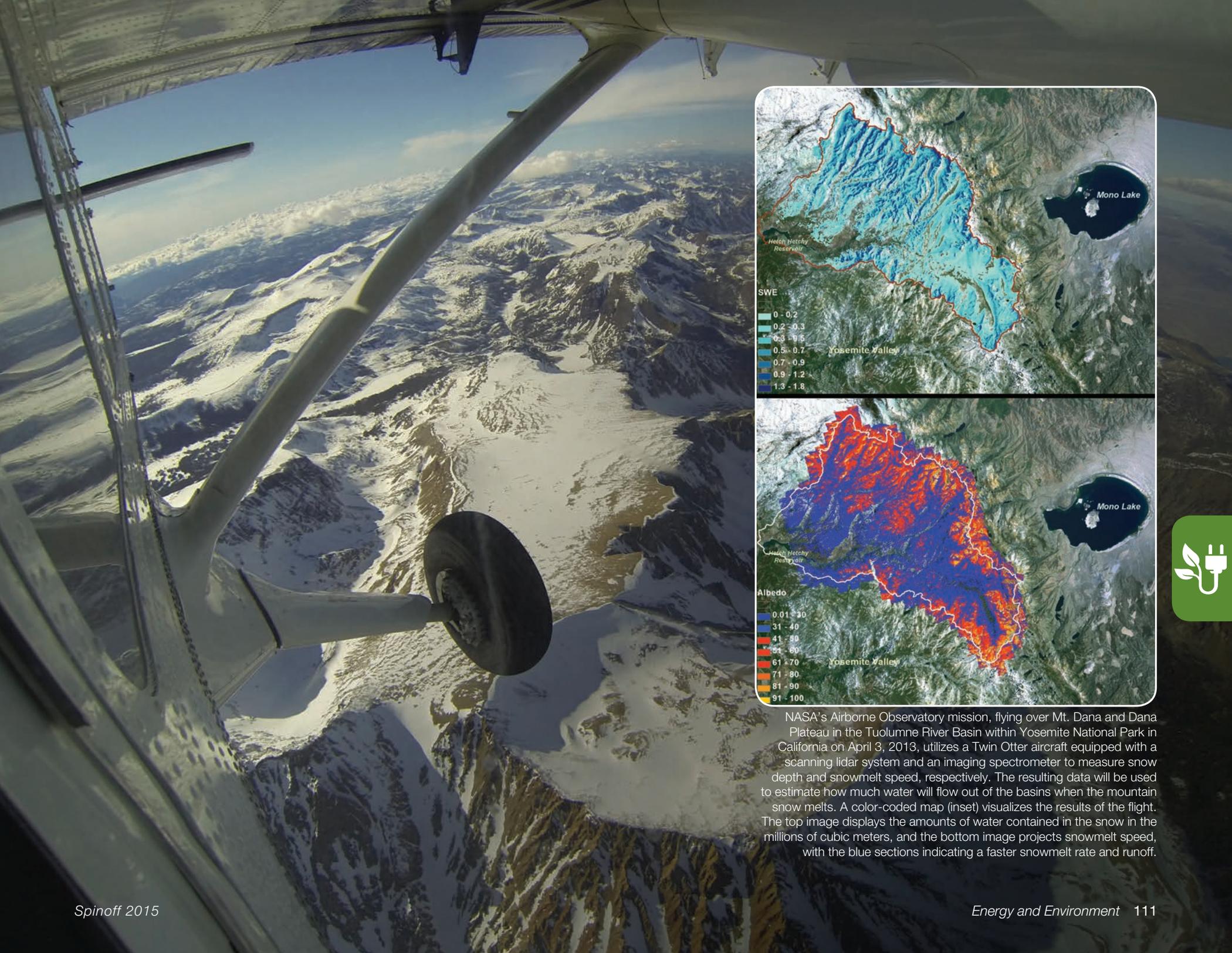
NASA's commitment to helping the state manage its water resources flows in still other directions. Another ongoing project involves measuring rates of land subsidence, or sinking, caused by depletion of groundwater, which can cause damage to water delivery infrastructure.

And the Airborne Snow Observatory, headed by Tom Painter at the Jet Propulsion Laboratory (JPL), uses an aircraft equipped with an imaging spectrometer and a scanning lidar system to collect snowpack depth and water measurements in the Sierra Nevada mountain range. Snowmelt supplies water to more than 25 million people and sustains nearly a million acres of farmland, which means the more accurate its estimation, the better the state's predictive capability for both drought conditions and flood risk.

"The idea is to expand the ability to monitor the snowpack in otherwise difficult-to-get-to places and hopefully allow us to provide more accurate runoff forecasts," Jones explains.

Another project she's keen on is JPL's research on the Madden-Julian Oscillation, a recurring pattern of tropical climate and weather that affects Earth's mid-latitudes, including California. "We're really interested in efforts to better understand it for improved climate forecasting."

She adds, "We look forward to a long-term working relationship with NASA on all of these projects. The agency's remote sensing-based data provides us with very useful information." ❖



NASA's Airborne Observatory mission, flying over Mt. Dana and Dana Plateau in the Tuolumne River Basin within Yosemite National Park in California on April 3, 2013, utilizes a Twin Otter aircraft equipped with a scanning lidar system and an imaging spectrometer to measure snow depth and snowmelt speed, respectively. The resulting data will be used to estimate how much water will flow out of the basins when the mountain snow melts. A color-coded map (inset) visualizes the results of the flight. The top image displays the amounts of water contained in the snow in the millions of cubic meters, and the bottom image projects snowmelt speed, with the blue sections indicating a faster snowmelt rate and runoff.



# Satellite Data Inform Forecasts of Crop Growth

## NASA Technology

Farming has never been more productive, but increasing demands from a growing economy and world population mean age-old risks such as insects and plant disease remain significant challenges for agriculture. To advance technologies that would make farming more efficient and productive, NASA teamed up with the United States Department of Agriculture in 2000 to form the Ag 20/20 program. An important intention of the Ag 20/20 program was to champion the use of remote sensing technology for operational use in agricultural crop management practices at the level of individual farms. Managed on NASA's end by scientists at Stennis Space Center, Ag 20/20 supported the incorporation of NASA geospatial data into the development of innovative crop management technology tools that could lead to increased production efficiency, decreased economic risks, and decreased environmental impacts from farming operations.

Among those supporting the program was the Institute for Technology Development, a nonprofit corporation based in Mississippi. One of its researchers, Ken Copenhaver, worked with NASA beginning in the mid-2000s to analyze satellite data, especially data coming from Moderate Resolution Imaging Spectroradiometer (MODIS), an instrument flown on two NASA satellites, Terra and Aqua. MODIS provides a complete picture of Earth's surface every one to two days in 36 spectral bands, giving us a wide-ranging view of what's happening on the planet, from forest fires and atmospheric water vapor

levels to phytoplankton blooms. Copenhaver worked with researchers at Stennis to match remote sensing imagery from MODIS into applied models that could yield information on crop health and vigor throughout the growing season.

## Technology Transfer

Several years later, the funds for the institute's contracts dried up, and Copenhaver joined the University of Illinois at Chicago (UIC), where a colleague of his named Steffen Mueller was working on similar land-use and agriculture projects. Because the local area is a big corn-producing region, Copenhaver and Mueller soon teamed up to develop models that could predict crop production. "It started with interest from ethanol plants, because they have to go out and buy directly from corn producers, and they want to know what corn production is like in the counties that surround them. Grain elevators were facing the same problem," says Copenhaver.

He used what he learned during the Ag 20/20 Project to incorporate geospatial information into his model, particularly data coming from MODIS's daily surface reflectance measurements—that is, measurements of how much solar radiation different parts of Earth's surface reflect, which reveals a great deal of information about ground cover and how it changes over time. With a 250-meter resolution, the information allowed Copenhaver to start predicting yield on a local scale, and the resulting software tool became known as LandViewer.

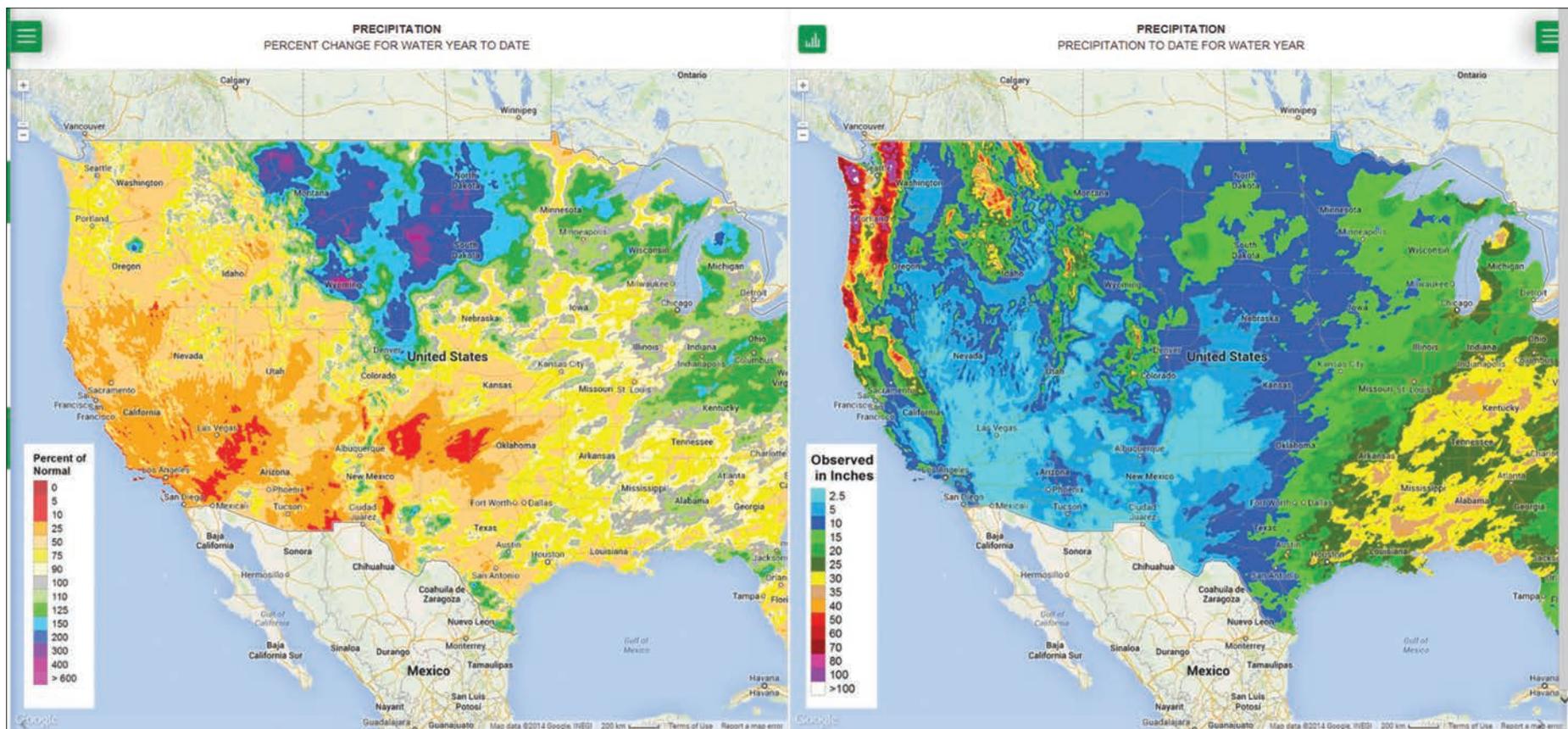
Not long after Copenhaver joined UIC, Mueller was at a conference and met Susan Olson, vice president of products for agriculture and biofuels at Genscape Inc., which has its corporate headquarters in Louisville, Kentucky. Genscape specializes in providing real-time data that informs decision-makers in energy markets, and the two got to talking about LandViewer and its applications in Genscape's area of interest. "One thing led to another," says Copenhaver, "and Genscape ended up buying LandViewer from UIC in 2013 and then hired us to develop it."

## Benefits

Now commercially available as subscription-based software, LandViewer uses a variety of data to provide daily updates on the state of corn vegetation, incorporating nearly 30 variables that include NASA satellite data. The result is a prediction of future corn production on national, state, and county scales—a level of detail that is rare among competing products, says Copenhaver.

"That's because of the way we incorporate NASA's geospatial data into the model," he says. "If we didn't have the NASA data, we'd just be offering what everyone else offers: a weather model that predicts yield. But the NASA data allows us to work at a high resolution, and it gives us the ability to adjust our model if crop production isn't matching what the weather models say it's supposed to be."

The NASA data LandViewer uses comes primarily from MODIS. Vegetation vigor measurements are well



LandViewer is an online, subscription-based product that predicts crop production. The software dashboard (above) provides real-time views of the latest data and includes tools such as comparison map views and data commentary.

known as an accurate predictor of eventual crop yield, and Genscape uses MODIS's daily surface reflectance measurements to develop vegetation vigor maps. These are supplemented and validated by nighttime surface temperature measurements provided by MODIS and then compared to previous years' models and yields to create forecasts.

These data don't just provide high-resolution geospatial information; Copenhaver says they can also give the company additional insights that weather-based prediction models miss. For example, when a corn plant overheats, its respiration and photosynthesis are both impaired, and that negatively affects yield in the long run. "Overheated crops tend to shut down at night, and we can actually see that by analyzing nighttime

surface temperatures on a field-by-field basis," he says. "Observations like that are factors in our model."

LandViewer's primary user base is still ethanol production plants, which, it turns out, really means the corn farmers themselves. "You might think that we're giving ethanol plants the advantage in bargaining with farmers, but the fact is that the farmers are the ones sitting on the boards of these plants, for the most part," says Copenhaver. "What we're finding is that this software gives everyone better information so that everybody can make the best decisions to help keep the wheels of this industry turning."

The software is still a relatively new product, and the company is exploring its potential in multiple markets. In addition to ethanol plants, the company is also promoting

the software to grain traders who buy and sell corn on a large scale daily. For traders, advance knowledge of probable corn production levels can help them set better prices and manage risk.

Genscape's NASA connection is an ongoing one, as the company grabs the latest satellite data every day to inform its prediction models. But Copenhaver says the real core of the technology is a product of his time at Stennis. "The model powering LandViewer came directly from those days: I worked with different groups that were using MODIS data, calibrating it, and developing new products for MODIS. It was while I was at NASA that I learned a lot about how to do this." ♦



# Probes Measure Gases for Environmental Research

## NASA Technology

To understand climate change, we need to understand the movement of carbon, one of the planet's most abundant resources and a building block of life that is endlessly being exchanged through people, plants, animals, oceans, land, and the air.

Geoffrey Bland, a research engineer at Goddard Space Flight Center, helps devise ways to improve the agency's models of the carbon cycle. Carbon is everywhere, contributing to nearly 10 million different known compounds. In our atmosphere, it's mostly present as carbon dioxide (CO<sub>2</sub>) but is also found in gases such as methane (CH<sub>4</sub>). "It's a real puzzle," says Bland, "to understand what is happening to carbon, and how it is potentially impacting our climate, food, and the environment. To do this, we need to understand where it is going."

Launched in 2014, NASA's Orbiting Carbon Observatory-2 (OCO-2) satellite is making the first space-based measurements of CO<sub>2</sub> in Earth's atmosphere. Such

measurements will contribute to a better understanding of how increasing CO<sub>2</sub> concentrations are affecting climate around the world. Bland explains, however, that while OCO-2 looks at the wide distribution of carbon over Earth, it will not necessarily see important small variations.

"If OCO-2 makes an observation of an area from space that has a high CO<sub>2</sub> concentration," he says, "then we could fly an airplane with a probe over that area to help us assess how much is coming out, where it is coming from, and where it is going."

## Technology Transfer

To construct an instrument that could be mounted on an aircraft to take measurements of the concentration and speed of gases like CO<sub>2</sub> moving through the air, Goddard started working with Christiansburg, Virginia-based Aeroprobe Corporation through the Small Business Innovation Research (SBIR) program in 2008.

"It's a hard thing to do," says Bland. "One of the issues is airplane motion. The aircraft does not fly perfectly steady, so even if you have a probe that can measure the three-dimensional wind field, the airplane motion complicates the measurement."

Working together, the partners developed and tested an instrument called the Fast Response Atmospheric Turbulence (FRAT) probe that could provide the acceleration and rate of speed of the plane that would carry it. "The electronics package can subtract the aircraft motion from the signal that it's getting at the end of the probe," describes Bland. "If you do this, you can more accurately assess what the undisturbed air is actually doing."

This key innovation translated not only to improved accuracy but saved time and resources by eliminating the need to perform additional analyses accounting for the plane's movement. A second innovation was the probe's ability to carry, within the measurement system, a device to measure CO<sub>2</sub>, CH<sub>4</sub>, and other gas concentrations.

The image shows the Orbiting Carbon Observatory-2 (OCO-2) satellite in orbit above Earth. The satellite is a rectangular box with two large, dark solar panel arrays extending outwards. The Earth's surface is visible below, showing a mix of blue oceans, white clouds, and brown and green landmasses. The satellite is positioned in the center of the frame, angled slightly towards the viewer.

The Orbiting Carbon Observatory-2, launched in 2014, watches Earth "breathe" from space by mapping carbon dioxide emissions.



Aeroprobe's new sensors can be employed on a variety of craft to measure atmospheric gases. The company sells fast-response sensor systems all over the world, including a recent commission by Turkish Aerospace Industries, a major manufacturer of aerospace equipment (such as the unmanned aerial vehicle pictured here) for research and military purposes.

“Those are typically separate instruments,” says Bland. “This one is very compact and you get the information right away.”

Nanci Hardwick, the CEO of Aeroprobe, says the innovation has been a significant one for the company. “In addition to being able to put electronics inside the probe, what we’ve never done before is put a different kind of sensor, like the one that measures CO<sub>2</sub>, inside the probe,” she says. “This is the novelty of our product.”

### Benefits

Aeroprobe is currently taking orders for the FRAT probe, and so far it has performed successfully on a small unmanned aerial vehicle from Virginia Polytechnic Institute and State University to measure gas contents, humidity, and other atmospheric thermodynamic quantities. The probe is also being tested on meteorological towers that are part of a multi-government agency effort to measure CO<sub>2</sub>: existing television, radio and cell phone towers are instrumented to sample gases and determine how the gases are moving high above the ground.

Potentially, the probe could be used by various public and private entities. In industry, for example, the probes could be employed for detecting leaks in natural gas lines or CO<sub>2</sub> leaks from underground sequestration sites. “These probes include sensors and electronic equipment that have seen great improvements in the last few years. It is now possible to build the same probes at a fraction of the original development cost,” says Hardwick.

Bland also sees potential for the probes at the Environmental Protection Agency and the Department of Energy. For environmental research purposes, the probe could be mounted on an aircraft or tethered to balloons to measure atmospheric turbulence, and it could be useful in applications examining air quality to measure heat, water vapor, and trace gas fluxes.

Hardwick adds that researchers at the National Oceanic and Atmospheric Administration may fly the probes into developing tropical storms or hurricanes to measure wind turbulence, the size and number density of droplets, and the fluxes of momentum, humidity, and more.

The Department of Defense or the Department of Homeland Security may also consider using the technology to monitor the dispersion of pollutants or atmospheric contamination generated by potential terrorist activities, explains Hardwick. “Now that we’ve established the product and the integration of different sensors, it doesn’t have to be carbon dioxide that we’re measuring. It could be some sort of biological weapon.”

Meanwhile, Bland remains excited for NASA’s work to get a better understanding of the planet’s changing climate. Between OCO-2 in space and aircraft fitted with innovative sensors in our atmosphere, he hopes to fill in the details of NASA’s understanding of the carbon cycle. “Getting a global picture is our primary objective,” he says, “but capturing those details is a challenge too—and the FRAT probe will play an important role in doing that.” ❖

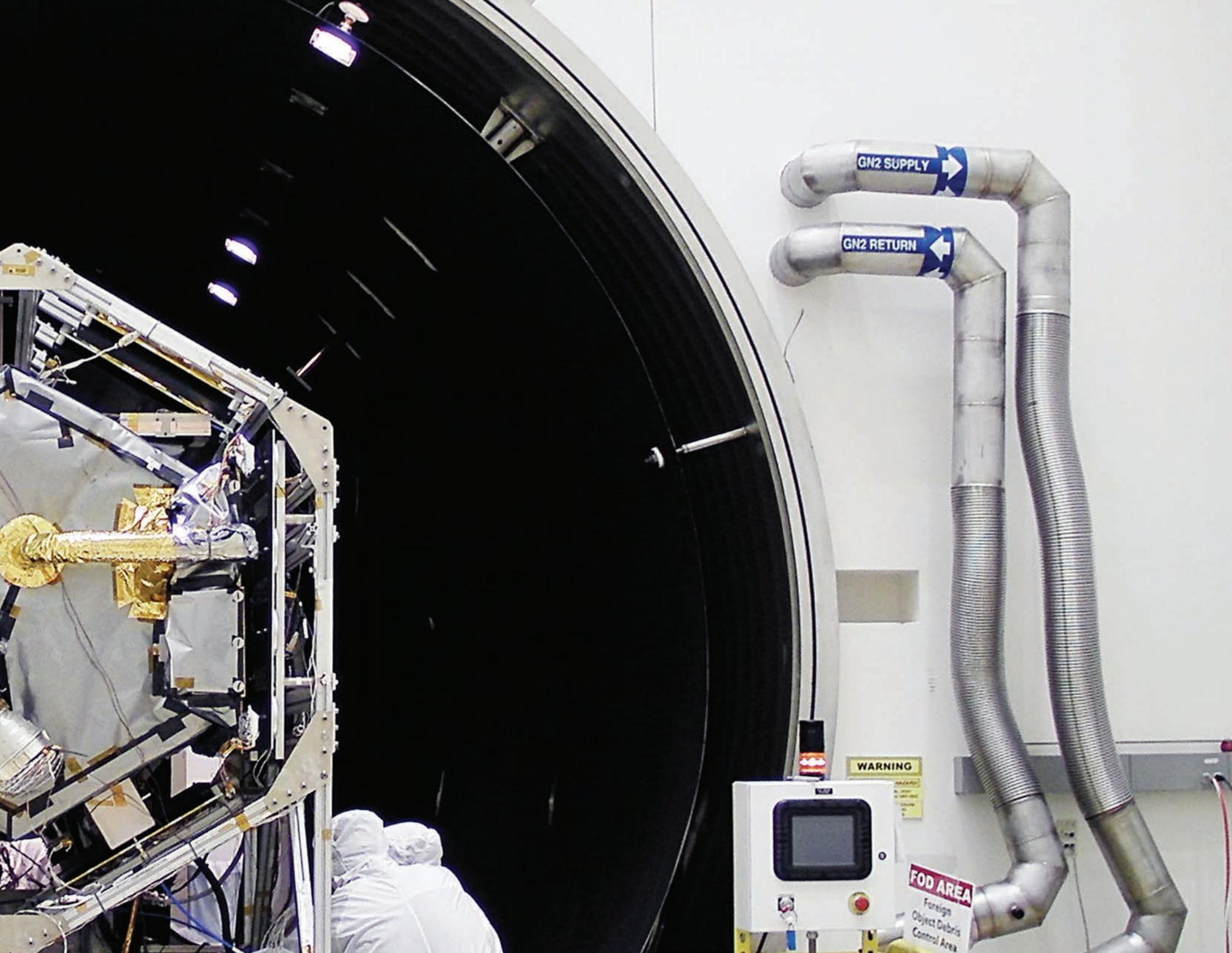




# Information Technology

The tremendous complexity of NASA missions has led the agency to develop information technology tools for countless functions, and many of these have since been licensed for commercial use, such as software that assists in home building, project planning, and vehicle-noise management. Commercial entities are also increasingly finding unique ways to employ NASA data in a variety of solutions, such as in cloud computing platforms that enable environmental research.





GN2 SUPPLY

GN2 RETURN

WARNING

**FOD AREA**  
Foreign Object Debris Control Area

# Cloud Computing Technologies Facilitate Earth Research

## NASA Technology

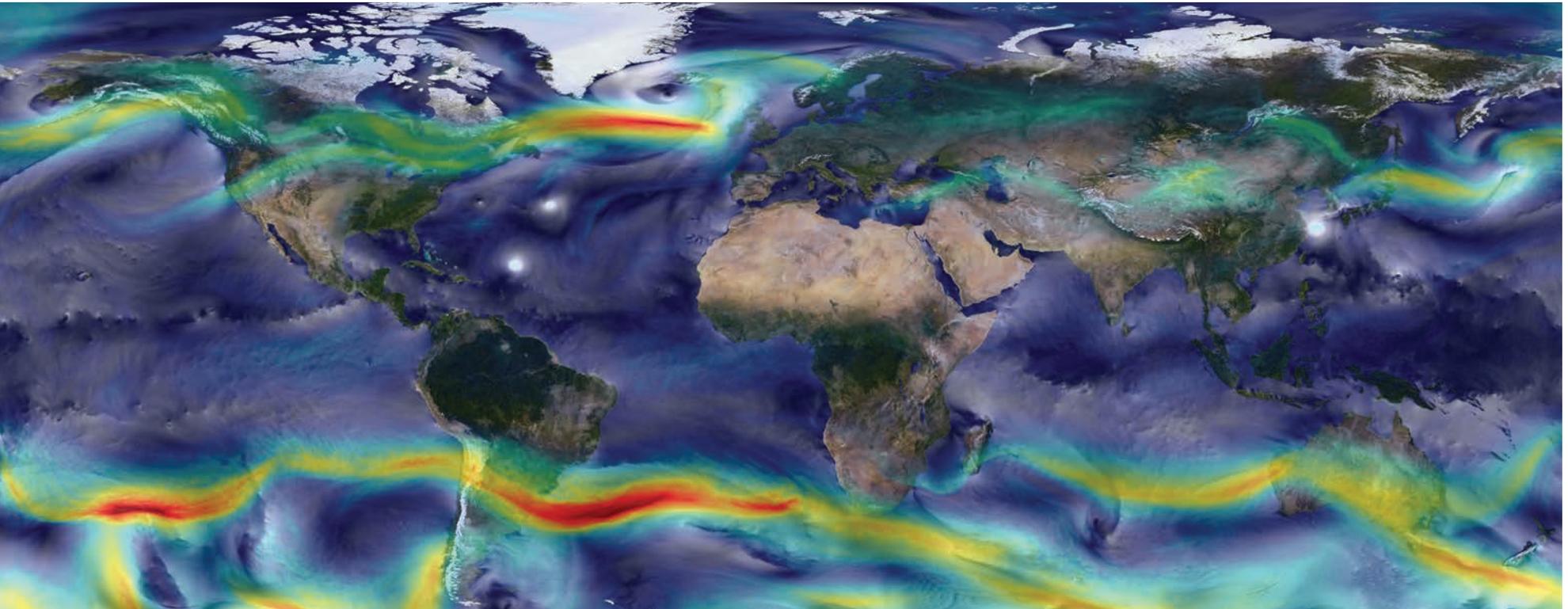
Throughout the years, NASA has done more than any agency to explore what lies beyond our world. It has sent rovers to traverse the Martian landscape and launched spacecraft to monitor the sun. Another satellite, Voyager, is even leaving the solar system for the uncharted territory of interstellar space. But equally important are its satellites whose lenses are trained back on Earth. Since 1972, Landsat satellites operated by NASA have been providing high-resolution topographical

land data, and the Moderate Resolution Imaging Spectroradiometer (MODIS), launched on Terra in 1999 and Aqua in 2002, offers a fresh perspective of Earth's surface every one to two days.

By using satellite data, NASA scientists are able to investigate an array of environmental issues, such as deforestation, aerosol accumulation, carbon cycles, and glacier recession, to name just a few. The data are expansive enough for tracking worldwide carbon emissions, yet refined enough for monitoring vacant Californian farmland.

In the late 1990s, NASA made all of its satellite data freely available to the public. Outside researchers could, and still do, make requests through NASA data centers, which upload requested information via File Transfer Protocol applications. But over the years, as datasets have grown larger in volume and are covering longer periods of time, it has become more time-consuming for data to be shared that way.

According to Rama Nemani, senior Earth scientist at the Advanced Supercomputing Division at Ames Research Center, "For somebody to do a large-scale



NASA's Goddard Earth Observing System Model, known as the GEOS-5, uses satellite data to simulate worldwide weather at resolutions as fine as 3.5 kilometers. Here it displays a snapshot of global winds with a 10-kilometer resolution. Slower surface winds, shown in white, trace features such as storm systems. Meanwhile, faster-moving upper-level winds are colored red.

continental or global analysis, things are difficult because you have to download all this data from the various centers, which takes weeks to months,” he says, “and then you have to write the code on your own to analyze the data instead of reusing the codes that other scientists already wrote.”

To help researchers—specifically those receiving NASA funding—more quickly access and analyze satellite data, in 2010 Nemani led the development of NASA Earth Exchange, or NEX. Through NEX, researchers not only have access to datasets; they are also able to tap into Ames’ Pleiades supercomputer—one of the world’s most powerful. The platform also facilitates collaboration and information sharing between participating scientists. “In this way, it’s like Facebook,” Nemani says. “We share results, algorithms and things like that, and in the forums, people suggest new ways of doing things.”

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**In November 2013, NASA and AWS [Amazon Web Services] announced the availability of climate and Earth science satellite data to researchers and educational users through the AWS cloud.**

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In the few years since its founding, the platform has been utilized in several studies and investigations, including the NASA Earth Exchange Downscaled Climate Projections, or NEX-DCP30. Scientists at Ames, the Climate Analytics Group in nearby Palo Alto, and California State University, Monterey Bay, collaborated on the dataset, which provides a view of future continental U.S. temperature and precipitation patterns based on four different greenhouse gas emissions scenarios, spanning the period from 1950 to 2099. What makes the projections even more intriguing is their scale: While most climate change forecasts cover large geographic areas on the order of 100-250 kilometers, the downscaled dataset can provide half-mile resolution analysis. “Folks can look at this data and see how their neighborhoods are

expected to change in the next 100 years,” notes Nemani. “That’s how fine the scale is.”

While NEX has done much to improve access to NASA satellite data and supercomputing services and to promote scientific collaboration, after two years, Nemani says, he and his colleagues concluded that more could be done to simplify access and encourage innovation. A few issues were apparent. First, because outside researchers were accessing NASA’s computer network, they were waiting as long as six to eight months to receive security clearance. Another bottleneck was that the large number of requests to use Pleiades often resulted in weeks of wait time. Lastly, only NASA-funded researchers were allowed access. “Given these constraints, we started looking for yet other ways of engaging the community,” Nemani says.

At about the same time, in 2012, the Obama administration announced its Open Data Executive Order, the aim being to make government data more accessible to the public. One way the White House was pushing to make that happen, says Tsengdar Lee, program manager for High-End Computing at NASA headquarters, was by encouraging more public-private partnerships. “That’s how we got into a conversation with Amazon.”

### Technology Transfer

Amazon.com Inc., headquartered in Seattle, started as a retail business in the mid-1990s. As the Internet began to play an increasing role in commerce, the company developed the infrastructure to meet demand. Its datacenters are now located all over the world and have the capacity to simultaneously handle millions of purchases and also stream multimedia to its global consumer base.

As it happens, the technology developed for this intricate computer network would also benefit researchers and companies that need access to both large amounts of data storage and supercomputing capabilities. As a result, in 2006, the company began offering those options through Amazon Web Services (AWS), which operates through a worldwide set of datacenters separate from its retail ones.

Some of AWS’s tools include Amazon S3, or Simple Storage Services, for keeping digital objects for website hosting, and EC2, or Amazon Elastic Compute Cloud, which hosts database servers and server infrastructure

for custom-developed applications, including large-scale supercomputing. Among its noted clients are the television show and movie provider Netflix, software company Adobe Systems, and Thomson Reuters news service.

AWS’s experience hosting data also extended to government. For example, earlier that year the company collaborated with the National Institutes of Health (NIH) to host the world’s largest set of data on human genetic variation, which was collected as part of the 1000 Genomes Project. Organizations and university researchers interested in the data now have easy access; in addition, they can pay to utilize Amazon’s EC2 services, giving them the necessary supercomputing power to pursue scientific objectives.

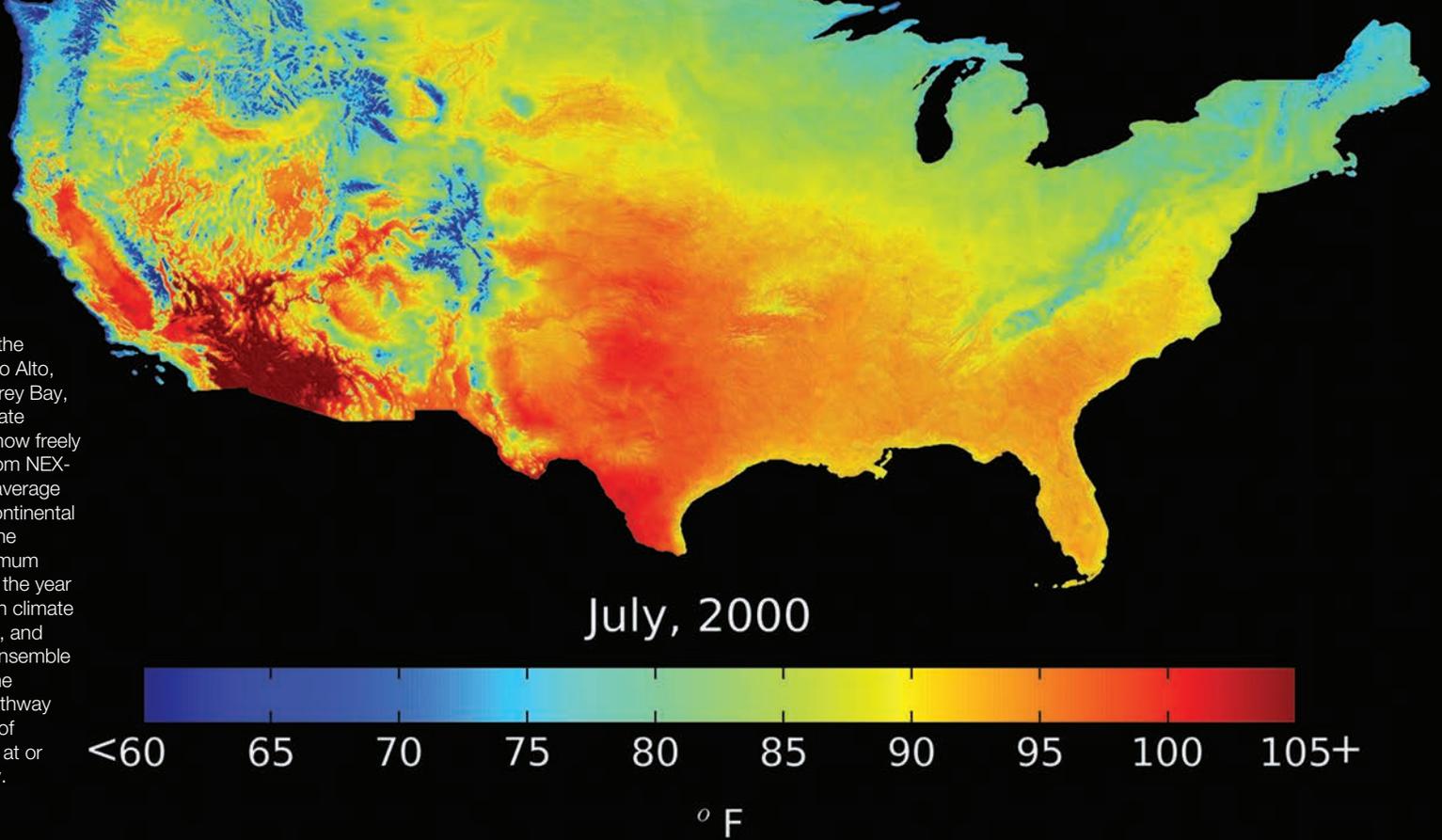
The successful NIH-AWS collaboration gave NASA the impetus to reach a similar agreement with the company because it would improve on NEX in all the ways that Nemani and his team had hoped. For one, NASA-funded researchers would be able to access the datasets directly, bypassing the time-consuming security clearance procedures for accessing the agency’s network. Work would also get done faster because there would be less of a backlog of requests to use Pleiades. Finally, the greater scientific community would also now have access to both NASA datasets and AWS’s supercomputing services.

With those goals in mind, following the signing of a NASA Nonreimbursable Space Act Agreement in November 2013, NASA and AWS announced an initial one-year partnership called OpenNEX, whereby select



Background image: Produced with vegetation indices gathered from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA’s Terra satellite, the map displays a multi-year average of leaf surface area to ground surface area in the Amazon rainforest. The darker the shade of green, the thicker the tree canopy. Through NASA’s partnership with Amazon Web Services, researchers will also have access to MODIS data.

Scientists at Ames Research Center, the Climate Analytics Group in nearby Palo Alto, and California State University, Monterey Bay, collaborated on the Downscaled Climate Projections (NEX-DCP30), which are now freely available through OpenNEX. Taken from NEX-DCP30, the image on the left shows average maximum temperatures across the continental US in July 2000, while the image on the right displays projected average maximum temperatures over the same region in the year 2100. Data for 1950-2000 is based on climate simulations driven with observed data, and data for 2010-2100 is based on the ensemble average of all climate models under the highest greenhouse gas emissions pathway evaluated. At present, the global rate of greenhouse gas emissions is tracking at or above this highest emissions pathway.



agency satellite data and climate change datasets would be freely available through the AWS cloud. Researchers could either download the datasets directly to their computers and run their own analysis, or they could access AWS's computing as a service (a pay-as-you-go approach), which comes with free data storage. In addition, through the OpenNEX platform, tens of thousands of researchers—climatologists and geophysicists, among many others—from around the world will have a means to collaborate and share information in order to address the world's most pressing environmental problems.

Data and models hosted on NEX and OpenNEX will aid researchers in their investigations for a plethora of

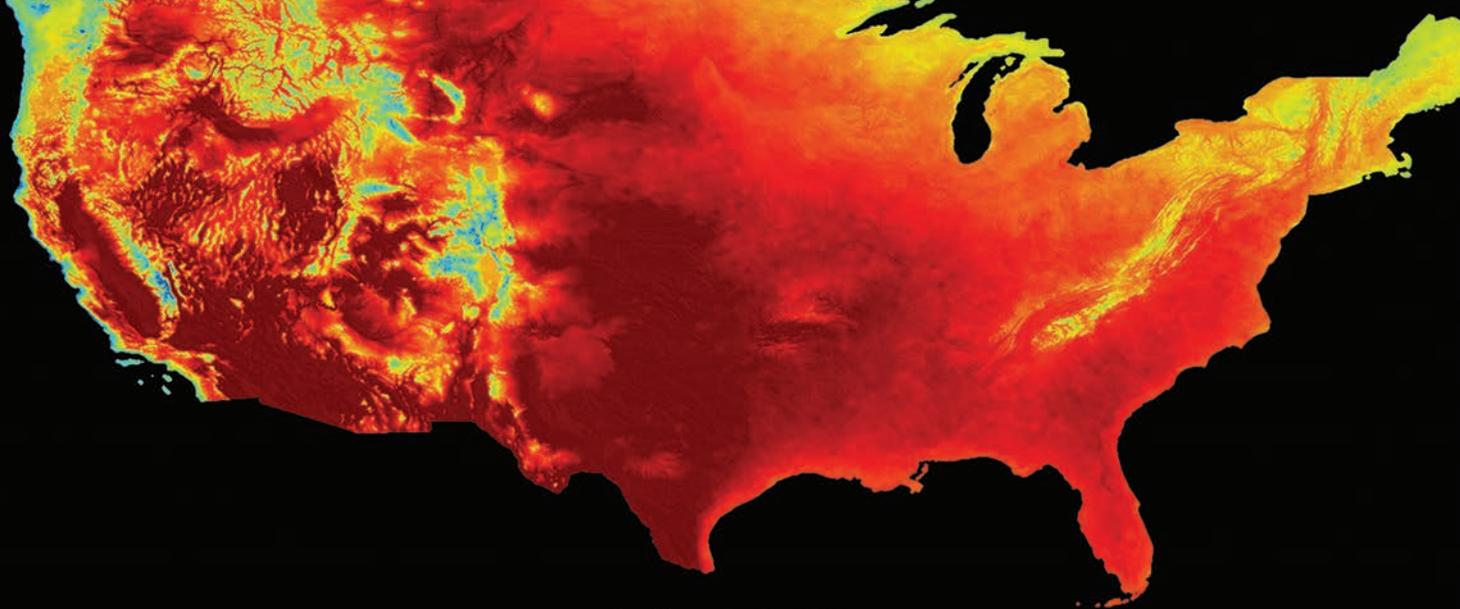
activities, including terrestrial ecology, land use and land cover, carbon cycle science, ecological forecasting, biodiversity, data mining, climate change impacts, and climate change mitigation strategies. Besides the datasets in NEX, the researchers have access to NASA Earth science models, such as TOPS (Terrestrial Observation and Prediction System), the Goddard Earth Observing System Model, Version 5 (GEOS-5) and the NASA-Unified Weather Research and Forecasting (NU-WRF) model.

### Benefits

Through the AWS platform, users can currently work with portions of three sizeable datasets: Landsat

Global Land Survey information from the 1970s to 2005, MODIS vegetation indices, and the NEX Downscaled Climate Projections. After the one-year agreement passes, the agency will review the feedback it has received from the scientific community. If the reception is positive, NASA plans on extending the agreement with AWS and will make available additional satellite datasets as well as provide regular updates of those that are currently available.

In exchange for freely hosting the data, AWS benefits from users having the option of purchasing the company's computing services. Jamie Kinney, principal solution architect at AWS, notes that there are two major benefits



July, 2100



Average Daily Max Temperature ( ° F )  
Highest Greenhouse Gas Concentration Pathway

of using AWS for computing: simplicity of use and cost-effectiveness.

“Now anybody who has access to the Amazon cloud, which is publicly available, can easily create an account and, within a few minutes, provision a cluster,” says Kinney. “For a few dollars or maybe 10 or 20 dollars an hour, they can provision a very powerful 25–30-teraflop cluster on Amazon and quickly analyze and visualize that data using the same exact software that NASA researchers are using on internal facilities.”

Moving forward, Kinney says that Amazon is looking forward to continuing its partnership with NASA, not only for increasing business but also because the company

is excited to help bring about future discoveries. “We make investments in public datasets and these types of grants so that we can really help develop the next generation of technologies that will be used by all of our customers down the road, both public sector and commercial,” he says. “So it’s a very natural partnership for us.”

In its short run, Nemani says reception to OpenNEX has been very positive. In June, the agency instituted a series of contests on OpenNEX that challenges citizen scientists to use the available datasets for developing applications and algorithms that promote climate resilience, or our ability to adapt to climate change. The contest falls in line with the White House Big Data and Climate

Data Initiatives, which encourage government agencies to improve their ability to extract knowledge and insight from their digital data collections, as well as President Obama’s calls for developing tools to fight climate change.

“We already have over 400 scientists signed up to be part of the challenges,” Nemani said in July, “so we’re pretty excited to see what they’ll come up with. But keep in mind that this is just the beginning; in a few years we hope to have a large section of the scientific community from around the planet using OpenNEX on a daily basis for climate change research. That’s our big goal.” ❖



# Software Cuts Homebuilding Costs, Increases Energy Efficiency

## NASA Technology

In order to prepare Curiosity for its trip to Mars, NASA had to pull out all the stops. Because the rover's payload is 10 times as massive as those of earlier rovers, it would enter the Martian atmosphere at speeds of more than 13,000 miles per hour—1,000 miles per hour faster than its predecessors. To decelerate the giant laboratory on wheels, NASA had to construct the largest supersonic parachute ever built for a mission; to prevent the ensuing rocket thrust from kicking up dust on sensitive equipment, a first-of-its-kind sky crane was created to gently lower the machine onto the ground.

And that is only the oversimplified version of the landing sequence.

Yet for all the planning and development that went into the rover's landing gear, its suite of scientific instruments, and its thermo-nuclear power generator—to name only a few components—the agency's lofty goal of sending humans to the Red Planet presents still greater technological and logistical challenges.

The fact that Curiosity's mission is to discover if Mars was ever capable of supporting life hints at one of the agency's major obstacles in pulling off a human mission: developing dependable astronaut life support systems for a planet that—despite its many similarities to Earth—is bereft of even so much as a breathable atmosphere. Then there are logistics such as the kinds of propulsion and power systems to be employed, whether payloads should be brought on separate flights, how habitation units should be designed, and so on.

To add to the complexity, each technology decision has to be made in relation to how it would impact other technologies being considered. Having to evaluate a multitude of components in relation to each other makes for an overwhelming number of possible systems, or architectures.

"We have literally thousands of architectures we could use to get to Mars," says Nantel Suzuki, a manager in NASA's Exploration division. "That's why there's a lot of uncertainty about the most feasible way to get there. We needed something that could bring some sanity to the process."

To incorporate a logistical framework for such an undertaking, throughout the 2000s NASA Headquarters awarded research grants to Massachusetts Institute of Technology (MIT), with Ed Crawley, Ford Professor of

Aeronautics and Astronautics at the university's department of the same name, serving as principal investigator. A systems engineer and former astronaut candidate, Crawley had had a long, distinguished history of working

with the agency on lunar and Earth-observing missions. He and his team of graduate students would ultimately develop an algorithm-based tool that evaluates the various tradespaces—or design combinations—and comes up with the best options.

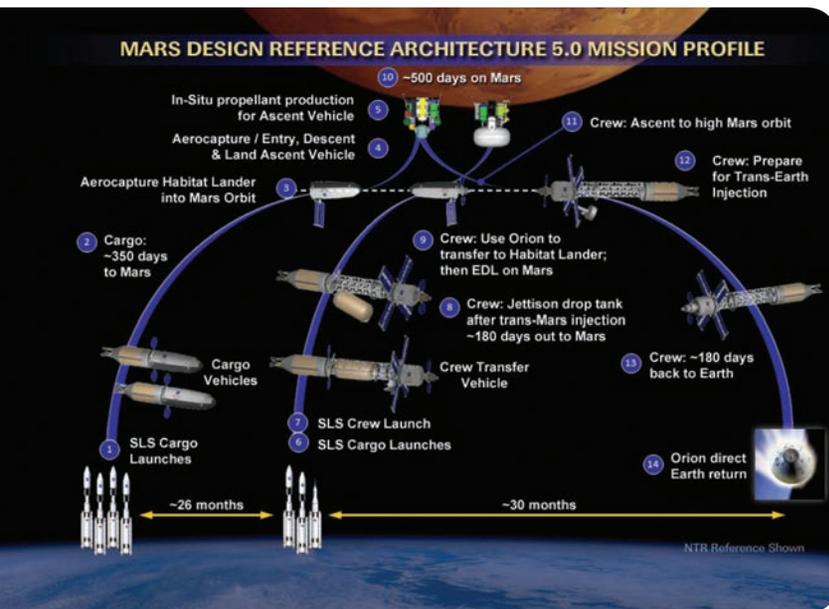
Arriving at those best options was accomplished by mathematically analyzing the thousands of possible tradespaces and deriving what's called the Pareto frontier: tradespaces that are the most promising in terms of cost and mass while also offering the highest chances for success. On a Pareto graph, mass is charted on the vertical axis; cost on the horizontal. The frontier is represented by dots—each representing a tradespace—that populate the edges, denoting the plans that use up the least amount of cost and mass. NASA is using that data to help guide its decision-making.

The tool not only helps determine the most efficient technologies but also advises the agency on how to prioritize their development. "Investment decisions made in the right order might save you time, money, and a lot of headaches," says Suzuki. For example, an oxygen processing plant developed for use on Mars would obviate the need for allocating space and mass for huge oxygen tanks onboard the spacecraft.

## Technology Transfer

One major step NASA has taken because of the tool's analysis is the decision to further develop technologies that support the use of liquid hydrogen as a fuel source. "We looked at all these thousands of ways to go to Mars, and no matter which way we choose, we know we're going to need this technology because of its high performance and efficiency," Suzuki says.

Liquid hydrogen makes a great fuel source, but one problem it poses is that because hydrogen atoms are very tiny, any microscopic hole in the carrying tank would result in the gas slowly boiling off and leaking. To prevent that scenario from posing a threat, the agency is currently developing hydrogen boil-off control technology. "The



An example of a Design Reference Architecture summary for a human mission to Mars. Ed Crawley and his team at Massachusetts Institute of Technology developed an algorithm-based software tool to help NASA choose the most cost-effective and efficient architectures, or systems of technologies, for what will be one of humankind's greatest achievements.

MIT analysis helped us to see why it was important to start there.”

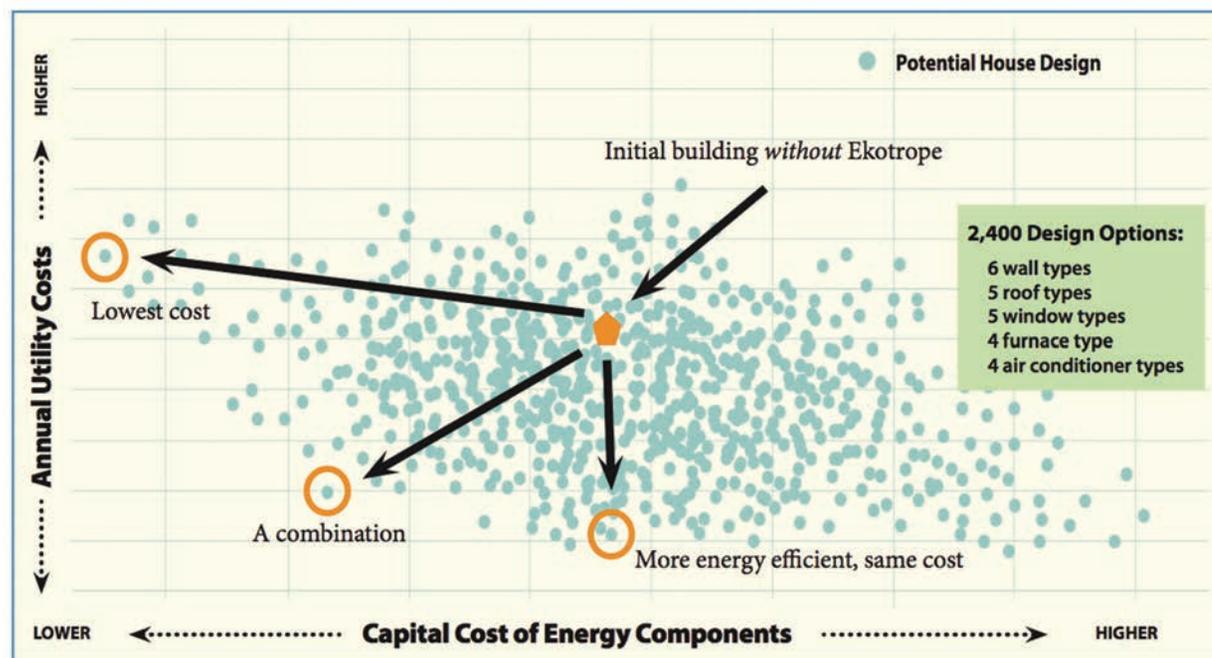
Using these tools for figuring out the most sensible plan of attack for a complex project would work well not only for space missions, as Crawley found out, but also for home construction. He was looking to build an energy-efficient and cost-effective home for himself, and he realized there was no sufficient way for his architect to analyze how different combinations of components impacted the trade-off between cost and energy efficiency. Inspired by his NASA experience, in 2010 Crawley and his team at MIT developed a Pareto frontier-based software program called Ekotrope, which he used to not only construct his home but also start a business.

## Benefits

For anyone who has ever been involved in designing and building a home with both cost effectiveness and energy efficiency in mind, the virtually endless number of construction methods can be overwhelming. “Manually trying to figure out optimal combinations of windows, walls, insulation levels and materials, HVAC systems and so on is too complicated and time-consuming,” says Ekotrope CEO Ziv Rozenblum.

But just like the Mars-oriented software tool, Ekotrope analyzes the numerous design options to arrive at the most promising architectures. All a builder needs to do is input into the cloud-based program known parameters for the future house, such as its interior and exterior dimensions, the potential materials (there is an extensive drag-and-drop menu that’s always being updated), and its orientation.

The software takes that information and runs it against a year’s worth of local weather data for the area. It quickly produces a graph with the vertical axis representing annual energy costs and the horizontal axis the total cost for building components and equipment. The graph contains thousands of dots representing all possible design options. But as with the Mars analysis, the builder need only pay attention to the Pareto frontier: the set of dots that populate the edges where either energy or construction costs, or both, are low. A builder can then



By utilizing his work with NASA, Crawley developed Ekotrope, a software tool that helps homebuilders narrow down the thousands of design options to the ones that are the most cost- and energy-efficient.

choose from those options based on specific cost, energy efficiency, and design considerations.

The resulting plan saves the builder a considerable amount of money. According to Rozenblum, a typical client will end up choosing a house that’s up to 40 percent more energy efficient and will save \$1,000–\$3,000 in construction costs. “For a company that constructs thousands of homes a year, that’s millions of dollars saved on building costs alone,” he adds. “The results are pretty staggering.”

Sometimes the results are even more dramatic, he says. For example, one customer believed her best investment would be to buy expensive walls that could retain heat during the winter. After using Ekotrope, the team convinced her to invest in a more efficient furnace instead. “A more energy-efficient furnace will get you the same result as the wall system while saving you 90 percent,” Rozenblum recalls telling her. “We ended up saving her \$20,000. It’s unbelievable.”

In the few years since its founding, the Cambridge, Massachusetts-based company has seen steady business

growth, with residential construction firms drawn to Ekotrope’s ease of use and ability to help builders meet energy codes cost-effectively. Another benefit is that builders are also equipped with the ability to display to prospective owners the financial benefits of energy-efficient improvements. As an example, a builder in Florida is using Ekotrope to improve design and demonstrate a less than one-year payback on a super-efficient house which, under normal usage, has zero utility costs.

The technology’s genesis couldn’t have come from a more audacious undertaking: sending humans to Mars.

“Everyone knows NASA is at the forefront of innovation and technology, but we don’t always get to see the benefits in other sectors on a day-to-day basis,” says Crawley, who is company chairman. “That is why spreading this innovation into new industries is so important and exciting; we can use it to immediately improve our world in so many different ways.” ❖

# Portable Planetariums Teach Science

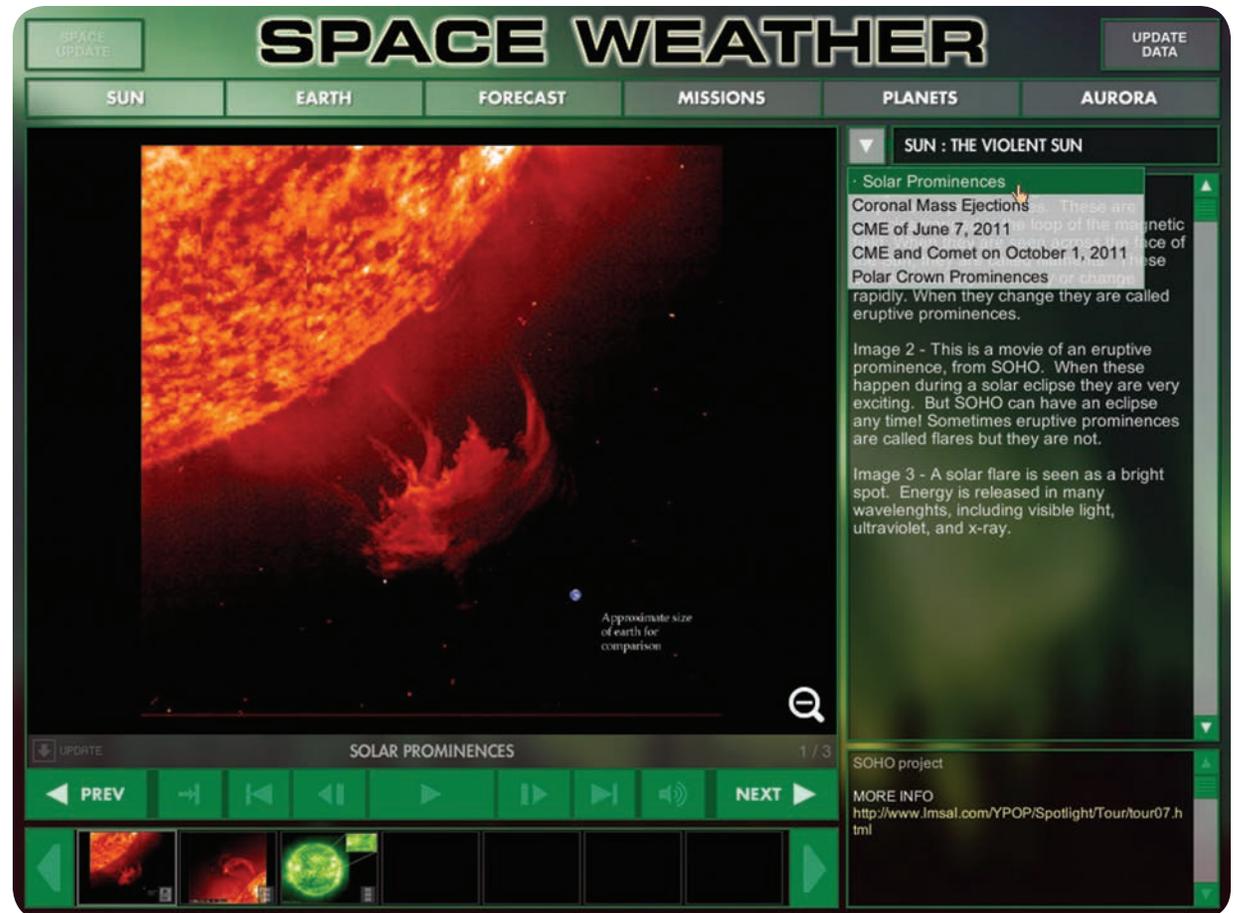
## NASA Technology

By the mid-1990s, NASA was collecting an enormous amount of information about Earth and the universe. For example, the Earth Observing System, comprising a fleet of satellites, was gathering long-term data on the world's atmosphere, land surface, and oceans. Meanwhile, the Hubble Telescope and other spacecraft were focusing their lenses toward the cosmos, amassing a trove of images that were helping scientists answer intriguing questions regarding the life cycles of stars and the formation of galaxies, and even proving the existence of black holes.

Traditionally, such information had been largely inaccessible to the public, because there was no infrastructure in place capable of distributing computer-based data to the masses. But in recent years, the Internet—a technology that would connect the planet in ways never before imagined—had begun to take the country by storm. The agency recognized the forthcoming Information Age and put out a call for proposals on how best to use the Internet to share NASA data.

## Technology Transfer

One successful proposal—the first of several—came from Rice University and the Houston Museum of Natural Science. Together they put forth an education outreach idea: to create the world's first Internet-accessible museum kiosk. In 1994 NASA entered into a joint cooperative agreement with the two institutions, which a year later resulted in an exhibit called *Earth Today*. In it, visitors could interact with three programs: *Welcome to Planet Earth* provided hourly global satellite weather photos, maps and forecasts; *Space Weather* described the plasma environment of Earth and showed how the planet's atmosphere and magnetic field protect it from the hazards of space; and *Houston Today* dispensed local weather information.



Rice University and the Houston Museum of Natural Science received NASA funding to develop the world's first Internet-accessible museum kiosk. One of its software programs is *Space Weather*, which describes how Earth's magnetic field and atmosphere protect it from the hazards of space.

The exhibit's achievement yielded further funding from NASA to transfer the kiosk programs into educational software that could be used in homes and schools. They developed a program called *Space Update* in 1996, followed by two others called *Space Weather* and *Earth Update*. In order to distribute the software, the institutions licensed the technology to Space Update, Inc.,

founded by Patricia Reiff, a space physicist at Rice University who, along with Carolyn Sumners, director of the museum's planetarium, were the co-principal investigators in the NASA-funded projects. A year earlier, the two partnering institutions, Reiff included, had also started working on another joint venture, this time through a cooperative agreement with the Earth System

Information Partners program, created by NASA's Office of Earth Science in order to promote such research. For this contract they put the agency's research literally under the bright lights by developing the country's first fully digital planetarium (and only the third in the world), which debuted at the Houston Museum of Natural Science in 1998. Another result of the contract was their production of an accompanying show called *Force Five*, the world's first Earth science planetarium show focused on hurricanes, tornadoes, and space storms. Soon afterward, Reiff founded Houston-based Museums Teaching Planet Earth Inc., or MTPE, in 1999, to distribute the Earth sciences show and software.

In 2002 came their third cooperative agreement with NASA, once again working with its Office of Earth Science. This time funding came from the Research, Education, and Applications Solutions Network, or REASoN program, which aimed to further educational outreach. The goal was to develop the world's first portable digital planetarium along with new educational shows. MTPE would be granted a license to promote and sell the technology to schools and other institutions.

Originally, the plan was to make use of the existing portable domes on the market, which were only running analog-based shows. After realizing that several improvements could be made to enhance user experience, it was decided that a new model would be developed. MTPE's needs and suggestions helped its supplier, Avela Corporation, to develop the groundbreaking double-door entrance, which acts like an airlock, preventing the dome from deflating. It also stops light pollution from seeping in and disrupting a show and is optimized for wheelchair access.

Another key improvement was the replacement of the standard shiny white finish, common with previous domes, with a dull gray microsurface. The new surface absorbed sound better and also minimized the reflections caused by the wrinkles in the fabric. "If all you're doing is projecting stars, it doesn't bother you that the reflection



With funding from NASA's Earth System Information Partners program, Rice University and the Houston Museum of Natural Science developed the country's first digital planetarium. Here, a fisheye lens photo shows students at the Houston museum watching *Lucy's Cradle*, a digital show about human origins in the East African Rift Valley.



NASA awarded grants under its Research, Education, and Applications Solutions Network, or REASoN program, to Rice University and the Houston Museum of Natural Science to develop the world's first portable digital planetarium, which would be called Discovery Dome, along with new educational shows. As a result, Museums Teaching Planet Earth, or MTPE, was created to sell and rent the domes to schools and other organizations.

surface is wrinkled,” Reiff says. “All it does is make the stars seem to twinkle. But if you try to show a movie that has bright scenes, you can see every single wrinkle on the inside of the dome.”

The movies Reiff is referring to are the new shows that were produced as part of the third agreement with NASA. Among the many titles are: *Earth's Wild Ride*, which imagines life in a lunar colony; *Dinosaur Prophecy*, which offers a glimpse at how dinosaurs throughout time lived and died; and *Impact Earth*, which explains the birth of the solar system, the origin of asteroids, and the surface features of Mars. *Force Five* was also rendered in high resolution. Also developed was a software package called *Media Show*, which plays not only the movies created through the NASA agreement but also traditional movies.

### Benefits

In 2005 the efforts undertaken by Rice University and the Houston Museum of Natural Science were realized when MTPE put the portable planetarium, Discovery Dome, on the market both for purchase and as a rental service. The venture has been an unqualified success, doubling its sales revenue every year from 2005 to 2008 and maintaining solid numbers since then, having sold 200 installations in 33 states and 33 countries. “We’ve had \$6 million worth of sales,” Reiff says, “which is more than a dollar-for-dollar payoff of NASA’s original investment. And it has not only fostered our company but also several of the vendor companies that we work with.”

Sumners, who is also vice president for astronomy and the physical sciences at the Houston Museum of Natural Science, notes that the space agency’s seed funding for the digital planetarium has also had a lasting impact on the educational institution. She says, “The spinoff for the museum is the creation of self-sustaining venues for exposing the public and students to astronomy and space flight.”

For Reiff, seeing the number children who have benefited from the technology has also been gratifying. She

now estimates that 70,000 children every year in Houston alone experience their shows in portable domes, which are often set up in school gyms. Educational outreach of that magnitude, she says, is made possible by affordability. “The average cost per child is a dollar and a half,” notes Reiff, “and children don’t have to miss their other classes or free lunches or get permission slips, and they don’t have to pay for big buses, which also reduces the school’s carbon footprint. Those are all things that I love about what we’ve been able to accomplish.”

MTPE continues to improve its product line in many ways, such as using technology that allows mirrors to reflect images for the dome instead of the more expensive fisheye lenses. The catalogue of shows also continues to expand. One of them is *We Choose Space!*, which is funded by another NASA education program and includes images taken on the International Space Station with the company’s lens. The latest show produced under the program, *The Great Planet Adventures*, allows visitors to experience living in low gravity on the various bodies of the solar system. For those who can’t make it to a dome viewing, all the shows may be watched free on the ePlanetarium YouTube channel. Scripts, posters and activities are also available for download at no charge from the website.

Part of what keeps Reiff inspired and on the cutting edge of innovation can be explained through a personal story. As a seven-year-old Brownie scout, Reiff went on a father-daughter trip to the Oklahoma City Planetarium, where she became hooked on the stars immediately. “I’ve always appreciated how that planetarium opened my eyes to the rest of the universe,” she says, “and that’s one of the reasons why I’ve always wanted to give back to planetariums things that they can use to help inspire future generations of scientists.” ❖



*The Great Planet Adventures* is a new program available for use on Discovery Dome. The program shows viewers what it would be like to explore planets that have low gravities.



# Schedule Analysis Software Saves Time for Project Planners

## NASA Technology

Schedules for major projects get long and complicated, involving a slew of interdependent tasks and timelines, and few organizations handle projects more complicated than NASA's.

When Jimmy Black joined a technical resource management team at Marshall Space Flight Center in 2003, finding a discrepancy in a schedule could mean hours or even days of tedious searching.

"When we used to have to analyze a schedule, you had to go through line by line, and a lot of these have thousands of lines," he says. "We finally realized, there's got to be a better way of doing this."

He and others on the team, responsible for performance analysis and assessment of programs and

projects at the center, already had a rudimentary set of filters to pull up and organize information in Microsoft Project, the primary software application NASA uses to develop and manage spacecraft build schedules. They came up with a list of common scheduling mistakes and programmed the filters to identify them, and they automated the filters to run simultaneously and pull up reports.

"This makes it a whole lot easier," Black says. "You know where to go and what to zero in on."

What once may have taken days now takes just a few minutes, he says.

However, the Microsoft Project add-on, now known as the Schedule Test and Assessment Tool (STAT) suite, was not born whole. The early version consisted of a single module that ran

a basic "health check" on a schedule, determining how well a project is meeting its objectives and adhering to established scheduling best practices.

That later expanded to three modules and then, a few years ago, to six. In addition to the basic health check, the current software can produce a summary report for the project manager, including any performance issues or scheduling errors, as well as a less technical summary for executive-level managers, who "don't want to get into the details and don't understand them," as Black puts it.

It can also show how many activities have been completed and how many are left to meet, and it allows the project manager to choose an endpoint and trace the "logic" behind it—the flow of various tasks that lead up to it. And it gives the scheduler the ability to add a cushion or reserve of time and monitor the reserve's depletion over time. It can also compare a current schedule with a previous version and show any changes.

## Technology Transfer

Like more than 1,000 software codes developed by NASA, STAT is offered for public release at no cost, although this particular suite is available for US release only.

"It's one of our top-requested codes each year," says Danny Garcia, Marshall's software release authority. "Sure, it works well in rocket design, but STAT has more general applications than that. It offers the tools schedulers need in order to make a good schedule."

Since it became available in 2009, the suite has been released to more than 200 companies, government agencies, universities, and other entities, and it is saving all of them money by saving them time, Garcia says.

He notes that the public might be surprised by how many of the technologies developed by NASA have a software component and how much of that software is licensed for free. "Software forms a good one-third of our technology transfer program."

Contractors planning the construction of NASA's Orion Multi-Purpose Crew Vehicle are using the Schedule Test and Assessment Tool developed at Marshall Space Flight Center to help them project and meet deadlines such as the spacecraft's first test flight in 2014 and its first mission in 2017.



## Benefits

Linda Milam of Tecolote Research Inc., a subcontractor and the principal analyst for the Orion Multi-Purpose Crew Vehicle project at Johnson Space Center, uses the analogy of building a house—first, there’s digging, then the foundation has to be laid and the plumbing and electrical hook-ups installed before wall construction can begin. The roof comes later.

“There’s a certain order things need to be done in, and if you do them out of order, your house isn’t going to stand up straight,” she says.

Schedulers prefer that a schedule be held together by the relationship of each task to the ones before and after it, rather than pinned to specific calendar dates, Milam says. “There are several ways you can do that, and the STAT tool helps you pick the best way.”

The software also identifies tasks that haven’t been designated as flowing from or to another job and finds other errors in logic, and it advises the planner when a scheduled workflow has fallen far enough behind that it should be updated or re-planned, Milam says. Goals for specific dates are sometimes necessary, and STAT lets the manager know if those are realistic or become unattainable, she adds.

James Perry has been using STAT since its early days, but he’s worked in planning and scheduling since the 1990s and remembers having to manually write out long, detailed spreadsheets. Now, he says, STAT can generate a multi-tab Excel notebook with a summary sheet, a count of activities, and lists of potential errors, such as milestones without predecessors.

“It’s mainly helpful to schedulers, but it also gives verification to your boss that you know what you’re doing and the things you’re doing are correct,” says Perry, a contractor through Lanham, Maryland-based Vantage Systems Inc. and the lead program planner and scheduler for the Geostationary Operational Environmental



The contractor planning the construction of the Geostationary Operational Environmental Satellites-R Series, better known as GOES-R—shown here under construction at NASA’s Goddard Space Flight Center—is among those who use the Schedule Test and Assessment Tool software add-on to help verify the integrity of the project schedule. The first of these Earth-observing satellites is scheduled for launch in 2015.

Satellite-R (GOES-R) program, one of NASA’s largest current programs.

The schedule for just one of its projects—the ground system—has about 60,000 tasks and milestones, he says. “So you can see why a tool like this is very helpful.”

During the review of schedules built by outside organizations that have contracts with the program, he says, the software helps by providing a list of “nonstandard uses” that should be scrutinized. “You can just send the output to the vendor and say, ‘Here’s where there’s a problem. Can you address this?’”

For internal schedules, STAT helps to demonstrate compliance with NASA and Government Accountability Office requirements, Perry says. “It’s very specific. It saves a lot of time.”

Since the birth of the STAT suite, a number of companies have created similar schedule-analysis software, although Black says many of those tend to complicate reports by offering the user more information than necessary.

He says members of his team are considering the possibility of expanding the code to make it compatible with project management software other than Microsoft Project when they have the resources.

“I think it’s made an impact,” he says. “And it caused other people to create some tools to do some of these things.” ❖



# Sound Modeling Simplifies Vehicle Noise Management

## NASA Technology

Exposure to a noise level of 105 decibels causes hearing damage after an hour or less. Concertgoers in the front row at a rock show can expect sustained noise of about 120 decibels. The sound of a lightning strike, up close, is 165 to 180 decibels. This is around the level that NASA acoustical engineers have to worry about, as rocket components during liftoff are exposed to sound levels up to about 170 decibels a blast so intense it could destroy the rocket or damage payloads if not properly managed.

Virtually no one but rocket scientists works to manage sustained acoustic levels of this magnitude.

While NASA has a clear interest in noise management, so do many commercial industries, such as car manufacturers and airplane builders, albeit at lower noise levels, and NASA often works with the aeronautics industry to develop efficient methods of noise management. An important part of this work is using computer software to predict and understand noise and vibrations.

Acoustical engineers generally use different analysis methods to predict noise and vibrations at different frequencies. One technique that simplifies modeling high-frequency noise and vibration was pioneered with NASA funding and is now in use by auto manufacturers and even found an application in locating hard-to-find leaks in the International Space Station (ISS).

To predict sound behavior at frequencies up to a few hundred hertz, engineers use what is called finite element analysis (FEA), explains Randolph Cabell, assistant head of the Structural Acoustics Branch at Langley Research Center. The method relies on a computer model of the structure in question, represented as a set of elements interconnected at nodes and assigned various properties, such as thickness, density, modulus of elasticity, and others.

Applying an FEA model, researchers can predict how relatively low-frequency sound or vibrations will travel in

and around the structure, Cabell says. “If you want to make it quiet, you want to know how energy is moving around a structure so you know how to stop it.”

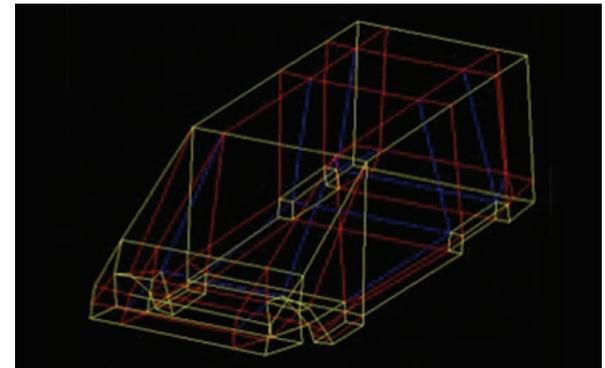
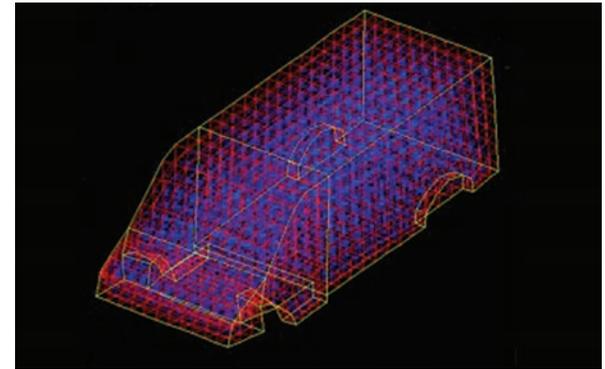
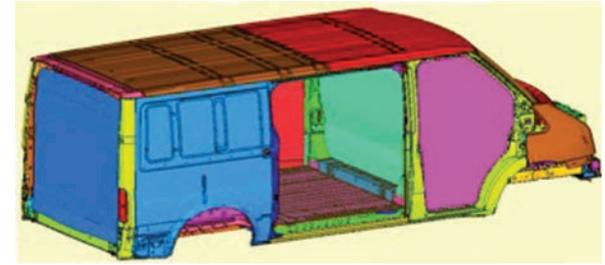
However, an FEA model requires a certain number of elements per wavelength, and as wavelengths get smaller at higher frequencies, the elements become so tiny and so numerous that conventional FEA becomes cumbersome, especially for a structure the size of an airplane, he says. Minute details such as fastener locations, the tightness of rivets or the number of coats of paint become significant for accurate sound and vibration prediction.

This is why acoustical engineers use a different method called statistical energy analysis (SEA) to predict high-frequency noise and vibrations. SEA uses a simpler model than FEA, with the vehicle's structure and interior cabin divided into a few large regions, but still provides practical information for understanding and reducing noise and vibrations. However, Cabell says, the accuracy of the SEA model depends on the user intelligently dividing the structure into analysis regions. More importantly, while aircraft designers often work with FEA, they don't use SEA, so it is up to the acoustical engineer to modify the SEA model each time the designers change the airplane design. This increases the workload and introduces possibilities for error in the acoustical analysis.

Despite this downside to SEA, no other method existed for predicting high-frequency sound behavior.

## Technology Transfer

In 2004 and 2005, NASA awarded Phase I and II Small Business Innovation Research (SBIR) contracts to Ann Arbor, Michigan-based Comet Technology Corporation (CTC), which was developing a way to eliminate the need to build two models. The company's chief technology officer, Ravi Raveendra, had proposed software that would enable energy finite element analysis—a method that would provide a unified framework for analysis of both low- and high-frequency noise.



Software for sound modeling using traditional finite element analysis (FEA) relies on a highly detailed computer model of the structure being analyzed, like the one at top. To predict the behavior of higher-frequency sound using statistical energy analysis, engineers have had to create another, coarser computer model. Comet EnFlow software eliminates that step by building less refined models, such as the lower two, based on the FEA model.

The company had just split from now-defunct Automated Analysis Corporation, where it had been developing vibroacoustics software since 1993.

“We thought it would be good if we could extend what we’d done for low-frequency to develop a method for high-frequency,” Raveendra says. “Most of the time, the customer’s not interested in the low-frequency area alone.”

The result of that NASA funding—Comet EnFlow software—went on the market in the late 2000s and has succeeded in eliminating the need for two models.

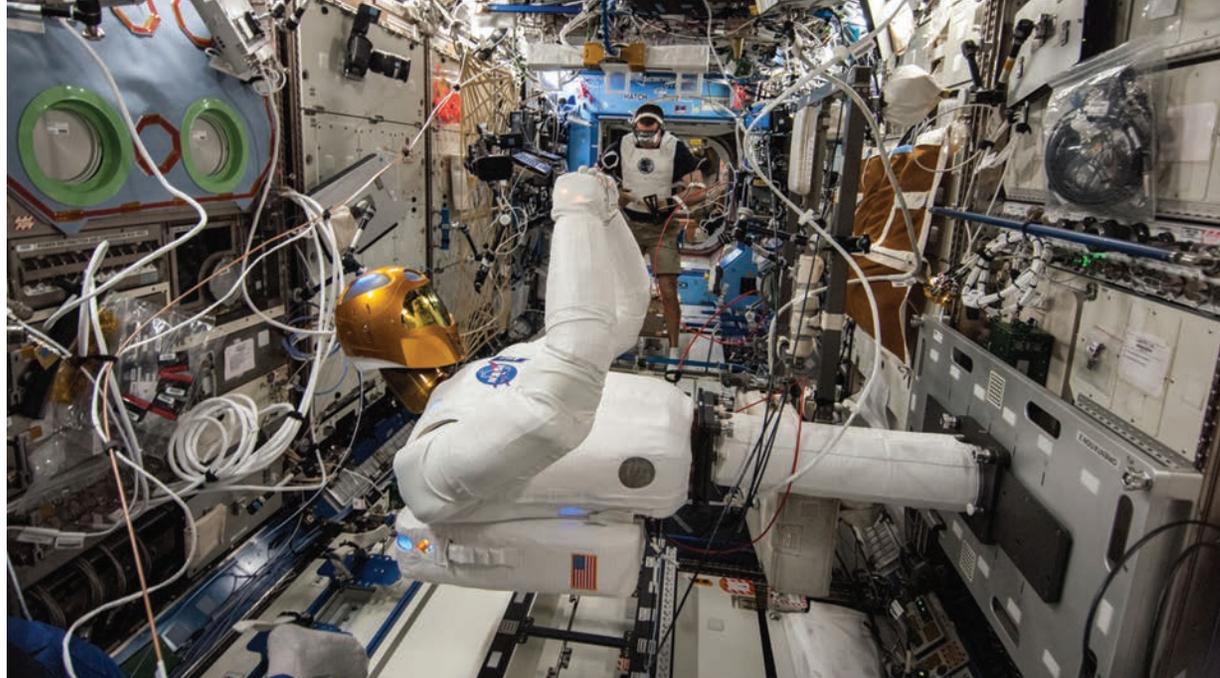
“EnFlow lets you do high-frequency analysis on the grid you used for low-frequency analysis,” Cabell says, explaining that the software takes the original model used for low-frequency FEA and creates an accurate but coarser model for predicting high-frequency sound and vibration. “It can read the node locations and parts that make up each element in that model so you don’t have to recreate it, and it will run the high-frequency analysis from that FEA model.”

## Benefits

Raveendra markets the software to automobile and aircraft manufacturers, some of whom have purchased it, and he says CTC has received interest from the consumer product industry and ship builders as well. Using this NASA-funded technology, these companies are able to achieve the cost savings and quality improvement that come with early-stage noise modeling while saving the time and money it takes to create new computer models for use in the SEA method.

In addition to being evaluated by NASA’s Structural Acoustics Branch, EnFlow also found an unexpected use in the Nondestructive Evaluation Sciences (NDES) Branch, also at Langley.

About 10 years ago, NASA’s Structures and Mechanisms systems manager for the ISS approached Eric Madaras, senior physicist with the NDES Branch, looking for ideas for a way to rapidly detect any leak in



NASA’s Robonaut works in the US Destiny Laboratory module of the International Space Station (ISS). Finding a pressure-wall leak with a handheld leak detector is a challenge in the ISS, where the interior walls are covered in storage and equipment. The agency found an unexpected use for Comet EnFlow software in detecting leaks with a series of sound sensors on the walls of the Destiny module.

the space station’s pressure walls. These can be caused by micrometeoroids or satellite debris. Astronauts on the ISS have a handheld ultrasonic leak detector, but it can only find an exposed leak. This limitation is problematic in a structure whose walls are often covered with stowage and equipment, Madaras says.

“Being able to have someone tell them, ‘it’s behind a rack on the portside, four racks down’—that’s a big help,” he says.

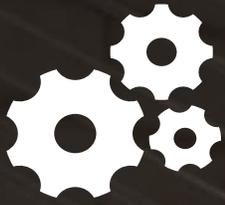
He dropped in on Cabell, who often works with the same sort of technologies Madaras uses, and learned of EnFlow, which was still in development. Since the software was being designed to analyze a structure’s vibro-acoustic field and predict energy flow, he thought it could be coupled with sensors to pinpoint the sound of a leak. And because it works with high frequencies, it could calculate for a leak in the ultrasonic range, where there is much less background noise. Most noise on the ISS is in the acoustic range, while a leak is “pretty efficient at producing sound in the ultrasonic range,” Madaras says.

He bought the software package in 2009, had the pressure walls of the US lab module outfitted with sensors and found that he was able to use Enflow to pinpoint direct, ultrasonic vibrations from equipment in the module. As a result, he says, “Our recommendation to senior management will be that they should outfit all permanent modules on the ISS with this technology.”

Raveendra said he hadn’t known his product was capable of leak detection until Madaras approached him. “We never thought about it,” he says, adding that he is in the process of making some modifications to EnFlow to market it not only for sound behavior prediction but also for ultrasonic leak detection, which is an area many companies have an interest in.

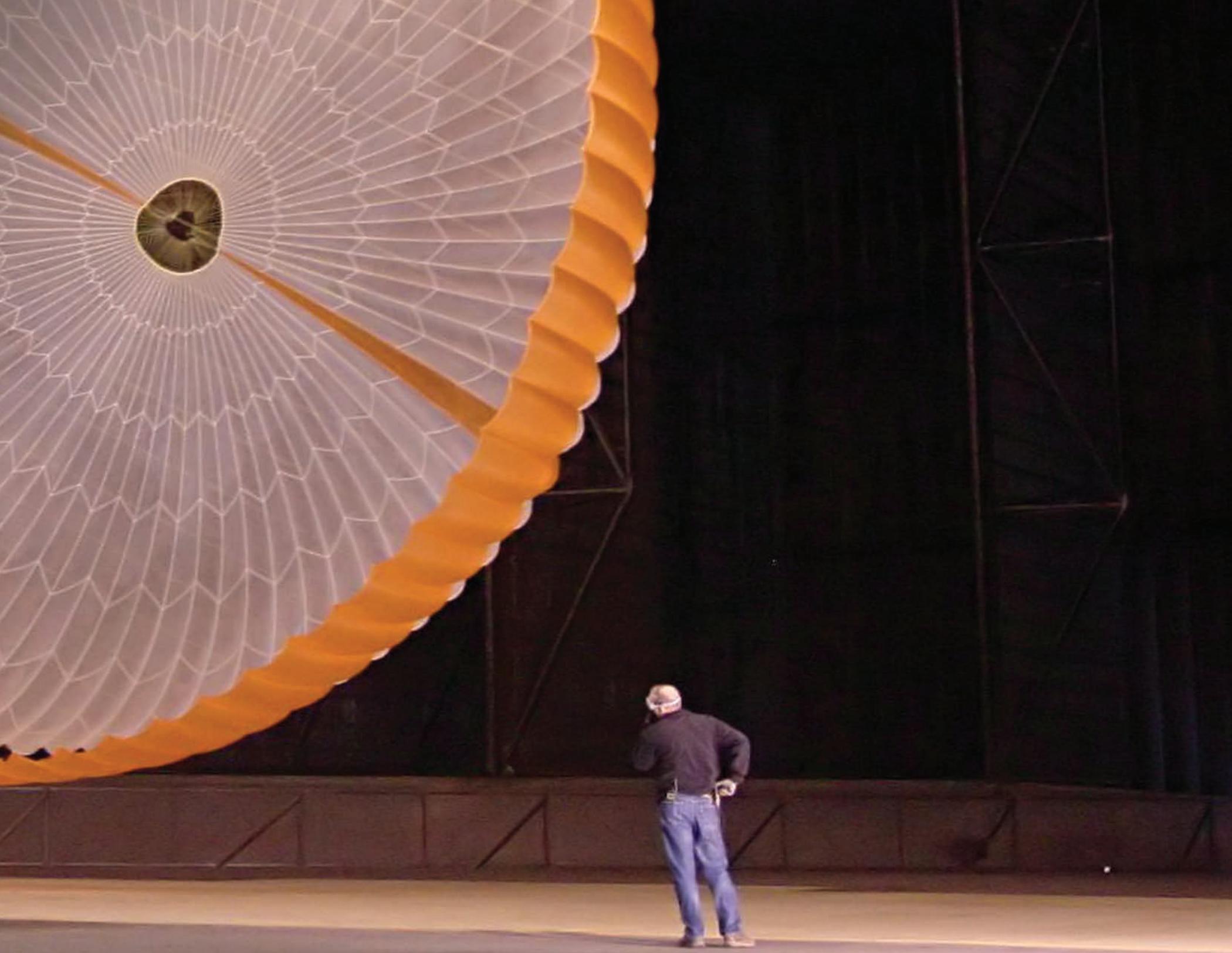
He adds that he probably couldn’t credibly repurpose the software without NASA’s experimentation to prove its effectiveness in a totally different function. “This is an application we’ll expand,” he says. “We needed that experimental work to validate what is possible with this software.” ❖





# Industrial Productivity

**B**ecause NASA often pushes the limits of technology in attempting to do what no one has done before, the agency has pioneered a wide variety of industrial innovations, many of which are just as useful to commercial manufacturers as they are in building rockets or developing space-rated electronics. These can be new alloys and lubricants, technology for mass-producing unbelievably tiny parts, large-scale camera calibrators, and more.



# Custom 3D Printers Revolutionize Space Supply Chain

## NASA Technology

Like a desert caravan, a space flight crew has to bring with it everything it will need over the course of its journey into an utterly barren environment. This has always meant allotting room for every gyroscope or astrolabe, every LED housing or oil lamp. In space travel, not only is payload capacity at a premium, but these objects also must be made to withstand the g-force and jarring vibrations of liftoff.

All of that is about to change.

In January of 2015, aboard the International Space Station (ISS), Made In Space Inc. and NASA's Marshall Space Flight Center plan to carry out the first additive manufacturing technology demonstration performed in space, using a customized 3D printer that the company developed over the previous three years with NASA support through the Small Business Innovation Research (SBIR) program.

"No one's ever done this before, where supplies are actually created in space," says Niki Werkheiser, NASA's project manager for the 3D Printing in Zero-G Technology Demonstration.

"You've got to imagine how cool this is," she says, noting that the biggest constraint on a space mission's distance and duration is the limit to what can be carried and the lack of a supply chain, making in-space manufacturing a necessity for any manned, interplanetary exploration. "We're using the space station as a test bed to test the technology we know we'll need on exploration missions. We'll absolutely need this."

That was just what the founders of Made In Space, located at Ames Research Center in Moffett Field, California, had in mind when they started the company in 2010 after meeting at Singularity University, also located at Ames, says Made In Space spokesman Grant Lowery. "We saw the supply chain as the biggest problem facing space travelers," he says. "With the rise of the commercial space industry, there's going to be a growing demand for



Made In Space Chief Strategy Officer Mike Chen, left, and Chief Technology Officer Jason Dunn test the company's prototype for a space-ready 3D printer in simulated microgravity aboard Zero G Corporation's modified Boeing 727 in 2013.



In the Made In Space “clean room,” Chief Technology Officer Jason Dunn pulls a sample part from the company’s prototype for a 3D printer that can operate in microgravity, as lead engineer and director of research and development Michael Snyder looks on.

the ability to manufacture out there. We think it will save time, money, and logistical difficulty.”

In 2011, through NASA’s Flight Opportunities Program, the company tested several existing 3D printers in simulated microgravity aboard Zero-G Corporation’s modified Boeing 727 and found them to be ill-suited to a weightless environment.

“Everything on Earth is built with gravity assumed,” Lowery says, explaining that the machines’ builders took for granted that certain parts would rest on others, for example.

Funded by an SBIR contract through Marshall, the Made In Space engineers set about building a model that was gravity-independent. It also had to be ruggedized to survive liftoff, and the builders couldn’t allow for any off-

gassing that would contaminate a hermetic atmosphere such as that found onboard the ISS. Machinery for use in space also has to take into account a lack of natural convection due to the lack of gravity, meaning air has to be forced to circulate.

“Those are some of the areas where NASA was able to provide some insight,” Werkheiser says.

“We’ve benefitted from the partnership, and they’ve been wonderful in offering their expertise,” Lowery says of the NASA team the company has worked with.

### Technology Transfer

In early 2013, Made In Space was awarded a Phase II SBIR to develop a commercial model to be permanently installed aboard the ISS, as well as a separate Phase III



contract to build the prototype that was tested aboard the space station in 2014. The prototype was first tested aboard Zero G's plane, which flies in parabolic arcs to create intervals of weightlessness, but these periods were too short to adequately prove the printer's effectiveness in consistent microgravity.

That problem is being addressed by flying the prototype, about the size of a small microwave, to the ISS for a demonstration in space. There, it will create more than 30 objects, including calibration coupons and tools such as a crowfoot wrench. Most will be based on files loaded on the machine before launch, but others will be uploaded to the printer from Earth while it is in orbit.

NASA has already identified a list of tools, parts, and other objects that are commonly lost or broken on the space station, including structural items, torque tools, containers, clips, and many others, from the crucial and complicated to the mundane. Lowery says crewmembers told the company one simple set of objects often in demand aboard the station is silverware.

"The crew gets really excited about this," Werkheiser says, noting that astronauts often have to wait months for simple parts that could be printed in a matter of minutes.

Lowery says a NASA study estimated the device would be able to print about 30 percent of the small parts and tools aboard the space station, and Werkheiser noted that even large items could be designed as a set of smaller parts that fit together.

The prototype prints objects from acrylonitrile butadiene styrene plastic, the same material that standard LEGO blocks are made of. Its successor, which will be slightly larger, will print with a variety of materials, and Werkheiser says NASA would eventually like a machine that can print metal parts. She says the team is also working on the capability to convert printed products back into the feedstock, essentially recycling the printer's output.

Lowery points out that with a 3D printer, the Apollo 13 crew could have easily recreated the carbon dioxide



The prototype for a 3D printer capable of operating in microgravity, created by Made In Space with the help of a couple of Small Business Innovation Research contracts with NASA's Marshall Space Flight Center, is slightly smaller than the one the company will create for installation aboard the International Space Station.

scrubber they needed, rather than adapting an ill-fitted scrubber with spacesuit hose and duct tape. “Now you can actually custom-make the part or piece or tool you need,” he says.

## Benefits

Under the agreement for use of the commercial 3D printer on the ISS, Made In Space will own the machine, and NASA will be a customer paying to use it. “We want commercial companies to make the things we need,” Werkheiser says.

However, she says NASA will be far from the only customer. “It’s actually a business in space.”

Much like NanoRacks, the company that built and owns 36 modular laboratories aboard the ISS and counts NASA and a host of other entities, including universities, foreign space agencies, and private companies, among its paying customers (*Spinoff* 2012), Made In Space expects broad appeal to the idea of manufacturing products in space. Indeed, NanoRacks’ chief technology officer has been an advisor to the Made In Space team, and the final printer will be located with the NanoRacks equipment in the station’s US lab.

With the ability to upload design specifications to the printer from Earth, customers “can essentially email their hardware to space,” Lowery says.

“We’re just trying to wake people up to the range of possibilities that exist because of this capability,” he says, adding that even the company isn’t sure exactly how wide that scope might turn out to be, in terms of commercial and research possibilities.

Lowery says Made In Space has already spoken with a number of companies, universities, government agencies, and even artists who are interested in the ability to easily create objects in space and even launch them into low orbit from the ISS.

A major application of the technology, as Lowery sees it, will be the creation and deployment of nanosatellites—little shells around four inches in diameter that can carry

any number of technologies or experiments. “You could print the satellite in a matter of hours, slip an electronics board into it, toss it outside the space station, and you’ve got a satellite,” he says.

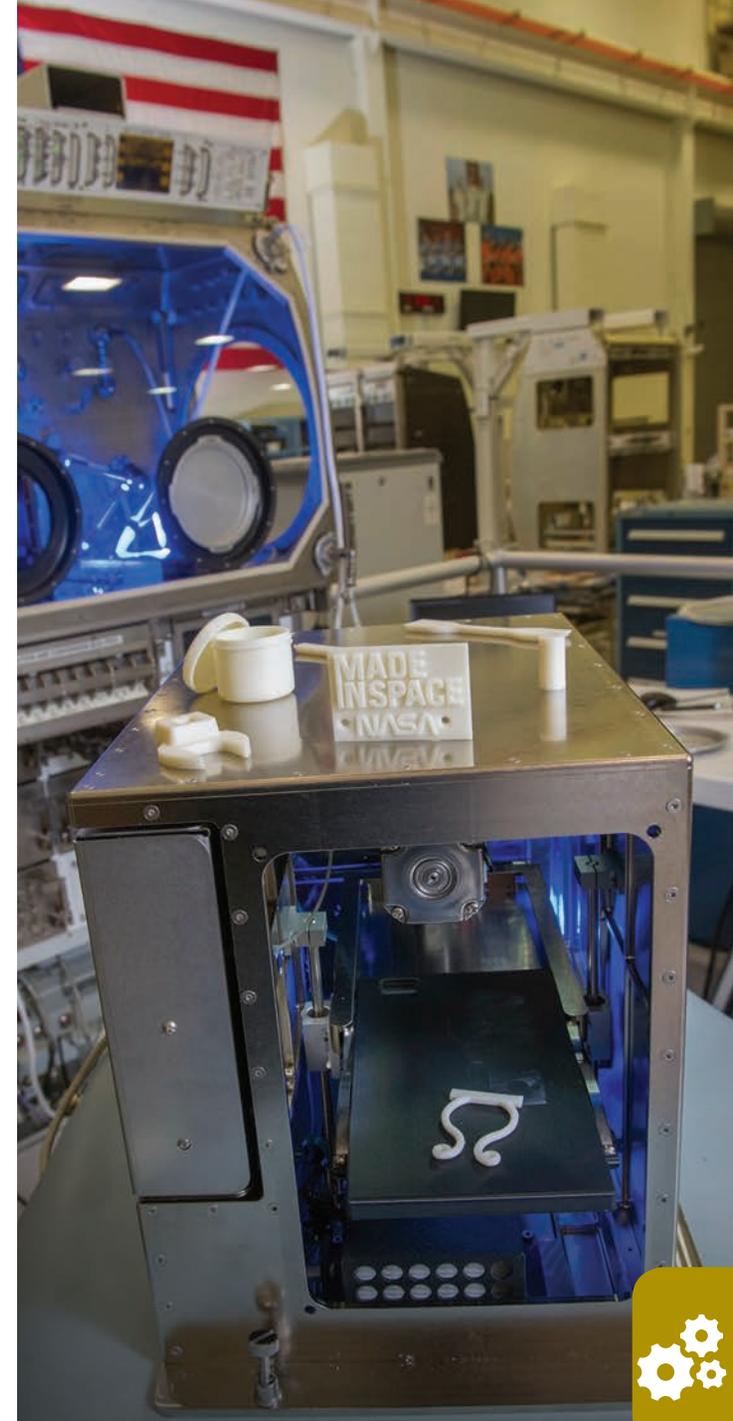
NanoRacks already has a system for nanosatellite deployment from the space station and has flown scores of the little packages into space on various rocket launches. NASA’s CubeSat Launch Initiative has helped to find room in rocket payloads for nanosatellites being used by a variety of entities for research and educational purposes.

The company’s 3D printer could drastically alter the CubeSat initiative. While the satellites’ cargo often would still have to be physically transported into space, payload logistics and size limits would present far fewer constraints.

Werkheiser notes that nanosatellites are already being made with 3D printing on the ground and are becoming widely used for defense, communications, education, research, and other applications. “I really think it’s going to be a big business,” she says.

She says the technology will also find uses on Earth, and military services have already expressed interest in a 3D printer capable of micro-precision in its output, ruggedized to withstand physical hardship, and built to meet the highest safety ratings. A durable, reliable 3D printer would be especially useful in a submarine, in the desert or “anyplace where you’re in a remote area and you’re dependent on the parts you have with you,” Werkheiser says.

She says this technology, which will make remote areas more habitable on Earth and in space, for astronauts and for others, and this partnership are prime examples of what can come from cooperation between NASA and the business community. “The SBIR process has been excellent for leveraging the capabilities of small companies to meet NASA’s objectives, and we can’t wait to see what comes next.” ❖



Made In Space’s prototype for a space-ready 3D printer is shown with some of the products the final model might produce aboard the International Space Station.

# Improved Calibration Shows Images' True Colors

## NASA Technology

In satellite images, the waters of the Pearl River, which winds around NASA's Stennis Space Center, are about the same brownish green typical of waterways the world over. It's easy to tell, for example, that the water in the center's small, round reservoir is much darker. Odds are, though, that these images do not capture the precise, true color of either body of water, or anything else they depict.

Radiometric calibration, which improves the color accuracy of an image and enables it to be used to solve remote sensing problems, has always been a costly endeavor. A cooperative effort between Stennis and Innovative Imaging and Research Corporation (I2R), a small business located on the center's campus in southern Mississippi, is changing that.

"What's only been possible in a comprehensive radiometric calibration facility, now anyone can do," says Tom Stanley, who manages the Small Business Innovation

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“What's only been possible in a comprehensive radiometric calibration facility, now anyone can do.”

— Tom Stanley, Stennis Space Center

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Research (SBIR) and Small Business Technology Transfer (STTR) programs at Stennis.

This is because I2R has built a better—and more efficient, and cheaper—integrating sphere.

An integrating sphere is a hollow globe whose internal surface is coated with a highly reflective white coating that diffuses light equally in all directions. The result is a

uniform glow with no discernable features, which, Stanley says, “gives you a disorienting feeling looking into it.”

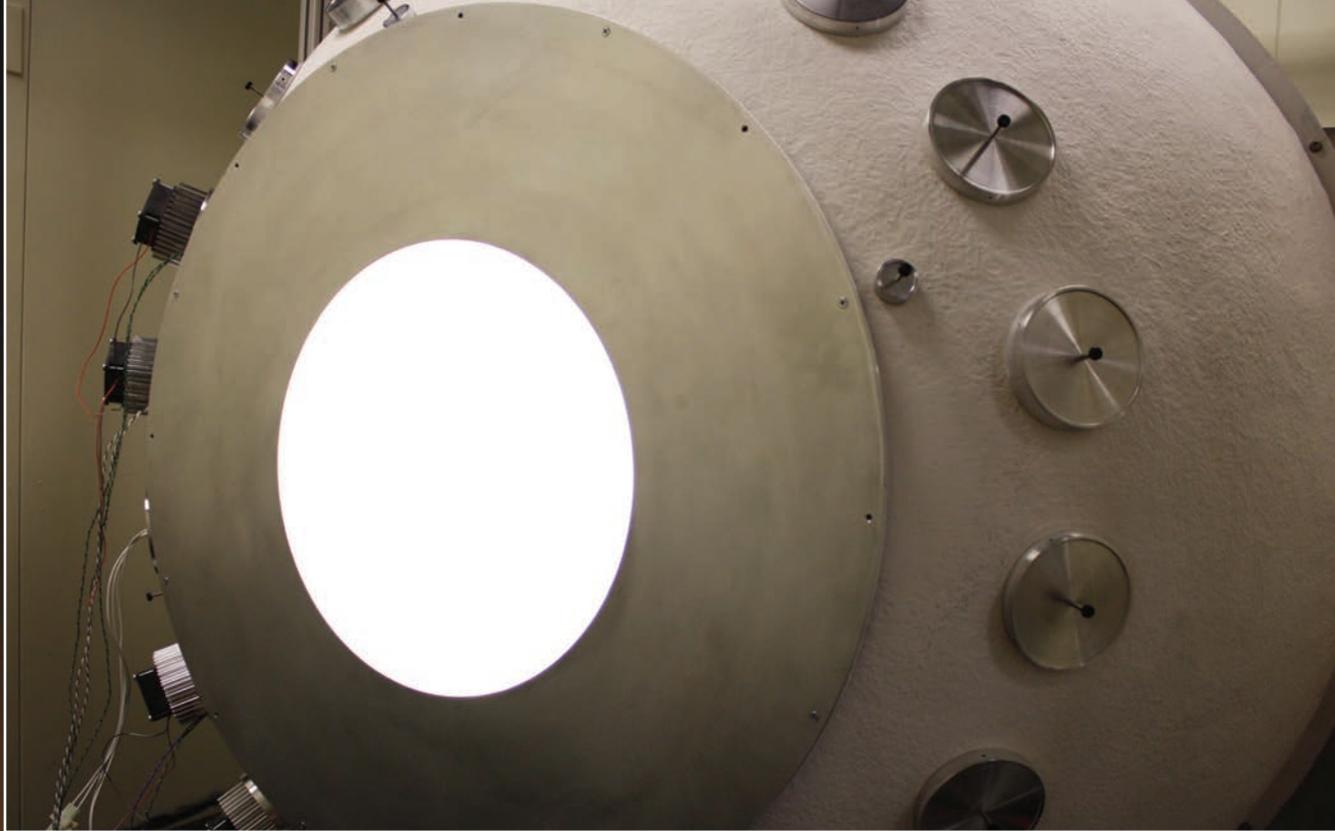
It's this blank uniformity that allows the operator to know that when a camera looks into the sphere, precisely the same wavelengths of light are hitting every pixel in the camera's focal plane with equal intensity. Then, the sensitivity of each of the individual photodetectors in the camera is adjusted until the resulting image reproduces the constant field of light in the integrating sphere.

Integrating spheres have normally been lit using tungsten halogen lamps, often paired with plasma arc lamps to simulate solar illumination, which is important for accurate radiometric calibration. The problem is that lighting a large sphere with this approach requires an inordinate amount of energy and large, expensive power supplies.

The construction of the spheres has also been costly, Stanley says. “The big spheres are tens of thousands of

One of NASA's applications for radiometrically calibrated cameras is “plume diagnostics”—using imaging to monitor propulsion tests, such as this test firing of Aerojet's AJ26 engine No. 8 at Stennis Space Center.





Large integrating spheres, used to calibrate entire arrays of cameras at once, have historically been almost prohibitively expensive to build and power. Innovative Imaging and Research Corporation (I2R) was able to affordably create and illuminate this massive, one-and-a-half-meter sphere by using LEDs instead of tungsten halogen and plasma arc lamps, making it from fiberglass instead of spun-cast aluminum, and making their own reflective paint.

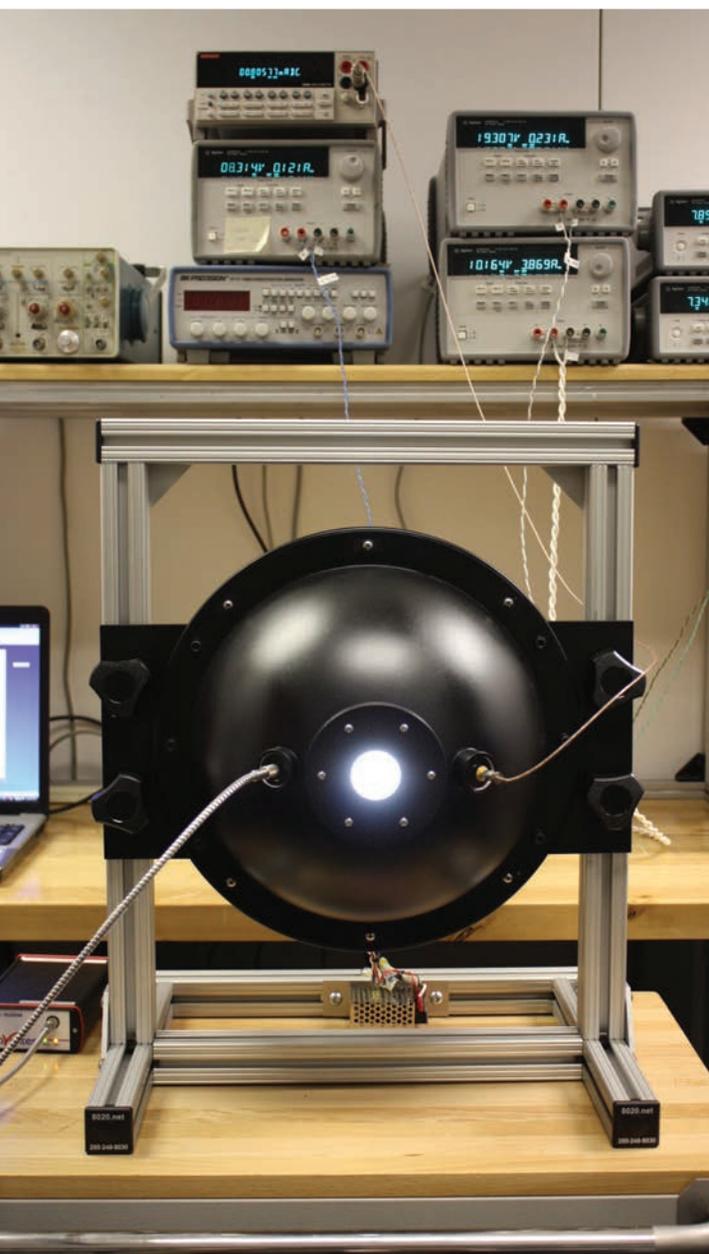
dollars, and a sphere that's a meter or more in diameter can cost more than \$100,000.”

However, having a large integrating sphere can pay off when calibrating complex camera arrangements, such as those used for aerial mapping. These can have multiple camera modules, each providing different colors or increasing the coverage area. To calibrate them all at once, the sphere might need a port 400 millimeters (about 16 inches) across or larger for the camera assembly to look through. But the bigger the port, the larger the sphere has to be, or the light inside will lose its uniformity.

One option is to take the camera arrangement apart, calibrate one camera module at a time, and then reassemble it. However, Stanley says, this is time-consuming and requires a follow-up geometric calibration to make sure the reassembled lenses all line up correctly. “You save yourself a whole bunch of money on the back end by not having to disassemble and reassemble and recalibrate,” he says.

Another complication with traditional integrating spheres is that tungsten halogen and plasma arc lamps degrade relatively quickly over time, which becomes a





I2R built this small integrating sphere, used to calibrate cameras, for sale to a commercial company. Using LEDs, the company was able to accurately and affordably reproduce the wavelengths of solar light for proper calibration.

bigger problem when the bulb can't be replaced because it's orbiting Earth on a satellite. And plasma arc lamps produce occasional spikes in their spectral output, which become more pronounced with time.

### Technology Transfer

Mary Pagnutti, president and owner of I2R, was a support contractor at NASA when Stennis experimented with light-emitting diodes (LEDs) to illuminate an integrating sphere in 2007. Because they lose far less energy through heat than most other lighting sources, LEDs are much more energy-efficient. They are also more stable and longer-lived than the competition, with a lifespan of about 100,000 hours—more than 10 times that of traditional lamps—when operated at normal currents. However, the project lay dormant until Pagnutti and her business partner, Robert Ryan, approached the center in 2012 with a proposal to build a low-cost integrating sphere.

The use of LEDs also had another advantage, besides lower cost.

"We investigated using high-power LEDs and put them in such an arrangement that we could simulate the solar spectrum," Pagnutti says.

"They can essentially create whatever color they want within the sphere," Stanley confirms.

Being able to simulate sunlight is important for accurate radiometric calibration. The light from a "white" LED, for example, actually has a high output in the blue spectral region and low outputs of green and yellow wavelengths. A camera calibrated with these white-light LEDs would not properly reproduce the colors found outdoors under natural sunlight.

Recognizing NASA's interest in affordable, high-fidelity calibration for everything from satellite imaging of Earth to astronomical observations and even "plume diagnostics"—using imaging to monitor propulsion tests—Stennis entered into a dual-use agreement with I2R, under which each party paid half the cost to develop the product.

Because color LEDs emit light in specific wavelengths within a narrow bandwidth, Pagnutti and Ryan were able to combine diodes of different colors and, by adjusting

the current input for each one, imitate sunlight or just about any other type of light. They developed a computer algorithm that automatically determines the current powering the different-colored LEDs based on their individual "spectral shapes" and that of the sunlight they should imitate as a whole. The program compares the actual output with the desired output and keeps readjusting until it gets it right.

Before summer of 2014, Pagnutti and Ryan had a functional integrating sphere a meter and a half in diameter, which operated on about one-fourth the energy that would be required to run a standard tungsten halogen-lit sphere of that size.

Pagnutti says this wouldn't have been possible just a few years ago. "People just couldn't do it before LEDs became bright enough and powerful enough."

By this time, I2R also had already sold a smaller solar-simulated calibration sphere to a Silicon Valley satellite start-up company for use in its constellation of small satellites and was in negotiation with a large aerial camera manufacturer to calibrate its cameras at the I2R facility.

I2R cut expenses in other ways, too. Rather than build their sphere of the usual spun-cast aluminum, they contracted a globe manufacturer to make it out of fiberglass. And instead of buying the specialized reflective paint off the shelf, which Pagnutti says is "wildly expensive," they made their own paint, seeding it with particulate matter to make it diffusely reflective. LEDs also cost considerably less than plasma arc lamps. In the end, she says, "I believe we can probably build it for around 25 percent of what they go for today—certainly less than half."

This savings in building the sphere was more a question of will than technological advance, she says. "Some of this has to do with a mentality, thinking this is the way people have always done it, so that's the way they continue to do it."

### Benefits

It's the savings in cost and energy that Stanley says is the most significant benefit of this new model for radiometric calibration.

"I think it's going to start putting a whole lot more fidelity in some of these commercial camera systems being



developed from off-the-shelf products,” he says. “It’s an industry-enabling technology.”

Now, he says, even many companies in the business of aerial imaging don’t calibrate properly. “Many don’t understand it, and it’s expensive, so they don’t do it.”

But proper radiometric calibration turns a camera into a scientific tool, Pagnutti says, explaining that in a calibrated camera, the digital number (DN) in each pixel can be assigned a reliable radiance value for each image. It becomes a measuring device. “You want more than a pretty picture. You want to know that DN value depicts a certain amount of radiance.”

When using digital satellite imagery to assess crop health or water resource management, for example, Stanley says, proper radiometry is essential. The same is true when using handheld units to determine the health of plants or human tissue. With the cost of calibration technology reduced, he says he foresees a day when cell phone cameras can become scientific instruments.

Indeed, NASA and I2R are already using the company’s integrating spheres to calibrate cell phone-grade imaging technology for use in monitoring indoor lighting under an STTR contract. This technology might be used on the International Space Station (ISS) one day. As the ISS has changed its lighting to LEDs, astronauts have found they have a harder time sleeping. Under the STTR, I2R will work to moderate lighting to either be conducive to sleep, or to induce focus or creative thinking—task-specific lighting, Stanley calls it—possibly to develop a lighting system for the space station.

He notes that three groups at Johnson Space Center were already keeping track of this LED lighting project before Pagnutti had even written her final report on the integrating sphere.

“One contract award doesn’t generally lead to a successful product,” he says, noting that I2R’s work seems to be an exception. ❖

Proper radiometric calibration is essential for satellite cameras used to monitor crop health, among other applications.



# Micromachined Parts Advance Medicine, Astrophysics, and More

## NASA Technology

Anyone who remembers the Micro Machines line of toys might be surprised to learn that the tiny model vehicles are positively gargantuan compared with actual micromachine manufacturing. While specimens of the miniature toy collection may indeed have been “smaller than a silver dollar,” some industrial micromachined parts compare similarly to the breadth of a human hair, which is around 75 microns.

For example, Potomac Photonics, a Baltimore-based company, might use a high-speed laser to drill a grid of 25,000 holes, each less than two microns across, through a steel surface with an accuracy of plus or minus 0.3 microns—and do it cheaply enough that the part can be considered disposable. “That’s pushing the limits in terms of machining capability,” says Mike Adelstein, the company’s president and CEO.

The company’s website is rife with photos in which looming pennies and dimes dwarf the intricate metal gears, microfluidic channels, and 3D-printed plastic parts it has produced.

Since its founding in 1982, the company has worked on a number of Small Business Innovation Research (SBIR) contracts with the Department of Defense, the National Science Foundation, and other agencies to develop technologies such as lasers and ultrasensitive detectors. However, Adelstein says it was a set of SBIR contracts with NASA’s Marshall Space Flight Center in the mid-1990s that was especially influential in putting the company on the cutting edge of micromachining, leading to the work it does today.

There were two objectives to the Phase I and II SBIR contracts awarded to the company. One was to prove the capability of excimer lasers in crafting intricate, diffractive optical elements—lenses etched with thin, micro-structure patterns that manipulate the light passing through them. These are used in a wide variety of applications, from sensors and monitoring equipment to fiber optics,

displays, and information storage. At the time, however, making these small-scale elements was time-consuming and hugely expensive.

While near-infrared lasers were commonly used to manufacture metal components, less was known about the use of excimer lasers, which operate in the deep ultraviolet range, to shape polymer and glass elements, such as lenses, Adelstein says. But the work proved the ultraviolet lasers were effective on these materials.

Then, the company wanted to develop an integrated, computerized workstation capable of mass-producing such optical components, using AutoCAD software to digitally control the process and make it faster, more flexible, and cheaper.

This 532-nanometer laser system is used for micromachining metal and silicon wafers.



“NASA certainly was interested, because they do a lot of work with lasers and light,” Adelstein says.

The work that Potomac Photonics carried out under NASA SBIRs ended up being a major breakthrough for the company, resulting in a workstation that allowed the user to custom-design diffractive optical elements and produce them cheaply and efficiently (*Spinoff* 1998).

## Technology Transfer

Although its work with NASA was geared toward manufacturing diffractive optics, the company found that the digital fabrication technology it had developed for the workstation was useful in all sorts of micromachining. And micromachining is, in fact, one common application



**“The work with NASA showed a different way of making these components and pushed the limits of the technology. It really set the tone for our direction in leading this field.”**

— Mike Adelstein,  
Potomac Photonics

Here, a grid of tiny holes has been drilled in stainless steel. Potomac Photonics can accurately place and drill holes as small as one micron, or a thousandth of a millimeter.

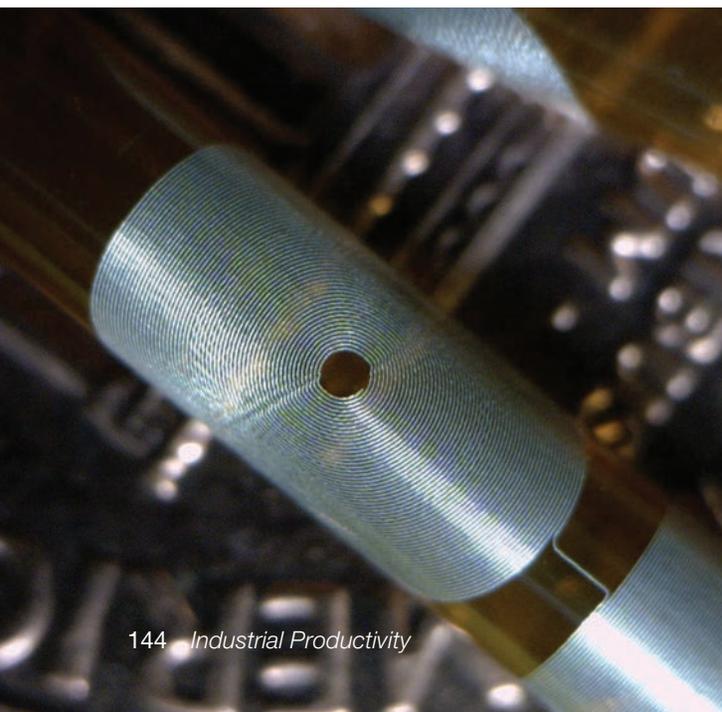


of the very diffractive lenses the workstations could now cheaply produce. These lenses allow optimized, precise laser cutting, drilling, and ablation—whereby a controlled amount of material is vaporized.

“It was that breakthrough that led to everything we do now,” Adelstein says of the work with NASA. “It showed a different way of making these components and pushed the limits of the technology. It really set the tone for our direction in leading this field.”

Over the years, he says, the company grew a contract manufacturing business, making tiny parts to order with quick turnaround times. Around 2008, the workstations were discontinued, and the company now focuses on “rapid contract micromanufacturing,” as Adelstein puts it, as well as continuing to develop new technologies to that end. The work ranges from microhole drilling and precise laser marking to hot embossing and 3D printing, working with metal, plastics, glass, ceramics, and silicon. Popular applications include medical devices, biotechnology manufacturing, and electronics, among others.

Software and laser technology have come a long way since the mid-1990s, and Adelstein says, in the company’s production line and in the world of modern technology, “everything’s gotten smaller, and everything’s gotten more precise.”



## Benefits

Potomac Photonics continues to work often with NASA as a supplier of parts and services. In the spring of 2014, the Center for Research and Exploration in Space Science and Technology (CRESST), formed by NASA, contracted the company to have laser markings inscribed on filter carriers for imaging systems on the ASTRO-H satellite being developed by the Japan Aerospace Exploration Agency, with participation from NASA and other space agencies.

“We needed some precision reference marks for which their laser system worked well,” says Meng Chiao, a research scientist with the University of Maryland Baltimore County, one of the institutions that comprise CRESST.

The satellite, scheduled for launch in 2015, will look for clues to the origins of the universe using several different imaging systems to observe X-ray and gamma ray activity around black holes and supernova remnants. To get a clear picture, the various telescopes and imagers must be precisely aligned, and the detector assembly team decided to accomplish this by putting reference marks on the rings of gold-plated aluminum that hold filters in the different instruments’ aperture assemblies. The marks can then be visually aligned, but they have to be placed with exact accuracy, as the slightest discrepancy would begin to take on a magnitude of light years as the imagers look deeper into space.

Chiao, who works closely with the X-ray calorimeter group in the Astrophysics Science Division at Goddard Space Flight Center, says Potomac Photonics came recommended to her by a colleague. “To my knowledge, they’re the only company with this laser marking system and with precision placement capability,” she says.

The company was able to turn the work around in less than 24 hours.

Here, silver nanoparticle conductive lines are embedded in Kapton tubing for use in a medical device.



This example demonstrates the company’s ability to laser micromachine polyethylene terephthalate, a thermoplastic polymer, at micron scale.

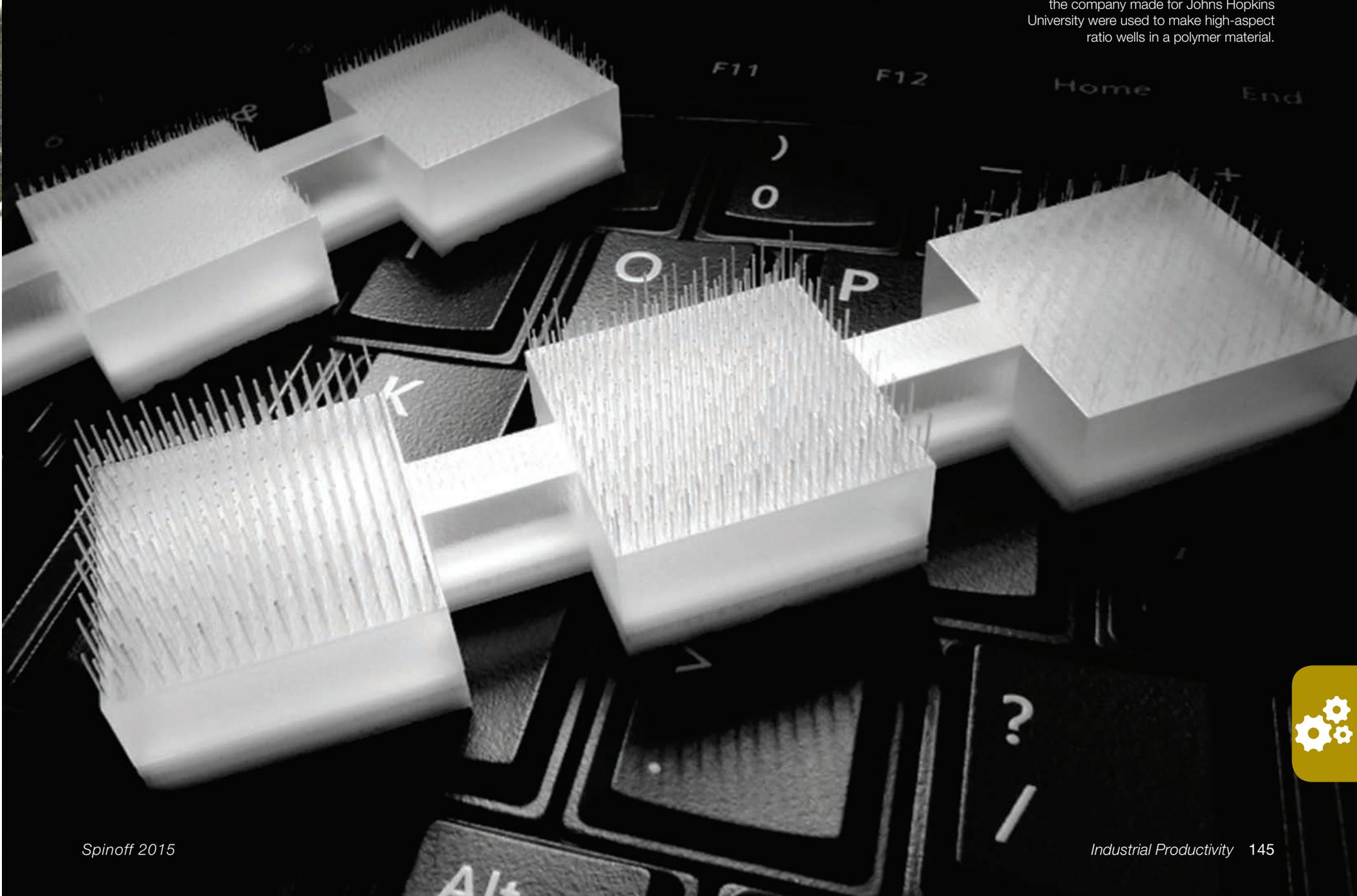
Since its SBIRs with NASA, Adelstein says, the company has grown by 50 to 75 percent. The staff has grown from about half a dozen to 20, and revenues for 2014 were projected at around \$3.2 million.

Another frequent client these days is Johns Hopkins Medicine, and around the time of the ASTRO-H project, Potomac Photonics returned to its roots to supply the organization with a diffractive optic lens. Also around this time, the company used its hyper-accurate 3D printer to produce a device designed to fight cervical cancer in the developing world for Jhpiego and Momo Scientific, two companies working with Johns Hopkins University.

Another recent medical project Adelstein takes pride in is the production of sutures with tiny wells in them, in which radiation can be embedded for localized cancer treatment. His wife still suffers from health issues due to radiation treatment she received for Hodgkin’s disease when she was a teenager, as do many who are subjected to massive doses of radiation in attempts to fight cancer, he says. These sutures allow a much safer alternative, at least for treatment of prostate and breast cancer.

“The ability to machine parts like this that are so small—it’s going to be life-changing,” Adelstein says. ❖

Not limited to lasers, Potomac Photonics also fabricates tiny, plastic parts with a high-precision 3D printer. These molds the company made for Johns Hopkins University were used to make high-aspect ratio wells in a polymer material.



# Metalworking Techniques Unlock a Unique Alloy

## NASA Technology

Half a century ago, a scientist at the Naval Ordnance Laboratory discovered that an alloy containing 60 percent nickel and 40 percent titanium could provide exceptional performance for rocket nose cones undergoing the rigors of atmospheric reentry. While the Navy experimented with this new material for a few years—in addition to rockets, it was also tested in mine detectors—it proved too difficult to work with to be of real practical value.

In the end, the Navy abandoned the project, but not before publishing its findings on the material, which was named 60 NiTiNOL; *Ni* and *Ti* after its atomic makeup and *NOL* after the lab where it was first developed. Though known to industry ever since, Nitinol 60 (as it is more commonly called) sat largely dormant for the next 50 years, inaccessible until someone could figure out an easier way to manufacture and manipulate it.

Without the persistence of one ball bearing engineer and the cooperation of a NASA technologist, the alloy's potential may have gone undiscovered for another half century.

In 2000, an engineer at Abbott Ball Company named Glenn Glennon saw in Nitinol 60 a potential solution to a problem that has long hampered the ball bearing industry. Typically, he says, bearings are made from stainless steel because of its hardness. But that comes at a cost, as stainless bearings typically can't handle much exposure to the elements before corroding. "We knew this industry standard could be replaced with something better if it was available," says Glennon.

However, the West Hartford, Connecticut-based firm is a small company and didn't have many resources to devote to research and development, so Glennon took on a lot of that work himself. In his search for partners with the ability to move the technology forward, he turned to NASA Glenn Research Center. The initial response wasn't what he had hoped it would be.



Titanium, which is a highly reactive metal, does not normally work in bearing applications that require lubrication. When combined in the right proportions with nickel, however, NASA discovered that it performs as well as the best bearing steels.

"I was very lukewarm on the idea of doing testing for them, for a couple of reasons," says Christopher DellaCorte, a senior technologist at Glenn. "For one, we always try to steer away from anything that would look like a product endorsement, and the easiest way to do that is simply not to do this kind of testing on request. But I was also skeptical of the claims they were making about the alloy as a bearing material, because it has a lot of titanium in it."

Titanium, he explains, while admired in aerospace engineering for its strength and light weight, is also

known across the industry for being extremely difficult to lubricate. Because it is highly reactive, oil and grease break down shortly after being applied, leading quickly to heavy wear and tear.

However, DellaCorte's reluctance wore down as Glennon, who believed he had something special in this material, persisted. The company stressed that it was only looking for independent testing—testing that it couldn't perform in-house due to a lack of the proper equipment—and that it wasn't planning on advertising its NASA connection. DellaCorte relented, and the parties agreed that if Abbott Ball could supply a small number of parts, his team would run its standard bevy of tests on the mysterious alloy.

## Technology Transfer

The first challenge to overcome was manufacturing those parts to high standards of quality. Up to that point, Abbott Ball had been using cast materials—created by melting down the metals and pouring them into molds—but this process proved too crude. Not only were they unable to make bearing balls that were smooth enough, but the titanium, once melted, had a tendency to absorb contaminants like carbon or oxygen that created flaws in the final product.

DellaCorte suggested that the company instead turn to powdered metallurgy, a process he was familiar with from his work in ceramics. In powdered metallurgy, particles of the material in powder form are combined and compacted in a container. The mixture is then heated to a temperature close to, but not reaching, the melting point of the materials. At that threshold, the atoms in the mixture begin bonding in a solid-state fashion, a process known as diffusion.

In addition to lowering the temperatures required to manufacture the final product, powdered metallurgy also avoids contamination that would otherwise weaken the alloy. Now with smooth, shiny bearings in hand, DellaCorte could finally run tests. The results came as a

shock to the team. “We were very surprised,” he says. “It had all of the strength you’d expect from the materials involved and was corrosion-proof, but in terms of lubricant life and friction levels, Nitinol 60 performed just as well as the best bearing steels.”

Glennon’s efforts to revive Nitinol 60 were finally coming to fruition, and suddenly the sky was the limit. Abbott Ball and Glenn refined the powdered metallurgy process specifically for Nitinol 60, and now the partners co-own patents on that process.

## Benefits

Engineers typically have to make tradeoffs when choosing bearings for particular applications. As DellaCrote explains, if those qualities are imagined as a Venn diagram—with overlapping circles denoting whether a given material is hard, corrosion resistant, lightweight, nonmagnetic, or elastic—then most materials only combine a few qualities. Nitinol 60, on the other hand, stands in the center of the diagram where the circles all overlap. “It’s the only material that combines all of those properties in a single bearing,” he says.

Because it is relatively new and still expensive to produce—several times the cost of other standard bearings—Nitinol 60 is currently a niche market. But it has found traction among aerospace clients, who will gladly pay the extra cost in bearing materials to avoid the weight, expense, and complexity of workarounds that other bearings might require, such as additional spacecraft components or protective coatings.

Abbott Ball is also exploring other avenues for new products. Among them are kitchen knives, taking advantage of the material’s hardness and corrosion resistance. The US Navy has funded two Small Business Innovation Research (SBIR) contracts to explore modern applications in various defense components. And the company is also exploring Nitinol 60’s use in medical equipment such as scalpels: that the material can withstand extreme temperatures and is nonmagnetic makes it ideal for reusable,



The equipment designed to recycle urine and other wastewater aboard the International Space Station (ISS) must reliably withstand a corrosive environment. A new wastewater processor scheduled to be installed on the ISS will incorporate Nitinol 60 ball bearings manufactured by Abbott Ball.

easy-to-sterilize tools that won’t unintentionally interfere with other equipment.

Engineers at Glenn have also continued testing and improving the material, which has led to a few more patents. For example, they recently discovered that adding third and fourth ingredients in small percentages makes Nitinol 60 easier to machine and process at lower temperatures, without compromising its desirable qualities. Glenn and Abbott Ball have also partnered to provide Nitinol 60 bearings for a wastewater processor scheduled to be installed on the International Space Station—exactly the kind of corrosive environment that has posed problems for traditional bearing materials.

Thanks in part to the partnership, Nitinol 60 likely has a bright future in space and on Earth. Glennon credits Abbott Ball owner Roger Bond and his son and company president Craig Bond for their support, financing research without any guarantee of a return on the investment. And DellaCorte wants to ensure no one forgets that it was Glennon’s advocacy that turned a 50-year-old curiosity into something poised for mainstream success.

“If it weren’t for his persistence, I don’t think the world would have given this material another thought,” he says. ❖



# Low-Cost Sensors Deliver Nanometer-Accurate Measurements

## NASA Technology

Carlos Capiro gathers his thoughts to relate how a single NASA sensor led to a product poised to disrupt his industry. “Really, a lot of it had to do with luck,” he begins.

Capiro, CEO of Juntura Group, was part of a team of MBA students at Rollins College near Orlando that in 2012 participated in the school’s Entrepreneurial Scholar of Distinction Program by lending their insight to NASA. Kennedy Space Center’s Technology Transfer Office had approached a professor at the school with a handful of patents it wanted better market analysis on. The professor in turn involved his students and had them evaluate the market potential of a NASA-patented technology—in



The space shuttle’s windows were one-inch-thick pieces of quartz, but they required an inspection following each mission to locate microscopic scratches and cracks that could pose safety risks in subsequent launches.

this case, a sensor originally created to help scientists inspect space shuttle windows for damage caused by micrometeoroids.

Micrometeoroid impacts happen often in low-Earth orbit: at that height is a very thin cloud of naturally-occurring debris that whips around the planet at a rate of about six miles per second. And while most of it is smaller than a grain of sand, at those speeds even particles of dust can act like microscopic bullets on a surface, leaving behind craters and scratches that run fractions of an inch deep.

“The orbiter windows are fairly large,” says Dr. Robert Youngquist, who runs the Applied Physics Lab at Kennedy and worked with the scientists who inspected the shuttle windows after each mission. “They’re one-inch-thick pieces of quartz. But if these craters are deep enough, there’s a chance that the windows will fracture during the next launch from the aerodynamic pressure and heating they undergo.”

For years, the best available method to measure defects discovered in the shuttle windows involved liquefying dental mold and pouring it over the scratch. When the material hardened, it was peeled off and examined using a microscope. “It was the only technique they had,” explains Youngquist. “It worked, but not as well as you would want.”

At NASA’s request, Youngquist devised an alternative method. Instead of measuring nicks and cracks directly, Youngquist used an optical technique that employs a small mirror to track the surface of the window. What that meant for Youngquist’s team, he says, was that “we had transferred the problem of trying to measure these pits over to the problem of measuring the position of a mirror—and that’s a lot easier to do.”

The final piece of the puzzle was finding a small, energy-efficient sensor to measure the mirror’s movement with accuracy down to the length of a micron, or one ten-thousandth of a centimeter. When their search turned up empty, Youngquist decided to create one himself.

The resulting sensor required minimal hardware—only a few inductors, or small coils of wire that generate a magnetic field when an electrical current runs through them. Two fixed inductors on either side of the mirror generate opposing magnetic fields; when the third inductor, which tracks with the mirror, moves closer to either field, it picks up that signal. Youngquist’s team could measure those minute changes in magnetic fields and convert them into highly accurate measurements of the pits and cracks in the shuttle’s quartz windows.

## Technology Transfer

When Kennedy’s Technology Transfer Office reached out to the MBA program at Rollins, Youngquist’s sensor was among the many technologies offered for analysis. “We showed them patents that we were passively marketing, technologies that could have benefited from additional work before bringing them to market,” says Jeff Kohler, who is a manager in the center’s Technology Transfer Office.

Reviewing the portfolio, the team of students came across Youngquist’s sensor and, feeling like they had discovered something special, got to work. “We had the right players involved,” says Capiro. “We all come from engineering backgrounds, and a couple of us had experience in business and finance.” The team members invested their own money to create a viable prototype of a commercial version of the sensor, as well as a marketing campaign to go with it. The effort paid off when, at the end of the semester, they presented a comprehensive analysis of the sensor’s market potential to Kohler, Youngquist, and other representatives from Kennedy.

“We were more than impressed with their presentation,” says Kohler. “They presented their prototype test kit in sealed boxes with a logo on it, showed us their extensive market research, and also expressed an interest in starting a company and seeing if they could take the technology somewhere.”



Juntura engineer Pankaj Patil holds a prototype of the company's first position sensor.

Immediately after, Capiro and four others formed Juntura Group Inc., based in Winter Park, Florida, and obtained an exclusive license to sell the sensor.

## Benefits

Since acquiring the license, Juntura has continued to advance the technology, increasing its capability from the original resolution of 400 nanometers down to 10 nanometers—approximately the thickness of a cell wall.

With a capability applicable in a multitude of fields, the company has set its sights first on what Capiro calls “low-hanging fruit”: 3D printers, laser holders and beam-steering mirrors, military technology, and robotics. “Imagine our sensor integrated into each component,



Image courtesy of Wikipedia user Schulbausteine, CC BY-SA 3.0.

Juntura's sensors have become part of 3D printers that may soon be found in remote areas, providing on-site medical care—such as printed skin grafts—that was not possible before.

whether that be a laser holder or the joints of a robot,” he says. “Now you can tell in real time, with just a signal, ‘Is my setup in line and ready to go? Is the joint returning exactly to where it was before, ensuring the repeatability of my robot’s motion?’ Those are markets we’re aggressively going after.”

One of Juntura’s primary advantages is the low cost of the core technology. Whereas sensors with similar capabilities currently on the market can cost about \$2,000 per unit, Capiro says his company aims to sell its product for close to \$500. Juntura even hopes to appeal to the growing “maker” community of tinkerers who like to assemble their own complex electronics and devices from low-cost parts. “By integrating our sensor with a 3D printer, you’re able to create commercial-grade products right in your home. The resolution is so good that you’d be hard pressed to determine whether it was created through an injection mold or a print job,” he says.

Juntura’s sensors have recently been purchased by a researcher at the Florida Institute of Technology who is using 3D printers to produce human tissue. Bioprinters

currently cost upwards of \$2 million, and the client hopes to reduce that price to something closer to \$50,000—something Juntura’s competitive prices help enable.

“Imagine being able to take one of these printers to Haiti or a country in Africa and printing out skin grafts for burn victims,” says Capiro. “I think we’re going to be part of changing the world, and we have NASA to thank for support in that.”

That worldwide perspective is an ambitious vision for a technology originally inspired by the inadequacy of liquefied dental mold. Capiro takes obvious pleasure in the way the technology has blossomed—perhaps partly due to luck, as he says, but also clearly the result of the hard work Juntura put in to make it viable.

“We’re a bunch of college kids who were able to create a fully functional business out of a simple patent and our dreams and aspirations. It’s turning into a pretty cool story to tell,” he says. ❖



# Electrical Monitoring Devices Save on Time and Cost



## NASA Technology

The sun requires no introduction. Earth orbits it; life happens because of it; we schedule our lives around its rhythmic risings and settings. Yet, despite its central importance in just about everything that concerns our planet, there's still a lot we don't know about this enormous ball of energy.

To further our understanding of how the sun impacts Earth, in 2001 NASA initiated the Living with a Star program, and among its various missions is its crown jewel: the Solar Dynamics Observatory (SDO). Launched in 2010, the SDO, even by agency standards, is a technologically advanced satellite. Through a suite of onboard instruments the spacecraft provides real-time, high-definition images of the sun's atmosphere and conducts measurements of both its magnetic field and its varying output of extreme ultraviolet (UV) radiation.

Much of the data gleaned from the SDO is being used to help scientists understand the nature and predictability of energetic particles, solar wind, and other potentially harmful radiation that finds its way toward Earth. In fact, Earth's magnetic field does much to shield the planet from most solar radiation. But anything that exists outside of its envelope is vulnerable, especially the SDO.

"You've got this spacecraft whose job it is to analyze the sun," says Dennis Krus, who was the satellite's lead components engineer at Goddard Space Flight Center. "It's going to get hit with all kinds of radioactive particles that can cause all sorts of electrical problems."

One such problem is called a single-event upset (SEU), where a radioactive particle transfers energy by ionizing a

The Solar Dynamics Observatory (SDO) is being lowered to a horizontal position for testing at Goddard Space Flight Center. Launched in February 2010, the satellite was developed as part of the Living with a Star program and is focused on analyzing energetic particles, solar wind, and other potentially harmful radiation that affect Earth.

satellite's circuits, igniting a fleeting surge of electricity, not quite powerful enough to fry a component such as a camera, for instance, but strong enough to blow its corresponding fuse, rendering the camera useless just the same.

On a spacecraft, fuses can be friend or foe. At best, they prevent overheating or even fire by cutting off the flow of electricity to a device when the passing current exceeds an allowable number of amps; at worst, as is the case with an SEU, they can knock an otherwise operational instrument permanently out of commission.

To prepare for any number of scenarios, the SDO was developed as a redundant satellite, meaning every critical piece of hardware—cameras, antennas, and heaters—has a spare. But NASA also wanted an alternative to the electrical fuse, a technology that could protect the spacecraft and other future big-ticket satellites from dangerous excess currents without needing to deactivate perfectly functioning hardware in the event of an SEU. The agency found what it wanted in a solid-state power controller, also known as an SSPC.

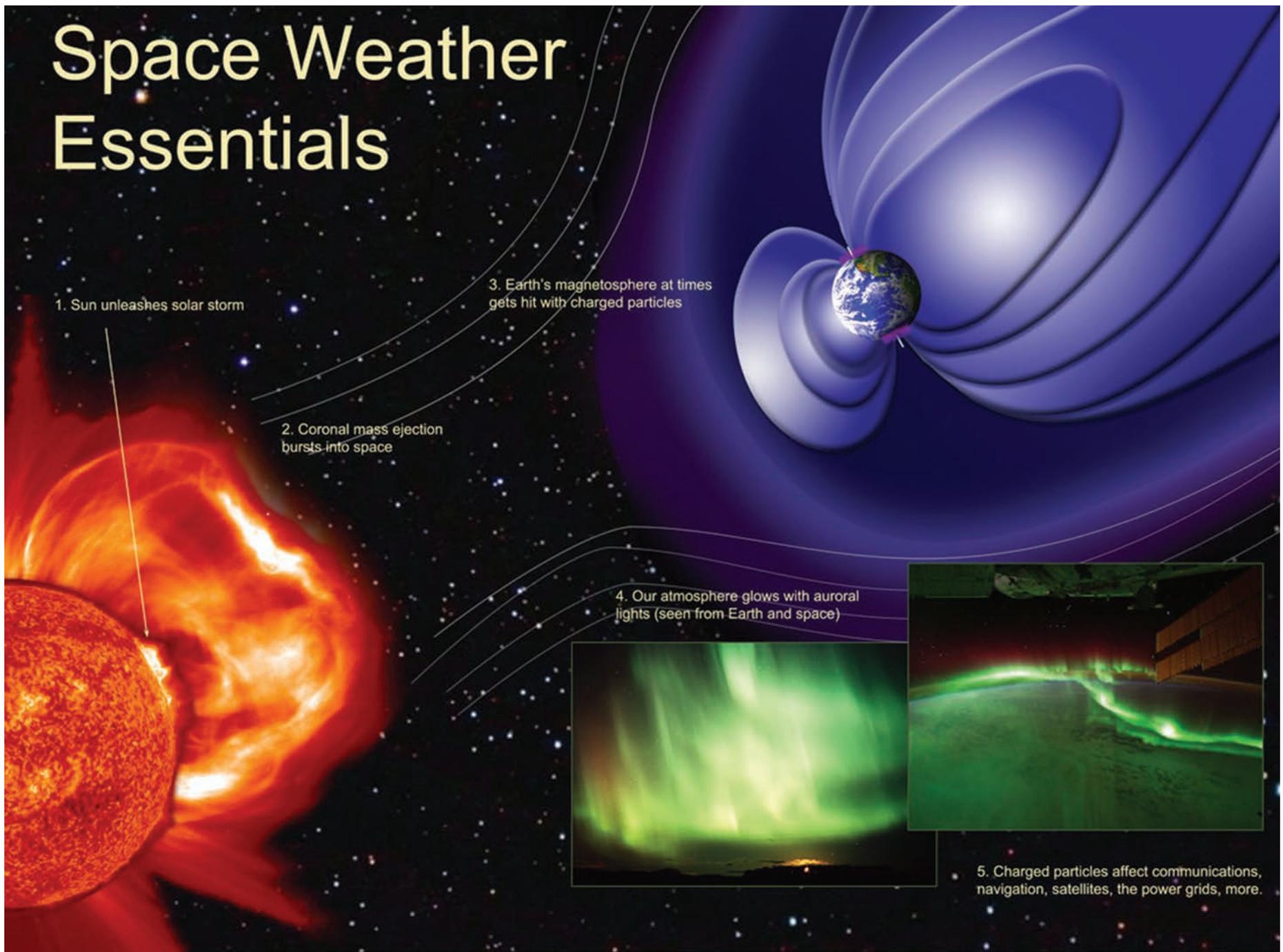
## Technology Transfer

Like electrical fuses, SSPCs control for current overloads by shutting off power to circuits when the number of amps goes above the allowable threshold. But unlike fuses, they don't operate on a one-way street—they also have the ability to switch the power back on. The technology also allows for remote monitoring and diagnosis, and if the issue is resolved, electricity flow can be restored through the push of a button.

NASA had to find a company that was willing to work with the agency to develop an SSPC that could withstand the constant bombardment of radiation in space. It was going to be a lot of work. But Goddard's Krus eventually found a partner in Garland, Texas-based Micropac Industries Inc.

In the early 2000s, Krus was already working with the 50-year-old electronics firm on developing hardware for the SDO when he broached the idea of reconfiguring its

# Space Weather Essentials



The illustration depicts how coronal mass ejections (CME) from the sun affect Earth. The SDO is charged with examining how the sun's magnetic field is generated, structured, and converted into solar events such as CMEs.





The cavity of one of Micropac's solid-state power controllers (SSPC) (inset), 96 of which are currently being used on the SDO to monitor instruments for power overloads. The technology replaces traditional fuses, which, once they're blown during a power surge, cut off power to space-based instruments permanently. Back on Earth, SSPCs are applicable for any system that uses electricity, from commercial buildings and sports complexes to industrial plants and hospitals. The device makes it possible to control the power supply to electrical devices remotely, saving time and money in the process.

Image courtesy of Wikipedia user Chensiyuan, CC-BY-SA 3.0

SSPC for use in space. After successfully tinkering with the engineering to fit the company's model into a smaller surface mount package, as was also required for the mission, Micropac agreed to move forward.

"We were up to the challenge of helping the agency develop an entirely new electrical power distribution system," says Micropac sales engineering manager Bill King.

Over the next few years the company worked hand-in-hand with NASA engineers to integrate various circuits, silicon components, and comparators in the power controller that were resistant to radiation. To test

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**“ We were up to the challenge of helping the agency develop an entirely new electrical power distribution system.”**

—Bill King, Micropac Industries

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their hardiness, at nearby Texas A&M University, Krus would schedule for what he calls "beam time," where high-energy radiation bombarded exposed sections of the SSPC. After every round, weaknesses were found and fixed.

"Eventually, we got the device to a point where it could withstand a dose of 100 kilorads of radiation," he says, "It was now single-event upset immune, which means the heaviest particles coming from the sun would not cause a problem. Thus was born the world's first high-reliability spaceflight solid-state power controller."

Along the way, Micropac also worked with NASA to further refine the SSPC's capabilities, including more adept handling of instant short circuits (sudden, intense spikes in electrical output), steady-state overloads (constant currents that are slightly higher than acceptable

levels), and inrush currents (momentary jolts of electricity triggered by switching on a device).

With its improved function and newfound radiation-hardness, in the mid-2000s 96 of Micropac's SSPC units were installed on printed circuit cards in the SDO, each device now monitoring a critical component, be it a camera, thruster, antenna, or computer system. Krus says, to his knowledge, because of its careful design the satellite has yet to experience an SEU, but the insurance provided by the SSPC lets him and his colleagues sleep a little easier at night.

"When you're talking about saving critical hardware on a multi-million-dollar satellite," he says, "it's worth having onboard. It gives us peace of mind."

Micropac's SSPCs are now also being used on other NASA spacecraft, including the Lunar Reconnaissance Orbiter, Lunar Crater Observation and Sensing Satellite, and the Global Precipitation Measurement satellite. Meanwhile, the company has introduced the product into other markets.

## Benefits

Soon after the NASA collaboration, Micropac's space-bound device drew the attention of the military, which purchased a number of them for various ground-based applications. And since most electrical systems on Earth do not require radiation resistance, these SSPCs were considerably less expensive.

The device's successful foray into the terrestrial market gave the company confidence to expand its offering, and in June 2013 safety certification firm Underwriters Laboratories approved the device for sale to the industrial sector. In turn, those companies are in the process of implementing the technology for use in a variety of settings.

For Micropac, SSPCs prove invaluable in virtually any setting where electricity plays a necessary role in operations. Consider gas stations or convenience stores, which now often use LED lighting for signage. Because those

bulbs are more prone to overheating, they're often closely monitored with circuit breakers, like the ones installed in homes. But a glitch caused by something as common as a sprinkler short circuit creates a hassle.

"The workers inspect it first, then they have to call somebody else to drive a truck out there," says sales engineering manager Bill King. "Then those people may have to use one of those cherry pickers to reach the top of the roof where the light is and flip the switch."

What about when the operating lights go out in a hospital? "Imagine if you had to climb through a roof panel to reset the circuit breaker," King says. "Now you've contaminated the operating room."

What about the traffic lights across the country that need constant checks for blown fuses, the conveyor belts at factories that require around-the-clock overcurrent monitoring, or the circuit breakers at home that need resetting in the basement? With SSPCs, King says, you can perform remote switching, protection, and resetting with the press of a button, and all through a smart phone application, if a company chooses to go that route.

"We're kind of overwhelmed," King continues. "When somebody asks, 'What's your market for this?' Well, any place you're switching power is our market. Where aren't you switching power?"

And the device's genesis was in sending NASA's satellites into orbit with that extra assurance King says these devices are becoming known for. "We had a great working relationship with Krus and the rest of the NASA folks," he says, "and we're excited about how this technology is set to take off." ♦



# Dry Lubricant Smooths the Way for Space Travel, Industry

## NASA Technology

Most of the power, communications, imaging, and computing technology on the Mariner planetary space probes—cutting-edge at the time—is now the NASA equivalent of stone tools. However, one technology, a dry lubricant that was developed for the later Mariner missions in the late 1960s and early '70s, is still essential to modern spacecraft, especially in the growing commercial space industry, and also to a number of other industrial applications.

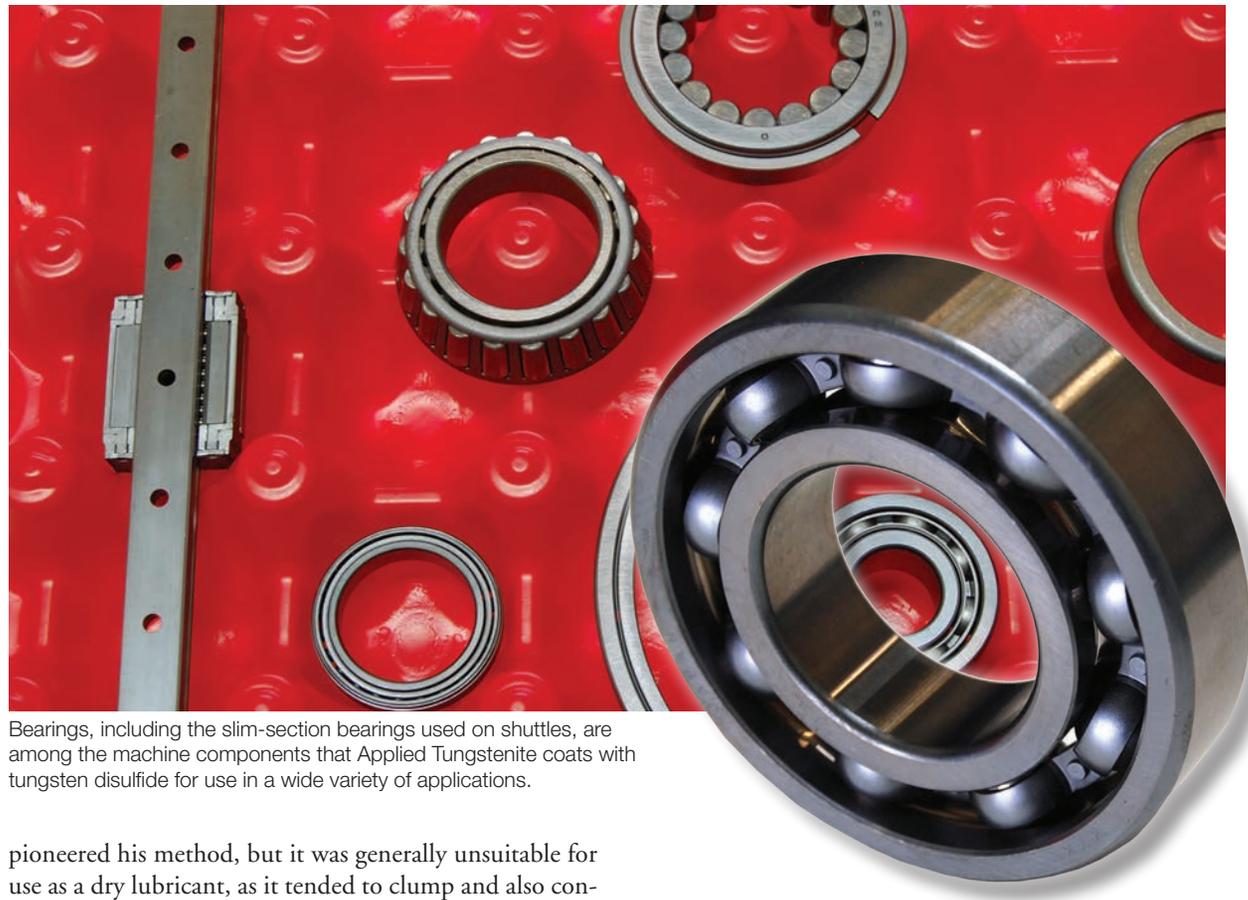
Robert Nelson of Stanford University originally came up with the idea and methodology to utilize tungsten disulfide, also known by its chemical name of  $WS_2$ , as a dry lubricant in support of the Mariner missions managed by NASA's Jet Propulsion Laboratory (JPL).

Soon, Nelson's technique found applications among aerospace and defense contractors and then, in the mid-1980s, exploded into the automotive, medical equipment, tool and die, robotics, and plastics industries, among others (*Spinoff* 1989).

This chemical compound exists naturally, if rarely, in the mineral tungstenite. As dry lubricants go, it is remarkably durable and effective. With a coefficient of friction value of 0.03, it is slicker than Teflon, and it's unaffected by temperatures ranging from -450 to 1,200 °F within Earth's atmosphere and an even greater range in the vacuum of space. Because it forms a molecular bond with the surface it's applied to, it also has one of the longest wear lives of any solid lubricant and can withstand loads of more than 300,000 pounds per square inch.

In part because of this direct, molecular bond, requiring no added binders, a coating of tungsten disulfide is only half a micron thick—about 20-millionths of an inch—and because it doesn't bond to itself, that thickness is uniform. This means it can coat the tiniest parts without affecting their dimensions or performance.

According to Nelson's patents, tungsten disulfide powder was already commercially available when he



Bearings, including the slim-section bearings used on shuttles, are among the machine components that Applied Tungstenite coats with tungsten disulfide for use in a wide variety of applications.

pioneered his method, but it was generally unsuitable for use as a dry lubricant, as it tended to clump and also contained free sulfur that could form sulfur dioxide, which would impede the coating process and cause corrosion. Nelson found that heating the substance, along with hydrogen, in a vacuum caused it to undergo a change that left it light, dry, fluffy, and ideal for coating. The hydrogen bonded with any free sulfur and carried it off in the form of hydrogen sulfide gas.

Nelson also developed a method for “impinging” the powder onto an object, blasting it onto the surface at around 700 mph, creating microscopic imperfections that help the lubricant to bond.

## Technology Transfer

Following its development for NASA, the technique for using tungsten disulfide as a dry lubricant became public knowledge and has most commonly been used to coat machine tools, gears, bearings, motor components, transmissions, compressors, bullets, and injection molds, among other items.

Specifications for the materials and methods to be used in applying  $WS_2$  as a dry lubricant were written up first by the company Aerojet General in 1966 and later by

the Department of Defense, the Society of Automotive Engineers (SAE), and a host of companies. Current SAE specifications for aerospace materials still include the stipulation that the lubricant be applied using the impinging process, just as Aerojet did almost 50 years ago. Many other companies' specifications, though, have become ambiguous on this point.

"Over the years, there have been all kinds of funny techniques to try to get around that expense," says Eric Woods, president of Applied Tungstenite Corporation of Temecula, California. What makes Applied Tungstenite unique is that it appears to be the only company that still uses the process in a certified facility.

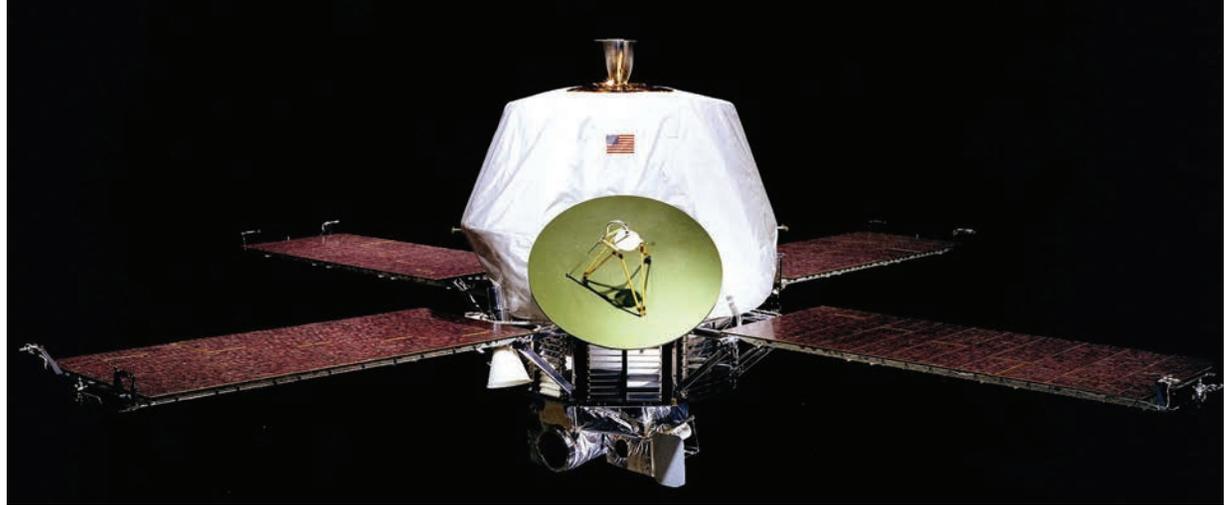
Impinging  $WS_2$ , especially onto small parts, is labor-intensive and costly, Woods says. "I understand where the industry has kind of moved away from the original science on this." Most companies that use tungsten disulfide apply it by burnishing it onto surfaces, for example with a brush, which is far easier but doesn't result in the same bonding achieved by impinging, he says.

"To do 16 million little aircraft pieces by impingement is just too inefficient, but, frankly, I don't see how you can control the quality if you don't impinge," he says.

By the mid-1980s, another, much cheaper dry lubricant—molybdenum disulfide—was also gaining popularity, and it now rules most of the market. However, this substance, better known as moly, requires a binder to adhere to a surface, making it thicker, and the coating is not uniform. The binder also may release gas, which can be problematic in an environment like a sealed spacecraft.

Because tungsten disulfide offers the precision that aerospace engineers need, and because Applied Tungstenite is the only company currently certified in applying it by the original method, Woods counts a number of commercial space companies among his end users, although the parts his company coats often find their way into commercial space systems through various subcontractors.

"Other than knowing it's a bearing or gear, I often have very little idea what these components are in the final application," he says. "But tungsten disulfide is still there in space, used extensively in hydraulics."



The Mariner 9 planetary space probe was among the later Mariner craft that tungsten disulfide was developed to support. The first spacecraft to orbit another planet, Mariner 9 gathered information on the composition and properties of Mars' atmosphere and surface, as well as images covering the entire planet.

## Benefits

Common spacecraft parts—including those being incorporated into a variety of commercial craft—coated at Applied Tungstenite include slim-section bearings, fasteners, blind bolts, pins, gimbals, gears, and hydraulic connections. Most of these are also technologies that haven't changed much since the Mariner days, although the company is also coating new fastener prototypes for JPL.

Among the other parts the company works with are camshafts and other engine parts for racecars, bearings for a longboard company attempting to break speed records, and molds for use in plastic injection molding, some of which can be as large as a desktop. "We're doing parts from a fraction of an ounce to about 1,700 pounds," Woods says.

Many of these, such as engine elements, are moving parts that need friction reduced as much as possible to improve functioning and extend wear life. In the case of injection molds, the lubricant helps the mold release its contents more easily. Others are what Woods calls one-time-only applications. For example, aircraft fasteners are coated simply to make them easier to install, after which the  $WS_2$  serves no function. Another example of this type of use is in "cold heading," in which a slug of metal is mashed into a finished shape at room temperature. A

coating of tungsten disulfide reduces the friction between the slug and the dies that will bash it into shape.

Woods says he also receives frequent requests to coat axles for Boy Scouts' pinewood derby cars, although he's still not sure if this constitutes a violation of the rules of competition.

Applied Tungstenite started up less than three years ago, as many other tungsten disulfide companies were closing, outcompeted by cheaper options. Woods, whose background is in corporate financial management, hoped to succeed by taking the substance back to its roots and capitalizing on the superior quality it can offer. He licensed the impinging technology from Micro Surface Corporation, the company that refined the process and introduced tungsten disulfide to general industry in 1984. "I thought, let's clean this thing up, go back to the original specification and see what we can get going," he says. "The material was designed to be impinged, and that was the whole original science."

He says the business is slowly growing, and he's talked with Langley Research Center about soliciting an SBIR that would help him automate more of the process, especially for parts too small to be grabbed by machine. "At some point we really do need to get to full automation on very small part impingement."

Woods says he's optimistic. "Holding right to that specification, the business grows because the quality is there." ♦



# Compact Vapor Chamber Cools Critical Components

## NASA Technology

Before the Apollo program sent the first men to the surface of the moon in 1969, in the early-to-mid-1960s NASA's Project Gemini performed much of the fundamental research required to get there. Over the course of 12 missions—10 of them crewed—Gemini spacecraft launched into orbit to enable the agency to study everything from the health impacts of exposure to microgravity to rendezvous and docking logistics and the demonstration of extravehicular activities.

Another aspect of research involved experimenting with alternative technologies to power a spacecraft's systems, as the agency believed batteries wouldn't last long enough for a lunar mission. One technology tested on several missions was the Proton Exchange Membrane (PEM) fuel cell. Invented by General Electric, the device provides electricity by means of a catalyst that strips hydrogen gas atoms of their electrons, which travel through electrical circuits, providing power.

Due to reliability issues, PEM fuel cells were replaced by alkaline fuel cells, which are bulkier but more dependable. The Apollo and Space Shuttle programs went on to use alkaline varieties to power their spacecraft. But recent improvements in PEM technology brought about by NASA, the US Department of Energy, and the private sector have once again opened up the possibility of using the device for space exploration.

In the interest of improving supporting technologies for PEM fuel cells, in the early 2000s Kenneth Burke, an electrical engineer at Glenn Research Center, began looking into new ways of cooling these power-producing devices. Traditionally, NASA has used liquid coolant, which flows into the fuel cells and carries the heat to a heat sink for disposal, adding another level of complication to the system. "The fuel cell has to seal and pump another fluid within it and manage all its plumbing and electronics. It was a system with more working parts than was desirable," Burke says.

As a workaround to this complexity, Burke turned to a kind of passive, closed-loop technology that would simplify the cooling process. What he had in mind were heat pipes: hermetically-sealed metal plates that use an internal phase-changing fluid to transfer heat. Basically, the heat pipe draws in heat from an adjacent source, which causes the liquid inside to evaporate. The vapor

travels to a lower-pressure area of the device where the energy is transferred to a heat sink. Having lost energy, the vapor condenses back into liquid and is wicked by a porous metal structure back to the evaporator section, where the process starts over again.

But the particulars of PEM fuel cell design, to say nothing of the special demands placed on devices destined



In 2012 Glenn Research Center partnered with the Greater Cleveland Regional Transit Authority (RTA) and other organizations to add a hydrogen-fueled demonstration bus to the RTA fleet. Here the bus is refueling at a station that uses an electrolyzer to convert water into hydrogen and oxygen. The vehicle's Proton Exchange Membrane (PEM) fuel cells use the hydrogen to generate electrical energy. NASA is looking to use PEM fuel cell technology to power future spacecraft.

for space, made existing heat pipes unworkable. For one, instead of the classic tubular design, Burke needed thin, planar heat pipes. The planar heat pipes would be wedged between each pair of fuel cells, which would be stacked one on top of the other. Second, because the stacked fuel cells would exert considerable pressure, the working metal had to be exceptionally strong. At the same time, fuel cost and space limitations meant the device had to be lighter than what was available at the time.

As has happened many times throughout its history, NASA would collaborate with the private sector to make such a device a reality.

### Technology Transfer

Founded in 1970, Thermacore Inc. specializes in passive thermal management technology. Burke had worked with the Lancaster, Pennsylvania-based firm in the past, calling them “the premier company” in that arena. “I listed the specs that I needed this heat pipe to have,” he says, “and they said, ‘Yes, of course we can do that.’”

The company first experimented with water paired with copper, a popular material for heat pipes because of its high thermal conductivity, but it was found to be too heavy. That meant they needed to find a lighter material and commit to more engineering research. As a result, in 2008 NASA granted Phase I Small Business Innovation Research (SBIR) funding to Thermacore, followed by Phase II funding later that year.

According to Thermacore’s senior research engineer, Sergey Semenov, what he and his colleagues came up with by 2008 is something that “no one else has in terms of its form factor,” he says, “and it fulfilled all of NASA’s requirements.”

Enter the water-based, titanium vapor chamber. Not only is titanium two times lighter than copper; it’s also considerably stronger. Its properties allow the overall thickness of the vapor chamber to measure a mere 1.3 millimeters while still being able to withstand 2,000 pounds per square inch of force, which means it has more

than enough strength to handle the force imposed by several fuel cells clamping together.

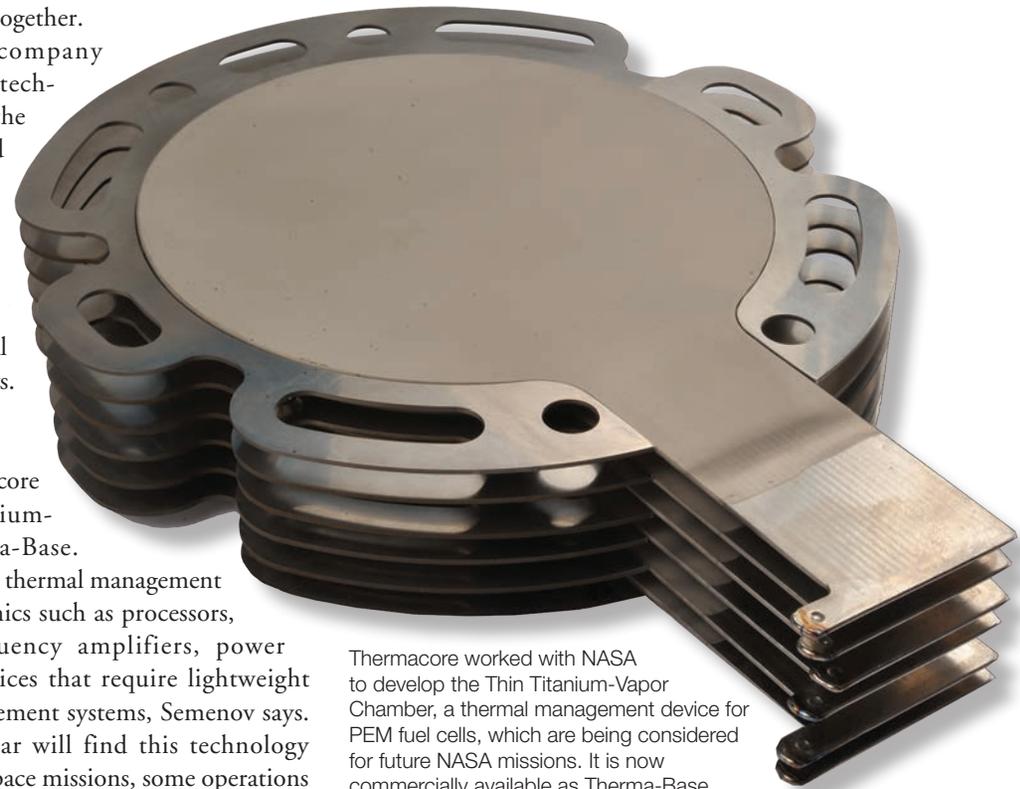
What’s more, the company developed a proprietary technique for manufacturing the device that, by the end of its development, had reduced production costs by 90 percent. “It was a big achievement for us because we wanted to make it affordable for commercial applications,” Semenov says.

### Benefits

In March 2013 Thermacore released the Thin Titanium-Vapor Chamber Therma-Base. The device provides passive thermal management to heat-generating electronics such as processors, video cards, radio-frequency amplifiers, power amplifiers, and other devices that require lightweight but strong thermal management systems, Semenov says. “The military in particular will find this technology useful because, similar to space missions, some operations also have to deal with space and weight constraints, and the same can also be said of some other commercial industries.”

As for dependability, titanium and water do not react chemically, which means they can’t produce gases that would eventually prevent the vapor chamber from working. With a nonreactive interior, if the device remains hermetically sealed, Semenov says, “it will work forever.”

The advent of this lightweight, thin yet exceptionally strong vapor chamber wouldn’t have happened without the agency, Semenov says. “Without NASA’s support, this product wouldn’t exist. We would still only be using copper-water combinations.”



Thermacore worked with NASA to develop the Thin Titanium-Vapor Chamber, a thermal management device for PEM fuel cells, which are being considered for future NASA missions. It is now commercially available as Therma-Base.

Burke says the technology was worth the investment. “With these titanium vapor chambers, the agency can one day use PEM fuel cells for manned or unmanned missions to the moon or Mars or to an asteroid. There’s no shortage of possibilities.” ❖



# Partnership News

**W**hat do a citizen-scientist hunt for asteroids and a smartphone app for tracking crops in rural Africa have in common? Both are examples of the many beneficial partnerships NASA engages in with government, business, industry, and academia. Collaborations with the space agency are improving educational toys and video games, refining alternative fuels, pioneering the future of aeronautics, and much more.



# Partnership News

## To Boldly Go where No Kerbal Has Gone Before

**K**erbal Space Program (*KSP*)—a computer game set on Kerbin, a distant, fictional planet that is home to enthusiastic space-faring creatures—just got an extra shot of realism thanks to a recent collaboration with NASA.

The game, which puts players in charge of Kerbin's burgeoning space agency, features big rockets, realistic physics and orbital mechanics, and plenty of humor. It is popular not just with the public but in particular with many NASA employees, who have used it to recreate historical missions such as the Apollo Program and Curiosity's recent trip to Mars.

NASA reached out to Squad (the company that develops *KSP*), and, following some discussion, both parties realized there was potential for a productive collaboration. The result was an asteroid redirect mission for *KSP* based largely on NASA's own plans to identify, capture, and redirect an asteroid; bring it into the moon's orbit; and send a manned mission to it.

Squad jumped at the opportunity to receive input from NASA scientists and engineers, who helped the company create realistic, in-game rocket and tool designs especially for the mission. In return, NASA hopes to raise awareness both about agency missions and goals and about the threat to Earth posed by asteroids.

"The collaboration with *Kerbal Space Program* can help drive interest by future explorers in next-generation technology development and deep space exploration," said Bob Jacobs, deputy associate administrator for communications at NASA. "Having an element of the experience based in the reality of NASA's exploration initiatives empowers players to manage their own space program while getting valuable insight into the reality of studying asteroids as a next step in getting to Mars."

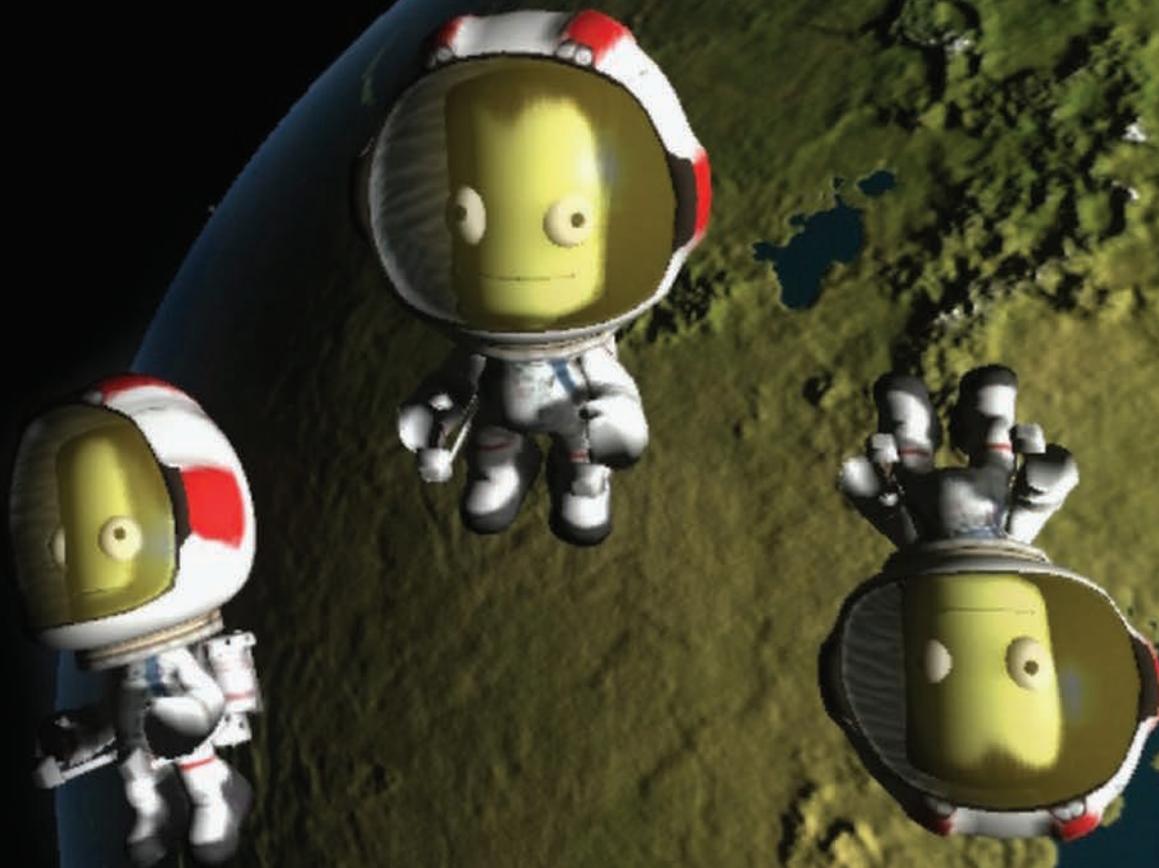


Image courtesy of Squad.

## A Crowdsourced Hunt for Asteroids

As part of the agency's Asteroid Grand Challenge, NASA partnered with private Internet technology company Slooh in 2014 to engage citizen scientists in the effort to track and characterize near-Earth asteroids (NEAs) that are potentially hazardous to our planet.

Slooh's global network of web-connected telescopes were made available for use by amateur astronomers for monitoring and characterizing NEAs, giving citizen scientists without access to professional equipment the chance to participate in the global challenge.

"We are excited by the opportunity to tap into Slooh's network of amateur astronomers, who are

already producing scientific papers with their work," said Jason Kessler, program executive for the Asteroid Grand Challenge. "We look forward to expanding the meaningful science the Slooh network can provide in support of the grand challenge."

Live astronomy events through the NASA and Slooh platforms increase the number of people who can watch and actively participate in science as it happens. Future events will include live commentary from NASA experts. Slooh plans to provide NASA with relevant observation data from these events, which may be used for further grand challenge citizen science efforts.

"This partnership is a great validation of our approach to engage the public in the exploration of space," says

Michael Paolucci, founder and CEO of Slooh. "NASA understands the importance of citizen science and knows a good way to get amateur astronomers involved is to offer them ways to do productive astronomy. Slooh does that by giving them remote access to great telescopes situated at leading observatory sites around the world."

The partnership with Slooh augments grand challenge partnerships with SpaceGambit and Planetary Resources Inc. and extends the search from existing data to direct observation through telescopes.



Astronomers have discovered what appears to be a large asteroid belt around the star Vega, the second brightest star in northern night skies. The scientists used data from NASA's Spitzer Space Telescope and the European Space Agency's Herschel Space Observatory, in which NASA plays an important role.



The Goldstone Deep Space Communications Complex, located in the Mojave Desert in California, is one of three complexes that comprise NASA's Deep Space Network (DSN). The DSN provides radio communications for all of NASA's interplanetary spacecraft and is also utilized for radio astronomy and radar observations of the solar system and universe—including the search for near-Earth asteroids.



Image courtesy of the Alliance for a Green Revolution in Africa.

## Enriching Agriculture in Africa

From hundreds of miles up in orbit, NASA satellites can measure how much rain falls in Niger or detect plant health in Mali. But on the ground, many African farmers and food distributors don't have good information about the growing conditions a few dozen miles down the road.

A new program is bringing together scientists in two branches of NASA's Goddard Space Flight Center with an African nonprofit organization to get relevant satellite data into the hands—and cell phones—of people who could use it the most.

"Putting the information in the hands of the agriculture users is one of the many ways that we can show that the satellite data has benefits to society," said Molly Brown, a research scientist with Goddard's Biospheric Sciences Laboratory.

Brown and her colleagues have already developed a 30-year dataset of satellite information on African precipitation rates, vegetation health, soil moisture, and evapotranspiration—all indicators of crop health in a given area. With researchers from Columbia University, New York, she is developing a system that can improve the way insurance companies set rates for drought protection.

That data, however, would also be key information for local farmers, and for food distributors, who have to determine which regions have a surplus of crops—and therefore which regions they should focus on to purchase excess food to sell at central markets. When distributors can buy excess food, it can encourage farmers to grow more in good years, knowing that there is a market.

More food production, and more efficient distribution, could improve food security for the region.

Brown is working through the mFarms platform to get satellite data to farmers and distributors. mFarms, a nonprofit organization, provides agricultural information via cell phones to their network—80,000 farmers and thousands of other distributors, warehouses, and others in 17 African countries. Agriculture in sub-Saharan Africa consists mostly of small farms. The mFarms platform connects farmers with marketing agents and buyers by creating a database of how many acres farmers plant and tracking the productivity of fields, among other features.

With NASA satellite data, the program can expand to include growing conditions for specific locations and notifications of potential weather-related problems.

## A Closer Look at the Cost of Air Pollution

**A**mmonia pollution from agricultural sources poses larger health costs than previously estimated, according to NASA-funded research.

Harvard University researchers Fabien Paulot and Daniel Jacob used computer models, including a NASA model of chemical reactions in the atmosphere, to better represent how ammonia interacts in the atmosphere to form harmful particulate matter. The improved simulation helped the scientists refine estimates of the health costs from air pollution associated with food produced for export—a growing sector of agriculture and a source of trade surplus.

“The ‘cost’ is an economic concept to measure how much people are willing to pay to avoid a risk,” Paulot

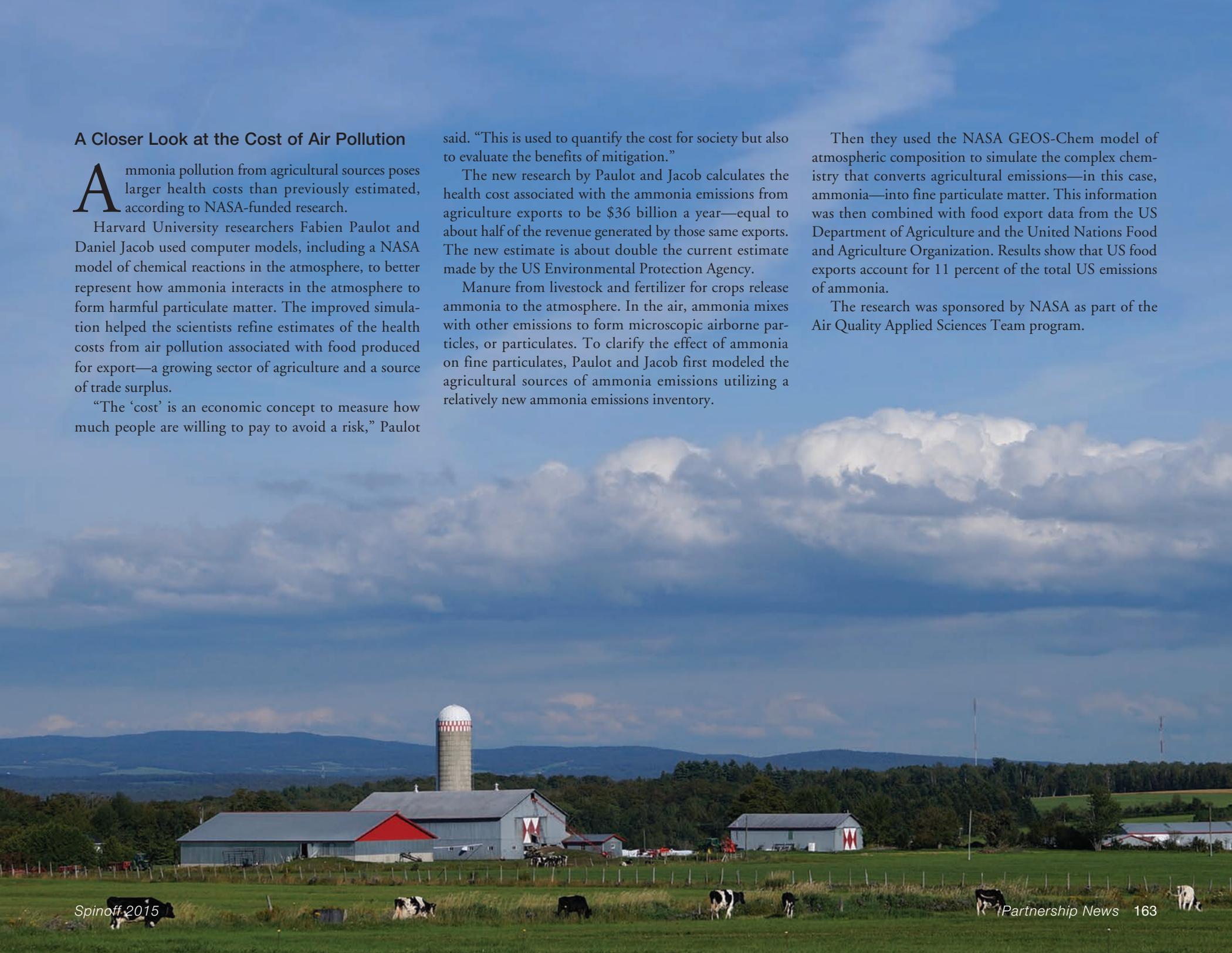
said. “This is used to quantify the cost for society but also to evaluate the benefits of mitigation.”

The new research by Paulot and Jacob calculates the health cost associated with the ammonia emissions from agriculture exports to be \$36 billion a year—equal to about half of the revenue generated by those same exports. The new estimate is about double the current estimate made by the US Environmental Protection Agency.

Manure from livestock and fertilizer for crops release ammonia to the atmosphere. In the air, ammonia mixes with other emissions to form microscopic airborne particles, or particulates. To clarify the effect of ammonia on fine particulates, Paulot and Jacob first modeled the agricultural sources of ammonia emissions utilizing a relatively new ammonia emissions inventory.

Then they used the NASA GEOS-Chem model of atmospheric composition to simulate the complex chemistry that converts agricultural emissions—in this case, ammonia—into fine particulate matter. This information was then combined with food export data from the US Department of Agriculture and the United Nations Food and Agriculture Organization. Results show that US food exports account for 11 percent of the total US emissions of ammonia.

The research was sponsored by NASA as part of the Air Quality Applied Sciences Team program.



## Good Things Come in Micro Packages

Invasive and systemic cancer treatment is a necessary evil for many people with the devastating diagnosis. These patients endure therapies with ravaging side effects, including nausea, immune suppression, hair loss, and even organ failure, in hopes of eradicating cancerous tissues in the body. If treatments better targeted a patient's cancerous tissues, they could provide clinicians with an alternative to lessen the delivery of toxic levels of chemotherapy or radiation. Thanks in part to NASA research, a solution to this problem may soon be commercialized.

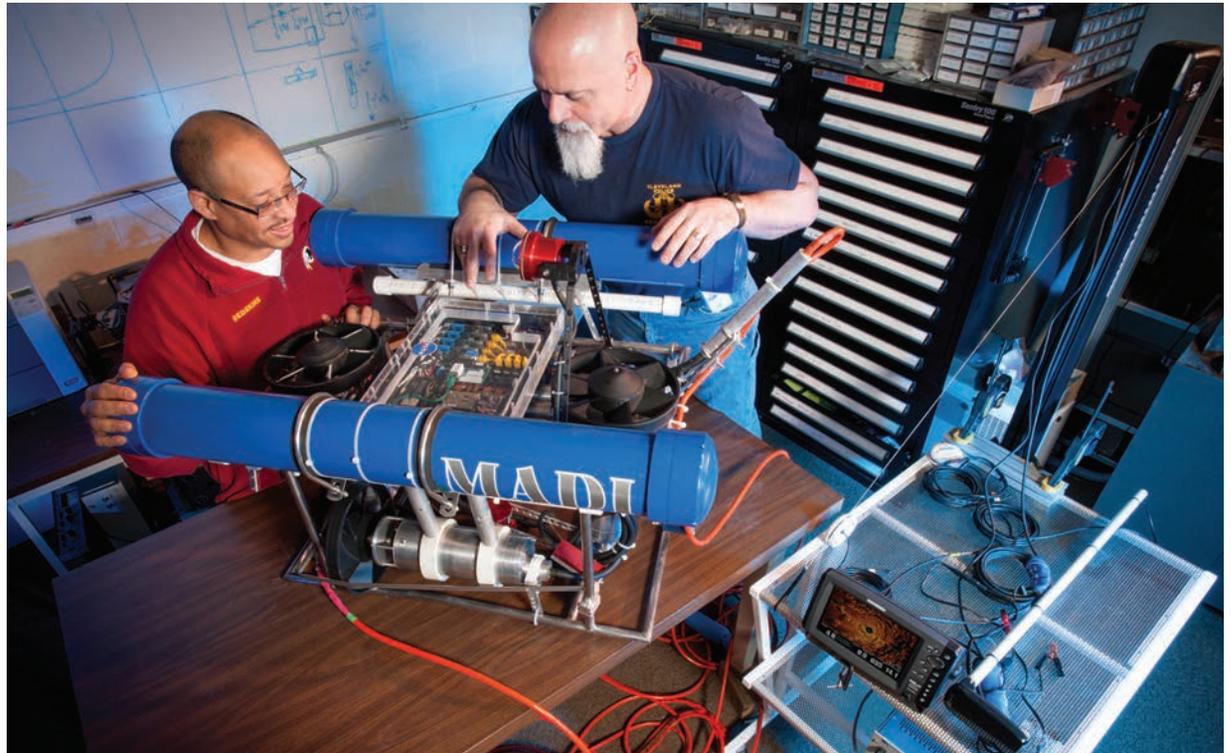
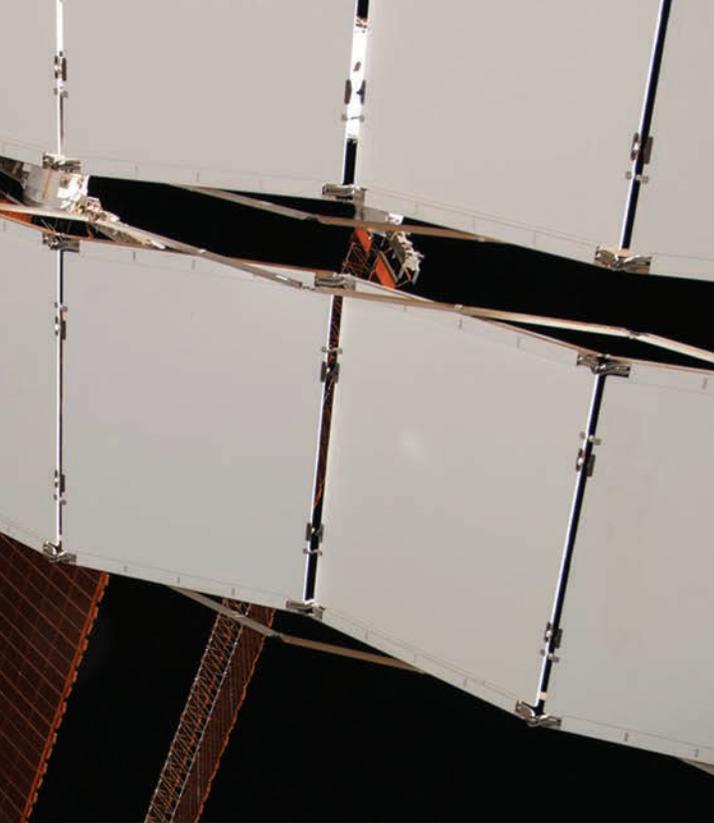
The Microencapsulation Electrostatic Processing System-II experiment, or MEPS-II, led by Johnson Space Center, was performed on the International Space Station in 2002 and included innovative encapsulation of several different anti-cancer drugs. The experiment system improved on existing microencapsulation technology by using microgravity to modify the fluid mechanics, interfacial behavior, and biological processing methods as compared to the way the microcapsules would be formed in gravity.

Space station research has led to 13 licensed microcapsule-related patents and 2 that are pending. In addition, NuVue Therapeutics Inc. has designed devices integrating the delivery of the microcapsules with enhanced ultrasound visualization and cryotherapeutic effects. The company is currently seeking FDA approval of MEPS microcapsules containing pharmaceuticals and marker imaging agents to view the microcapsules during an ultrasound.

Though it will take a few years to get approval to use microcapsules filled with anti-tumor drug therapies as a treatment option, several devices that will aid in drug delivery are planned for pre-clinical study as early as next year. NuVue's ultrasound-enhanced needles and the imaging marker microcapsules, which do not contain drugs, can be combined for use within the cancer patient.

After achieving full FDA approval, planned clinical trials will involve injecting microcapsules with anti-tumor drugs directly into tumor sites.





## Now Available: Underwater Crime-Fighting Robot

**G**lenn Research Center's Mobile and Remote Sensing (MARS) team specializes in refurbishing and repurposing modern robots. A Space Act Agreement with the city of Cleveland has the team busy improving city-owned assets to assist first responders and perform valuable scientific research on Earth, with future applications in space.

One such robot is now known as the MARS Lab Aquatic Descent Instrument, or MADI. It's an underwater robotic device fitted with interfaces for sensors and instruments for applications in law enforcement and underwater science in fresh and salt water.

"The beauty of MADI is that it can be tailored to meet the needs of any underwater mission," says Mike Krasowski, a senior engineer on the team. "If first responders want to use it, we can fit the robot with metal detectors and sonar imaging equipment to locate underwater evidence in the murky depths of Lake Erie."

Diving is always dangerous, and many first-responder divers are injured each year. A robot like MADI, outfitted with specialized sensors, can dive into the water first and search an underwater scene, keeping humans out of harm's way. Then if a diver is needed, he or she can follow MADI's tether down to an area of interest. The robot was recently used to test student-designed instruments and may soon be sent to study the health of lakes and streams.

Beyond Earth, the team believes MADI could be a research tool on celestial bodies such as Titan. One of the moons orbiting Saturn, Titan has many lakes of liquid methane. "In astrobiology, we are always looking for biomarkers or biosignatures, which point to signs of life," says Krasowski. "Scientists developing submersible instruments for Titan lake science missions can proof instruments using MADI to perform underwater tests and demonstrations on Earth."

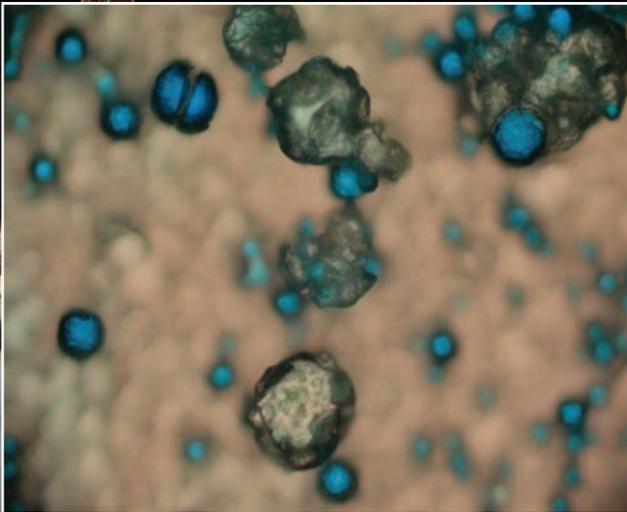


Image courtesy of NuVue Therapeutics Inc

Thanks to research on the International Space Station, microencapsulation technology continues to improve. Shown here is oil (blue) that contains a visualization marker to allow doctors to follow microcapsules (brown) during site-specific delivery of drugs to a tumor.



## Launching into Orbit—From Orbit

It used to be that building and launching a working satellite was an enormously expensive and complex undertaking, feasible only for governmental and military agencies. But the CubeSat revolution of the past decade has placed satellite technology within reach of private companies, universities and even unaffiliated individuals. CubeSats are a class of research spacecraft called nanosatellites. The cube-shaped satellites measure about four inches on each side, have a volume of about a quart, and weigh less than three pounds.

That revolution has been boosted by the existence of the International Space Station (ISS), which now provides a launching platform through regular commercial cargo flights. At present, two CubeSat deployers operate aboard the station: the Japanese Experiment Module Small Satellite Orbital Deployer and the NanoRacks CubeSat Deployer. The SpaceX-4 commercial resupply mission, conducted in August, enhanced the ISS's satellite deployment capabilities with the delivery of yet another deployment tool, called Cyclops.

CubeSats have varied missions, and this year has been a particularly busy one for satellite deployments from the space station. Whether they're helping to image Earth for weather and ground data or advancing communications capabilities, the ability to set these satellites into orbit from the space station is the first step to enabling their missions.

Camille Alleyne, assistant space station program scientist, explained: "Because of the relatively low costs to build this technology, the demand for the CubeSat deployment capability has increased dramatically. Adding this third deployer as a space station facility allows us to meet demand and demonstrates the value of the unique platform for both space research and STEM education."



A set of NanoRacks CubeSats are deployed by the NanoRacks Launcher attached to the end of the Japanese robotic arm. The CubeSats program includes a variety of experiments such as Earth observations and advanced electronics testing.

## Solving Aviation Challenges around the World

NASA has signed separate agreements with the German Aerospace Center and the National Research Council of Canada to conduct a series of joint flight tests to study the atmospheric effects of emissions from jet engines burning alternative fuels.

The Alternative Fuel Effects on Contrails and Cruise Emissions (ACCESS II) mission began in May and was flown from NASA's Armstrong Flight Research Center.

NASA flew multiple craft, burning a mix of different fuel blends, followed by other aircraft that measured emissions and contrail formation. ACCESS II is the latest in a series of ground and flight tests begun in 2009 to study emissions and contrail formation from new blends of aviation fuels that include biofuel from renewable sources. ACCESS I testing, conducted in 2013, indicated the biofuel blends tested may substantially reduce emissions of black carbon, sulfates, and organics.

Understanding the impacts of alternative fuel use in aviation could enable widespread use of one or more substitutes to fossil fuels as these new fuels become more readily available and cost-competitive with conventional jet fuels.

As part of an international team involved in this research, NASA will share its findings with the 24 member nations that make up the International Forum for Aviation Research.



The Dassault Falcon 20E has been extensively modified by the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, or DLR) for the kind of atmospheric research it will conduct as part of ACCESS II.

A heavily instrumented NASA HU-25 Guardian measures chemical components from the larger DC-8's exhaust, generated by a 50/50 mix of conventional jet fuel and a plant-derived biofuel.



Image courtesy of the German Aerospace Center



## Measuring Rain from Above and Below

Rain, ice, hail, severe winds, thunderstorms, and heavy fog—the Appalachian Mountains in the United States have it all. In 2014, NASA and some of its partners began a campaign in western North Carolina to better understand the difficult-to-predict weather patterns of mountain regions.

“What we’re trying to do is study and learn about the precipitation from the summit to sea, how it evolves as it moves from the mountains to the plains,” said Walt Petersen of NASA’s Wallops Flight Facility in Virginia, who led the project.

Involved were public authorities in the Upper Tennessee, Catawba-Santee, Yadkin-Pee Dee, and Savannah river basins to set up the rain-monitoring network for the campaign. Satellite overpasses provided the view from space. For those times when satellites weren’t overhead during a storm, NASA flew its ER-2 high-altitude research plane at 65,000 feet, armed with sensors that could simulate satellite measurements. Meanwhile, at 10,000 to 25,000 feet, the University of North Dakota’s Citation aircraft flew through clouds to measure raindrops and ice particles where they form.

The field campaign also served as validation for measurements made by the Global Precipitation Measurement (GPM) mission’s Core Observatory. GPM is an international satellite mission, launched in 2014, to observe rain and snow around the world. The advanced instruments on the GPM Core Observatory satellite provide the next generation of precipitation measurements, including the new capability to detect snow and light rain.



Above: The Global Precipitation Measurement mission will set a new standard for precipitation measurements from space, providing observations of rain and snow worldwide every three hours. Below: As a part of its study of rain in the Appalachian mountains, NASA flew the ER-2 aircraft to simulate satellite measurements when satellites were not overhead.



Image courtesy of the National Oceanic and Atmospheric Administration

## A Race against Time

Scientists at the Jet Propulsion Laboratory and Scripps Institution of Oceanography at University of California, San Diego have enhanced existing GPS technologies to develop new systems for California and elsewhere to warn of hazards from earthquakes, tsunamis, and extreme weather events.

The technology was demonstrated in July by forecasters at the National Oceanic and Atmospheric Administration's National Weather Service offices in Oxnard, California, and San Diego. They used it to track a summer monsoon rain event affecting Southern California and issue more accurate and timely flash flood warnings. The system uses real-time information from GPS stations upgraded with small, inexpensive seismic and meteorological sensors.

The technology is also being integrated into other real-world cases. "These advancements in monitoring

are being applied to public safety threats, from tall buildings and bridges to hospitals in regions of risk for natural hazards," said Yehuda Bock of Scripps Institution of Oceanography.

One example is making damage assessments for hospitals, bridges, and other critical infrastructure that can be used in real time by emergency personnel and public authorities. For hospitals, the primary goal is to shut down elevators automatically and send alerts to operating room personnel—for example, when an earthquake early warning is received.

"Meaningful warnings can save lives when issued within one to two minutes of a destructive earthquake, several tens of minutes for tsunamis, possibly an hour or more for flash floods, and several days or more for extreme winter storms," said Bock.

Planning is underway to integrate the technology into earthquake and tsunami early-warning and structural-monitoring systems for locations throughout California.



## Shape-Shifting Wings

NASA has joined forces with the US Air Force Research Laboratory and commercial industry to help reduce aircraft drag, wing weight, and noise. The Adaptive Compliant Trailing Edge (ACTE) project is part of NASA's larger Environmentally Responsible Aviation effort that explores and documents the feasibility, benefits, and technical risk of vehicle

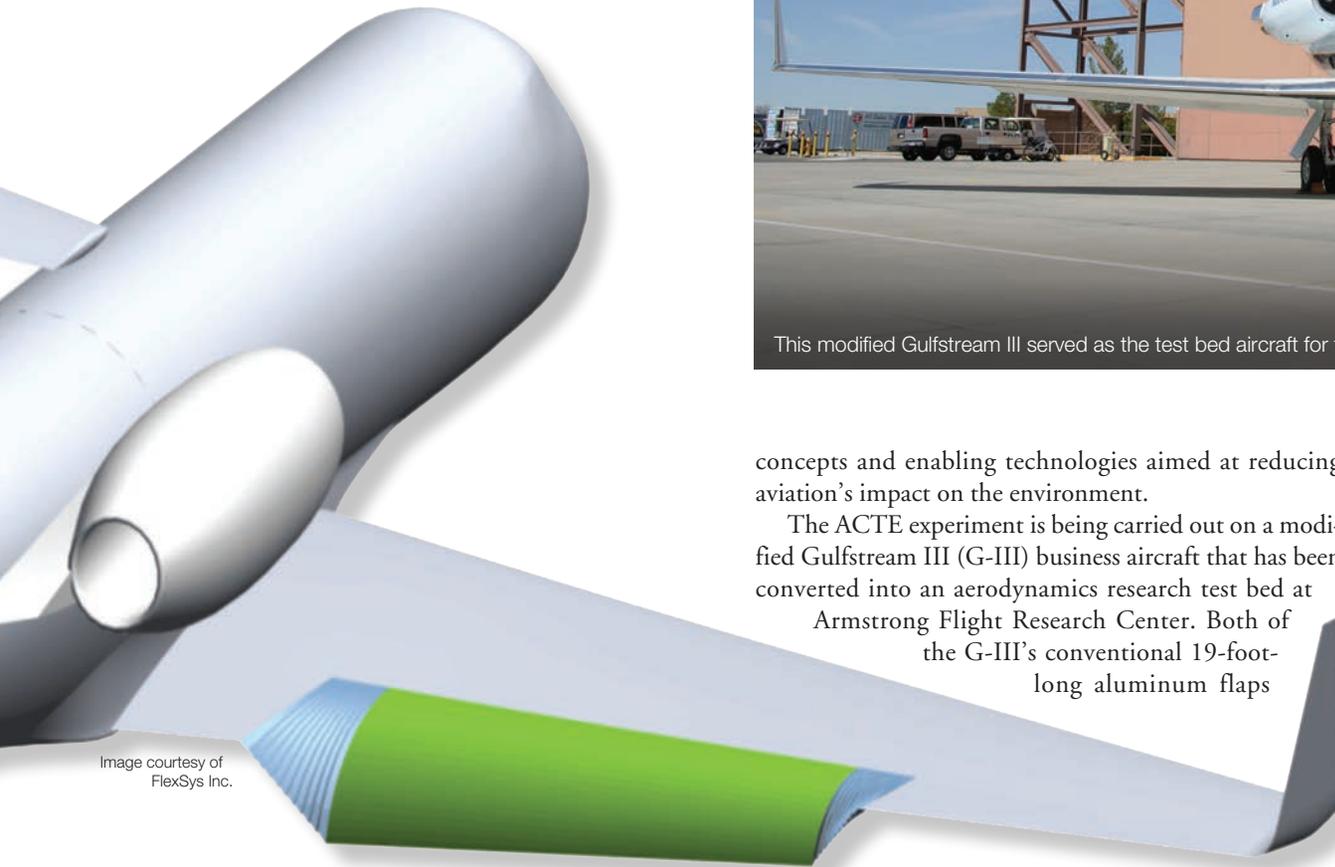


Image courtesy of FlexSys Inc.

FlexSys ACTE flap technology bridges gaps in wing for a seamless surface.



This modified Gulfstream III served as the test bed aircraft for the Adaptive Compliant Trailing Edge (ACTE) flexible-flap research project.

concepts and enabling technologies aimed at reducing aviation's impact on the environment.

The ACTE experiment is being carried out on a modified Gulfstream III (G-III) business aircraft that has been converted into an aerodynamics research test bed at Armstrong Flight Research Center. Both of the G-III's conventional 19-foot-long aluminum flaps

were replaced with advanced, shape-changing flaps that form continuous bendable surfaces. The flexible flaps are made of composite materials to a patented design from FlexSys Inc.

When conventional flaps are lowered, gaps exist between the forward edge and sides of the flaps and the wing surface. The ACTE flaps are gapless, forming a seamless transition region with the wing while remaining attached at the forward edge and sides. The improved flap should eliminate a major source of airframe noise generation and, in addition, should improve flight efficiency.



## IceBridging the Gap

Monitoring changes to polar ice is a never-ending job. Following the end of NASA's ICESat mission in 2009, however, the space agency had no space-based mission to dedicate to the task until ICESat's successor, ICESat-2, launches in 2017.

Enter Operation IceBridge, the largest airborne survey of Earth's polar ice ever flown. Over the past five years, IceBridge—managed by Goddard Space Flight Center—has surveyed large portions of the Greenland and Antarctic ice sheets, as well as sea ice in both polar regions. IceBridge data have been used to build detailed maps of bedrock in Greenland and Antarctica, calculate changes in Arctic sea ice thickness and volume, and improve our understanding of the rate at which glaciers in Greenland are flowing into the sea.

Throughout 2014, the IceBridge team coordinated its efforts with other research groups: They partnered with the CryoSat-2 Validation Experiment team, which operates a campaign to verify measurements made by the European Space Agency's ice-monitoring satellite, CryoSat-2. And researchers from the European Space Agency, York University in Toronto, and the Technical University of Denmark likewise flew airborne instruments alongside NASA's to measure ice and snow.

Three high school science teachers from the United States, Denmark, and Greenland also joined IceBridge to get first-hand experience and knowledge they can bring back to their classrooms. These teachers came to IceBridge through partnerships with the US-Denmark-Greenland Joint Committee and PolarTREC, a US-based program that pairs teachers with polar research expeditions.

Background: a fjord in east Greenland as seen by NASA's Operation IceBridge.

## Little Bits, Lots of Science

NASA Goddard Space Flight Center's Innovative Partnerships Office has entered into a Space Act Agreement with electronics toy and learning company littleBits to stimulate student interest in science, technology, engineering, and mathematics (STEM).

The activities in the littleBits Space Kit were designed and written by NASA scientists and engineers in collaboration with littleBits, which designed and manufactured the electronics. The company makes an open-source library of electronic modules that connect with magnets, allowing novices and experts alike to learn electronics and create projects—no soldering, wiring, or programming required.

The goal of the partnership is to provide a STEM resource for science explorations for everyday use in after-school programs, science centers, workshops, and other informal education settings. The activities introduce children to the fundamentals of energy and its connection to NASA science and satellite instruments.

The Space Kit allows children to conduct experiments that illustrate the basics of NASA technologies, such as remote sensing instruments used on NASA's Earth-observing satellites. Projects include instructions on how to build a grapppler, a working satellite dish, and a remote-controlled Mars rover, with additional projects and lessons available online to explore energy, robotics, and other areas of NASA science and engineering.

"This type of collaboration benefits everyone—NASA, littleBits, and explorers of all ages in homes and classrooms across the country," said Blanche Meeson, chief of higher education for NASA's Science and Exploration Directorate. "We are able to bring our love and knowledge of science and engineering to a new generation of explorers through littleBits' simple yet powerful platform."



Images courtesy of littleBits

## Rover Racing: The New Era

For nearly 20 years, the Great Moonbuggy Race was an annual fixture at NASA's Marshall Space Flight Center—a challenge taken on by thousands of students to build and race a vehicle capable of overcoming terrain similar to that found on the moon.

This year, NASA retired the moonbuggy motif in order to make way for a new theme: the first NASA Human Exploration Rover Challenge, held at Marshall in April. Building on the previous decades of competitive student innovation, the new event challenged students to design, build, and race lightweight, human-powered roving vehicles through a greater variety of obstacles. Participating were more than 500 students from 70 high school, college, and university teams from 19 states, Puerto Rico, Germany, India, Mexico, and Russia.

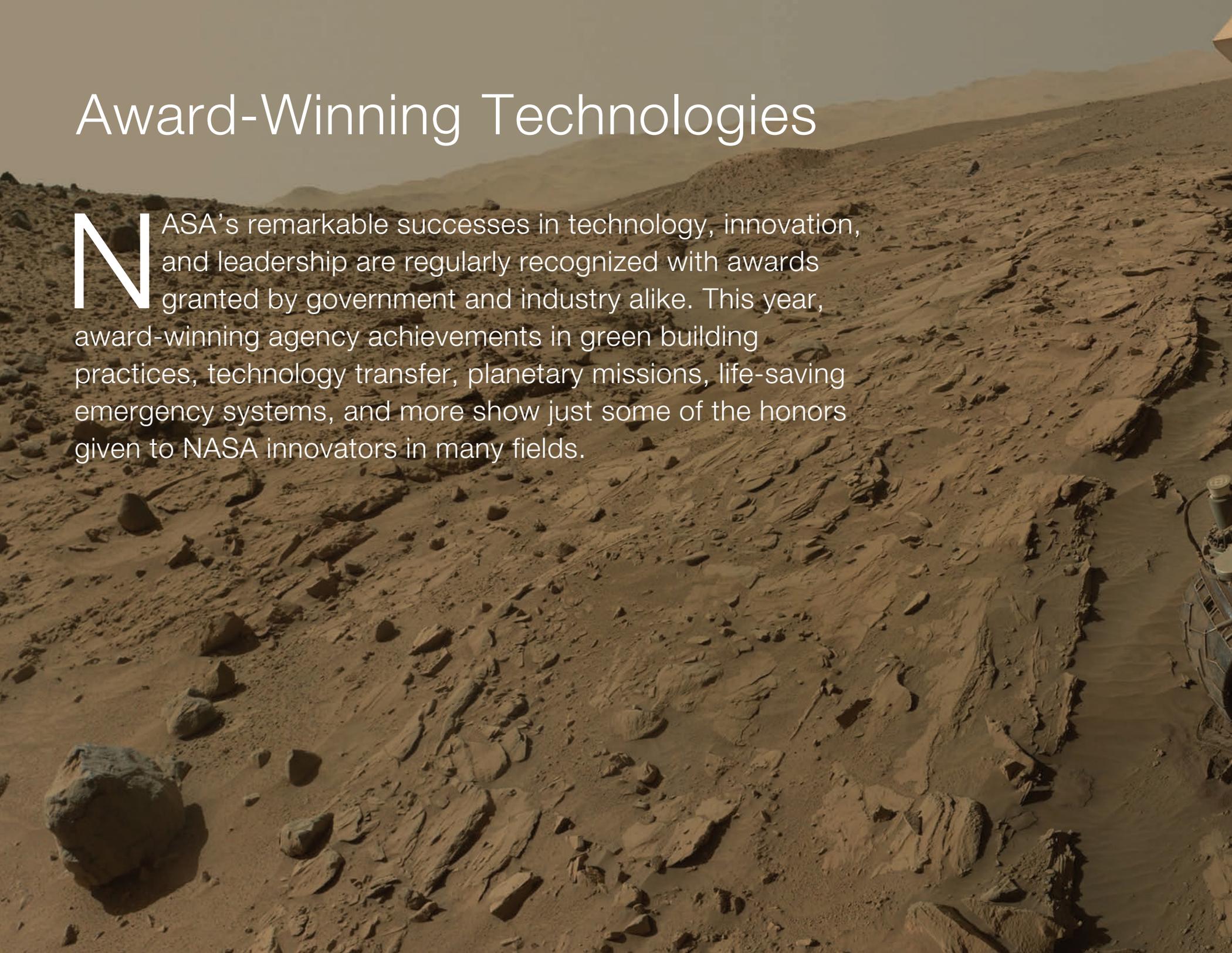
Not only did the students have to solve technical problems along the way—just as NASA must—but engineers from the space agency attended the race and will examine the winning hardware designs for potential applications to future rover and space transportation missions. ❖

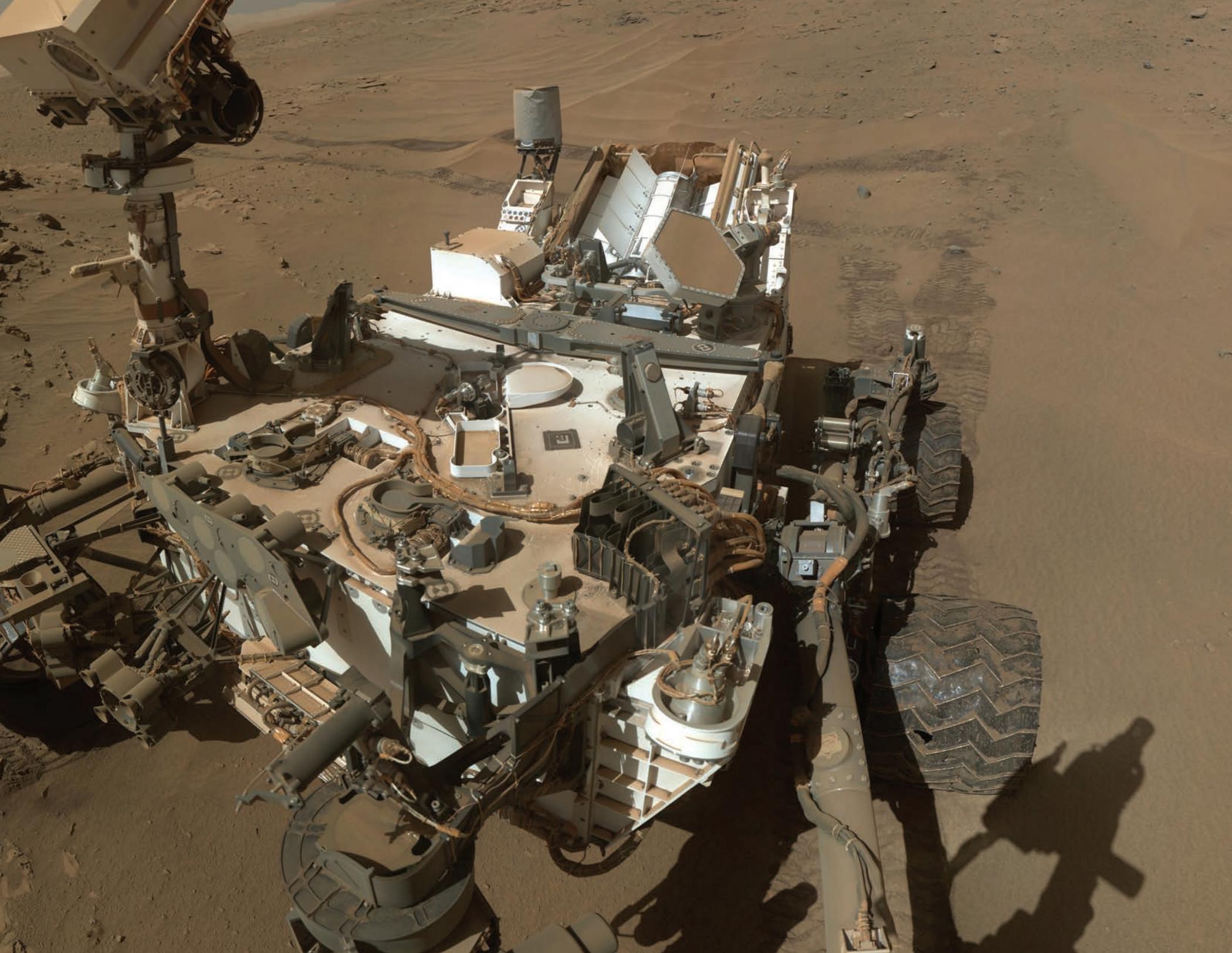




# Award-Winning Technologies

**N**ASA's remarkable successes in technology, innovation, and leadership are regularly recognized with awards granted by government and industry alike. This year, award-winning agency achievements in green building practices, technology transfer, planetary missions, life-saving emergency systems, and more show just some of the honors given to NASA innovators in many fields.





# Award-Winning Technologies

## Mean, Green, Recycling Machine

**T**hirteen California organizations, including NASA's Ames Research Center, were recognized with the 2013 Governor's Environmental and Economic Leadership Award (GEELA), the state's highest environmental honor. Ames received the honor "for building the first federal facility to receive LEED Platinum rating for new construction." That's the highest certification in Leadership in Energy and Environmental Design.

NASA's Sustainability Base is unlike any other government building ever created. Using NASA innovations originally engineered for space travel and exploration—such as Bloom Energy servers that provide clean electricity (*Spinoff* 2010)—the 50,000-square-foot Sustainability Base is simultaneously a working office space, a showcase for NASA technology, and an evolving exemplar for the future of buildings.

Sustainability Base is an intelligent facility, designed to anticipate and react to changes in sunlight, temperature, wind, and occupancy. The building can optimize its performance automatically, in real time, in response to internal and external changes. The building is oriented to take maximum advantage of the sun and natural light, which is enhanced by an extensive use of glass enclosures for offices and other internal workspaces.

Among its other innovations, Sustainability Base deploys a NASA-developed gray water recycling system that takes soapy water from sinks and showers, reclaiming it through a three-stage process, and uses it secondarily to flush low-flow toilets. On the whole, the facility saves between 85 and 90 percent on potable water demand thanks to building design.

"The award recognizes the creative solutions and transformative results that Californians are achieving on some of our most significant environmental challenges," said Secretary for Environmental Protection Matt Rodriguez.



The Sustainability Base, pictured here in the foreground on Ames' campus, is the first federal facility to achieve a LEED Platinum rating.

## Improve Locally, Compete Globally

In 2014, the Federal Laboratory Consortium (FLC) recognized Glenn Research Center; the Manufacturing Advocacy and Growth Network (MAGNET); the City of Cleveland; and Cuyahoga County, Ohio, with its State and Local Economic Development Award. The honor came as a result of the organizations' joint work on the "Adopt a City" Manufacturing Innovation Project, part of the Obama administration's ongoing Strong Cities, Strong Communities initiative.

FLC is a national network of federal laboratories whose mission is to promote and facilitate the rapid movement of federal laboratory research results and technologies into the US economy. "Adopt a City" matched small and mid-sized manufacturers with subject matter experts from Glenn to help those companies solve challenges they were experiencing with a new or existing product. Glenn provided up to 40 hours of free assistance to each company, and the city of Cleveland and Cuyahoga County made low-interest loans available to companies needing financial assistance. MAGNET served as the project coordinator.

Participants from Glenn hoped that giving local companies quick access to technical expertise would allow them to improve their products, increase profits, hire more employees, and compete on a global scale.

"The award shows the national significance these efforts have taken on in putting together this unique partnership in our geographic area," said Glenn Director James Free. "These awards have become one of the most prestigious honors in technology transfer."



In an effort to boost local manufacturing, the "Adopt a City" campaign arranged for experts from Glenn to provide 40 free hours of consultation to Cleveland businesses. The city of Cleveland also made low-interest loans available to companies needing financial assistance to create or improve products.

Background: Cleveland at night.

Image courtesy of Rob Sinclair, CC-BY-SA 2.0.

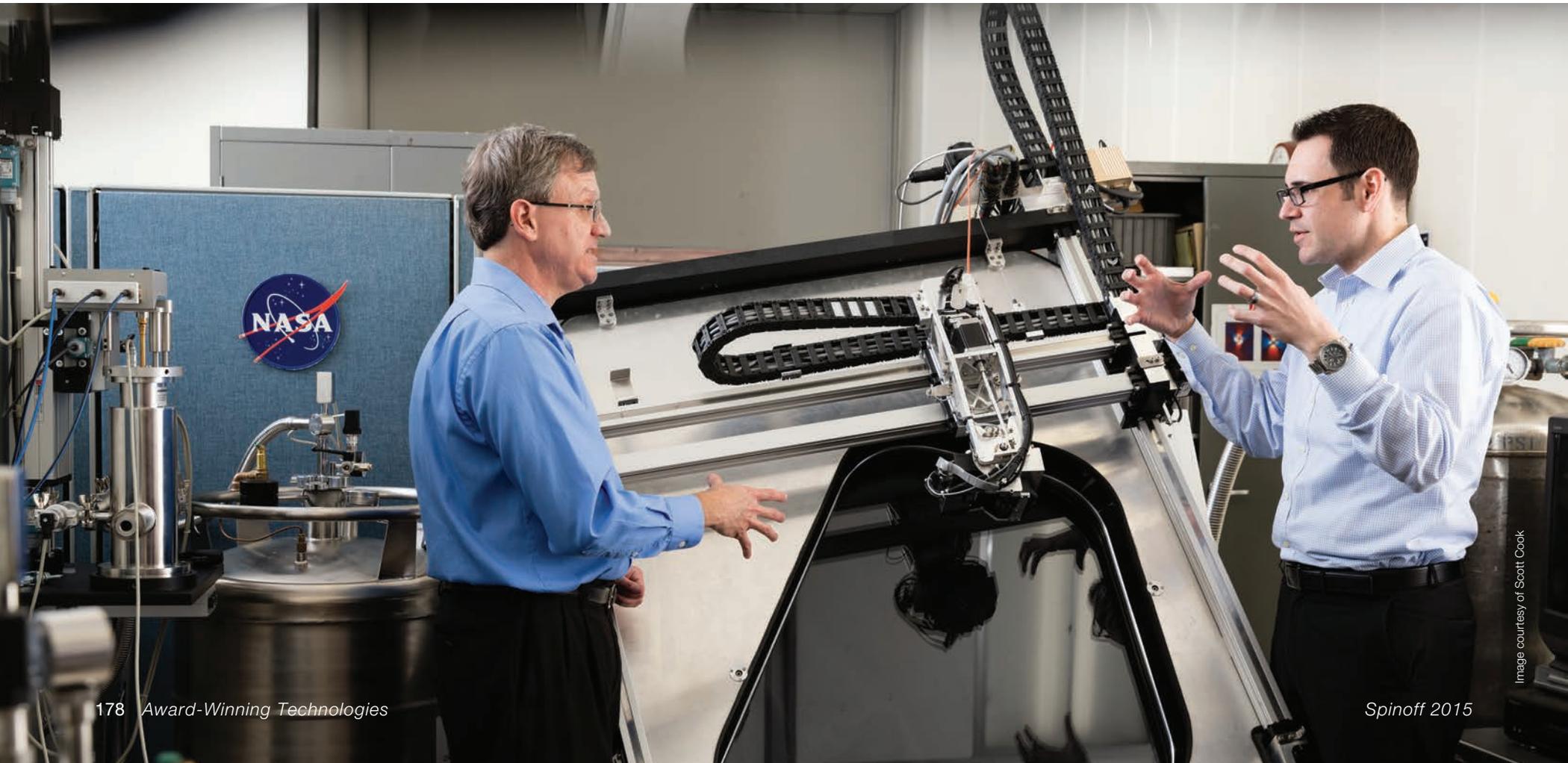
## Little Sensor, Big Potential

The technology transfer partnership pursued by Kennedy Space Center and Rollins College that resulted in a commercial version of a NASA sensor (page 148) turned out to be an award-winning effort: the Federal Laboratory Consortium (FLC) honored Kennedy with its 2014 Award for Excellence in Technology Transfer for the unique initiative. The award recognizes the efforts made by Kennedy to reach out to Rollins with a technology portfolio the college could take advantage of and the responsiveness of the college and its students to the opportunity.

Participating students were hand-selected by a professor and given a number of technologies to review. After picking one they liked, consulting with NASA experts, and undertaking a good deal of market research, the students decided to form a new company, called Juntura Group, to sell a sensor based on technology originally created to inspect the space shuttle's windows. They then created a prototype of the sensor and presented it to NASA along with a full marketing plan. Juntura licensed the technology and now offers it for sale in a number of markets.

The success of this project has led to the execution of a Space Act Agreement between NASA and Rollins that will continue a similar program in future semesters. Kennedy's Technology Transfer Office hopes it will not only give future students an opportunity to see how technology transfer works but also result in more start-up companies that license and sell NASA technology.

A Rollins College business student speaks with a NASA scientist about a sensor technology originally created to inspect the space shuttle windows.



## Planetary Science on a Galactic Scale

NASA's planet-hunting telescope, Kepler, has unveiled to us a galaxy jam-packed with planets of every kind. The mission was honored for its accomplishments with the Robert H. Goddard Memorial Trophy, awarded by the National Space Club, in March.

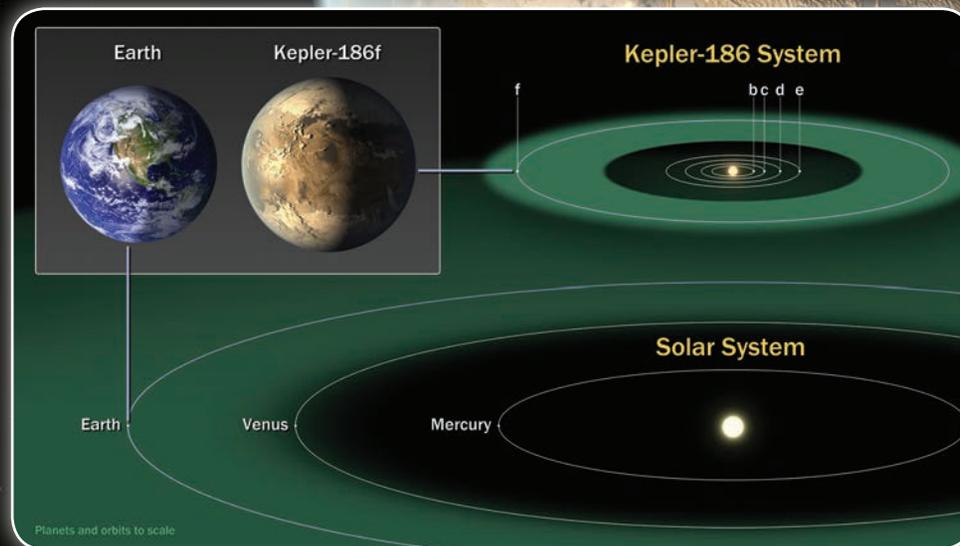
The trophy is the organization's preeminent award, and it was given for revolutionizing astrophysics and exoplanet science by expanding the census of planets beyond our solar system and fundamentally altering our understanding of our place in the Milky Way galaxy. The award citation acknowledges the Kepler team's significant contribution to US leadership in the field of rocketry and astronautics.

"This is an outstanding achievement for the entire Kepler team," said John Grunsfeld, NASA's associate administrator for science in Washington. "Kepler continues to surprise and inspire us on a regular basis, and I'm delighted to see the team's pioneering work acknowledged with the Goddard Trophy."

Developed jointly by NASA's Jet Propulsion Laboratory and Ames Research Center, Kepler was launched in 2009. It is the first NASA mission to find Earth-sized exoplanets in or near the habitable zone, the region in a planetary system where liquid water can exist on the surface of an orbiting planet. So far the satellite has identified nearly 1,000 confirmed exoplanets and more than 4,000 planet candidates.

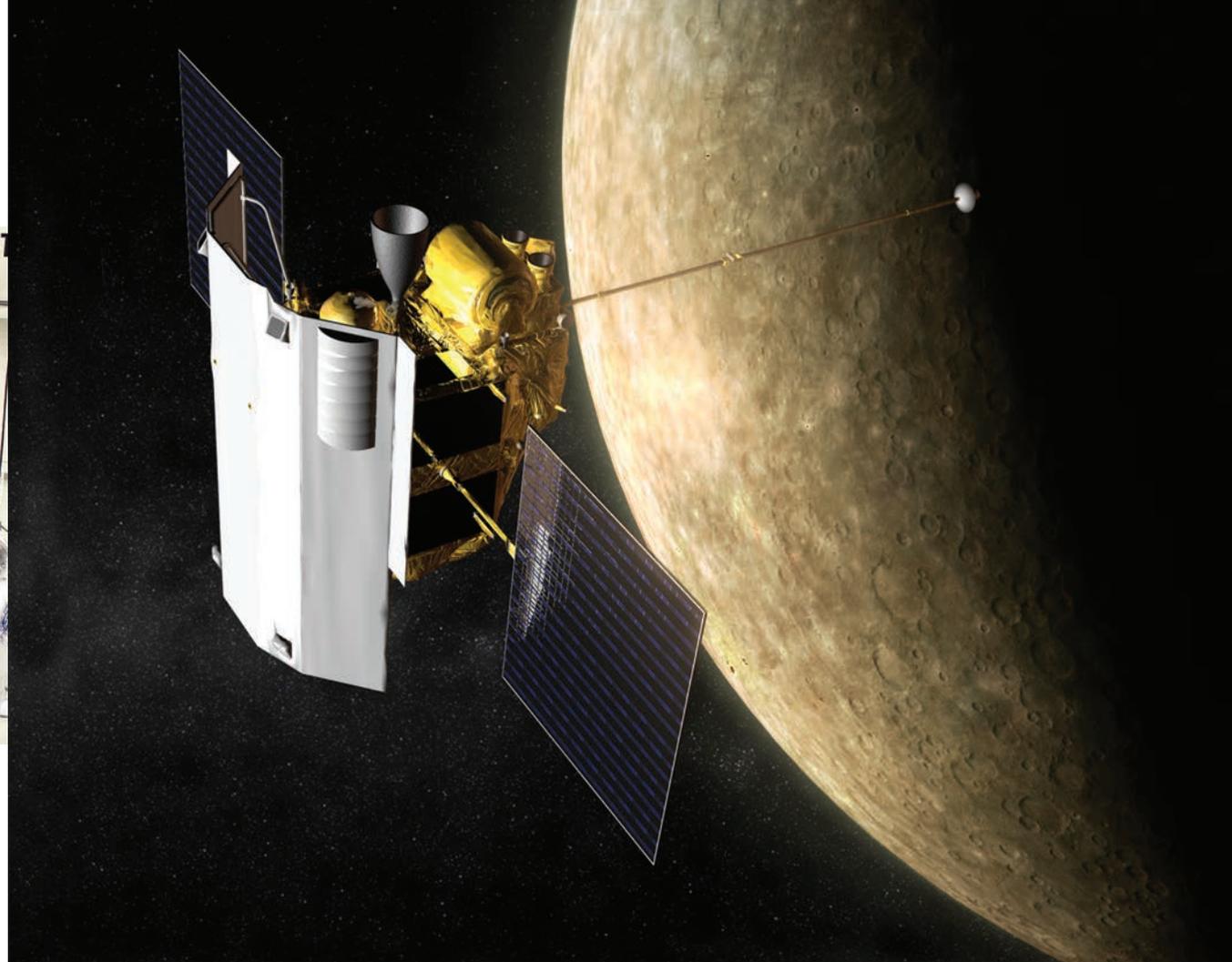
"Kepler's determination that most stars have planets and that Earth-size planets are common provides impetus to future missions that will determine whether many planets have atmospheres compatible with the possibility of life," said William Borucki, Kepler's principal investigator at Ames. "The future science enabled by the Kepler results will be one of the mission's greatest legacies."

In April of 2014, scientists confirmed the existence of Kepler-186f, the first Earth-sized exoplanet ever discovered in its star's habitable zone. Using Kepler data, NASA has determined that a substantial percentage of the star systems in our galaxy contain rocky planets similar in size to Earth. Future missions, such as the James Webb Space Telescope, will build on this discovery by looking for specific attributes of those planets (such as atmospheric composition) that could give us clues regarding the possibility of life on other worlds.





MESSENGER, the first spacecraft dedicated to surveying Mercury, is shown during its construction (left) and depicted in orbit around its target (right).



## Messages from Mercury

In May, the National Space Society (NSS) awarded its Space Pioneer Award for the Science and Engineering category to the team that developed and is also overseeing the Mercury Surface, Space Environment, Geochemistry, and Ranging satellite, also known as MESSENGER—the first spacecraft dedicated to surveying the planet closest to the sun and least explored of the solar system’s inner planets.

The award recognized both the construction of the satellite and the significance of the scientific results

released since the start of its orbit around Mercury in March 2011. Having orbited the planet over 3,000 times, MESSENGER’s findings include confirmations of past major volcanic activity, the presence of water ice and organic chemicals at its poles, and the off-set orientation of the planet’s magnetic field.

“The MESSENGER team is deeply honored to receive this recognition from the National Space Society,” said principal investigator Sean Solomon of Columbia University. “Our engineers have met the profound challenges of inserting a spacecraft into orbit about

Mercury and operating for years in the harsh environment of the inner solar system. And that vantage has permitted MESSENGER to make a series of discoveries that are changing our views on how the inner planets formed and evolved.”

The NSS Awards have been presented every year since 1988 and recognize individuals and teams whose accomplishments have helped open the space frontier.



## Life-Saving Technologies Inducted into Space Technology Hall of Fame

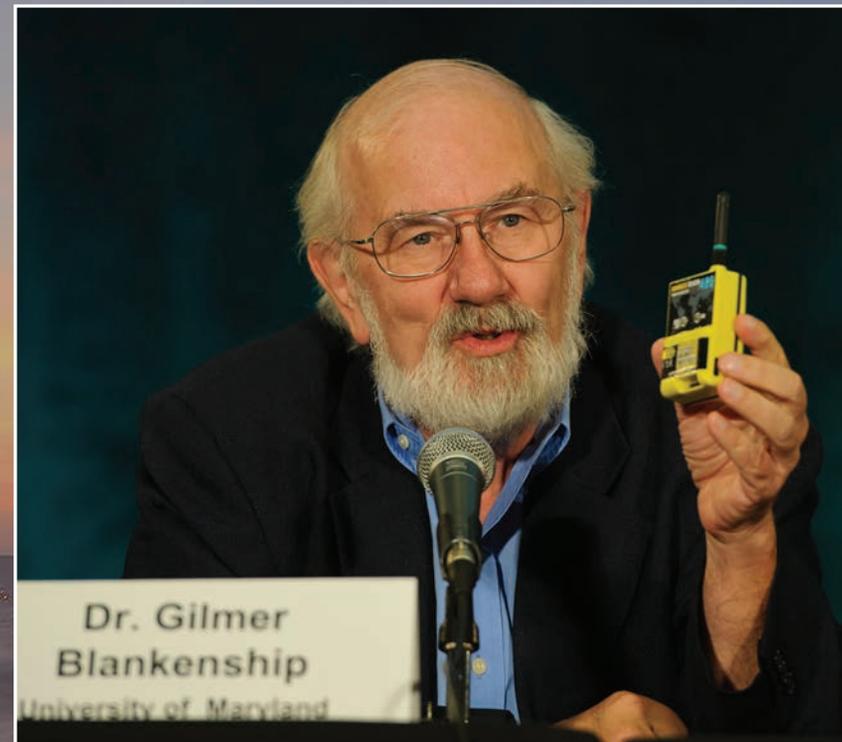
The Space Foundation's Space Technology Hall of Fame inducted two life-saving space technologies in 2014: neuroArm, an image-guided surgical robot arm developed from advances originally made in the creation of the space shuttle and the space station's Canadarm; and Cospas-Sarsat, the international search-and-rescue system developed by NASA, the US and international governments, and commercial partners.

neuroArm began with the search for a device that would allow surgeons to perform surgery while a patient was inside a magnetic resonance imaging (MRI) machine. That meant designing a robot with capabilities similar to the human hand but even more precise and tremor-free. Operating inside the MRI also meant it had to be made entirely from nonmagnetic materials so that it would not be affected by the MRI's magnetic field or, conversely, disrupt the MRI's images.

MDA Inc., the same company that originally worked on the Canadarm for the Canadian Space Agency and NASA, developed neuroArm using technology it has created for space applications since the 1980s. During its research phase, neuroArm has been successfully deployed in dozens of surgeries, including life-saving operations such as removing cancerous tumors from a patient's head. MDA and IMRIS Inc. are now working to further improve the design of the device, seek regulatory approval, and eventually commercialize it for the healthcare market.

Cospas-Sarsat has its origins in a tragic 1972 plane crash in Alaska that resulted in the deaths of two US congressmen. At the time, emergency communications for crashed or stranded planes offered little hope that someone in a position to help would hear and take action. Congress directed that an effort be made to find a better technology for processing and responding to distress calls, an effort that NASA led.

Following partnerships with US government entities, international governments, and commercial partners, NASA helped launch Cospas-Sarsat in 1985. Today, 41 countries participate in the operation and management of the system, and there are more than 1 million registered personal locator beacons worldwide. In the last three decades, more than 37,000 people worldwide have been saved.



Don Blankenship of Techno-Sciences Inc. (TSi) holds up a personal locator beacon while discussing Cospas-Sarsat at a recent NASA forum. TSi builds and operates ground stations that contribute to the international search-and-rescue system.

## Top of the Class, Four Times Over

NASA is often among those recognized in the prestigious R&D 100 Awards, annually presented by *R&D Magazine*, which honor the top 100 revolutionary technologies newly introduced to the market. Over the past few decades, many R&D 100 Award winners have gone on to become household names. For 2013, four NASA technologies made the list, demonstrating the numerous ongoing benefits created through the nation's investment in space and aeronautics research.

### Software Defined Radio

With greater demands for bandwidth and reliability in space communications, NASA has begun to exploit the Ka-band, a range of frequencies typically not used in radio communication but which allow high-speed connectivity for digital video and audio transmission. Glenn Research Center and Harris Corporation have partnered to create a Software Defined Radio (SDR) that is the first fully reprogrammable, space-qualified SDR operating in the Ka-band frequency range. Providing exceptionally higher data communication rates than previously possible, the SDR offers in-orbit reconfiguration, multiwaveform operation, and fast deployment due to its highly modular hardware and software architecture.

Currently in operation on the International Space Station, the technology is being used by NASA to investigate navigation and networking in the space environment. It offers extensive financial and technological benefits for NASA missions, private space communications companies, military applications, and civilian air space safety.

The modular SDR and the NASA Space Telecommunications Radio System (STRS) architecture are the basis for Harris' own reusable, digital signal-processing space platform. In addition, Harris is currently developing new products similar to the Ka-band SDR for military applications and NASA's next-generation Ka-band radio.

### Fiber-Optic Sensing System

Working in partnership with 4DSP LLC, Armstrong Flight Research Center created a fiber-optic sensing system (FOSS) that greatly improves the speed of operational monitoring and sensing. Featured in *Spinoff* 2012, the technology gives access to real-time information about wing shape, stress, temperature, pressure, and strength; and it can enable adjustments to aircraft wings to maximize aircraft performance, affecting everything from safety to efficiency.

To develop the capability to alter the shape of wings during flight, researchers at Armstrong turned to 4DSP for assistance with data processing and algorithms. Thanks to the processing engines inside 4DSP's field programmable gate array, the team was able to perform calculations 15 to 20 times faster than it had done previously.

After achieving real-time processing speeds, NASA recognized the commercial potential of the technology and licensed the fiber-optic sensor system to 4DSP. The company has since created new products with first-of-their-kind processing speeds for a variety of applications in health and medicine, oil and gas, and transportation.



NASA's Ikhana unmanned aerial vehicle served as the test bed for the award-winning fiber-optic sensing system developed with 4DSP.

## Uranium-Based Nuclear Reactor

Another Glenn technology that won an R&D 100 Award is an alternative type of nuclear reactor that uses uranium as a fuel source. Previously, nuclear reactors relied on plutonium; since the end of the Cold War, however, plutonium has become increasingly scarce.

Working with Los Alamos National Laboratory and National Security Technologies, Glenn created KiloPower, a reactor that can produce between 500 and 1,500 watts of electricity for up to 30 years. With KiloPower, it is possible for NASA and other government and industrial organizations to continue developing probes and spacecraft for the exploration of deep space. Other applications include providing power on the surfaces of planets, mobile power for forward-operating bases (of interest to the Department of Defense), and power in remote locations (of interest to intelligence agencies).



A test operator inserts a water-filled heat pipe into a small nuclear reactor to extract fission heat from the uranium core.



Image courtesy of General Motors, CC-BY 3.0.

## Robo-Glove

Robo-Glove, one of the many exciting technologies to come from Johnson Space Center in recent years, is the product of a collaboration between Johnson, General Motors, and Oceanering Space Systems. The wearable device works as a complement to the human grip, empowering the hand and arm to grip with greater force for longer periods of time without fatiguing or causing injury.

The glove uses linear actuators and high-strength polymer tendons that are controlled by pressure sensors located in the fingers of the glove. When the user grasps an object such as a tool, the polymer tendons pull his or her fingers into a gripping position and holds them there until the sensor is released. Algorithms and a microcontroller ensure that the optimal amount of force is supplied by the glove to assist the user.

## Seeing a Flood before It Happens

The Poquoson, Virginia City Council in February awarded NASA's Langley Research Center with a certificate of appreciation for transferring a technology application that maps storm surge predictions. Langley's Flood Impact Analysis Tool uses Geographical Information Systems (GIS) technology to visualize flood maps. GIS is a computerized database management system used for the capture, storage, retrieval, analysis, and display of spatial data. Software generates computer maps and links the underlying data stored in traditional electronic databases to them.

The coastal city of 12,000 residents is situated less than seven feet above mean sea level and is periodically inundated by storm surges. When Hurricane Isabel swept through in 2003, two people died, 50 homes were destroyed, and another 2,000 were severely damaged. As part of its emergency plan, the city educates residents on preparedness and takes steps to mitigate damage from storm surges.

The NASA tool allows the city to show maps visualizing the anticipated areas of flooding on their public television station so that residents can prepare. "We feel very lucky to be able to partner with NASA on this," said the city's engineer, Ellen Roberts. "We are going to use this tool constantly, and it's going to help tremendously with our hazard mitigation planning and engineering analysis."

The Langley GIS team is led by Brad Ball, who noted that the Hampton Roads region of Virginia—where Poquoson is located—is second only to New Orleans in flooding risk from tidal storm surge and sea level rise. Ball credited GIS team members Berch Smithson for taking the lead on the project, Shane Wolf for customizing the application for Poquoson, and Mike Golub for configuring a server to support it.



Background: When Hurricane Isabel hit the area in 2003, the towns near Langley Research Center were inundated. Pictured here is Hampton, Virginia. Inset: Members of Langley's Geographical Information Systems team are presented with a certificate by the city of Poquoson.

## Sun and Earth, Set to Visual Poetry

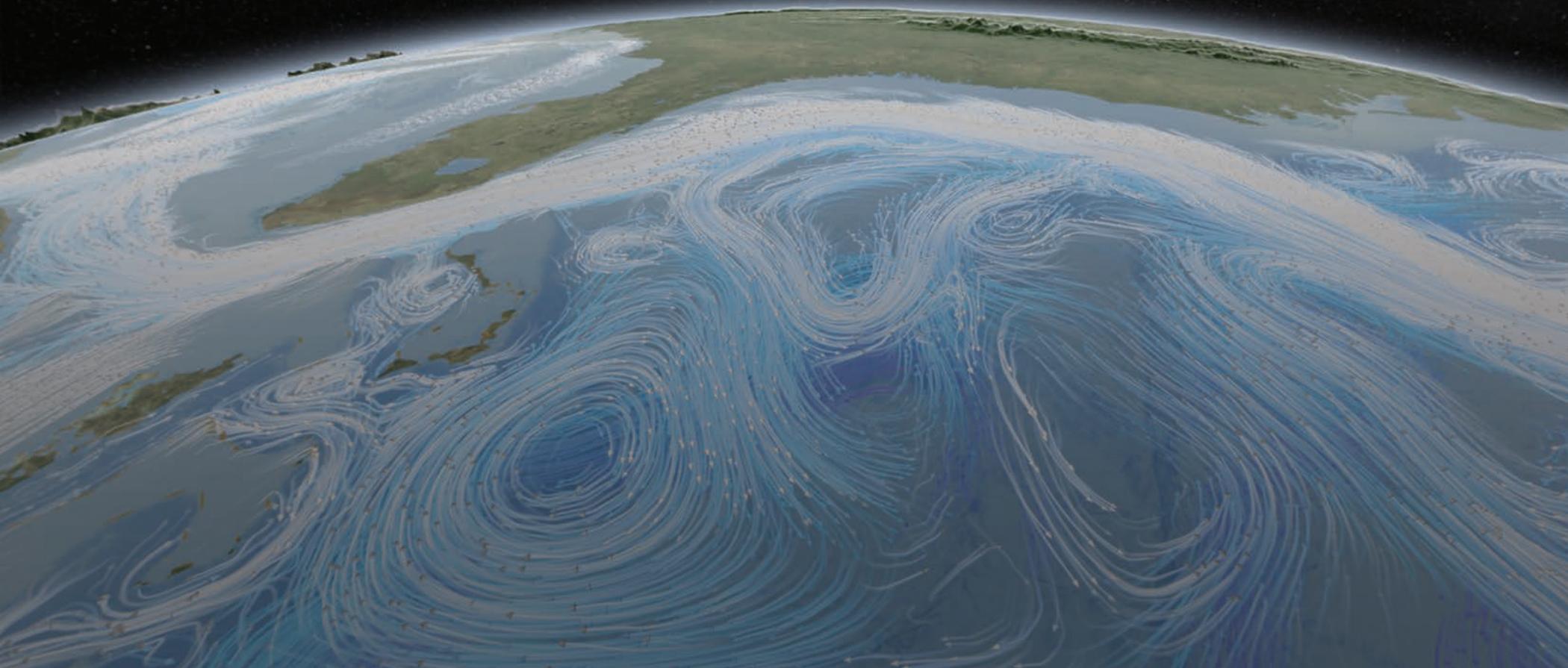
The data visualization studio at NASA's Goddard Space Flight Center in February was awarded first place for its video entry in a visualization challenge sponsored by the journal *Science* and the National Science Foundation. It also won first place in the video category in the 2013 International Science and Engineering Visualization Challenge.

The winning entry was created by the Scientific Visualization Studio (SVS) to show how the particles from solar storms bombard Earth and how the sun's heat energy drives Earth's climate and weather. The sequence was created for a movie called *Dynamic Earth*, a full-length planetarium film narrated by actor Liam Neeson. The film is showing around the world to an estimated viewership of 500,000 people.

While the full movie highlights many aspects of Earth's complexity, the contribution from the SVS depicts the vast scale of the sun's influence on Earth, from the flowing particles of the solar wind and the fury of coronal mass ejections to the winds and currents driven by the solar heating of the atmosphere and ocean. "Moving through these flows gives the viewer a sense of grandeur in the order and chaos exhibited by these dynamic systems," said Horace Mitchell, director of the Scientific Visualization Studio.

The visualization reflects SVS's work in recent years to visualize flows—ocean currents, winds, and the movement of glaciers and ice sheets. By using lines and arrows to represent velocities of water, air, and ice—and in the case of *Dynamic Earth*, the solar wind—the SVS visualizers were able to produce a new way to envision these unseen forces.

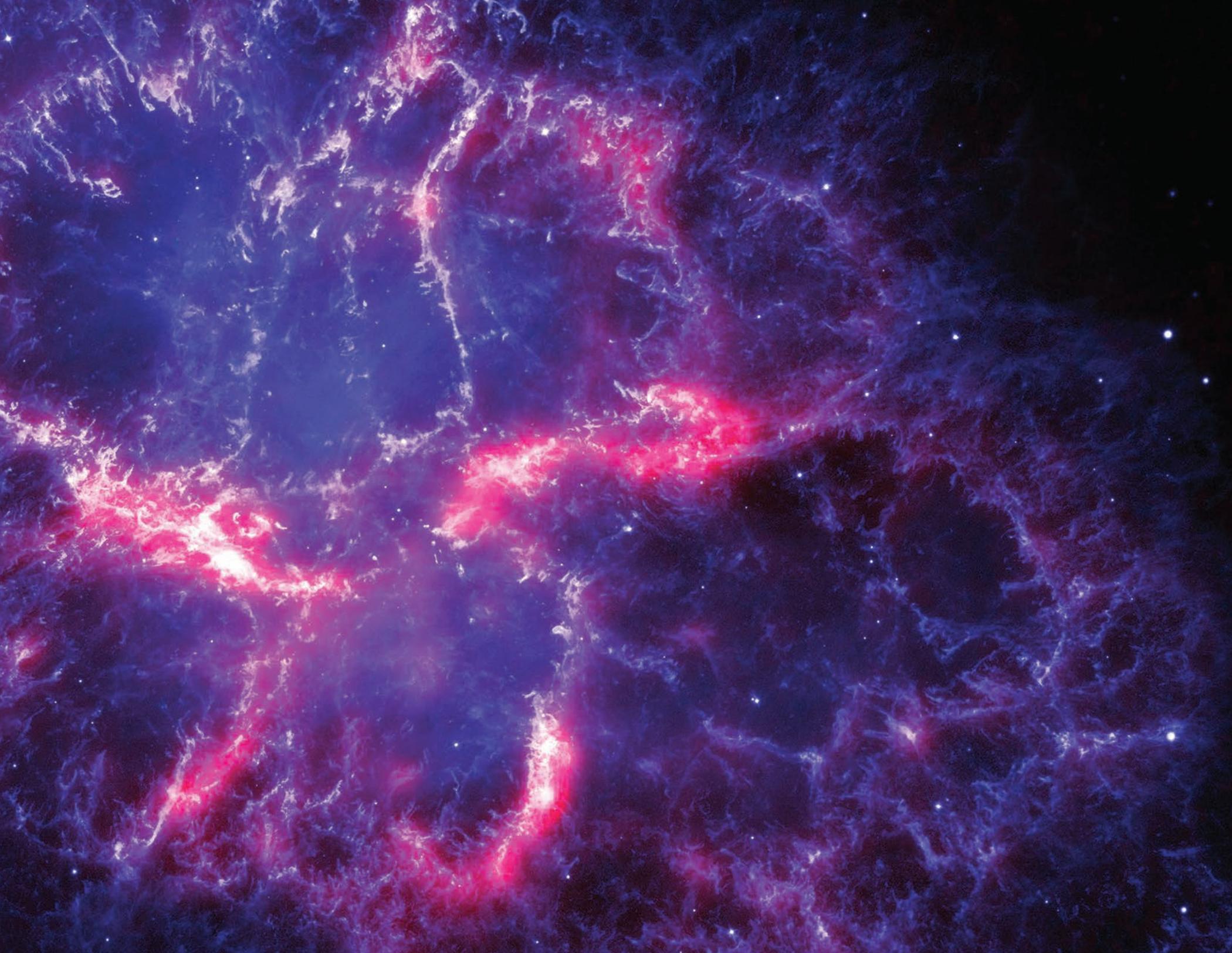
"Usually we visualize things like temperature in the ocean or clouds in the sky. You see these things change, but that's not really visualizing the flow. That's visualizing something reacting to the flow," Mitchell said. "You can't really see currents in the ocean. But in your mind's eye you can picture how the currents would move as arrows or lines. And that's what we developed." ❖



# Spinoffs of Tomorrow

**N**ASA's Technology Transfer Program is working every day to facilitate the transfer of agency technology into secondary applications. Among the program's achievements are a software catalog bringing together more than 1,000 software codes available for license and innovative partnerships with crowdsourcing websites. Included in this section are just 20 of the thousands of technologies that are today available for licensing from the agency.





# NASA's Technology Transfer Program

## Bringing NASA technology down to Earth

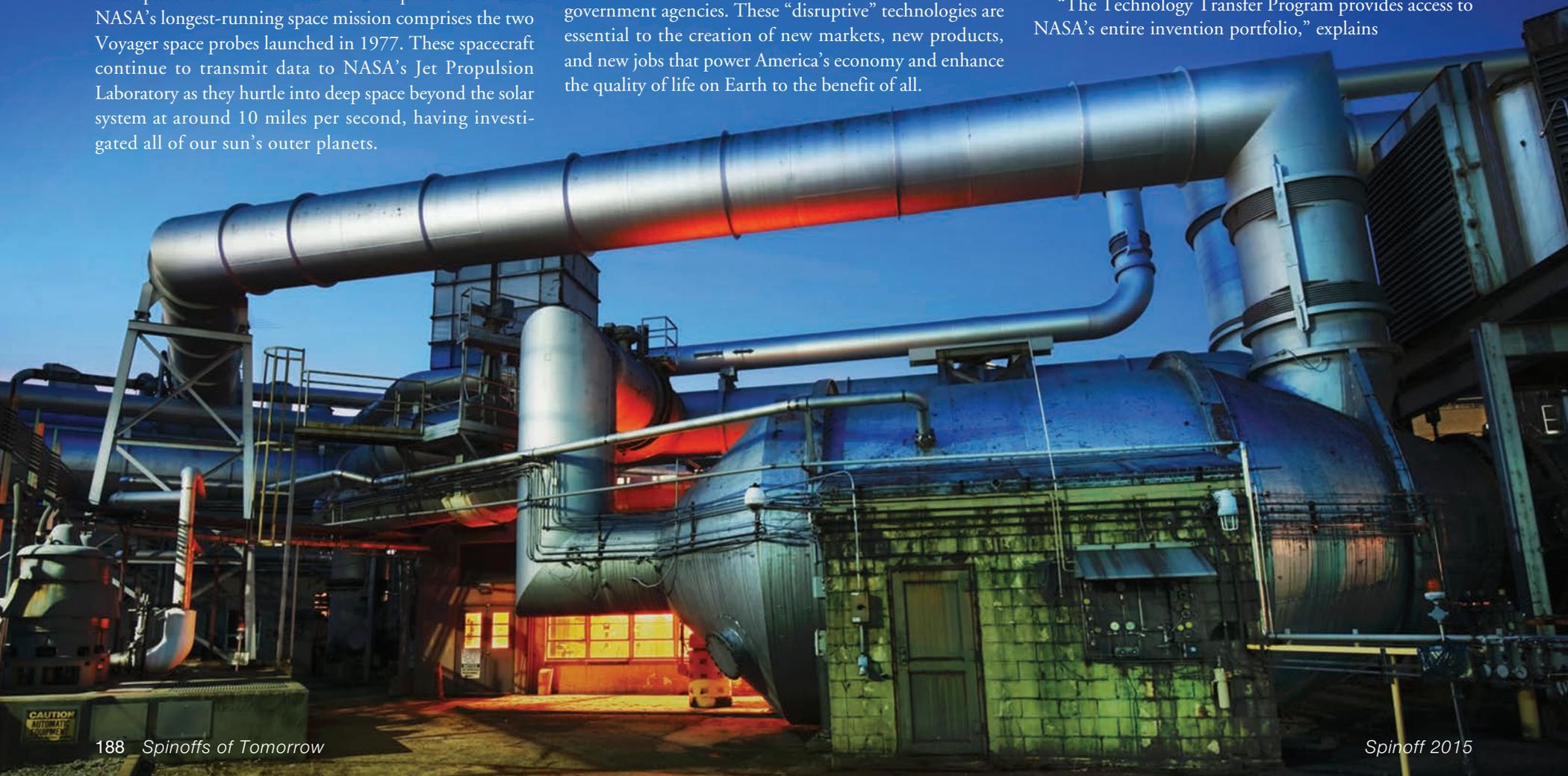
For a relatively young agency, NASA has a remarkable history of long missions. Despite its short, 90-day planned mission, the Opportunity rover, for instance, continues to transit the surface of Mars, inspecting craters and investigating soil and rock samples more than 11 years after it tore through the planet's thin atmosphere and bounced into an impact crater. And NASA's longest-running space mission comprises the two Voyager space probes launched in 1977. These spacecraft continue to transmit data to NASA's Jet Propulsion Laboratory as they hurtle into deep space beyond the solar system at around 10 miles per second, having investigated all of our sun's outer planets.

Then of course there is the decades-long Space Shuttle Program that, among other things, made possible the construction of the International Space Station, itself now continuously inhabited for more than a dozen years and a platform for scientific discoveries.

But NASA's longest continuously running, and arguably most successful, mission isn't in space at all. It's the one that's been working diligently since 1964 to transfer its cutting-edge space exploration and aeronautics technologies to US companies, universities, and government agencies. These "disruptive" technologies are essential to the creation of new markets, new products, and new jobs that power America's economy and enhance the quality of life on Earth to the benefit of all.

Recently, NASA's Technology Transfer Program was reorganized and refocused in response to a 2011 memo from the White House asking federal agencies to redouble their technology transfer efforts. To that end, NASA designed a five-year plan to increase the rate and quantity of its technology transfer activities. Efforts are underway encompassing process improvements, increasing efficiency, lowering access restrictions, and working directly with industry to ensure effective transfer of NASA technology.

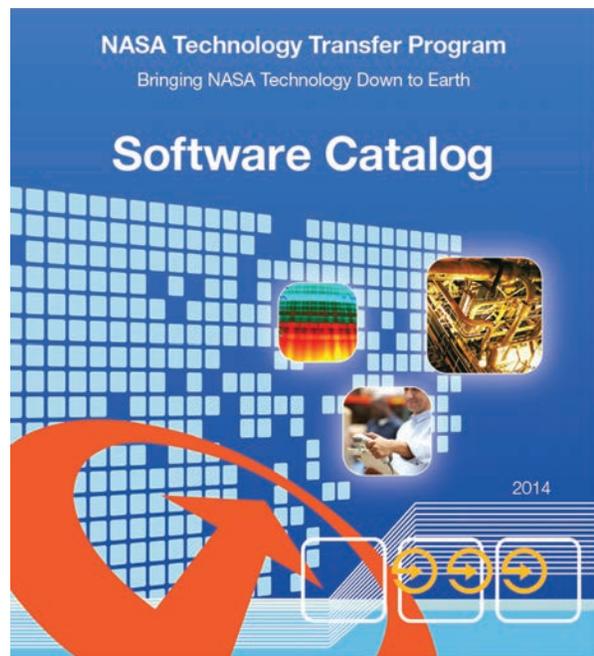
"The Technology Transfer Program provides access to NASA's entire invention portfolio," explains



Daniel Lockney, program executive in the Office of the Chief Technologist at NASA headquarters. “That includes patented technologies with apparent commercial potential, non-patented technologies that may have commercial potential, and software that has a wide variety of industrial, academic, and government uses.”

While that portfolio was always publicly available, most of it was distributed among the agency’s 10 field centers and managed locally. Since 2011, Lockney has overseen consolidation of NASA’s technology portfolio into one body of easily identifiable, searchable categories targeted at relevant industries.

Formerly, the centers engaged in partnerships and technology transfer agreements with companies in their



Opposite page: A water cooling system in Glenn Research Center’s Engine Research Building shields against superheated exhaust that can approach 1,000° F. The exhaust is a byproduct of testing on the latest engine equipment, technology that might one day power space travel and the US economy. Above: The year 2014 saw the release of more than 1,000 NASA codes in one software catalog. Above right: members of NASA’s Technology Transfer Program visiting a rocket test stand at Stennis Space Center in September 2014.



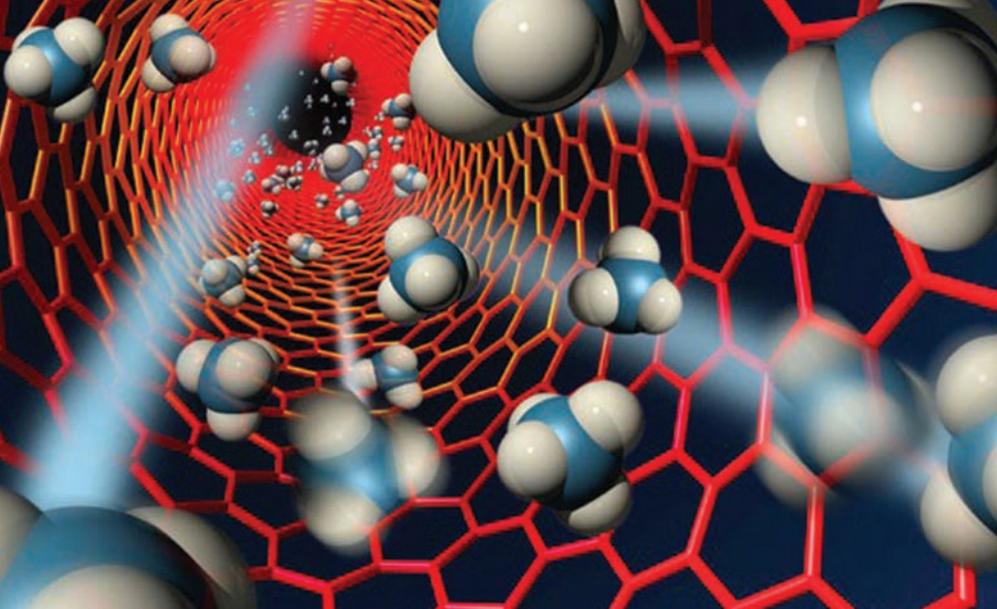
respective regions as part of the agency’s Innovative Partnerships Program. Now, NASA’s Technology Transfer Program features headquarters-coordinated portfolio management, supported by the centers in the identification of new technologies, assessment of commercial applications and feasibility, and determination of best technology transfer vehicles to relevant industries.

The effort took some of its inspiration from *NASA Tech Briefs* magazine, a joint publishing venture between NASA and Tech Briefs Media Group (based in New York City). *Tech Briefs* is the world’s largest-circulation design and engineering magazine, with nearly 200,000 subscribers and about 750,000 monthly readers between print and PDF formats. Each of NASA’s field centers reports its best new technologies to *Tech Briefs*, which organizes them into categories and publishes a number of them each month. Engineers and companies from a wide variety of fields take design ideas from the publication. They can also partner with NASA to further develop agency technologies with commercial potential.

“ We are using some state-of-the-art patent portfolio analysis tools to help us assess the strength, quality, and value of our patent portfolio and to help identify companies that might want to license or co-develop these technologies with NASA.”

— Terry Taylor, Marshall Space Flight Center

“Technology,” Lockney explains, “is geographically agnostic. A company looking for a technical solution is foremost interested in finding the right technology, not necessarily the technology from the nearest field center. Through strategic agency-level management and marketing of our entire technology portfolio, we are



A NASA-invented gas sensor using carbon nanotubes, above left, could find applications in inert gas analysis, thermal conductivity sensing, infrared spectroscopy, and other fields. The Technology Transfer Program just made the patented device available for licensing in 2014. Above right, an Armstrong Flight Research Center flight loads engineer monitors testing of experimental wing flaps that could enable commercial aircraft to be significantly quieter during takeoff, approach, and landing.

ensuring accessibility to the full range of NASA-developed technologies and making it simpler for companies to find the right solutions to their technical challenges.”

“NASA has over 1,600 patented or patent-pending technologies in its portfolio from all 10 field centers,” says Terry Taylor, manager of the Technology Transfer Office at Marshall Space Flight Center in Huntsville, Alabama. “We are using some state-of-the-art patent portfolio analysis tools to help us assess the strength, quality, and value of our patent portfolio and to help identify companies that might want to license or co-develop these technologies with NASA.” Taylor believes that a focused, agency-wide marketing approach to its patent portfolio will dramatically boost licensing and commercialization of NASA’s technologies for all 10 field centers.

“One of the first things we did was release the NASA Technology Transfer portal,” Lockney says. “It’s an agency-level, searchable website where you can find software solutions, patent solutions, and *Spinoff* content.” He says his office is in the process of updating the portal and finding better ways of displaying the technologies, based on feedback from industry and partner companies. For example, the inventions will be categorized according

to the industry needs they meet, rather than just what they do.

This is how the NASA Software Catalog, released in April 2014, is already organized. There, NASA consolidated more than 1,000 of its software codes into 15 clearly defined and readily searchable categories. The codes are available at no cost, although they are designated for different types of release, from programs available to all US citizens to those that can only be licensed to other US government agencies. Again, the software, which ranges from rocket science to project management and robotics, was available prior to the catalog but not always easy to find. By 2016, NASA plans to have the software codes themselves gathered in one place and available for direct download.

In a further effort to transfer its technology both rapidly and cost-effectively to the commercial sector, in November 2013 NASA announced the agency-wide implementation of its new QuickLaunch program developed at Ames Research Center. QuickLaunch makes a set of more than 100 agency technologies available for non-exclusive licensing at pre-established prices and terms.

“It changes the model for licensing,” Lockney says, comparing it to any standard online purchase: “nonexclusive, non-negotiated, upfront fee, downstream royalties and income. We’ve already seen commercial licenses come as a result of it.” By cutting out license negotiations for a specially selected group of patents, QuickLaunch has dramatically simplified the process and significantly decreased the time required to obtain a new license from months to, in some cases, just days.

The agency is also finding new ways to involve the public in discovering viable commercial applications for its technology, including a couple of recent experiments in crowdsourcing and a Technology Transfer University (T2U) program.

In November 2013, NASA announced it would post 40 patents on the website of Marblar, a product development startup, and allow the public to offer ideas and contribute to submitted ideas for possible commercial uses. The Technology Transfer Program hosted an online Google+ hangout where anyone could ask some of the inventors about their technologies. By the summer of 2014, at least one commercial license had been issued as a result of the effort.

Research and testing at Langley Research Center has yielded numerous advances for the airline and aeronautics industries over the years. Here, researchers have sprayed fluorescent oil on a scale model of a futuristic hybrid wing body during tests in one of the center's wind tunnels to allow them to see air flow patterns.



**“We are ensuring accessibility to the full range of NASA-developed technologies and making it simpler for companies to find the right solutions to their technical challenges.”**

— Daniel Lockney, Technology Transfer Program



Above, an algorithm to shorten airline flights designed at Ames Research Center was licensed to Boeing through the Technology Transfer Program. The company now uses it to offer the Direct Routes subscription service to airlines, business aviation, military, and others. Existing complementary metal-oxide semiconductor image sensors were improved at the Jet Propulsion Laboratory with active pixel sensors, and after the technology was licensed it was, at one point, used in one in every three cell phone cameras, right.

More recently, NASA has entered a similar partnership with Edison Nation, another company that seeks product ideas from the public and offers part ownership to those whose ideas succeed. This time, the technology in question, called MindShift by its inventors at Langley Research Center, uses a video-game platform to deliver biofeedback based on the user's psychological state, helping to enhance focus and manage stress.

One of the program's next big efforts is T2U, which has enjoyed an organic evolution that began with a few field centers reaching out to local business schools. Traditionally, business school students working toward master's degrees spend a semester doing market analysis for a product and another semester coming up with a business plan to sell it. Under T2U, NASA provides patented technologies for the students to browse and work with.

Lockney sees multiple layers of benefits in the idea. "For a start, they get the benefit of real-world experience, and we get the benefit of new and creative ideas on how to market our technologies," he says. "Instead of working on fictional widgets, they're analyzing NASA technology, and we have a well-earned reputation for high-tech solutions with proven results and reliability—you know that if NASA built it, it's built really well."

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““ These are tomorrow’s business leaders, and we’re reaching them by the hundreds—and soon thousands—teaching them that NASA and other federal agencies are places to turn to for technology solutions.”

— Daniel Lockney, Technology Transfer Program

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An additional benefit to the arrangement is that the country's emerging entrepreneurs develop an awareness and understanding of the availability of federal assets. "These are tomorrow's business leaders, and we're reaching them by the hundreds—and soon thousands—teaching them that NASA and other federal agencies are places to turn to for technology solutions," he explains.

Even better, Lockney says, some students—product and business plan in hand—will actually decide to license the technology they worked with and start a company to sell it. "These are people with an entrepreneurial

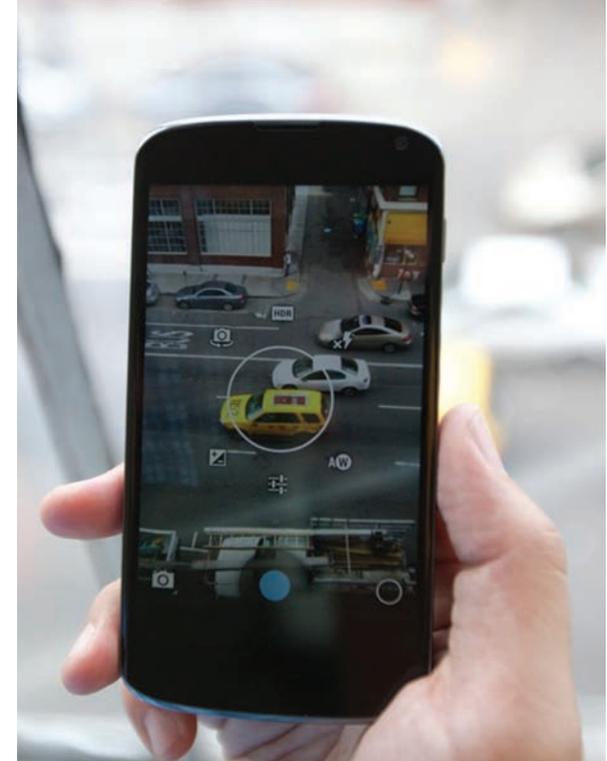


Image courtesy of WIRED, CC BY-NC 3.0

spirit; they're students of business. We suspected that in some instances they would like what they came up with so much they would want to pursue commercial applications." But initially, Lockney and others involved didn't expect that to happen for some time. "I thought we might see it a few years down the road," he concedes. "Then at Kennedy this year, a group of students did it and won an award."

That award recognized a partnership between Kennedy Space Center and Rollins College Graduate School of Business in Winter Park, Florida, as well as Juntura Group, the company that grew out of that relationship to market a sensor technology—also featured in this edition of *Spinoff* (page 148, 178).

Lockney expects others to follow, but he stresses that the primary benefit of the program remains its ability to reach a generation of entrepreneurs and leaders. "Even if they don't do anything with the technology right away, these business leaders will go out into the community, and they'll become advocates for federal research and

development assets. That’s a valuable lesson for them and a long-term benefit for us.”

In light of its early successes, T2U is being expanded to all 10 NASA field centers. For now, the centers will reach out to local schools—for example, Johnson Space Center plans on partnering with Rice University, Langley Research Center with the College of William and Mary, Ames Research Center with the Presidio Graduate School, and so on. But Lockney anticipates that the effort will soon reach out to schools all over the country through a scaled-up version of the program.

Although the Technology Transfer Program at NASA Headquarters is the smallest of any federal agency, it is one of the most active. This is due to a distributed management model where the field centers all take part in managing agency-wide initiatives ranging from policy guidance, streamlining and standardizing processes, building common infrastructure, and designing and launching pilot initiatives.

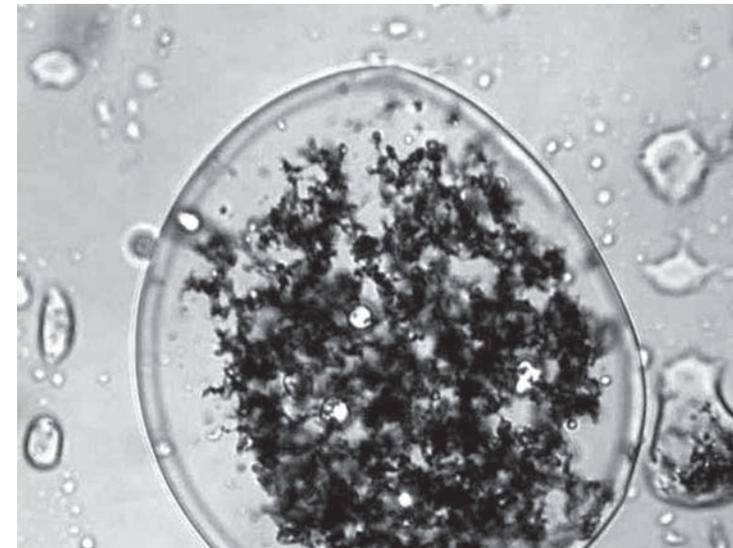
It is through this network of program offices that the Technology Transfer Program continues to drive efficiencies while expanding the avenues by which it leverages its cachet as a hotbed of cutting-edge technology to bring new inventions and software to American industry. Since

2010, between 1,600 and 1,725 new technologies stemming from NASA funding or research have been reported every year, the overwhelming majority of them by small entities outside the government. For each of those years, NASA also processed between 850 and 1,350 software usage agreements.

This is how the technologies that power space exploration missions get additional mileage—by fueling the US economy. “The Apollo Program inspired a generation of young people to learn about science, technology, engineering, and mathematics,” says Lockney. “In the same way, we’re inspiring entrepreneurs and the business leaders of tomorrow by showing them the power and value that NASA technologies have in a multitude of commercial applications.” ❖

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*The following are just 20 of the thousands of NASA technologies currently on offer—two from each field center. For a full listing of available agency technologies, or to download the full software catalog, visit <http://technology.nasa.gov>.*



An air scrubber created at Marshall Space Flight Center for the International Space Station was later licensed for a home air purifier, left, that can remove all kinds of unwanted organic particles from the air. NASA web developers ended up pushing the boundaries of cloud computing in an agency project known as Nebula, top, which with Rackspace Inc.’s help went open source under the name OpenStack. OpenStack is now the world’s largest open source cloud computing platform. The Emulsified Zero-Valent Iron (EZVI), above, invented for environmental cleanup at Kennedy Space Center, has been licensed by numerous companies for groundwater remediation.



# Ames

## Heart Electrical Actions as Biometric Identifier

### Verifying individuals' identities by heartbeat

Everyone has a heartbeat, but no two heartbeats are quite the same. Ames Research Center is offering a new, patented biometric technique that takes advantage of this fact. The center has created a system that can verify a person's identity using his or her heartbeat. Often, one or more biometric indicators, such as fingerprints, voice-recognition, retinal scans, and facial features, are used to authenticate the identity of a user seeking access to a secure resource. Ames' new system can be used for everything from replacing an individual's computer passwords to accessing a bank account.

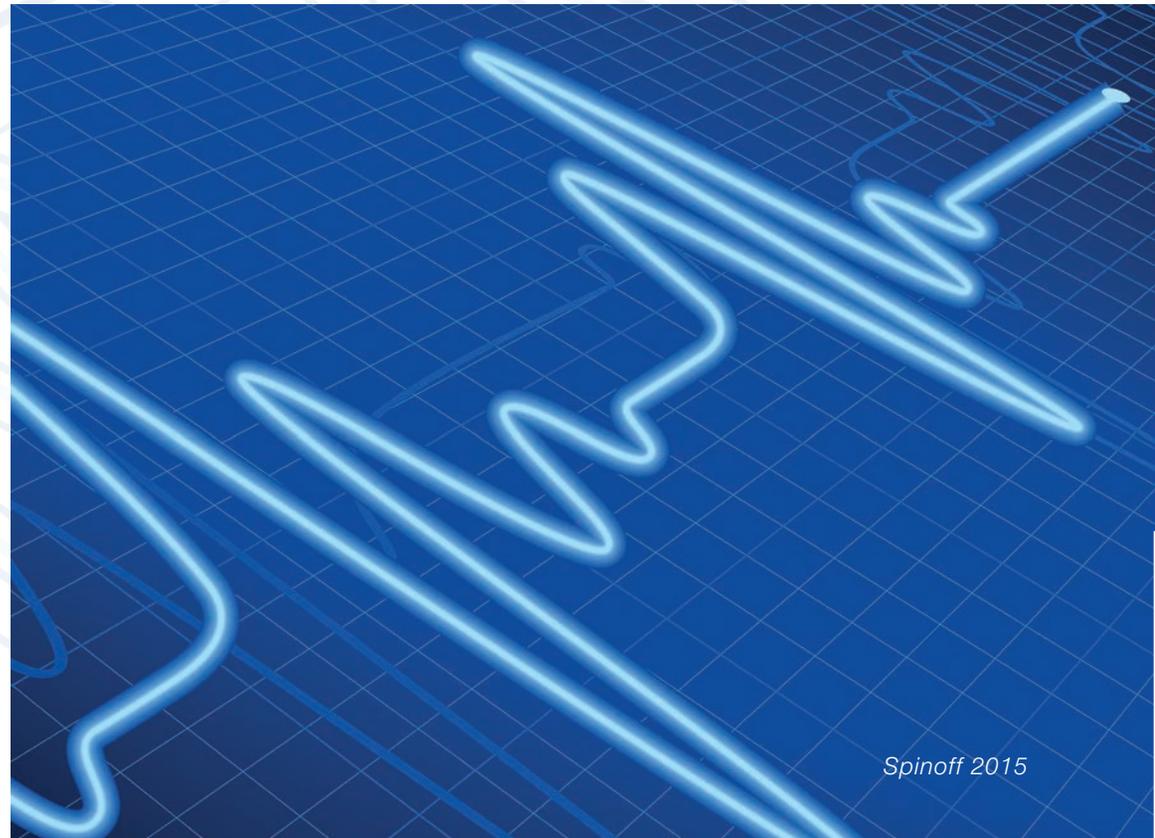
The technology uses more than 190 statistical parameters to analyze the amplitudes, intervals, and vector angles and vector lengths of the depolarization and repolarization of electrical signals associated with heart waves to authenticate or decline a person's asserted identity. In the enrollment mode, the raw electrocardiography (ECG) signal is processed, and the results, in the form of parameters, are serialized and saved. The verification and identification procedures use these parameters for recognition of heartbeats from the ECG signal of a person to be verified or identified.

### Benefits

- Fast and accurate
- Ability to identify whether a subject is already in the database
- User-friendly graphical interface
- Portable enough for use in a mobile platform
- Highly secure

### Applications

- Justice and law enforcement
- Mobile biometrics
- Banks and financial institutions
- Network and computer login security
- E-commerce and web applications
- Homeland Security, airports, and national ID documents



## Contaminated Water Treatment

### Making a fortified drink from urine, other contaminated liquid

**A**mes Research Center has a patented technology available for licensing that offers a novel way of processing and recycling liquids to remove contaminants. Space exploration requires that life-support systems reduce the mass required to keep humans alive. As water accounts for about 80 percent of a human's daily mass intake, recycling water offers a high return on investment.

The invention, created by scientists at Ames Research Center, involves a two-step process. It includes a contaminant treatment pouch—the “urine cell” or “contaminant cell”—which converts urine or another contaminated liquid into a fortified drink, engineered to meet human hydration, electrolyte, and caloric requirements. Osmosis draws the water into the drink, and an activated carbon pre-treatment removes most organic molecules. The salt content of the initial liquid mix helps to transform organic molecules dissolved in the liquid into solid particles, allowing activated carbon to remove most organics. An osmotic bag is then used to remove inorganic contaminants.

### Benefits

- Reduces the amount of potable water that must be carried
- Provides biologically safe, recycled drinking water
- Provides a temporary source of additional nutrients
- Reduces the volume of biological waste stored
- Eliminates the need for urine dumping during space voyages
- Portable and low-cost

### Applications

- Space missions
- Military missions
- Water source for the developing world
- Extreme environments such as hiking, camping, yachting, mountaineering, and Antarctic exploration missions



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Image courtesy of Wikipedia user Acdx, CC-BY 3.0

# Armstrong

## Real-Time Sonic Boom Display

**Interactive display provides pilots, controllers with real-time sonic boom information**

Engineers at NASA's Armstrong Flight Research Center have a Real-Time Sonic Boom Display available for licensing. The technology enables a pilot to control the placement of the deafening sonic boom created when an aircraft passes the speed of sound. The first of its kind, the system can be integrated into a cockpit or flight control room to help pilots place booms away from populated areas by predicting where a boom will hit the ground. It can be used on existing supersonic aircraft, as well as future-generation lowboom aircraft, anticipated to be quiet enough to fly over land.

Factors that influence sonic booms include the aircraft's weight, size, shape, altitude, speed, acceleration, and flight path, along with weather and atmospheric conditions. The Real-Time Sonic Boom Display takes all these factors into account by incorporating 3D Earth modeling and inputs of 3D atmospheric data, calculating the sonic boom and tracing it to the ground to generate a moving-map display that shows the aircraft's sonic boom footprint at all times. It also calculates cutoff altitudes and airspeeds to avoid a boom. A pilot can choose from a menu of pre-programmed maneuvers—such as accelerations, turns, or pushovers—and the predicted sonic boom footprint for that maneuver appears on the map display.

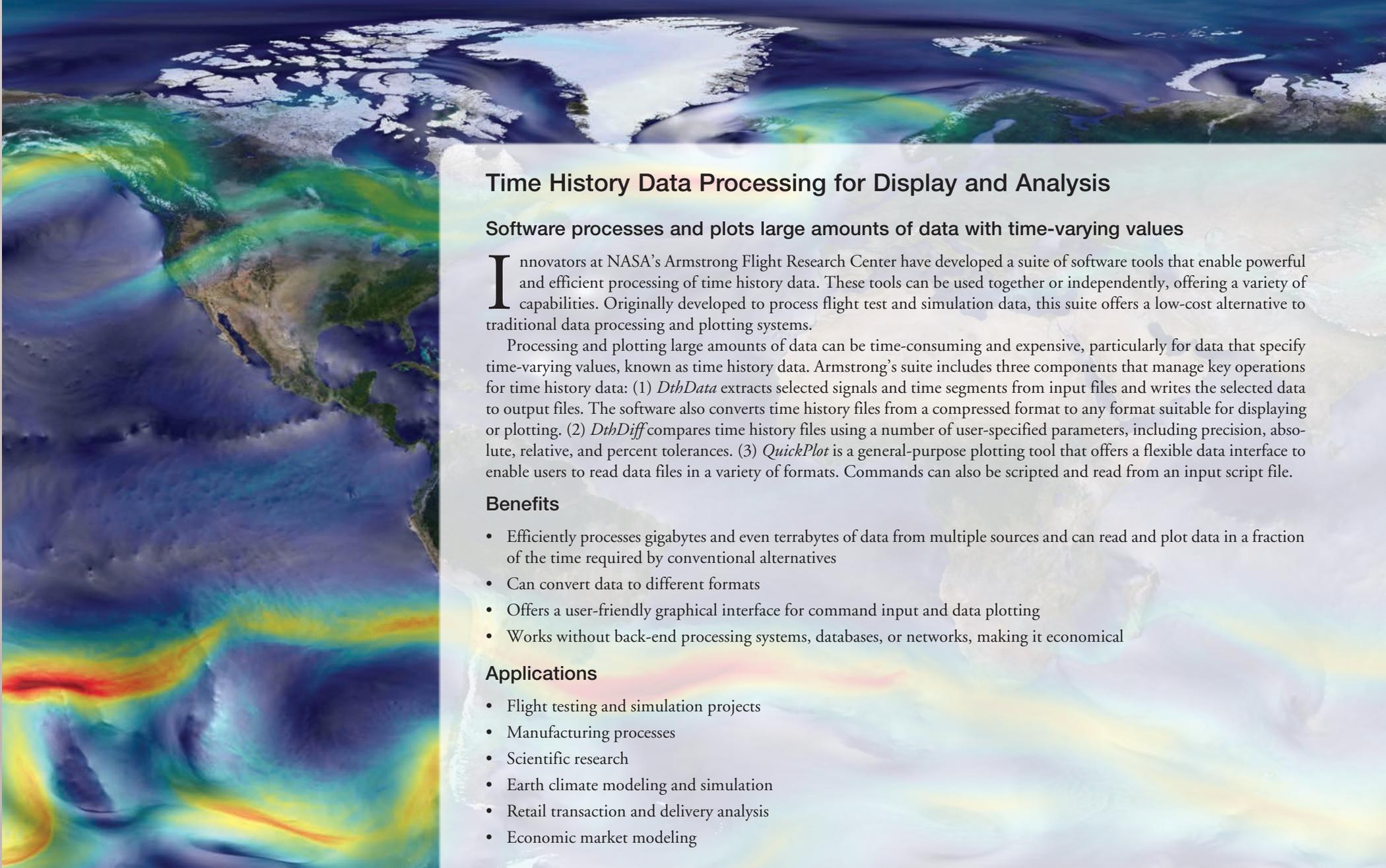
### Benefits

- Works in cockpits and flight control rooms, enabling both in-flight carpet boom predictions and control-room flight planning and analysis
- Reduces noise pollution, allowing for appropriate placement of the boom
- Provides information in real time, allowing pilots to respond to changes in flight parameters or atmospheric conditions

### Applications

- Commercial supersonic vehicles
- Meeting current and future Federal Aviation Administration requirements





## Time History Data Processing for Display and Analysis

### Software processes and plots large amounts of data with time-varying values

Innovators at NASA's Armstrong Flight Research Center have developed a suite of software tools that enable powerful and efficient processing of time history data. These tools can be used together or independently, offering a variety of capabilities. Originally developed to process flight test and simulation data, this suite offers a low-cost alternative to traditional data processing and plotting systems.

Processing and plotting large amounts of data can be time-consuming and expensive, particularly for data that specify time-varying values, known as time history data. Armstrong's suite includes three components that manage key operations for time history data: (1) *DthData* extracts selected signals and time segments from input files and writes the selected data to output files. The software also converts time history files from a compressed format to any format suitable for displaying or plotting. (2) *DthDiff* compares time history files using a number of user-specified parameters, including precision, absolute, relative, and percent tolerances. (3) *QuickPlot* is a general-purpose plotting tool that offers a flexible data interface to enable users to read data files in a variety of formats. Commands can also be scripted and read from an input script file.

### Benefits

- Efficiently processes gigabytes and even terabytes of data from multiple sources and can read and plot data in a fraction of the time required by conventional alternatives
- Can convert data to different formats
- Offers a user-friendly graphical interface for command input and data plotting
- Works without back-end processing systems, databases, or networks, making it economical

### Applications

- Flight testing and simulation projects
- Manufacturing processes
- Scientific research
- Earth climate modeling and simulation
- Retail transaction and delivery analysis
- Economic market modeling



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# Glenn

## Raman Spectroscopy for Combustion Diagnostics

### New method increases signal-to-noise ratio in detection of Raman scattering

Innovators at Glenn Research Center have developed a technology that uses a single charge-coupled device (CCD) sensor to detect Raman scattering from flames, a development that enables more accurate diagnostics of combustion systems such as engines. Measuring changes in chemical composition and temperature in turbulent flames is important for characterizing complex phenomena in most combustion systems, including gas turbine engines, power utility boilers, and internal combustion engines. A given spectrum of Raman scattering—inelastic light scattering from excited molecules—indicates what molecules are present and their state of excitement. Identifying this spectrum is a popular method of examining flames.

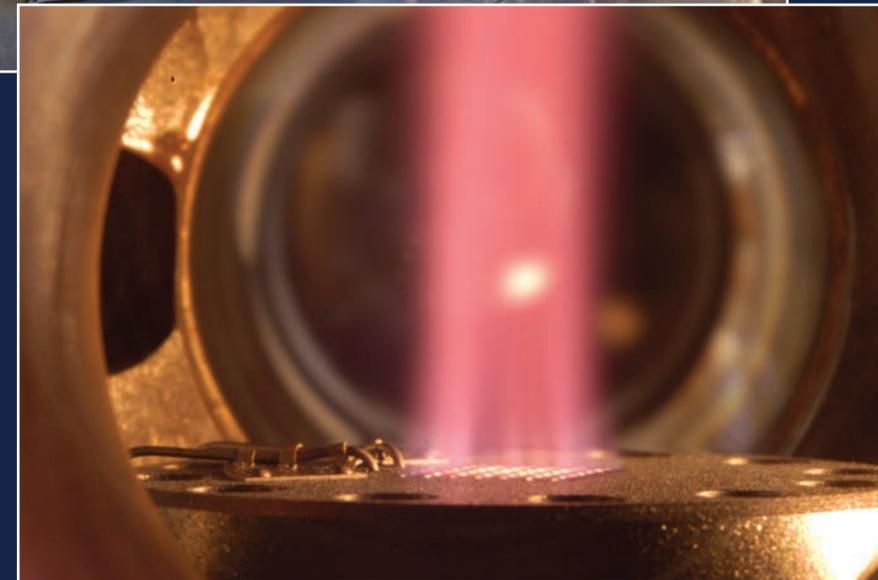
Glenn's new diagnostic technology represents an entirely new method for conducting this sort of spectroscopy and employs two key optical devices: a nanosecond-pulsed laser and a frame-transfer CCD sensor. The technology permits not only faster optical gating but also high optical throughput, resulting in a significant increase in signal-to-noise ratio. It much more effectively isolates Raman scatter from any interferences or background. It could potentially benefit the development of advanced combustion engines for aerospace, defense, and commercial systems.

### Benefits

- Enables Raman signal measurements for more accurate combustion diagnostics without image intensifiers or mechanical shutters
- Features fast, efficient electronic gating for spectroscopy, with no mechanical moving parts required
- Enables Raman spectroscopy resolved for time, space, and polarization with a single sensor and a single collector but without loss in the detection train

### Applications

- Gas turbine engines
- Internal combustion engines
- Power utility boilers





## Shape Memory Alloys

### Compound Metals for Heat-Sensitive Applications

**N**ASA's Glenn Research Center invites companies to partner in investigating applications for shape memory alloys (SMAs). SMAs are materials that can be deformed at low temperature and recover their original shape upon heating. Glenn has been working to develop new alloys that can operate up to around 300 °C, compared to the limit of around 80 °C in commercially available alloys. NASA has also been working on supporting technologies—such as modeling tools, design methodologies, test standards, and material supply chains—that will promote the application of shape memory alloys for adaptive structures and actuators.

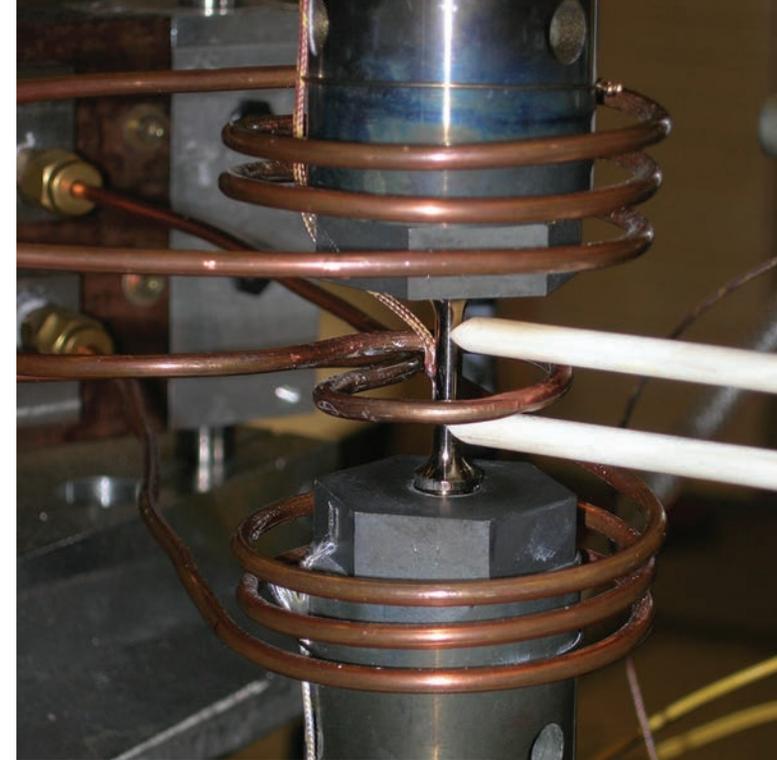
Applications of SMAs have been limited due to their low transformation temperatures. As a result of its work in this field, Glenn has developed expertise, a suite of high work-output SMAs, and design tools for the materials. SMAs can be used in passive, active, or super-elastic design applications. Passive design applications result from the material heating during normal operation and returning to its original form, resulting in an actuation force. Active design applications use the material below its transformation temperature and use supplemental heat to provide an “on-demand” actuation force. Superelastic design applications use the material above its transformation temperature and transform it through stress. SMAs are ideal for high-force, large-stroke, and modest-frequency response operations and can be used to replace larger, costlier actuators such as motors.

### Benefits

- Provides high force, allowing lightweight, compact actuator designs
- Eliminates extraneous systems such as hydraulics, pneumatics, and motors
- Allows passive control by responding to temperature changes, eliminating the need for sensors and electronics
- Simple, frictionless designs result in less maintenance

### Applications

- Automotive industry
- Aeronautics industry
- Aviation industry
- Robotics industry



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# Goddard

## AeroPod Test and Measurement Technology

### Aerodynamically stabilized instrument platform for kites and tethered blimps

The AeroPod, created by innovators at Goddard Space Flight Center and now available for licensing, is a passive device that uses aerodynamic forces to stabilize an instrument package suspended from a kite or tethered blimp. It is a low-altitude, remote-sensing craft designed for, but not limited to, agricultural and environmental research purposes.

The AeroPod's design for steadying and damping payloads includes the use of a tail boom and fin combination. The design provides a simple alternative to traditional methods for suspending equipment from kites or blimps, such as the classic "Picavet" pulley-style suspension system for kite flight, because it is lightweight and simple to construct, and it has no moving parts. It is also superior to the traditional, tethered-blimp suspension technique because the AeroPod is free of direct motions of the tether. It can accommodate various instruments, including cameras, weather meters, and pollution sensors, among others.

### Benefits

- Lightweight and simple to construct, with no moving parts
- Useful for a variety of remote-sensing and in-situ observations from low-altitude kites or tethered blimps
- Unique features and geometry allow for many different-sized instruments, even bulky ones
- Lower cost than other remote-sensing and observation techniques

### Applications

- Crop monitoring
- Observing and documenting forest canopy and cover
- Wetland studies
- Archeological and geological mapping
- Urban pattern mapping



## Molecular Adsorber Coating

### Capturing outgassed volatiles using a simple spray coating

**M**any materials contain gases trapped on or within the surface that escape over time, a process known as outgassing. To address outgassing, NASA has historically used zeolite-based molecular adsorbers—adsorption being the adhesion of atoms, ions, or molecules to a surface—in spacecraft and instruments to trap molecules outgassed from potting compounds, epoxies, lubricants, and other spacecraft materials, protecting contamination-sensitive surfaces. Uncontrolled molecular contamination can degrade a wide variety of systems.

As an alternative to previously flown, complex adsorber puck systems, Goddard Space Flight Center has developed a set of molecular adsorber coatings (MAC). MAC is a zeolite-based coating that traps molecules in its microscopically porous structure. It provides a large surface area-to-mass ratio that maximizes trapping efficiency, and it works in air as well as vacuum systems. The sprayable coatings eliminate the weight, size, and hardware needs of puck-type adsorbers, resulting in savings in cost and mass. They are easier to use and provide for a greater adsorber surface area, more flexibility, and higher efficiency.

Potential ground-based spinoffs include applications where contaminants and volatiles need to be collected and contained.

### Benefits

- Five times better adsorption than other coating slurries
- Coats virtually any surface
- Based on inexpensive, commercially available chemicals, MAC can easily be applied with simple, water-based spray techniques

### Applications

- Pharmaceutical production
- Food industry
- Electronics manufacturing
- Laser manufacturing
- Vacuum systems
- Chemical processing
- General gas and water adsorption



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# Johnson

## Flash Infrared Thermography Software

### Imager accurately measures defects in surfaces, subsurfaces

Researchers at Johnson Space Center have developed an effective, cost-efficient, infrared flash thermography software program capable of detecting anomalies such as voids, cracks, and delamination in composite and metallic structures. This software accurately measures flaw depth, width, and diameter.

In infrared thermography, a pulse of infrared light is directed onto a material, and the reflection generates an infrared image. If a defect is present in the subsurface of the material, heat directed at the front surface is impeded relative to the surrounding regions, and variations in the material show up as anomalies in the image. This analysis uses the evolution of measured pixel intensity over time and compares it with a calibrated empirical simulation to evaluate anomaly depth and size.

Currently available commercial thermography software does not distinguish between image contrast and temperature contrast and therefore provides less accurate characterization of defects. And because this software normalizes data, it provides more stable measurements and greatly minimizes errors due to operator variability.

### Benefits

- Provides detailed characterization of a flaw's shape, size, depth, and location
- Provides objective, repeatable numerical measurements of subsurface anomalies
- Normalizes data, which reduces errors due to operator and equipment variability
- Can be used to analyze composite or metallic materials and flat or curved surfaces
- Can be incorporated easily and inexpensively into existing equipment

### Applications

- Aerospace: aircraft wings and propeller blades
- Power generation: turbine blades and pipelines
- Manufacturing: welds, adhesive joints, and semiconductors
- Chemical and petrochemical industries
- Infrared camera manufacturers



## Portable Communications Signal Booster

### Fresnel ring in fabric can configure as umbrella, window shade

Innovators at Johnson Space Center have invented a portable communications signal booster that is currently available for licensing. Originally designed to improve communications for lunar missions, this lightweight, portable device can boost incoming signals to improve local reception for cell phones, laptops, and satellite and wi-fi receivers without power plugs, cables, or batteries. The signal booster can be configured as an umbrella or window shade for easy deployment and compact storage. It has the flexibility to be designed in different shapes and sizes to offer variations in booster strength and degree of directional focus.

This innovation integrates the classic “Fresnel ring” model into a conductive fabric structure. The result is an ultralight, deployable device that acts as a lens to significantly enhance the realizable gain of an antenna. The Fresnel ring is shaped to cancel specific phases of the signal. This makes more desirable parts of the signal more prominent. A round, medium-sized unit could expect to increase signal gain in all directions by about 7 decibels. A larger, elliptical-shaped unit could expect to increase signal gain in a focused direction by up to 15 decibels.

### Benefits

- Creates a 7-15 decibel gain increase
- Requires no physical connection to wireless devices, no power plugs or batteries
- Compact, portable, and lightweight
- Easy to set up, easy to store
- Simple, low-cost manufacturing

### Applications

- Military
- Remote industrial
- Logistics
- Home and work
- Field work
- Travel
- Emergency and rescue

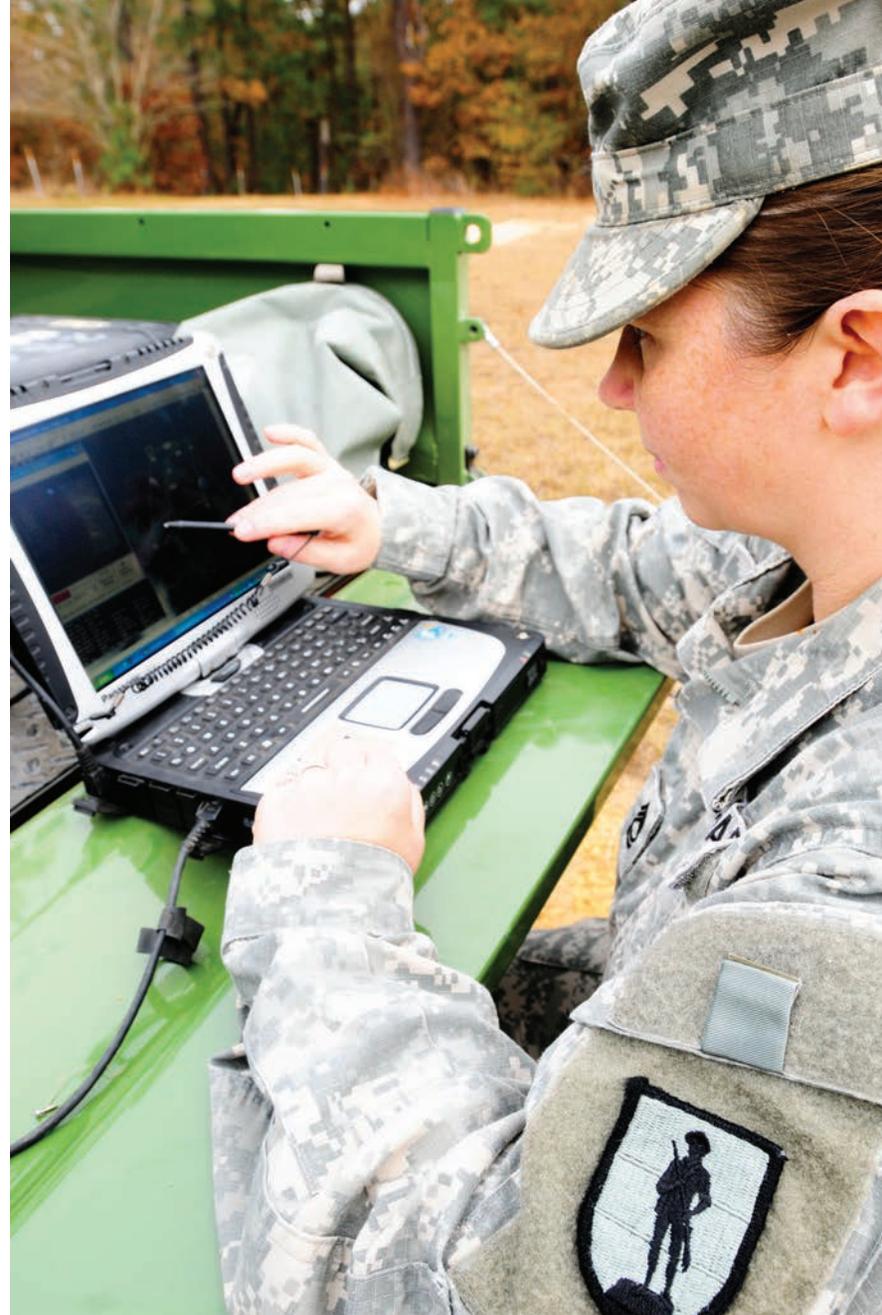


Image courtesy of US Army



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# Kennedy

## Redeployable Polymer Blanket for PCB Removal

### Onsite remediation of PCB-contaminated sediment

Scientists at Kennedy Space Center have developed a novel method for the onsite removal of polychlorinated biphenyls (PCBs) from sediment systems, and the center is offering licensing or partnering opportunities in the development and commercialization of this technology. PCB is a synthetic organic compound, once widely used in industry but now classified as a pollutant. Current methods for removing PCBs from sediments, however, are severely limited.

The invention is designed to be deployed in rectangular segments that can be hooked together to form a blanket. The bottom of a segment is molded from polymer and contains hollow, star-shaped spikes, to which metal tips can be added to help penetrate the sediment, into which the blanket is inserted. The top of the segment has a hermetically sealed opening through which an environmentally friendly solvent, such as ethanol, is introduced. The blanket's spikes attract PCBs through the polymer into the solvent until equilibrium is achieved. The blanket is then removed from the sediment, and the now PCB-laden solvent is drained. The solvent is then treated using a derivative of a NASA-patented PCB treatment technology—the activated metal treatment system—to break down the PCBs into benign by-products. The blanket can then be decontaminated, refilled with fresh solvent, and deployed again.

### Benefits

- Low cost
- Contaminants cannot be reintroduced into the water table
- Eliminates PCBs rather than containing or relocating them

### Applications

- Cleanup of PCB-contaminated sediment
- Conformance with Environmental Protection Agency regulations



## Smart Coating for Corrosion Detection and Protection

### Formulated particles detect corrosion and stop it

**K**ennedy Space Center seeks partners interested in the commercial application of smart coating for corrosion detection and protection. Researchers at Kennedy have developed a smart, environmentally friendly coating system for early detection and inhibition of corrosion and self-healing of mechanical damage without external intervention. This coating will have the inherent ability to detect the onset of corrosion in the coated object and respond autonomously to control it.

The high salt content, sunlight, heat, and humidity of Kennedy's environment makes it the country's most corrosive area, according to the American Society of Metals. These conditions are exacerbated at the center's launch pads by extreme heat and acidic exhaust from the solid rocket motors of space vehicles.

The smart coating is based on the controlled release of corrosion inhibitors and indicators from specially formulated microcapsules and particles. The corrosion-responsive microcapsules detect the chemical changes that occur when corrosion begins and respond by releasing their contents. A corrosion indicator will identify the affected region with a color change, and healing agents and corrosion inhibitors help mitigate the corrosion. The microcapsules can be tailored for incorporation into different coating systems.

### Benefits

- Autonomous, early corrosion detection and protection
- Environmentally friendly
- Self-healing of mechanical damage
- Reduces inspection times and repair work
- Improves safety by preventing failures due to corrosion

### Applications

- Bridges
- Automobiles
- Ships
- Pipes and other infrastructure
- Machinery
- Airplanes

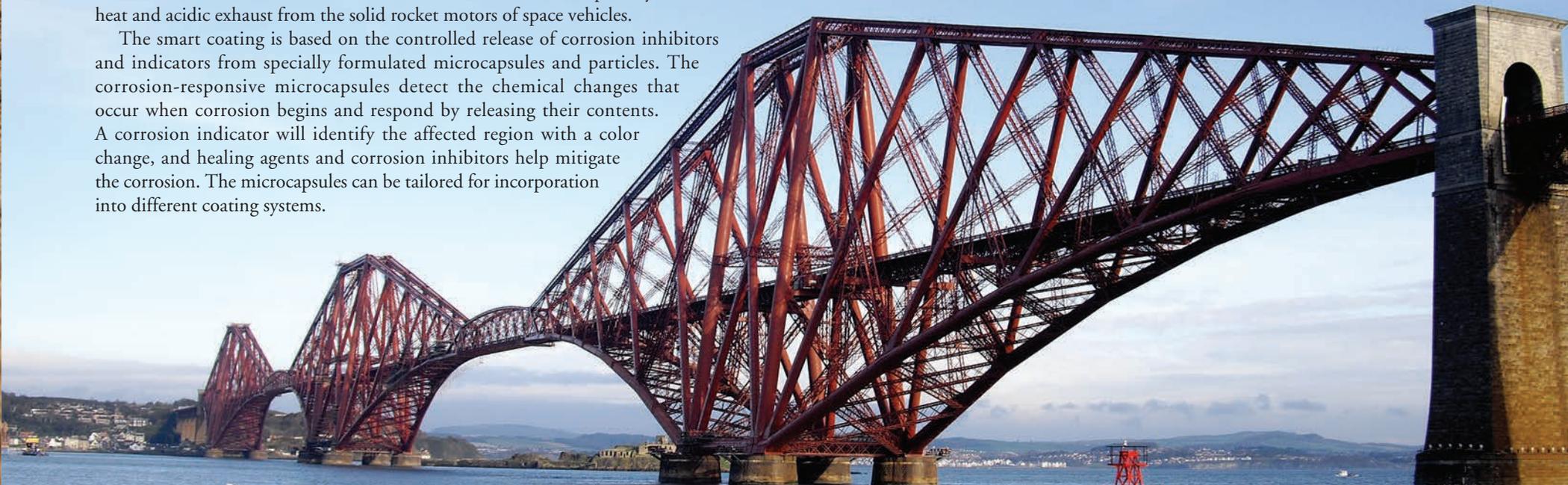


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# Langley

## Particle Contamination Mitigation Methods

### Surface properties resist dust, water

Researchers at Langley Research Center have developed methods for particle contamination mitigation, originally intended for use during exploration missions to destinations such as the moon, Mars, and asteroids. During past missions, lunar dust caused an array of issues, including compromised seals, clogged filters, and abraded visors and spacesuit surfaces. Lunar dust was also a significant health concern. Langley's methods for particle contamination mitigation include both controlled chemical and topographical modifications. These methods offer a wealth of applications and commercial opportunities. The technologies include films, coatings, and surface treatments with antifouling, dust resistance, hydrophobic, super-hydrophobic, low adhesion/friction, and self-cleaning characteristics.

NASA's two novel methods include both controlled chemical and topographical modifications—and they can be used individually or in combination to create superhydrophobic surfaces. First is a polyimide coating with added oxetane reactant containing fluorine, which provides a unique surface chemistry that mitigates particle adhesion and fouling. The second is a method that uses lasers to create nanoscale patterns in the surface of the material in such a way that it increases the surfaces hydrophobicity. The method is fast and single-step; it is scalable, requires no chemicals, and can be applied to a variety of materials.

### Benefits

- Antifouling
- Dust-resistant
- Hydrophobic to superhydrophobic
- Low adhesion/friction
- Self-cleaning

### Applications

- Biological templating
- Biomedical devices
- Corrosion and stain resistance
- Drag reduction
- Reduced ice and water adhesion
- Reduced insect adhesion on aircraft and automobiles
- Marine antifouling coatings
- Microfluidics
- Self-cleaning of many kinds of surfaces
- Sensors
- Surface-specific chemical sensing



Image courtesy of Flickr user Tarakawho, CC-BY 2.0

# Compact Active Vibration Control System

## Point sensor and piezoelectric actuator reduce vibration in flexible structures

Langley Research Center has developed a point sensor and piezoelectric actuator system to sense and actively reduce vibrations in flexible structures. Piezoelectric material generates vibration in response to an electrical field, and it also generates electricity when mechanical pressure is applied. Miniature accelerometers in the system sense vibration in the structure and feed signals to control circuits that amplify the signal. Interlocking electrodes in the actuator apply a charge across the piezoelectric material, causing compressive stress contrary to the vibration of the structure.

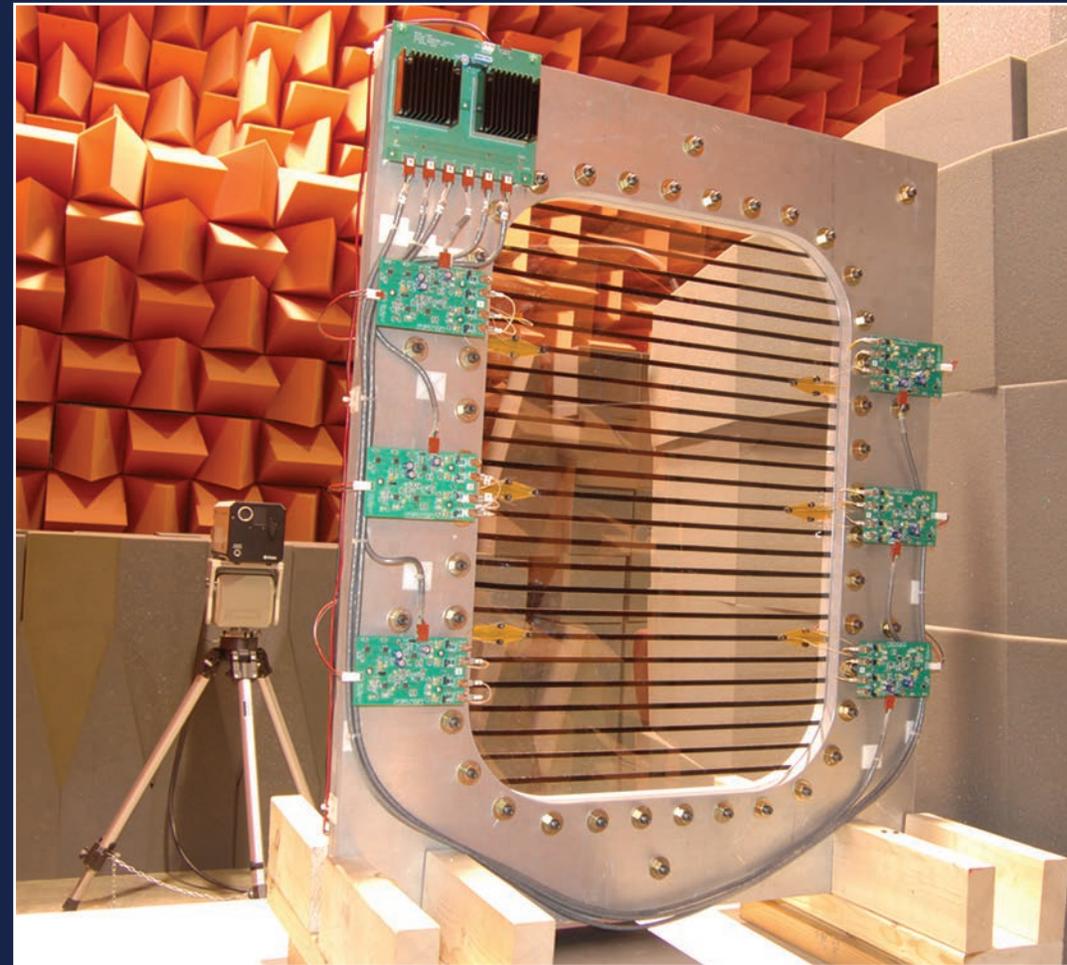
The size and placement of the actuator can be optimized to allow for a broad operating bandwidth or can be focused on a more narrow range of problem frequencies. It is effective at frequencies ranging from 500 to 3,000 hertz. The system's compact, lightweight design features a Macro Fiber Composite actuator weighing less than half a gram, made possible by a technology developed at Langley and licensed to Smart Material Corporation in 2002. The compact design allows for the actuator to be mounted on a surface or incorporated within the structure.

### Benefits

- Compact, lightweight design
- Simple, 28-volt electronics
- Effective operation over a broad frequency range
- Improved actuator geometry and design offers precise coupling with vibrating structure and better control, especially at high frequencies
- Versatile sensor and actuator array can be located anywhere on the flexible structure

### Applications

- Reduce vibration and noise in commercial helicopters or airplanes
- Stabilize large, flexible space structures
- Reduce noise radiation from vibrating panels during manufacturing
- Stabilize optical components or other sensitive machinery in electronics



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# Marshall



## NASA-427 Aluminum Alloy

### New metal has improved toughness, speeds heat treatment

Researchers at Marshall Space Flight Center have developed a new, stronger aluminum alloy, ideal for cast aluminum products that have powder or paint-baked thermal coatings. The NASA-427 alloy shows greater tensile strength and increased ability to bend without breaking, providing substantial improvement in impact toughness. This alloy also improves the thermal coating process by decreasing the time required for heat treatment. With improvements in both strength and processing time, the alloy allows for reduced materials and production costs, lower product weight, and better product performance. The superior properties of the alloy can benefit many industries, including automotive, where it is particularly well-suited for use in aluminum wheels.

This technology uses precise chemistry to improve the mechanical properties of cast aluminum products. It also offers improved corrosion resistance, meeting or exceeding the performance of A356-T6 alloy, as well as offering significant cost savings over forging 6061-T6 alloy when elongation is less than 7 percent. Because of its superior tensile strength, coupled with significant process improvements, NASA-427 yields energy and cost savings for both the manufacturer of cast aluminum components and the end-user.

### Benefits

- Improvements in tensile strength and ductility result in high-impact toughness
- Lightweight, as a stronger alloy means less aluminum is required
- Reduced materials cost
- Energy efficient, due to shorter processing time
- Meets or exceeds the corrosion resistance of other commonly used alloys

### Applications

- Aluminum wheels
- Control arms
- Steering knuckles
- Brake calipers
- Automotive cross members
- Differential carriers

# Fluid Structure Coupling Technology

## Uses existing liquid stores to reduce vibrations in large structures

**M**arshall Space Flight Center's Fluid Structure Coupling (FSC) technology is an efficient, passive method to control the way fluids and structures communicate and dictate the behavior of a system. An FSC device developed at Marshall and weighing less than 200 pounds has successfully mitigated a potentially detrimental resonant response of a 650,000-pound structure. This technology has the demonstrated ability to mitigate various types of vibration issues and can be applied anywhere where internal or external fluids interact with physical structures. For example, in a multistory building, water from a rooftop tank or swimming pool could be used to mitigate seismic or wind-induced vibration by simply adding an FSC device that controls the way the building engages the water.

FSC is a passive technology that can operate in different modes to control vibration. In harmonic absorber mode, the fluid can be leveraged to act like a classic harmonic absorber to control low-frequency vibrations. Alternately, the device can couple itself into the shell mode and act as an additional spring in the series, making the entire system appear dynamically softer and reducing the frequency. In tuned mass damper mode, a small modification allows the device to act like an optimized, classic, tuned mass damper, enabling the primary structure to take unmitigated system response on the damping characteristics of the FSC device.

### Benefits

- Passive device
- Minimized size and weight by leveraging existing fluids
- Inexpensive and easy to retrofit to existing fluid systems
- Reduced complexity, with control achieved with a single fluid source
- Highly efficient

### Applications

- Multistory buildings, stacks, towers, bridges, pools for spent nuclear fuel
- Offshore oil rigs, above-ground oil storage tanks
- Water tanks and towers
- Control of vibration from wet wings and sloshing fuel in aircraft
- Stabilization of marine vessels or platforms

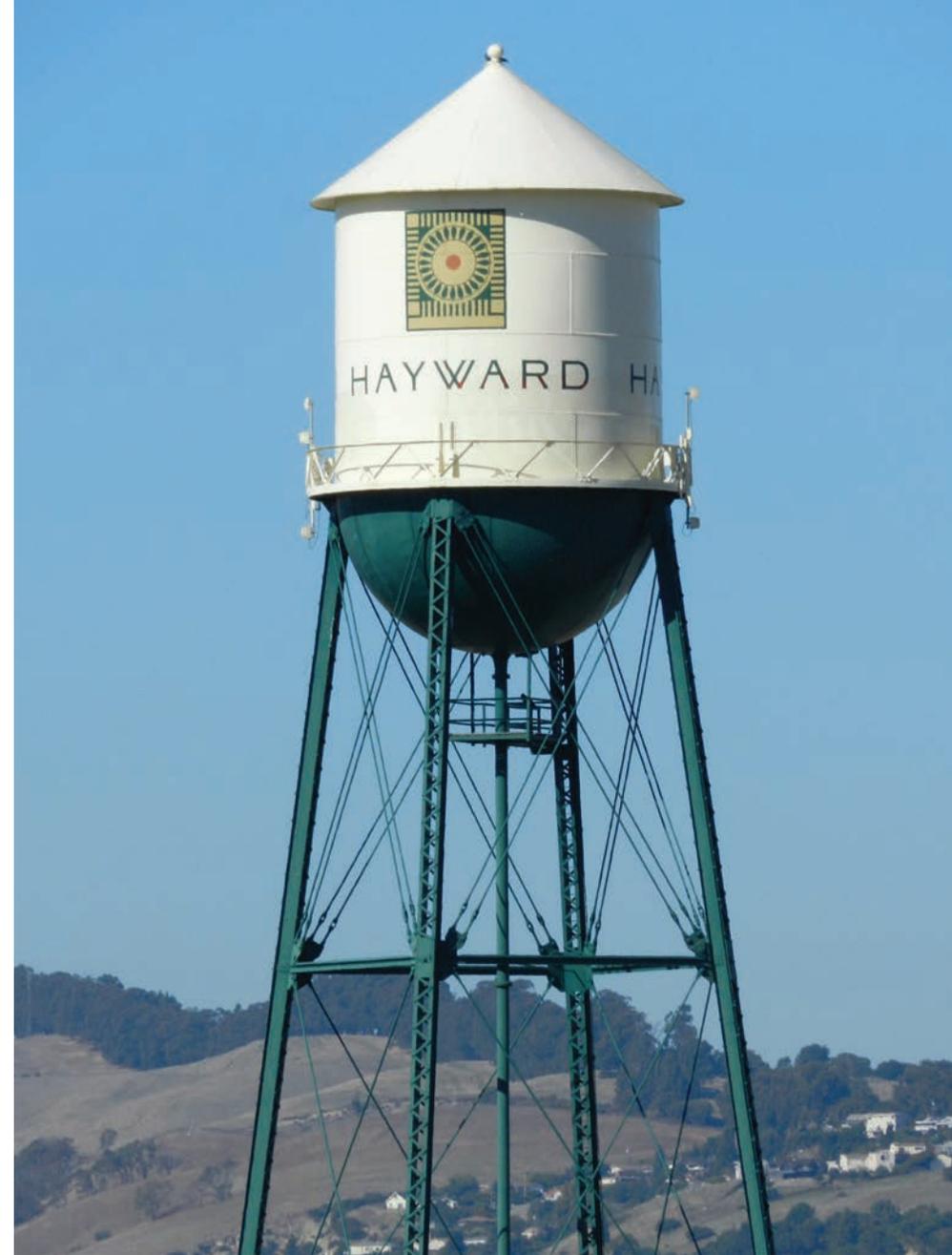


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## Cryogenic Butterfly Cam Valve

### No-leak valve performs in broad range of temperatures

**S**tennis Space Center is looking for partners interested in the commercial application of the Cryogenic Butterfly Cam Valve created by the center's scientists. The main disadvantage of currently available butterfly valves is that more energy can't be added to reduce leakage, as with globe valves. The disc has to create a tight seal with the seat around it exactly when the disc hits 90 degrees. If additional torque is added, the disc will just rotate past 90 degrees, and the valve will open again, allowing fluid or gas to flow through the valve. Typical butterfly valves also fail leakage tests in liquid nitrogen.

The Cryogenic Butterfly Cam Valve design allows additional rotation of the shaft so the disc can slide toward the valve body until it seals tightly. This high-performance design enables a bubble-tight seal at both ambient and cryogenic temperatures, allowing it to prevent leakage no matter how drastic the dimensional changes are due to changing temperatures.

### Benefits

- Improves performance over a wide range of temperatures
- Disc can rotate and translate
- Holds a bubble-tight seal regardless of dimensional changes due to changing temperatures
- Zero leakage
- Simple design with larger machining tolerances

### Applications

- Aerospace industry
- Liquefied natural gas industries
- Air-gas separation industries
- Cryogenic plants
- Food hydrogenation



Image courtesy of Alloy Valve Stockist, CC-BY 3.0

## Wireless Health-Monitoring Sensor

### Low-energy, low-maintenance monitoring of valves, structures, and more

**R**esearchers at Stennis Space Center have created a monitoring system that includes at least one smart sensor unit in wireless, one-way communication with a base station. The sensor lies dormant until it receives a voltage trigger from a vibration-sensitive switch, which consumes no stored power from the battery. When activated, the sensor takes a measurement, transmits the data to the base station, and then returns to its dormant state. The measurement is recorded and time-stamped. Units are optimized for low power consumption and extended operational durations without maintenance.

This system, which is available for licensing, was designed for monitoring ball valves used in rocket propulsion testing to more accurately predict valve lifespan and premature failure, but it can be used to monitor conditions on a variety of structures. Types of data collected include cryogenic cycles, total cycles, inlet and outlet temperature, body temperature, torsional strain, linear bonnet strain, preload position, total travel, and total directional changes. Data is organized into a text file and stored in a compact flash memory card for database upload.

### Benefits

- Sensor units are compact, encapsulated in a small package
- Data is time-stamped for synchronization to within one millisecond, enabling alignment with events on other systems
- Designed for an explosive environment and monitored to safeguard against outside temperature limits
- Can include a solar panel for reducing or eliminating battery drain
- Establishes connectivity only when necessary, eliminating the need for continually powering a receiver
- Targets data events associated with degraded performance and failure, reducing amounts of data accumulation

### Applications

- Automotive industry
- Cryogenics
- Petroleum industry
- Chemical industry



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## Automated Scheduling and Planning Environment

### Artificial intelligence powers framework for scheduling and planning applications

The Artificial Intelligence Group at the Jet Propulsion Laboratory has been working on a system called Automated Scheduling and Planning Environment (ASPEN). Based on artificial intelligence techniques, ASPEN is a modular, reconfigurable application framework capable of supporting a wide variety of planning and scheduling applications. ASPEN provides a set of reusable software components that implement the elements commonly found in complex planning/scheduling systems, including an expressive modeling language, a resource management system, a temporal reasoning system, and a graphical interface.

Automated planning/scheduling technologies have great promise in reducing operations costs and increasing the autonomy of systems in aerospace and other industries. By automating the sequence-generation process and by encapsulating operation-specific knowledge, we hope to allow procedures such as command of a spacecraft by non-operations personnel.

### Benefits

- Modeling language that requires no user knowledge in the areas of computer programming, planning, or scheduling
- Generic architecture allows users to choose from several search engines and propagation algorithms to optimize the planning process
- Allows re-planning during plan execution, enabling continuous real-time planning for embedded applications
- Plans can be optimized for a specific set of goals, such as maximizing science data or minimizing power consumption



### Applications

- Make-to-order manufacturing
- Capital-intensive production with constrained plant capacity
- Production in facilities where many different products are manufactured
- Products requiring a high number of components or tasks
- Production requiring frequent, unpredictable schedule changes

## Ultrasonic, Percussive Drill

### Drilling with low power, low noise

Engineers at the Jet Propulsion Laboratory have developed the technology for drills that operate in the ultrasonic range and incorporate an augments that puts the drilling capacity of large, heavy rotary drills into smaller, rotary hammering drills. These drills require low torque power and, by operating at ultrasonic frequencies, reduce noise. They are based on technology developed to enable sampling in low-gravity and extreme environments.

Generally, hammering fractures media, while rotation of fluted bits removes cuttings. To benefit from these two actions, a novel configuration of the percussive mechanism was developed to produce an augments of rotary drills. The drills are driven by piezoelectric-actuated percussive mechanisms that can be operated using low average power. They were demonstrated to penetrate rocks as hard as basalt, and one design was made as light as 400 grams. Piezoelectric actuators have only two moving parts and no gears or motors. The drill can be adapted easily to operations in a range of temperatures, from extremely cold to very hot.

### Benefits

- Noise reduction
- Low average power requirement
- Compact and lightweight

### Applications

- Construction industry
- Shallow mining
- Demolition
- Medical applications, such as extracting pacemaker leads, drilling bone, and ablating gallbladder and kidney stones



The Jet Propulsion Laboratory is a Federally Funded Research and Development Center run under contract for NASA by the California Institute of Technology. If your company is interested in these or other Jet Propulsion Laboratory technologies, scan this code or visit <http://scienceandtechnology.jpl.nasa.gov/opportunities>.

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## NASA Headquarters

### National Aeronautics and Space Administration

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



## Jet Propulsion Laboratory

4800 Oak Grove Drive  
Pasadena, California 91109  
Technology Transfer Office Chief:  
*Daniel Broderick*  
Phone: (818) 354-1314  
E-mail: daniel.f.broderick@jpl.nasa.gov

## Johnson Space Center

Houston, Texas 77058  
Technology Transfer Office Chief:  
*Jack James*  
Phone: (281) 244-9097  
E-mail: john.e.james@nasa.gov



## Kennedy Space Center

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



## Langley Research Center

Hampton, Virginia 23681-2199  
Technology Transfer Office Chief:  
*Kathy Dezern*  
Phone: (757) 864-5704  
E-mail: kathy.a.dezern@nasa.gov



## Marshall Space Flight Center

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



## Stennis Space Center

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



## Field Centers

### Ames Research Center

Moffett Field, California 94035  
Technology Transfer Office Chief:  
*David Morse*  
Phone: (650) 604-4724  
E-mail: david.r.morse@nasa.gov



### Armstrong Flight Research Center

4800 Lilly Drive, Building 4839  
Edwards, California 93523-0273  
Technology Transfer Office Chief:  
*Laura Fobel*  
Phone: (661) 276-3967  
E-mail: laura.j.fobel@nasa.gov



### Glenn Research Center

21000 Brookpark Road  
Cleveland, Ohio 44135  
Technology Transfer Office Chief:  
*Kim Dalglish-Miller*  
Phone: (216) 433-8047  
E-mail: kimberly.a.dalglish@nasa.gov



### Goddard Space Flight Center

Greenbelt, Maryland 20771  
Technology Transfer Office Chief:  
*Nona Cheeks*  
Phone: (301) 286-5810  
E-mail: nona.k.cheeks@nasa.gov



## Allied Organizations

### Space Foundation

310 S. 14th Street  
Colorado Springs, Colorado 80904  
*Kevin Cook*, Vice President, Marketing and Communications  
Phone: (719) 576-8000  
E-mail: kcook@spacefoundation.org

### Federal Laboratory Consortium

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

### Tech Briefs Media Group

1466 Broadway, Suite 910  
New York, NY 10036  
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www.techbriefs.com

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Goddard Space Flight Center, Building 26  
Greenbelt, Maryland 20771  
E-mail: spinoff@nasa.gov  
*Daniel Coleman*, Editor-in-chief  
Phone: (301) 286-4058  
E-mail: daniel.p.coleman@nasa.gov  
*Samson Reiny*, Senior Science Writer  
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