National Aeronautics and Space Administration

SPINOFF

2016

SPINOFF

2016

Technology Transfer Program

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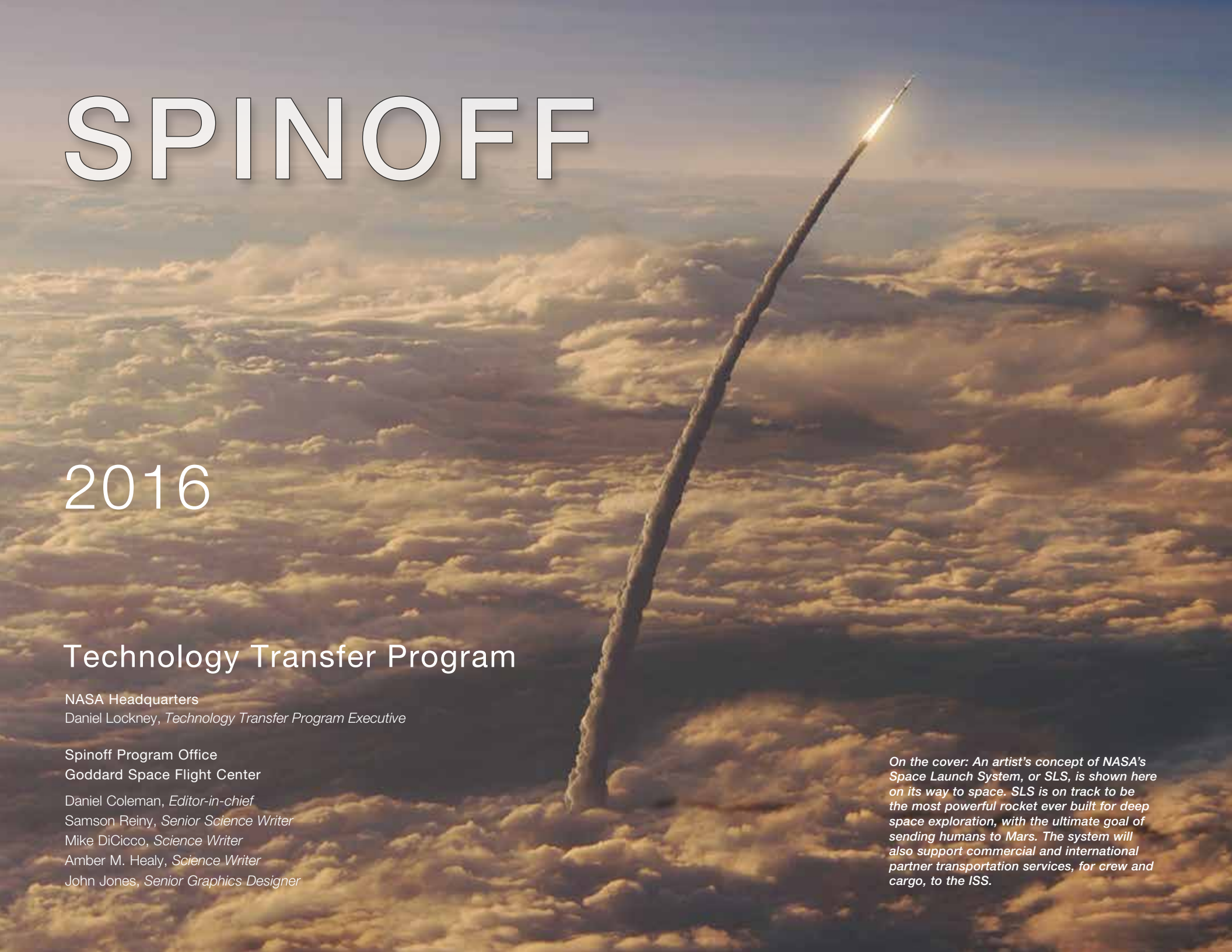

On the cover: An artist's concept of NASA's Space Launch System, or SLS, is shown here on its way to space. SLS is on track to be the most powerful rocket ever built for deep space exploration, with the ultimate goal of sending humans to Mars. The system will also support commercial and international partner transportation services, for crew and cargo, to the ISS.

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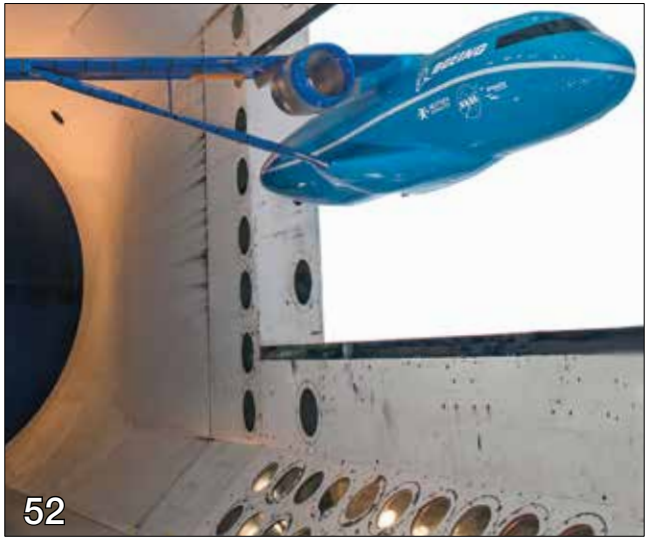

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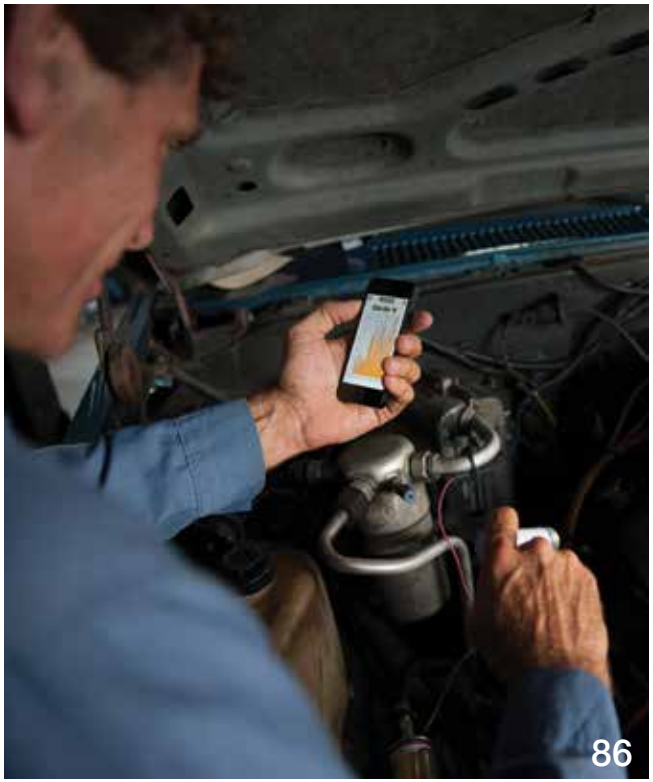

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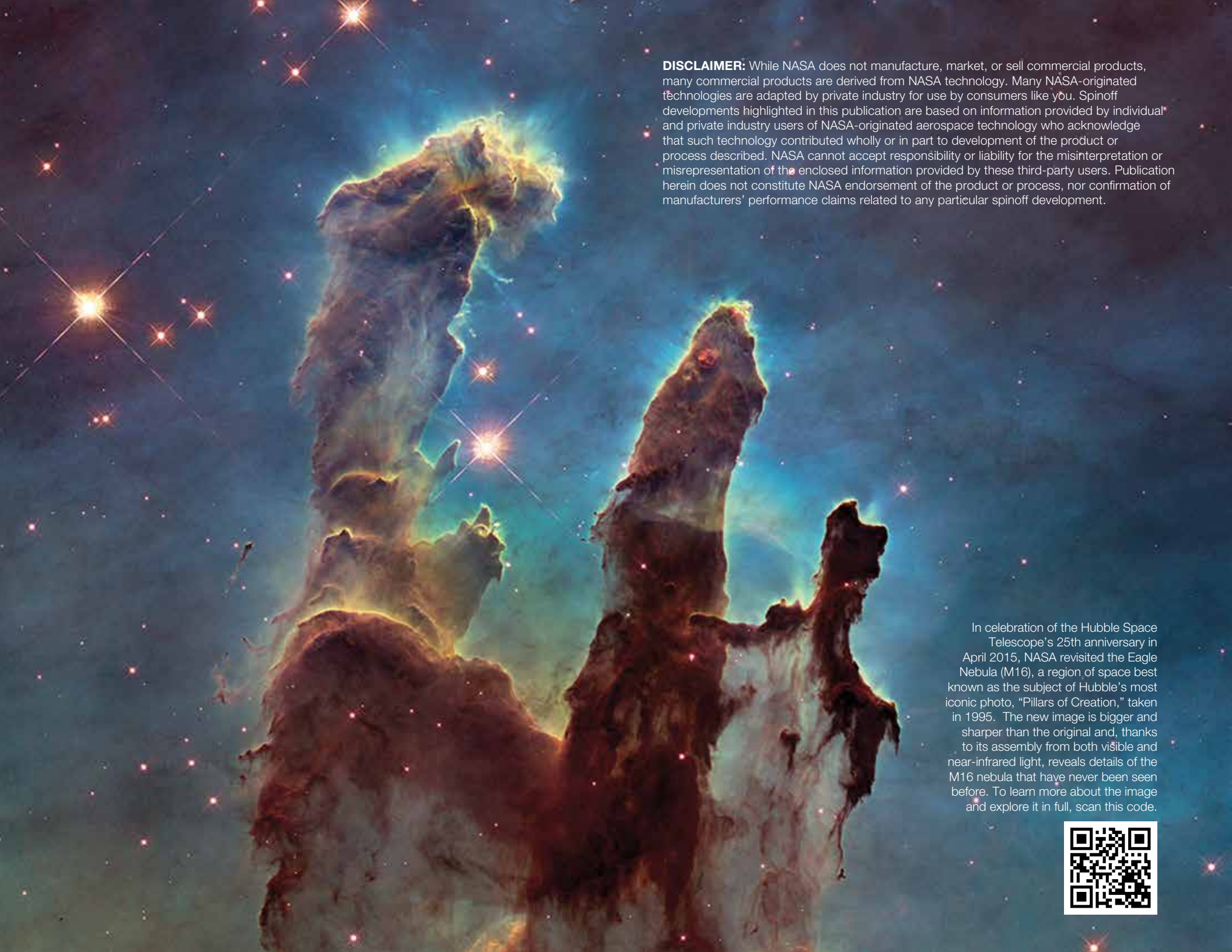


DISCLAIMER: While NASA does not manufacture, market, or sell commercial products, many commercial products are derived from NASA technology. Many NASA-originated technologies are adapted by private industry for use by consumers like you. Spinoff developments highlighted in this publication are based 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.

In celebration of the Hubble Space Telescope's 25th anniversary in April 2015, NASA revisited the Eagle Nebula (M16), a region of space best known as the subject of Hubble's most iconic photo, "Pillars of Creation," taken in 1995. The new image is bigger and sharper than the original and, thanks to its assembly from both visible and near-infrared light, reveals details of the M16 nebula that have never been seen before. To learn more about the image and explore it in full, scan this code.

Foreword

"The history of astronomy is a history of receding horizons."

These words were penned by Edwin Hubble, the great astronomer whose namesake has, perhaps more than any other scientific instrument, expanded our knowledge of the universe. In 2015 we celebrated the Hubble Space Telescope's 25th year in operation, and what a quarter century it has been for NASA missions—not to mention the tangible benefits those missions have had for the public, recorded each year in *Spinoff*.

Hubble has provided us with some of the most spectacular images ever taken, and it has facilitated some of the most important scientific discoveries ever made. Its 25th anniversary has a special significance to me, as I served as a pilot on the Shuttle mission that placed Hubble in orbit. For me, Hubble and everything it has accomplished serve as an enduring symbol of the great things our Nation is capable of when we test the limits of human possibility.

A lot can happen in 25 years. Twenty-five years ago, astronomers were confident that many stars in our galaxy also harbored planets, but we had yet to confirm their existence. Today—thanks to Hubble and the Kepler Mission—we've identified and confirmed more than one thousand exoplanets, some of them Earth-sized and orbiting within the habitable zone around their stars.

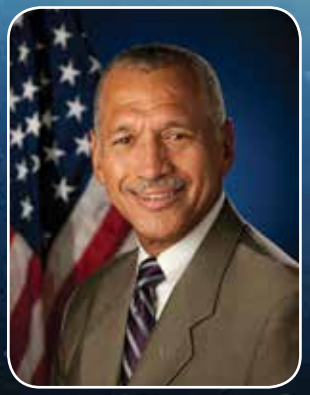
In that same timespan, NASA and its international partners constructed, flew, and assembled a permanent home for humans off the planet. Today, the International Space Station serves as a test bed for new technologies, a national laboratory for unique scientific research, and a training ground for us to learn how humans can live safely and even flourish in space.

Meanwhile, since 1990 NASA robotic missions have flown by, orbited, or landed on all but two of our solar system's planets, as well as many of their moons, and they have given us our first up-close look at two dwarf planets, Pluto and Ceres, this past year.

There are many other groundbreaking accomplishments I could tell you about, but I would also like to mention the numerous secondary benefits that have resulted from Agency endeavors. Since the year Hubble went into orbit, *Spinoff* has recorded nearly 1,200 examples of NASA technology coming down to Earth in the form of commercial products and services. Spinoffs have made an impact on nearly every facet of American life, from consumer goods used daily to critical improvements to our Nation's productive capacity and public infrastructure. Here at NASA, transferring technology to the private sector is one of our core missions.

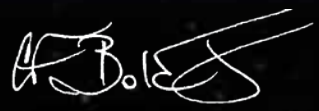
A lot can happen in 25 years. A quarter century from now is the close of the decade in which we are planning the first trip to Mars by human explorers, sent there by the Space Launch System and Orion spacecraft. And by 2040, Hubble's successor, the powerful James Webb Space Telescope, will have completed its mission, giving us even greater insight into the early universe and the birth of the first galaxies. It will even allow us to study the composition of exoplanet atmospheres, a key capability for determining whether there is life on other worlds.

At NASA, we are as excited as ever at the prospects the next several decades of U.S. space and aeronautics missions hold in store for us. And the American public can rest assured that the missions we invest in today will not only continue to push back the horizons of human exploration but also produce practical benefits that make life better on Earth.



Charles F. Bolden, Jr.
Administrator

National Aeronautics and Space Administration



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.

In recent years, NASA astronauts have become celebrities on social media thanks to the stunning photos they capture from their unique perspective orbiting Earth. Expedition 40 Commander Steve Swanson posted this photograph, noting, "Western Sahara—the contrast between the sand and the water is spectacular from here." To view the official Twitter feed of NASA astronauts, scan this code.

Introduction

Written in the Space Act that established NASA in 1958 is a call for the Agency to preserve the United States' place as a leader in space technology—to pursue new knowledge that enables challenging missions into uncharted territory. While the first applications of these technologies are for the specific requirements of NASA missions, the Agency also recognizes that such knowledge will nearly always have broader applications, and we regard the collective potential of our knowledge base as a national resource. Also written into our foundational legislation is the requirement to "provide for the widest practicable and appropriate dissemination" of this knowledge.

Whether these technologies are patented inventions, innovations created through partnerships with industry, or software, the goal of the Technology Transfer Program is to see them dispersed to the public as broadly as possible. We also track results of our efforts—the commercial products and services known as spinoffs that you will read about in the following pages. Each has its unique history, but all are examples of how missions to space lead to wider practical benefits in every sector of the economy.

This year's *Spinoff* features 52 technologies. Among my favorites are:

- An FDA-approved drug, Prolia, used to treat osteoporosis. Research on the effects of microgravity on mice, conducted during Space Shuttle missions as well as aboard the International Space Station, validated the effectiveness of an antibody incorporated in the drug for preventing bone loss. The company is using data from its NASA partnership in two other drugs still in development. (page 30)
- The Rice Decision Support System, created under contracts with NASA and using data from various Earth-imaging satellites. Rice is among the world's most important crops, but a shortage of useful data during its growth season has led to unstable markets, sharp price fluctuations, and shortages. The new system provides real-time crop yield predictions that will reduce risk and volatility in rice markets and, ultimately, help keep hungry people fed. (page 60)
- The world's largest private fleet of nanosatellites now in orbit. A researcher at NASA who helped start the Agency's innovative PhoneSat Project—which demonstrated the feasibility of constructing small, affordable satellites using off-the-shelf parts—is now cofounder of a startup company that has raised over $100 million in investment. Planet Labs' groundbreaking flock of nanosatellites provides a daily picture of Earth that benefits a range of commercial, research, nonprofit, and government organizations. (page 104)

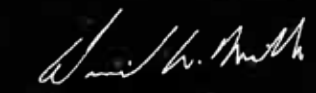
Alongside these success stories, you will also find 20 NASA inventions that the Technology Transfer Program has identified as having notable commercial potential, including information on how you can acquire them or partner with us to develop them further (page 212).

Technology transfer is the Agency's oldest continuously operated mission, but our work is ongoing and of continuing significance. Today there are many new technologies being developed at NASA, and we are hard at work accelerating the rate at which they end up in the hands of companies and organizations that can put them to use in spinoff applications. We are proud to present *Spinoff* 2016 as the latest showcase of success stories from this effort, and I hope that you enjoy reading it.

David Miller

Chief Technologist

National Aeronautics and Space Administration



Monumental Opportunities of the SLS

As NASA sets its sights once again on pushing the boundaries of human space exploration, the Agency is returning to the Apollo-like configuration of a small crew capsule launched by a massive rocket. Nonetheless, the Space Launch System, set to become the world's biggest rocket, also conceals traces of the Space Shuttle Program. And, as a familiar design is brought into the 21st century, it carries the promise of untold spinoff technologies over the coming decades.

Monumental Opportunities of the SLS

NASA's Space Launch System will travel to new frontiers of human exploration—and bring home spinoff technologies that benefit the public

Following the Apollo missions that put the first human beings on the Moon, NASA refocused its spaceflight missions toward expanding our access to low-Earth orbit. To carry out its new primary directive, the Agency developed and employed a spacecraft drastically different from Apollo's capsule and rockets.

The Space Shuttle Program introduced the world's first reusable spacecraft, designed with an ample cargo bay that would carry large components, including such Earth-orbit mainstays as the Hubble Space Telescope and the modules that would make up the bulk of the International Space Station. Rather than riding atop a single heavy-lift rocket, the Shuttles carried their own rocket engines, fueled by a huge external tank, and were powered at launch by dual solid-fuel rocket boosters. Following their work in space, the Shuttles returned to Earth like gliders instead of parachuting to an ocean splashdown.

Now, as NASA once again sets its sights on new frontiers, the Agency is revisiting the model of a tiny capsule perched atop a massive rocket. However, while the new Orion spacecraft and the Space Launch System (SLS) that will carry it away from Earth recall the basic Apollo configuration, early versions of the craft—particularly the SLS—conceal a remarkable amount of Space Shuttle DNA, making use of parts and manufacturing equipment that were fundamental to its immediate predecessor.

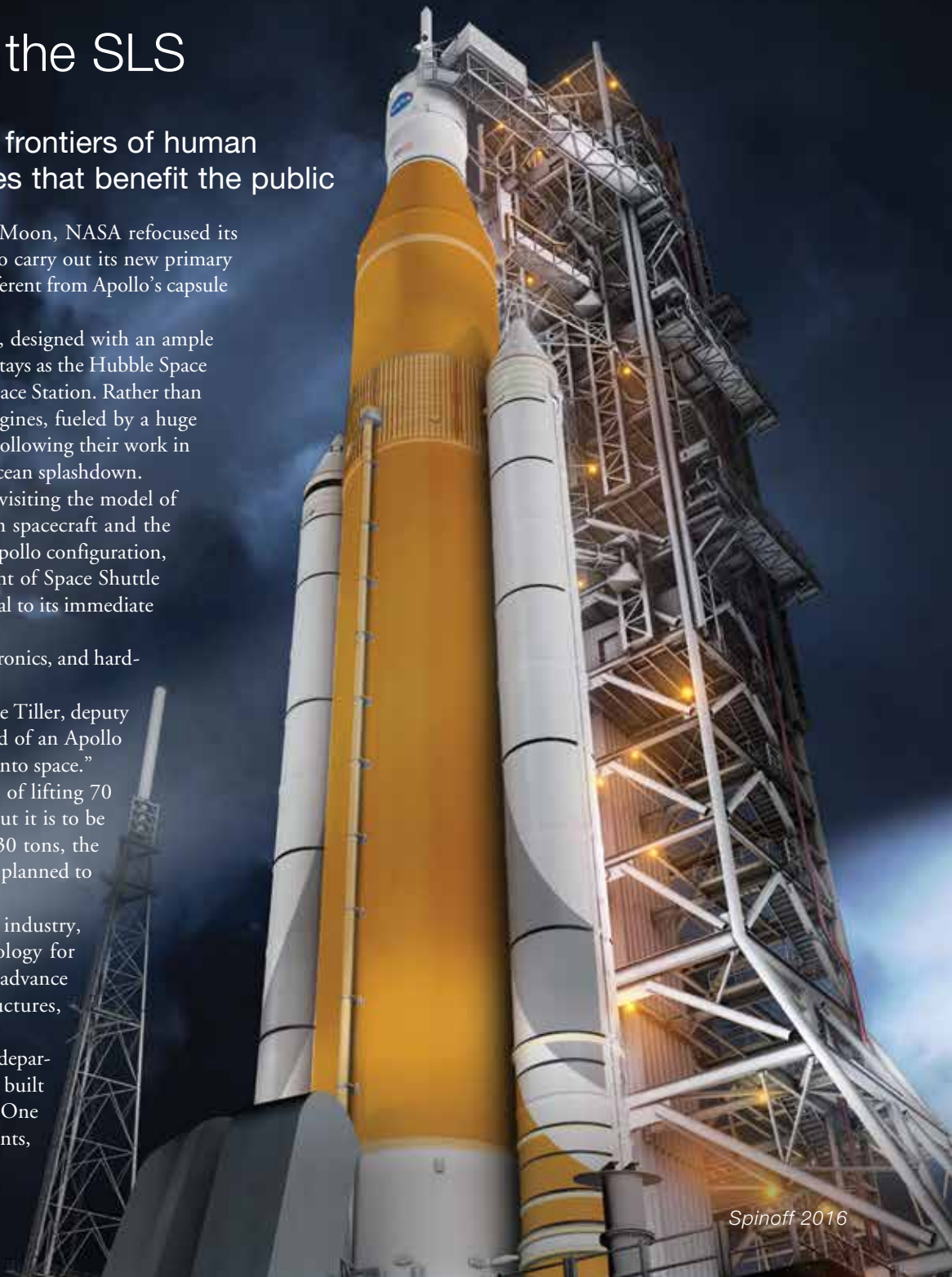
These are being augmented, however, with new and advanced software, electronics, and hardware reconfigurations.

"We saved a lot of money by using those existing heritage designs," says Bruce Tiller, deputy for the SLS booster team at Marshall Space Flight Center. "The design is kind of an Apollo 2.0, but we're going to use it for a greater variety of missions and to go deeper into space."

The SLS currently under construction, known as Block 1, will be capable of lifting 70 metric tons of payload (equivalent in weight to about 40 average-sized cars), but it is to be followed by Block 1B and 2 versions with lift capabilities of 105 and then 130 tons, the last of which will be the most powerful rocket ever built. This is the SLS that is planned to launch the first human flight to Mars by the mid-2030s.

To enable that feat, the project's advanced development team is engaging industry, academia, and the Department of Defense to find and develop new technology for boosters whose performance will exceed anything that currently exists and to advance cutting-edge, high-performance technology in the fields of propulsion, structures, materials, manufacturing, avionics, and software.

Tiller's boosters, which will flank the SLS core stage, mark the most obvious departure from the Apollo design and similarity to the Space Shuttle. In fact, they're built from the same cases, nosepieces, and aft skirts used for the Shuttle's boosters. One major difference is that the SLS boosters, built by Orbital ATK, have five segments,



rather than the Shuttle boosters' four, increasing each booster's thrust to 3.6 million pounds. They'll use the same polybutadiene acrylonitrile solid propellant, which Tiller describes as having the consistency of a rubber eraser. The solid propellant segments will be stacked with a hollow column running down the center, so when that center is lit, all five sections will burn simultaneously.

"It burns from the inside to the outer wall," Tiller explains, noting that because of this, despite their added size, the boosters will expend themselves in about the same two minutes that the Shuttles' did. Together, the two boosters will provide about 75 percent of the total vehicle thrust during those first two minutes.

The rest will come from the core stage, which Boeing developed especially for SLS. Even this new component, though, will have the same 27.6-foot diameter as the Space Shuttle external tank, all the way through the 130-ton version, to capitalize on existing manufacturing and processing infrastructure. Like the Shuttle's external tank, the core stage will be filled with a liquid hydrogen fuel tank and a tank of liquid oxygen to oxidize the fuel as it's burnt. But the Block 1 rocket will stand 212 feet tall and carry about 25 percent more propellant than the Shuttle's 143-foot tank.

Converting that fuel to lift will be modified versions of the same RS-25 rocket engines that powered the Shuttle, although SLS will use four engines rather than three. And Aerojet Rocketdyne is optimizing the engines to fire at 512,000 pounds of thrust each, up from 491,000 pounds on the Shuttle, and replacing the electronic engine control with a new version.

The Space Launch System's (SLS) core stage will be powered by the same RS-25 rocket engines that powered the Space Shuttle, although the SLS will use four engines rather than three, and they'll be optimized to increase thrust. Providing about 75 percent of the force at liftoff, though, will be solid-propellant boosters, again similar to those that launched the Shuttle, but bigger and more powerful. Altogether, the rocket will have 8.4 million pounds of thrust at liftoff.

All this will serve to put the capsule in a higher orbit than the Shuttle inhabited, with enough fuel left over in the upper stage to get to the Moon and back, even with the initial Block 1 vehicle.

"We're using much less of the upper-stage performance to get to orbit," says Steve Creech, deputy of the SLS upper-stage team at Marshall. "We're using most of the performance from that stage to do the translunar injection burn."

The 70-ton SLS is expected to power a Moon mission, in which it will launch into a highly elliptical orbit, swing once around Earth to check out systems and build up speed, and then use that momentum and the upper stage engines to escape Earth's gravity and set a course for the Moon.

In this rocket, the upper stage will be a modified version of United Launch Alliance's existing Delta IV Heavy upper stages. As in that rocket, the unit is powered by an RL-10 engine, capable of more than 25,000 pounds of thrust.

Although it will provide 10 percent more thrust at launch than Apollo's Saturn V rocket (8.4 million pounds, versus the Saturn's 7.5 million pounds), the initial SLS rocket will not have nearly the overall lift capacity those missions had. While Block 1 will be capable of propelling Orion into lunar orbit, it would not also be able to launch a lunar landing vehicle, says Tiller. "It's the mission the Agency wants to do that drives the size of the rocket," he says.

Creech adds, "We could not do a lunar landing mission with the Block 1 rockets. Only the Block 2 SLS will finally surpass the Saturn V's 120-metric-ton lift capability."

This final SLS will be Saturn's true successor, capable of producing 9.2 million pounds of thrust and launching a payload of 130 metric tons. It is planned to achieve this power without any substantial changes to the core stage and engines but with more power in the boosters and upper stage.

Saturn V, a three-stage rocket, used refined kerosene in its first stage instead of hydrogen, the advantage being that, while not as efficient a fuel source, kerosene is denser, allowing for a smaller tank. Block 2 SLS boosters may use liquid or solid propellant, perhaps in composite tanks that could withstand higher pressure than the steel segments being used in the early version, Tiller says.

Capable of carrying the world's largest payload fairings, SLS is planned to launch missions to more places

than just Mars and carry more than just astronauts. A trip to Jupiter's moon Europa is under consideration, as well as the possible construction of a new large space observatory far more powerful than the Hubble Space Telescope, in addition to the plan to capture a boulder from an asteroid and put it in orbit around the Moon for study.

"I think it's going to open a lot of possibilities other than just human spaceflight," Tiller says.

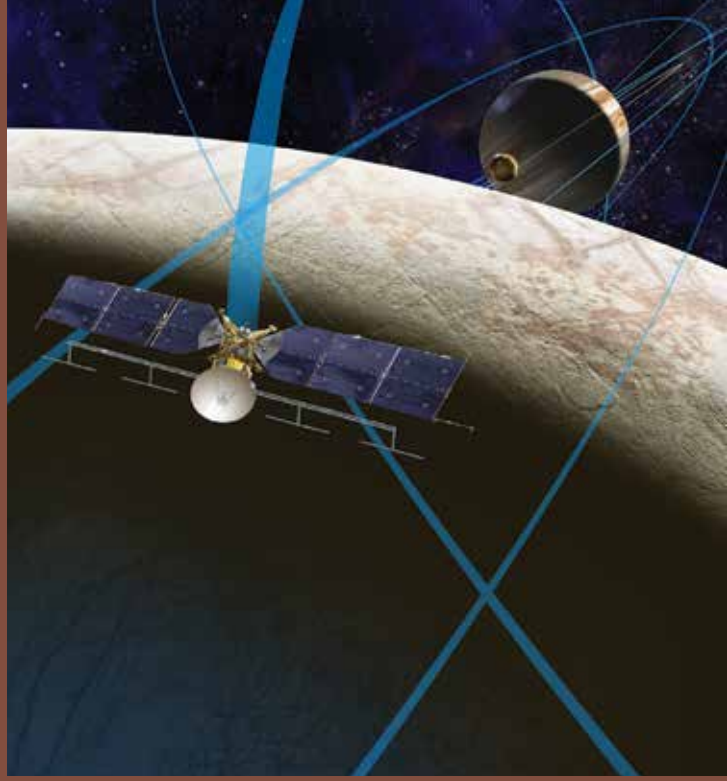
Other grand possibilities from this historically huge rocket include the promise of a diverse set of spinoff technologies. As was the case with the Apollo and Space Shuttle programs that came before SLS, the challenges the Agency takes on in setting new records in human spaceflight are sure to become a fruitful source of innovation, not just for NASA needs but for the public as well.

NASA partnerships with businesses, new NASA-created technologies made available for licensing, and software created for SLS and its missions have already given way to new products and services in the global economy. More than a dozen technologies originally created for SLS and Orion have already spun off as commercial products (and have been featured in *Spinoff*), as well as numerous other products derived from NASA's work in developing the infrastructure required to sustain a human mission to the Red Planet.

Among the most important of these are advances to friction stir welding, a technique that creates stronger bonds than traditional welding and enables the joining of previously unweldable materials. Innovations made for SLS manufacturing removed several of the technology's limitations, allowing it to join metals that vary in thickness and to create seams in complex shapes.

The SLS team has also honed the selective laser melting technique for additive manufacturing, or 3D printing, using the method to create stronger rocket parts quickly and cheaply. These advances hold promise for applications well outside the field of space exploration.

These spinoffs come from just the first few years of an ambitious, decades-long initiative—and if history is any indicator, they are but a sampling of the many benefits that will accrue as NASA realizes a truly monumental undertaking. ❖



More **than** a **dozen technologies** originally **created** for **SLS** and **Orion** have already **spun off** as **commercial products.**

Opposite page, bottom left: All the mass and might of NASA's Space Launch System, which is to evolve into the biggest, most powerful rocket ever built, will serve to propel the relatively tiny Orion Multipurpose Crew Vehicle, pictured here with its service module and upper stage, deeper into space than humanity has ever traveled. At about 16.5 by 11 feet, the capsule is still larger than its Apollo predecessor. Top: One concept mission under study by NASA would use SLS to send a spacecraft into an elaborate orbit around Jupiter to perform repeated flybys of Europa, one of the gas giant's moons and a possible host to extraterrestrial life. Bottom right: SLS is also planned to power a mission to collect a boulder from an asteroid and put it into orbit around Earth's Moon for study. Background: Whatever missions NASA settles on for SLS, the Agency is especially determined to use the giant rocket to finally put astronauts on the surface of Earth's neighbor, Mars.

Executive Summary

Each year, *Spinoff* features dozens of commercial products derived from NASA technology that are improving everything from medical care and software tools to agricultural production and vehicle efficiency. 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

HEALTH AND MEDICINE

(30) Rodent Research Contributes to Osteoporosis Treatments

NASA has long worked to mitigate bone loss caused by visits to space. Ames Research Center worked with Amgen Inc., a Thousand Oaks, California-based biotechnology company, to test a series of new osteoporosis treatments on mice in microgravity, in the hopes of helping astronauts and the earthbound alike. The results obtained on the missions supported studies on Earth that resulted in Prolia, a new bone treatment drug, and other drugs still in development.

(34) Pressure Garments Save New Mothers' Lives

In the 1960s, Ames Research Center used an astronaut G-suit to successfully treat a woman suffering from post-obstetric hemorrhaging. Subsequent research showed that a noninflatable garment could effectively and more safely treat the condition. Suellen Miller, a professor of obstetrics and gynecology at the University of California, San Francisco and founder of the Safe Motherhood Initiative, now uses a garment developed using NASA's research to help women suffering from post-obstetric hemorrhaging in low-resource settings around the world.

(38) Tool Kit Simplifies Development of High-Affinity Molecules

A human trip to Mars will require new medical diagnostic technology because antibodies, used in measuring biomarkers, degrade in space. Through SBIR funding from Johnson Space Center in 2007, AM Biotechnologies LLC in Houston developed X-Aptamers, antibody alternatives that are longer-lasting and easy and quick to produce. The company's X-Aptamer Selection Kit is now available to pharmaceutical companies and research universities for drug development.

(42) Space-Ready Spectrometer Offers Terrestrial Advantages

Under two SBIR contracts with the Jet Propulsion Laboratory in the 1990s, Brimrose Corporation of Sparks, Maryland, made its acousto-optic tunable-filter (AOTF) spectrometers smaller, lighter, sturdier, and more energy-efficient. The company now sells 14 different AOTF spectrometer models that are used in industries ranging from pharmaceuticals and medical imaging to agriculture and oil and gas.

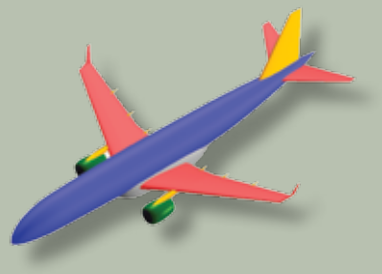
TRANSPORTATION

(46) Unmanned Research Aircraft Test Cutting-Edge Innovations

Many of NASA's aeronautical advances go through testing with unmanned experimental aircraft before they see any commercial flight time. Armstrong Flight Research Center awarded multiple SBIR contracts to Kennesaw, Georgia-based Area-I Inc. for the development of a medium-range, narrow-body, twinjet airliner for aerodynamics investigations. The result is the Prototype-Technology Evaluation Research Aircraft, or PTERA, which is now on offer to research universities and aerospace companies at a fraction of the cost of comparable experimental aircraft.

(48) Data Visualizer Enhances Modeling for Cars, Consumer Products

Computational fluid dynamics has come a long way in the past few decades, and Intelligent Light Inc., of Rutherford, New Jersey, continues to be a leader in the field. From its first SBIR contracts with Langley Research Center, the company's FieldView product has evolved past visualization capabilities to provide the best solutions for complex problems, winning over Formula One teams and manufacturers in the process.



(50) **Lightweight, Ultra-Strong Nanotubes to Transform Industry**

First synthesized in the mid-1990s, boron nitride nanotubes (BNNT) are strong, lightweight, and heat-resistant and absorb neutron and ultraviolet radiation—making them ideal spacecraft heat shields. But no method existed to create them in appreciable quantities until Langley Research Center accomplished the feat in 2008. Having licensed the NASA technology, Newport News, Virginia-based BNNT LLC is supplying the material to companies while working with the Space Agency to further improve the production process.

(52) **Multidisciplinary Software to Help Take Aircraft to the Next Level**

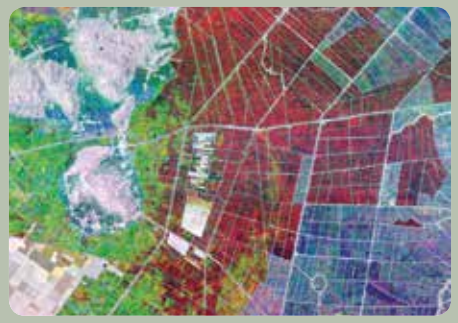
Future advances in commercial aircraft will require multidisciplinary analysis and optimization (MDAO), which finds optimal designs by considering how each aircraft component interacts with every other in light of multiple engineering fields. In order to simplify this complex process, Glenn Research Center developed OpenMDAO, an open source software program that allows researchers to perform these analyses without needing to be experts in MDAO. The University of Michigan is among those now using OpenMDAO for research into fuel-saving aircraft wing designs.

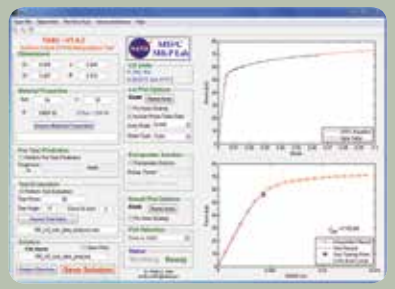
(54) **Orbital Trajectory Analyzer Takes Mission Planning to New Heights**

A team of engineers at Goddard Space Flight Center created the General Mission Analysis Tool (GMAT), specializing in trajectory optimization to design better flight plans for their spacecraft. Publicly released in 2013 as open source software, GMAT has been embraced by users around the world, with defense contractors like Columbia, Maryland-based Applied Defense Solutions Inc. making use of it. A number of universities also use the software as an educational tool.

(56) **Open Source Aircraft Design Software Helps Industry, Hobbyists**

For years, the only people with access to computer-aided drafting software were engineers. Hobbyist aviators were left out until a group of engineers from Langley Research Center and California Polytechnic State University teamed up to create OpenVSP, an open source program for designing aircraft and other vehicles. Desktop Aeronautics Inc., of Palo Alto, California, is among several companies that use OpenVSP for new aircraft concepts.





Public Safety

(60) **Rice Crop Models Stabilize Global Markets, Enable Efficient Irrigation**

Among the world's major dietary staples, rice is the most difficult crop to predict in terms of yield. In 2012, Stennis Space Center granted Applied Geosolutions Inc., based in Newmarket, New Hampshire, two SBIR contracts to create the Rice Decision Support System. The Web-based software uses data from Earth-imaging satellites to generate real-time global information about rice coverage, growth stages, and expected yields. The information will stabilize rice markets and is already helping farmers use more sustainable irrigation practices.

(64) **GPS Sensor Web Helps Forecasters Warn of Monsoon Flash Floods**

In Southern California, summertime monsoons bring a variety of hazards and are notoriously difficult to predict. In a project funded by NASA's Earth Science Technology Office through the Jet Propulsion Laboratory, 37 GPS stations there were outfitted with meteorological sensors, generating data on air moisture. The National Oceanic and Atmospheric Administration's San Diego and Los Angeles/Oxnard Weather Forecast Offices use the data to improve monsoon forecasting and issue storm warnings.

(68) **Analytic Tool Simplifies Metal Fracture Assessments**

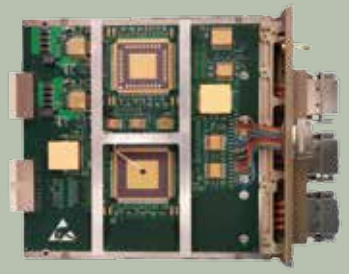
Determining a metal's fracture toughness is critical to knowing when a spacecraft or structure needs repairs, but it's a time-consuming job and the disciplines involved are complex. Marshall Space Flight Center engineer Phillip Allen developed software called Tool Analysis of Surface Cracks, or TASC, to streamline the process. Quest Integrity Group in Boulder, Colorado, is one of many organizations that use the technology commercially to ensure the safety of structures.

(70) **Mars Methane Detector Identifies Harmful Gas Leaks**

In order to determine whether Mars is, or ever was, host to life, the Jet Propulsion Laboratory (JPL) outfitted the Mars Science Laboratory rover with the Tunable Laser Spectrometer to detect methane, a possible sign of microbial life. Through a Space Act Agreement with various organizations, including San Francisco, California-based Pacific Gas & Electric, JPL utilized the technology to develop a handheld methane detector for industry that finds potentially dangerous and greenhouse gas-contributing pipe leaks.

(72) **Hydrogen Detection Tape Saves Time and Lives**

During the Space Shuttle Program, NASA relied on liquid hydrogen to fuel rocket launches, but the element's propensity to leak and its flammability meant miles of pipeline had to be inspected routinely. To make the process more efficient, Kennedy Space Center collaborated with the University of Central Florida (UCF) to develop a color-changing hydrogen detection tape. UCF chemist Nahid Mohajeri now sells the tape to industrial plants through her company, HySense Inc., headquartered in Rockledge, Florida.



(76) **Single-Photon Lidar Maps Ground Features Quickly, Efficiently**

When John Degnan left Goddard Space Flight Center and joined Lanham, Maryland-based Sigma Space Corporation, four decades of NASA laser-ranging experience came with him. Sigma licensed two of Degnan's Goddard patents and developed low-energy, high-fidelity, airborne single-photon lidar (SPL) imagers. They provide reconnaissance, measure biomass, and map topography for the military, local governments, and companies. Sigma also helped Goddard develop the SPL device that will monitor polar ice on the ICESat-2 mission.

(80) **Temperature Sensors Cement Integrity of Bridges**

When the White House called on Glenn Research Center to get involved in its community, the center launched an Adopt a City program to find companies to mentor. Pile Dynamics Inc. (PDI), in nearby Cleveland, Ohio, needed help crafting a sensor to ensure the structural integrity of concrete shafts like the ones it was pouring for a massive new bridge. With NASA's help, PDI validated its thermal integrity profilers, which have since been used in 40 construction projects worldwide.

(82) **Primer Stops Corrosion without Requiring Rust Removal**

In the mid-1990s, Pittsburgh-based Surtreat Holdings LLC developed two corrosion inhibitors that, applied to the surface of concrete, migrated to the rebar inside. The company entered into a Space Act Agreement with Kennedy Space Center, conducting tests that validated the inhibitors as among the most effective on the market. Recently, Surtreat used a compound similar to one tested at Kennedy to develop a new pigmented primer that can be applied directly to rusty steel to inhibit corrosion.

Consumer Goods

(86) **NODE+ Platform Integrates Sensors with Smartphones**

IIn 2007, George Yu helped Ames Research Center integrate a sensor for detecting dangerous gases and chemicals with a smartphone. Most of the design for the microprocessor, memory, communication protocol, back-end Web structure, and data storage Yu developed under this NASA subcontract later appeared in the wireless sensor platform he created after founding Chattanooga, Tennessee-based Variable Inc. The award-winning NODE+ platform integrates a line of off-the-shelf sensors with smart devices.

(90) **Precision Coffeemaker Adapts Brews to Beans, Taste**

During four summer internships at NASA Research Park, part of Ames Research Center, Matt Walliser learned various skills related to building intelligent, autonomous robotic systems. Some of these, like proportional-integral-derivative (PID) controllers and embedded communications, became central to the Blossom One coffee brewer created by San Francisco-based Blossom Coffee Inc., where Walliser is now chief engineer. The technology holds brew temperatures constant, ensuring consistent results, and allows the machine to brew according to recipes stored in the cloud.

(92) **CO_2 Recovery System Saves Brewers Money, Puts Bubbles into Beer**

Work that Robert Zubrin did with Johnson Space Center focused on breaking down elements abundant on Mars and turning them into resources, including capturing and manipulating carbon dioxide (CO_2). In the beer world, large systems allow major brewers to capture CO_2 generated during fermentation and use it for carbonation, but the technology hasn't been available on smaller scales. Now, the CO_2 Craft Brewery Recovery System, made by Zubrin's Lakewood, Colorado-based Pioneer Energy Inc., is available for microbreweries.

(94) **Space Blanket-Inspired Cases Protect Expensive Devices**

Smartphones, laptops, and tablets are susceptible to damage if exposed to very high or low temperatures. Inspired by the "space blankets" he used as a Boy Scout, Nick Blanton, founder of Portland, Maine-based Salt Cases Company, developed fabric cases that incorporate thermal sheet technology created by Marshall Space Flight Center decades ago to protect 21st-century technology.

(96) **Antimicrobial Agent Updates Ancient Industry of Prayer Mats**

Two NASA experiments testing the antimicrobial properties of chitosan—especially one test carried out on Johnson Space Center's Cell Culture Module aboard the International Space Station—inspired a feature of what Calgary-based TIMEZ5 Inc. calls "the world's first physiological prayer mat." NASA's research resulted in the incorporation of chitosan, which is derived from the main compound in arthropod exoskeletons, into the company's mats, where it fends off bacteria, fungi, and mold.

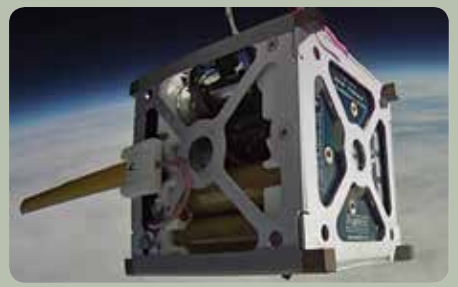
(98) **Heat-Reflecting Material Regulates Body Temperature**

In the 1990s, Ames Research Center was investigating the feasibility of rocket planes to reduce the cost of launching payloads into space, and Protective Ceramic Coating Material, or PCCM, was developed as a heat shield for use during reentry. The versatile technology has since been licensed for a variety of uses, such as a substrate in various combustion processes. In its latest incarnation, Mooresville, North Carolina-based Trizar Technology Inc. is incorporating PCCMs into clothing lines for heat management.

(100) **Modified Monitor Provides Glasses-Free 3D for Pilots, Gamers**

Pilots have to vigorously monitor a mental checklist while flying planes. In the hopes of making things easier for them, Langley Research Center has been working with Rochester, New York-based Dimension Technologies Inc. for several years to develop displays capable of 3D imaging without requiring glasses. The monitor has already won over video-game enthusiasts for its lifelike imagery and eye-tracking software that allows users freedom of movement.

Energy and Environment



(104) **Flock of Nanosatellites Provides a Daily Picture of Earth**

While working at Ames Research Center, physicist Chris Boshuizen helped start the PhoneSat project, which aims to make satellites more affordable to build and launch without sacrificing performance. He took those same ideas with him when he cofounded San Francisco-based Planet Labs Inc. in 2011. The company is launching flocks of nanosatellites made from cheap, off-the-shelf parts that will provide a daily snapshot of Earth, benefiting a range of industries.

(108) **Multispectral Satellite Imagery Shows Farmers' Fields in New Light**

When the Internet was young, Goddard Space Flight Center granted the University of Minnesota funds to develop applications to let the state of Minnesota make use of satellite imagery of its forests. Needing to process datasets and make them accessible on the Web, the team created MapServer, an open source development environment thousands of Web sites still use, including that of Fargo, North Dakota-based Satshot. Satellite images the company distributes help farmers allocate resources, spot equipment problems, and monitor crop health.

(112) **Software Helps Restore Fire-Ravaged Habitats**

The Bureau of Land Management not only puts out wildfires but also restores the charred land. To help the Agency draft its required restoration plans more quickly, Idaho State University wildlife biologist Keith Weber worked with Goddard Space Flight Center scientists through funding from NASA's Research Opportunities in Space and Earth Science program to develop the Rehabilitation Capability Convergence for Ecosystem Recovery, or RECOVER software. The program has also found use in fire containment and prevention.

(116) **Buildings for Manipulating Magnetism Revolutionize Magnetometers**

A pair of buildings where magnetism can be manipulated at Ames Research Center fell into disuse by the 1990s, but they piqued the interest of San Jose, California-based Geometrics Inc., which needed a test facility for its magnetometers, used to find magnetic anomalies in soil and water. The company leased the buildings through a Space Act Agreement, and its devices are now used to find buried objects and calibrate underground drill rigs.

(118) **Cost-Saving Method Yields Solar Cells for Exploration, Gadgets**

Solar cells are expensive, but through a series of SBIR contracts from Glenn Research Center, Niles, Illinois-based MicroLink Devices Inc. has come up with a new way to create flexible cells that reduces manufacturing costs. NASA is considering the technology for massive solar arrays on future space exploration missions, and the award-winning commercial version has already been employed by the military for use as a portable power supply.

(120) **Wide Area Thermal Imaging System Brings the Landscape into Focus**

NASA has a number of imaging systems for finding fires, but none were capable of identifying small fires or indicating the flames' intensity. Thanks to a series of SBIR contracts between Ames Research Center and Ypsilanti, Michigan-based Xiomas Technologies LLC, the Wide Area Imager aerial scanner does just that. While NASA and the U.S. Forest Service use it for fire detection, the tool is also being used by municipalities for detailed aerial surveillance projects.

(122) **Photocatalytic Water Splitter Stores Energy as Hydrogen**

When titania is exposed to ultraviolet light, it becomes a photocatalyst to split water into hydrogen and oxygen. Only 4 percent of sunlight, however, is ultraviolet. Under two SBIR contracts with Ames Research Center, Nanoptek Corp., based in Concord, Massachusetts, grew titania crystals with such surface tension that they became responsive to 29 percent of total sunlight. Nanoptek's photocatalytic panels convert energy to stored hydrogen, representing the first electrolyzer to be competitive with batteries.

(126) **Recycling Technology Converts Plastic Waste to Energy**

Through the Obama administration's Strong Cities, Strong Communities Initiative, Glenn Research Center worked with Vadxx Energy LLC, based in Cleveland, Ohio, to optimize the company's proprietary process for converting used plastics into diesel additives, fuel gas, and inert char. The technology stands to lessen both the hazardous emissions from landfills and the amount of trash ending up in the world's oceans and other waterways, while also reducing the Nation's dependence on foreign oil.

(128) **Tiny Capsules Enable a World of Possibilities**

Tiny capsules made of beeswax, dreamed up by engineers at Marshall Space Flight Center and perfected by Lenoire, North Carolina-based RMANNCO Inc., have revolutionized the way oil spills are cleaned. Joe Resnick, who worked with NASA to perfect the capsules in the 1980s, has made them even smaller and has developed a host of products, ranging from medical kits for dogs to synthetic pollen that could result in natural honey suitable for diabetics.

Information Technology

(132) **System-Health Monitor Predicts Failures before They Happen**

In 2012 Phoenix-based CEMSol LLC licensed system-monitoring software from Ames Research Center. The program mines years' worth of data samples from a given system to establish relationships between components, determine a baseline for normal behavior, and detect any deviation from that norm that might indicate an impending failure. The company enhanced the program's presentation and developed its Integrated System Health Management products, which essentially give any system the ability to verbalize symptoms before a failure occurs.

(136) **Algorithm Predicts and Evaluates Storm Surges**

With new remote sensing technologies able to provide more accurate observations of Earth's weather and topography, in the early 2000s Stennis Space Center put out a call through the SBIR program for technologies that could make use of those advances. Stennis awarded funding to WorldWinds Inc., based at the Stennis campus in Mississippi, which developed what would become StormWinds—a program that can model storm surges and help homeowners file insurance claims following a disaster.

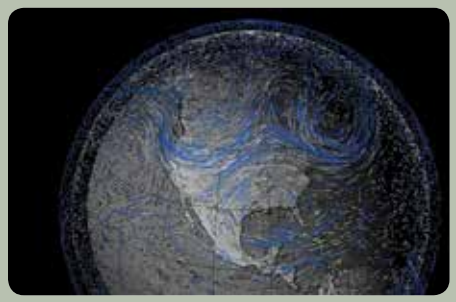
(140) **Mars Rover Work Spawns PDF Collaboration Software**

Among the first projects undertaken by Alliance Space Systems, founded by NASA engineers, were robotic arms for Jet Propulsion Laboratory rovers Spirit and Opportunity. The company wanted to streamline circulation and editing of documents and improve conversions of computer-aided designs into PDFs. The software it developed became the first product from spinoff company Bluebeam Software Inc. of Pasadena, California. The company has more than 650,000 users and was recently purchased for $100 million.

(142) **Open Source Tools Popularize Infrastructure for Cloud Computing**

Shortly after software developers at Ames Research Center partnered with industry to create OpenStack, the world's most popular open source cloud-computing platform, Canonical Ltd., an international organization with offices in Boston, incorporated the software into its Linux-based operating system called Ubuntu. Canonical then created a tightly integrated suite of hardware and software products based on OpenStack that make cloud computing available to more users than ever before.

(144) **Software Optimizes Designs from Spaceships to Wind Turbines**
Craig Collier created software at Langley Research Center in the late 1980s to optimize designs for a planned hypersonic spaceplane. He later founded Newport News, Virginia-based Collier Research Corporation and continued developing the software, which calculated weights of different vehicle configurations and suggested changes to meet load requirements, as HyperSizer. Several NASA SBIR contracts geared HyperSizer toward developing alternate designs for the Orion spacecraft. Having optimized countless commercial craft, the company recently broke into the wind turbine industry.



(148) **NASA Climate Analytics Support Biological Research**
NASA's Modern-Era Retrospective Analysis for Research and Applications, or MERRA, integrates data from a variety of observational instruments to create a synthetic data record of the weather. To make the data more accessible to outside researchers, computer scientists at Goddard Space Flight Center created Climate Analytics-as-a-Service, or CAaaS. Tucson-based iPlant Collaborative is among the first organizations to adopt the service. Member scientists can use CAaaS to investigate, for example, climate change's impacts on agriculture and husbandry.

(152) **Artificial Intelligence Targets Advertising by Understanding User**
Thousand Oaks, California startup Beyond Limits Corporation licensed an artificial intelligence program and language-understanding software from the Jet Propulsion Laboratory in 2013 and retooled the programs to target online advertising. Rather than simply remembering that a user once bought something from a particular store or pushing content based on words a user has typed, the software seeks to understand a person's intent and sentiment at a given time and use that data to push relevant content.

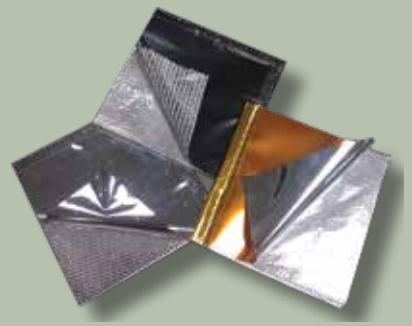
(154) **Modeling Software Helps Rocket Scientists Go with the Flow**
To facilitate development of the Fastrac turbo pump, in the mid-1990s Marshall Space Flight Center coded the Generalized Fluid System Simulation Program (GFSSP) to model computational fluid dynamics. The software is free to Government agencies and contractors, and Concepts NREC Inc., based in White River Junction, Vermont, licensed the technology and now sells the code to other entities as part of its turbomachinery software package.

(156) **Electro-Optic Ceramic Creates High-Speed Fiber-Optic Networks**
A 2002 SBIR with Langley Research Center allowed Boston Applied Technologies Inc. (BATi) to demonstrate an electro-optic ceramic it had developed but not proven. Electro-optic ceramics alter properties of light based on applied electrical charges. The Woburn, Massachusetts-based company designed a laser Q switch that proved its OptoCeramic to have nearly 100 times the electro-optical effect of more traditional options. The material became central to most BATi products—components used in telecommunications, lidar, remote sensing, and other applications.

Industrial Productivity

(160) **DigitalClone Software Predicts, Extends Machine Life**
Buffalo, New York-based Sentient Science Inc. developed software called DigitalClone, which predicts the lifespan of machine components. Under an SBIR contract, Glenn Research Center validated DigitalClone's predictions for a particular gear against 25 years' worth of data, prompting the company to go commercial. DigitalClone and DigitalClone Live, which incorporates real-time data from sensors, have been used for prognosis of planes, helicopters, and more than 5,000 wind turbines from eight operators.

(162) **Cryocoolers Fuel Exploration in Space and on Earth**
When NASA needed a cryocooler to install on the Reuven Ramaty High Energy Solar Spectroscopic Imager, engineers at Goddard Space Flight Center turned to Athens, Ohio-based Sunpower Inc. for help. The company's cryocoolers feature just two moving parts and have a long lifespan. After 18 SBIR contracts, the company has a dozen models of cryocoolers that are aiding research in space and are employed in high-powered telescopes, multispectral and hyperspectral scanners, and superconductors on Earth.



(164) **Temperature-Resistant Materials Enable Space-Like Cold on Earth**
Since the 1980s, Dunmore Corporation of Bristol, Pennsylvania, has worked with the Jet Propulsion Laboratory and other NASA centers to develop temperature-resistant products, helping the company establish a massive catalog. Many of its multilayer insulations were developed for NASA and are now used in building insulation, cryogenic material transport, MRI machines, and particle accelerators. Heat-resistant labels and electrostatic shields for circuit boards, as well as temperature-resistant tapes for electronics, also have stemmed from products designed for spacecraft.

(168) **Lasers Enable Alternative Power Transmission**

To advance the concept of a space elevator, the NASA Space Technology Mission Directorate's Centennial Challenges Program held the Power Beaming Challenge, which called on inventors to wirelessly power robot "climbers" using lasers. The winning group for the 2009 competition founded Seattle-based LaserMotive Inc., which provides power for applications that require electrical and radio-frequency isolation. The company's upcoming technology will use laser light to power unmanned aerial vehicles in mid-air.

(172) **Helium Recapture System Reclaims Hydrogen for Industry Use**

Under two STTR contracts with Stennis Space Center, Sustainable Innovations LLC, based in East Hartford, Connecticut, built a system that filters, cleans, and pressurizes hydrogen, based on a reverse fuel cell technology. The H2RENEW device will enable industries like glass, steel, and silicon manufacturers to efficiently recycle hydrogen used in production processes. The company also sees an opportunity in the nascent hydrogen-fuel market, and it's working on two more products based on the same electrochemical platform.

(174) **Laser Vision Helps Hubble, Package Shippers See Clearly**

In preparation for a repair mission for the Hubble Space Telescope, which was launched with a misshapen mirror, Goddard Space Flight Center issued a call for optics companies to accurately measure replacement parts. AOA Xinetics, now a division of Northrop Grumman Corporation based in Cambridge, Massachusetts, created a tool to detect mirror defects, which it has incorporated into a commercial 3D imaging system. Among its applications is a package-detection device now used by all major shipping companies.

(176) **Space-Ready Durometers Measure Hardness on Earth**

When the Space Shuttles were flying, NASA needed a tool to ensure any tiles repaired on the craft's underbelly after launch could withstand the heat of reentry into Earth's atmosphere. Johnson Space Center called on Buffalo Grove, Illinois-based Rex Gauge Durometers Inc. to modify its existing durometer for use in space by astronauts. Sales of the company's improved digital durometers increased 35 percent after its NASA work.

(178) **High-Temperature Superconductors Deliver Power without Heat**

In 2008 Goddard Space Flight Center hired Knoxville, Tennessee-based Tai Yang Research Company, now known as Energy to Power Solutions, to develop superconducting ceramic leads to carry power to an electromagnet operating near absolute zero. While superconductive ceramics operate at higher temperatures than their metal counterparts, they produce no heat and conduct almost none. The resulting durable, ultra-low-heat lead is the first of its kind and is being marketed for MRI machines and other devices with cryogenic components.

(180) **Electrospray Thrusters Boost Efficiency, Precision**

To equip the disturbance reduction system it provided for the European Space Agency's LISA Pathfinder mission, the Jet Propulsion Laboratory hired Natick, Massachusetts-based Busek to develop the most delicate thrusters ever flown. Using electrospray technology, the highly efficient and long-lived thrusters can control the number of atoms of ionic liquid they spray, and they max out at a thrust weight equivalent to a grain of sand.

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TECHNOLOGY TRANSFER PROGRAM

BRINGING NASA TECHNOLOGY DOWN TO EARTH

NASA Spinoff Technology across the Nation

Health and Medicine

1. Rodent Research Contributes to Osteoporosis Treatments (CA)
2. Pressure Garments Save New Mothers' Lives (CA)
3. Tool Kit Simplifies Development of High-Affinity Molecules (TX)
4. Space-Ready Spectrometer Offers Terrestrial Advantages (MD)

Transportation

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6. Data Visualizer Enhances Modeling for Cars, Consumer Products (NJ)
7. Lightweight, Ultra-Strong Nanotubes to Transform Industry (VA)
8. Multidisciplinary Software to Help Take Aircraft to the Next Level (MI)
9. Orbital Trajectory Analyzer Takes Mission Planning to New Heights (MD)
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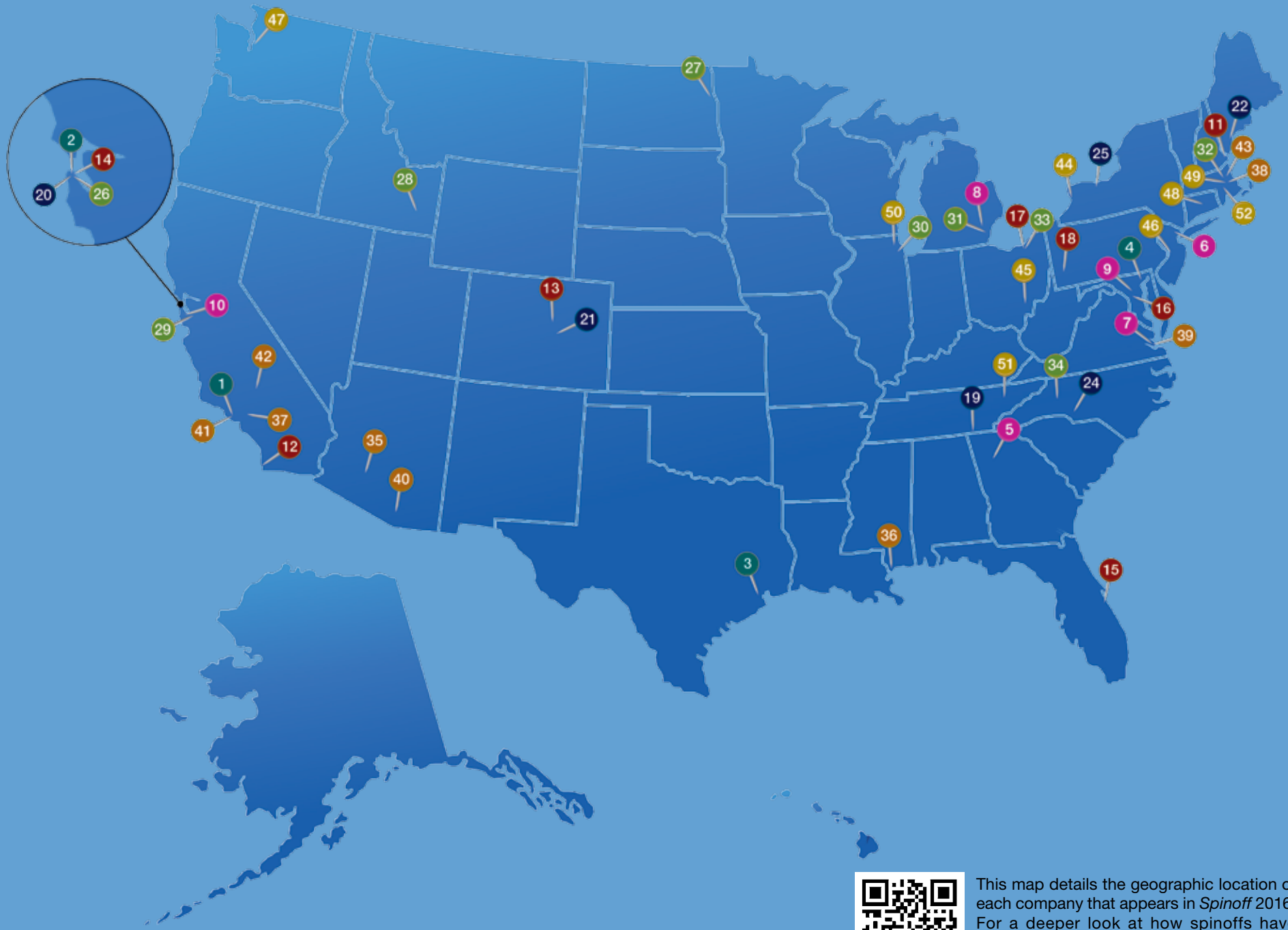


This map details the geographic location of each company that appears in *Spinoff* 2016. For a deeper look at how spinoffs have benefited your state and local economy, scan this code.

NASA Technologies Benefiting Society

There's more space in your life than you think: NASA research and development have tangible benefits that go beyond supporting mission needs. Spinoffs create jobs, generate revenue, and save costs for businesses. They even save lives. Through global crop forecasting, new sources of energy, vehicle design software, and more, NASA technology works for the benefit of the Nation and world.

Health and Medicine

If preventing and treating health problems is complicated on the ground, it's far more challenging in space, where resources are limited and healthcare professionals are remote. Many of the solutions NASA funds or develops, such as quick and easy diagnostic tools or treatments to maintain the bone density that's lost in zero-gravity, however, are just as helpful on Earth as they are in space.

Rodent Research Contributes to Osteoporosis Treatments

NASA Technology

Astronauts know their bodies will be tested during time spent on the International Space Station (ISS), from the multiple sunrises and sunsets per day wreaking havoc on their circadian rhythms to the lack of gravity causing bone-density and muscle loss. NASA is conducting research to counteract these otherworldly conditions to enable long-term human exploration of space—for example, special lighting helps induce sleep, and rigorous exercise schedules help keep astronauts' bodies healthy—but bone loss continues to occur.

Jacob Cohen, chief scientist at Ames Research Center, says NASA scientists and other researchers know this loss is driven by loading and unloading, or the absence of gravity's pull on the body. Understanding how the body responds to the space environment will allow NASA to develop more effective countermeasures for long-duration missions—and help fight diseases encountered on Earth.

"As scientists, we want to know what are the mechanisms that effect bone loss, what are the mechanisms that effect muscle loss," Cohen says. "We want to make sure we keep the crew as healthy as possible so when they come back, they have a normal life."

Terrestrial concerns about bone-density loss center largely on osteoporosis in middle-aged women and older men.

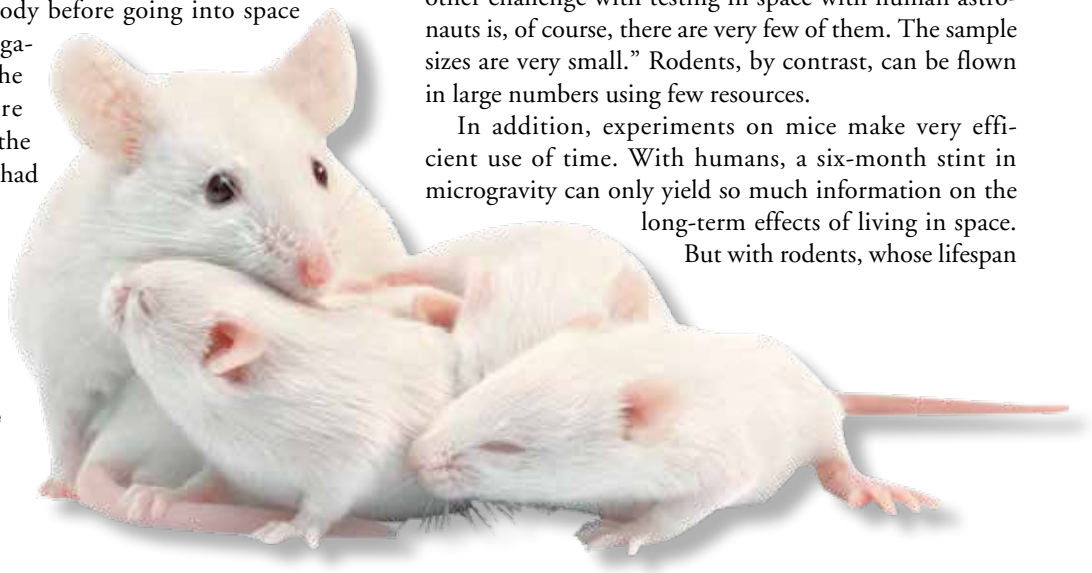
Amgen, a biotechnology company based in Thousand Oaks, California, has been working on new treatments for osteoporosis for many years. Teaming up with Louis Stodieck, a research professor at the University of Colorado at Boulder and director of BioServe Space Technologies, Amgen worked with NASA to devise a rodent-based experiment that could benefit astronauts and earthbound humans alike.

Technology Transfer

"The idea is, you can assess how things might occur in humans if you have good animal models that can predict what the human response is going to be, both to the environment as well as to any countermeasure you might want to test to mitigate any issues of that environment," Stodieck explains.

In this case, it meant subjecting a group of mice to a short trip to space. Using the Commercial Biomedical Testing Module (CBTM) designed by researchers at Ames, 15 mice, all about 10 weeks old, were given a sclerostin antibody molecule developed by Amgen one day before launch, while another 15 mice of the same age were given a placebo treatment, says Chris Paszty, the company's research lead for the sclerostin program. Another two groups of mice stayed behind on Earth and were given the same treatments at the same time.

Sclerostin is a protein secreted by bones that notifies the body to dial down the formation of new bone by acting like a brake in a car, Paszty says. The sclerostin antibody, which blocks sclerostin, "lets up on the brake" and allows for increased bone formation, which results in increased mineral density and improved bone structure and strength. The hypothesis for the 2011 Space Shuttle experiment was that the bones of the mice injected with the sclerostin antibody before going into space wouldn't be as negatively affected by the two-week exposure to microgravity as the control groups that had received placebos.



Mice have long been used in medical research on Earth, but some companies, including Amgen, have partnered with NASA to send mice to space to test treatments in microgravity.

"We know that sclerostin production in bone is regulated by mechanical loading, but what we didn't know was if you completely unloaded the skeleton's bone formation pathway, which is essentially what happens in microgravity, whether our molecule that blocks sclerostin would still result in increased bone formation and bone strength," he says.

Paszty and Stodieck both note that although space-based experiments aren't a requirement for the clinical trials and FDA approval process for new treatments, much can be learned about basic biology using space-based experimentation.

It's possible to simulate the effects of microgravity on Earth by keeping human test subjects in bed for months at a time, but the opportunity to get real data from space provides a more accurate picture of the conditions astronauts face.

"There are some unique attributes of space that make for potentially very interesting animal models that can be used to evaluate the effects of therapeutics for bone and muscle atrophy and muscle wasting and so forth that aren't as easily tested in humans," Stodieck says. "The other challenge with testing in space with human astronauts is, of course, there are very few of them. The sample sizes are very small." Rodents, by contrast, can be flown in large numbers using few resources.

In addition, experiments on mice make very efficient use of time. With humans, a six-month stint in microgravity can only yield so much information on the long-term effects of living in space. But with rodents, whose lifespan

“For us, that was part of the **excitement:** not only **are we working** on **bone loss** for **human disease,** but there’s this other part of **human endeavor,** going into **space, and bone** loss is an **issue there.”**

— Chris Paszty, Amgen

When the final Space Shuttle launched in 2011, it carried with it mice treated with a sclerostin antibody under development by Amgen. The company’s work on bone health treatments is of interest to NASA as it continues to explore ways to protect astronauts’ health in space, but the research has benefits for people suffering from osteoporosis here on Earth.

is so much shorter, even a two-week trip can reveal biological trends and effects that can be scaled into useful data on what might happen in the human body over a longer period of time.

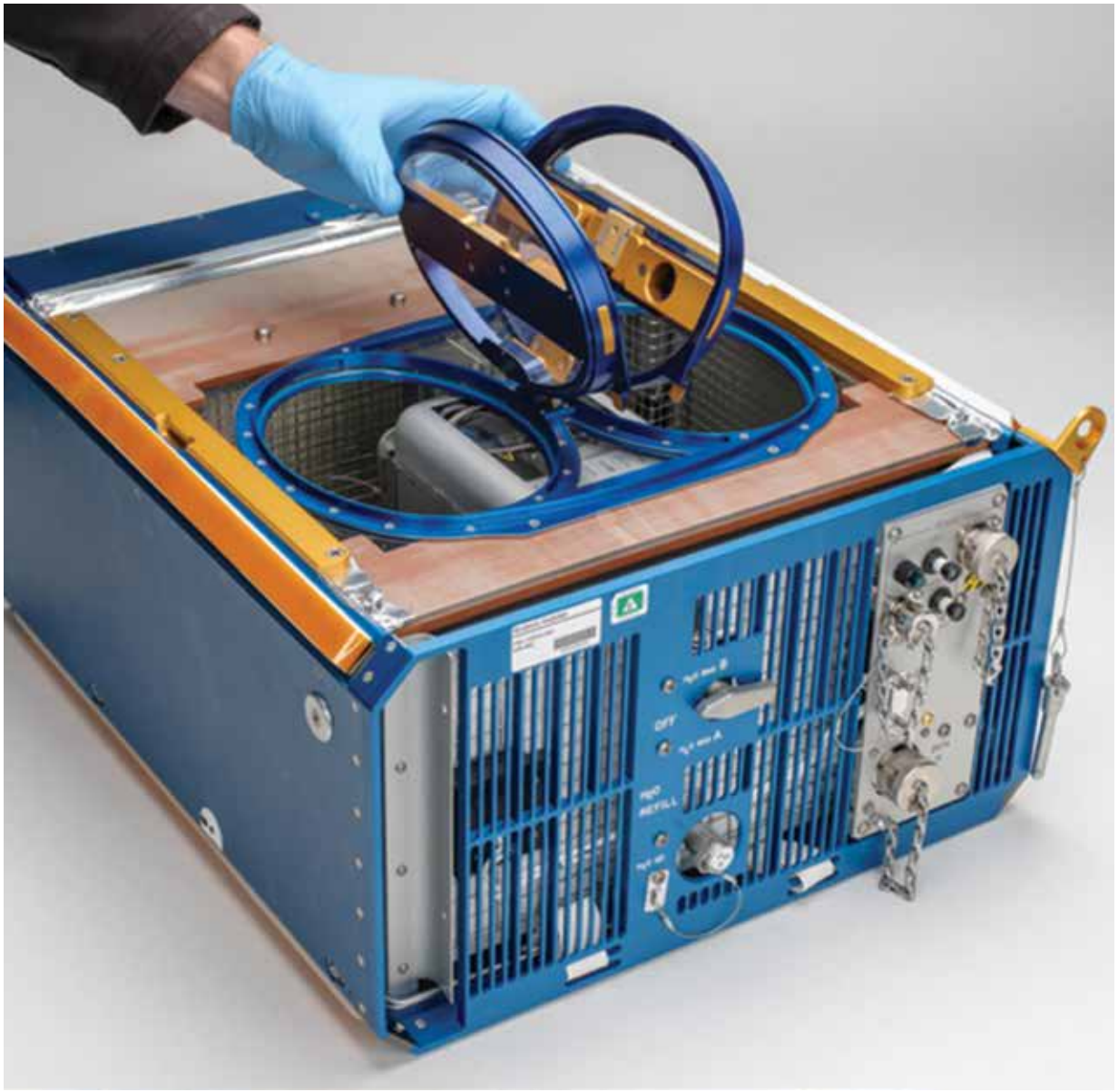
When CBTM launched with Space Shuttle Atlantis in July 2011 for the sclerostin antibody experiment, the mice on board were in for a shock. Like humans, mice are subject to some initial discomfort when they leave full gravity, and from observations made during these missions, it was apparent they were confused, grabbing on to the sides of their enclosure and then each other before learning how to navigate their new environment. Unlike astronauts, rodents' bodies are incapable of alleviating nausea by vomiting. "You're never going to see a mouse toss its cookies," Stodieck says. "It's not going to happen. But within a few days, they are completely adapted. They free-float, they move around with ease, they've learned how to essentially fly and glide and eat and drink, no problem."

When the mice returned to Earth two weeks later, the results of the experiment were promising. "What we found was that the mice that had received our sclerostin antibody had increased bone formation and improved bone structure, and even increased bone strength," Paszty says. "That's exactly what we've found here on Earth. We were very pleased to see we had gotten the same results in space."

Amgen has been involved in three rounds of experimentation with Stodieck and NASA in space involving mice, flying experiments on STS-108 in 2001 (a bone-loss study); STS-118 in 2007 (a muscle wasting/atrophy study); and STS-135—the Shuttle program's final mission—in 2011 (a bone-loss study). These studies each used different test molecules that blocked three different targets in three distinct biological pathways.

Benefits

"For musculoskeletal issues, microgravity is really a unique model of disuse, what I would consider extreme



This commercial biomedical testing module, developed at Ames Research Center, served as a home away from home for mice traveling into microgravity aboard NASA's Space Shuttles. A new enclosure is being developed for the ISS.

> “What we found was that the mice that had received our sclerostin antibody had increased bone formation and increased bone mass, and even increased bone strength.”
>
> — Chris Paszty, Amgen

disuse,” says Stodieck. “If you take a human or an animal and put them in microgravity, they will lose muscle and bone at rates that are incredibly fast, much faster than a patient on Earth suffering from osteoporosis. They’ll lose bone at a rate 10 times faster in space than that individual.”

It’s the Earth-based versions of bone loss and muscle loss that have been part of Amgen’s research over the years. Indeed, Amgen’s first space experiment (STS-108) was in the area of bone loss and used an engineered version of a protein called osteoprotegerin. As it turns out, Amgen’s focused research in that biological pathway resulted in the FDA’s 2010 approval of the company’s drug, denosumab, which is marketed under the brand name Prolia.

Initially approved exclusively for use by postmenopausal women at high risk for bone fracture, Prolia also was later approved as a treatment to increase bone mass for women at a high risk for fracture who are also undergoing treatment for breast cancer, and for men receiving treatment for nonmetastatic prostate cancer.

During the Phase 3 trials conducted before the drug’s approval, patients receiving the treatment showed a 68 percent reduction in vertebral fractures, a 40 percent reduction in hip fractures, a 20 percent reduction in nonvertebral fractures, and a significant increase in bone density at all sites measured.

Amgen and UCB Pharma, its corporate partner on the sclerostin program, currently have a clinical candidate sclerostin antibody (Romosozumab) in Phase 3 trials. “The drug that Chris is helping to bring into the market, the sclerostin antibody, is really going to shake things up,” Stodieck says. “It can substantially reverse bone that has gotten very fragile, as opposed to just preventing it from breaking down further. It has the potential to help a lot of people who have gotten into a very weakened state. It’s one we’re pretty excited about.”

If astronauts suffer bone and muscle loss from a few months in space, a mission to Mars or other destinations could further weaken their bodies, Cohen adds. “How are astronauts ever going to come back to Earth from deep space missions? They’re not going to be able to stand without rigorous exercise combined, potentially, with other therapeutic treatments.” It’s possible that the body will adapt when exposed to microgravity over a long period of time and that bone and muscle loss will plateau, or that partial gravity will be determined to be adequate for maintaining bone density and muscle health, but that still needs to be researched, he says.

Cohen also adds that the development of biological-based countermeasures will lead to astronauts having the ability to produce the drugs needed during a space exploration mission while being months or years away from Earth. This is part of a space-exploration synthetic-biology vision that will allow crew to produce most of the materials and tools to sustain life on demand and at the destination.

There’s an additional benefit to using four-footed travelers for space studies. When the tissues needed for a particular experiment have been collected, there are typically surplus tissue samples available, which provide a rare opportunity for other researchers with an interest in the biological effects of microgravity.

For its tissue-sharing program, NASA issues a call for investigators, either for new research or ongoing work that has previously benefited from tissues exposed to microgravity, to determine where the samples should be distributed. The Agency asks for the amount of tissue needed for examination and what science would be tested, and the submissions are peer-reviewed to ensure the best candidates are selected. The tissue collected during the Amgen flight continue to result in high-quality, impactful, peer-reviewed publications by NASA tissue-sharing program investigators.

“Any time there’s a spaceflight experiment, there are lots of publications that come out of the tissue-sharing program,” Cohen says. Research aided by these tissue samples also helps NASA meet the Space Biology priorities set every decade by the Academy of Science, which suggests topics for study based on the Agency’s budget and ongoing work.

Going forward, Ames and the team at its Space Biosciences Division have redesigned its CBTM for use on the ISS and have developed other hardware and the support needed to conduct research that maximizes the science return on the ISS. Meanwhile, NASA astronaut Scott Kelly is dedicating an unprecedented full year to living aboard the ISS to further our understanding of how the human body responds to microgravity over long stretches of time.

“The news is more and more filled with all kinds of exciting NASA projects. Things seem to really be coming to an exciting moment in history in terms of space exploration and the potential there,” Paszty says. “For us, that was part of the excitement: not only are we working on bone loss for human disease, but there’s this other part of human endeavor, going into space, and bone loss is a big issue there as well.” ❖

Pressure Garments Save New Mothers' Lives

From the left: Astronaut Joe Acaba and Russian cosmonauts Gennady Padalka and Sergei Revin aboard the Soyuz spacecraft preparing for their return trip to Earth from the ISS on September 17, 2012. Upon reentry into Earth's atmosphere, gravity pulls blood away from the head and into the lower body, which can cause dizziness. As a preventive measure, crewmembers wear G-suits, which are rubberized suits that squeeze the arms and legs to push blood back toward the head.

NASA Technology

In 1969 NASA Ames Research Center received an unusual call for help: a local woman who had given birth continued to experience abdominal bleeding weeks later despite every attempt to halt it, including nine surgical procedures. Her condition, known as postpartum hemorrhage (PPH), can result from a number of different complications during childbirth, and left untreated it can prove fatal. The patient had been transferred to Stanford University Hospital, where doctors continued to transfuse the woman with blood, but they still needed a way to stop the bleeding.

After studying the problem, researchers and engineers from NASA Ames' Environmental Control Research Branch, Flight Operations Branch, and other areas, proposed that applying pressure to the woman's entire lower body using external pressure from an inflated anti-gravity suit, or G-suit, might stop the bleeding—just as tightly wrapping a gash on a limb can slow blood loss. NASA has long used G-suits, or inflatable compression garments that prevent blood from pooling in the legs, to keep its test pilots and astronauts from blacking out during moments of extreme acceleration and upon return to the pull of Earth's gravity after spaceflight.

The team quickly modified a G-suit to allow for a range of pressures and to retrofit it to the hospital's gas supply cylinders, then hurried the garment to the hospital where it was immediately applied to the patient. After wearing the suit for just 10 hours, the woman began to recover, with her body's natural healing process taking over once the rate of bleeding had slowed. Three months later, doctors proclaimed her fully healed.

Subsequent research by NASA Ames scientists led to a better understanding of the physiology of anti-gravity suits and the realization that much lower pressures could be used to decrease bleeding and rapidly shift needed blood, a process known as autotransfusion, from the legs and lower body toward the heart and brain—to treat hemorrhage or dehydration, for example. Indeed, reviews by NASA Ames scientists and others showed that higher anti-gravity suit pressures, such as those standard in military and aviation applications, could be harmful by cutting off circulation to vital tissues and organs. Some of these findings, along with original data from experiments on low blood-pressure states, were gathered by an Ames-funded researcher and published in a 1989 NASA technical memorandum on the use of the anti-gravity suit to apply positive pressure to the lower body.

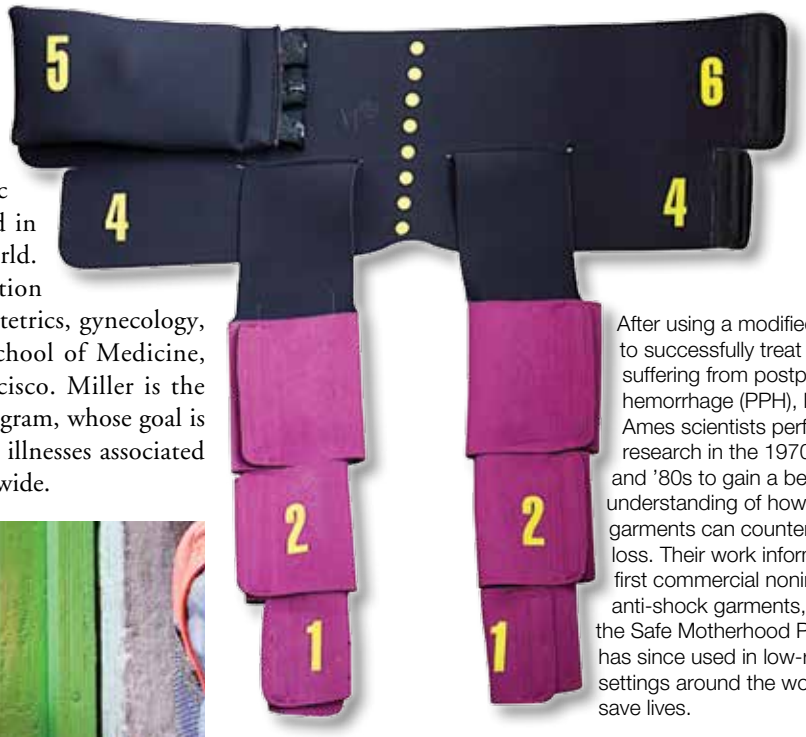
Technology Transfer

Drawing on the information found in the memorandum and other reviews, Palo Alto, California-based Zoex Corporation developed the first commercially available version of the technology in the early 1990s. Zoex recognized that these lower yet effective pressures, in the range of 20–40 torr, were achievable using simpler elastic com-

> “We have the potential to save 35,000 young, healthy, otherwise productive women every year.”
>
> — Suellen Miller, Safe Motherhood Program

pression garments, rather than the old-style inflatable air and water bladders of military G-suits. The noninflatable suit, which Zoex branded the Non-Inflatable Anti-Shock Garment, or NIASG, has been used to counter shock in a variety of situations (*Spinoff* 1996).

The use of noninflatable pressure garments specifically for treating PPH remained a promising application and area of further study. By 2002, Dr. Paul Hensleigh, who was chief of obstetrics and gynecology at Santa Clara Valley Medical Center in California, was using the NIASG to treat patients suffering from obstetric hemorrhage, both in California and in low-resource settings around the world. His work in turn caught the attention of Suellen Miller, a professor of obstetrics, gynecology, and reproductive sciences at the School of Medicine, University of California, San Francisco. Miller is the founder of the Safe Motherhood Program, whose goal is to reduce the number of deaths and illnesses associated with pregnancy and childbirth worldwide.



After using a modified G-suit to successfully treat a woman suffering from postpartum hemorrhage (PPH), NASA Ames scientists performed research in the 1970s and ’80s to gain a better understanding of how pressure garments can counteract blood loss. Their work informed the first commercial noninflatable anti-shock garments, which the Safe Motherhood Program has since used in low-resource settings around the world to save lives.

Worldwide, at least 280,000 women die each year as a result of childbirth, with PPH accounting for nearly 70,000 of those deaths. The NASA-derived LifeWrap, which costs about a dollar per use, has been shown to reduce PPH-caused mortality by 50 percent.

After attending a presentation given by Hensleigh, Miller joined with him, an Ames scientist, and another researcher to conduct and publish a 2004 study based on 14 cases of hypovolemic shock in Pakistan where the NIASG was used as a primary intervention. The garment had helped save the lives of 13 of the patients.

In high-resource medical centers, such as those in the United States, blood transfusions, surgery, and drugs are readily available treatments. But for women in many rural areas in developing countries, getting them the care they need can take days—time they cannot afford in the case of PPH. “I empathize with the doctors and midwives in these low-resource settings,” Miller says. “They often have nothing at their disposal to save that mother’s life, and she ends up dying in their hands.”

In Cambodia, the LifeWrap is applied to a woman suffering from PPH to reduce blood loss until she reaches a hospital for treatment.

Miller, who calls the garment an NASG (Non-Pneumatic Anti-Shock Garment), began performing clinical research with the aim of getting it recognized by the World Health Organization, or WHO, the body that sanctions the use of medical devices and procedures in developing countries. NASG's inclusion in WHO's clinical-practice guidelines would open the doors for nongovernmental organizations and government healthcare systems to consider adding the device in policy and practice.

In 2004, Miller and her colleagues, including Hensleigh, conducted comparative studies in Egypt and Nigeria. Their results, published in 2007, showed that using the garment reduced both blood loss and mortality in PPH patients by 50 percent. "In the field of maternal health, we generally don't see that kind of a reduction," Miller says, "and even less so when it's the result of a single, simple intervention."

Funding from the Bill & Melinda Gates Foundation and the National Institutes of Health allowed Miller to expand her work with a five-year randomized trial in Zimbabwe and Zambia. While the final analysis from those tests was being completed, the WHO and the International Federation of Gynecologists and Obstetricians both decided in late 2012 that enough evidence had been presented to officially include the NASG in their guidelines on the management of PPH.

Benefits

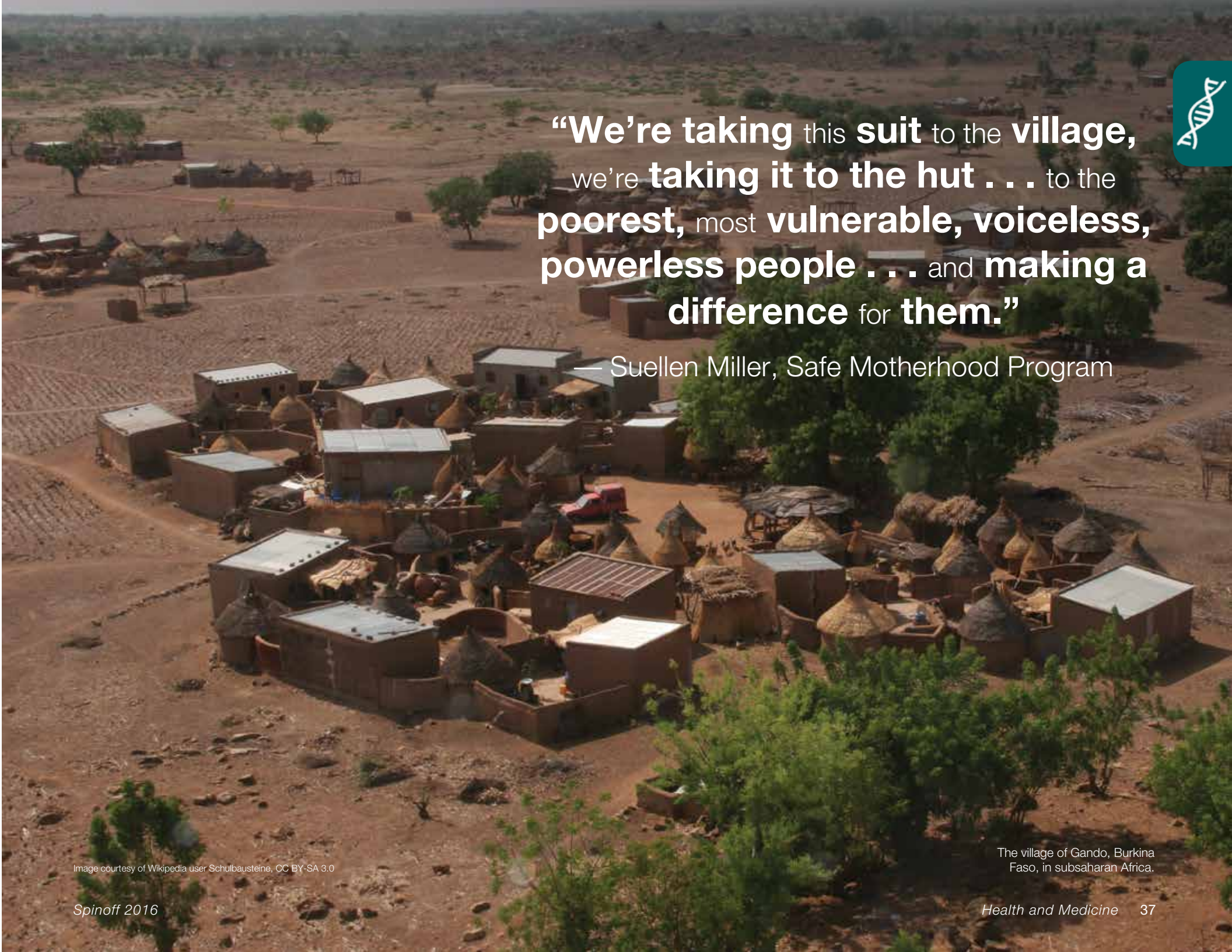
Around the world, each year at least 280,000 women die as a result of childbirth—70,000 of them from obstetric hemorrhage. "If under clinical study conditions we can reduce that number by 50 percent, then we have the potential to save 35,000 young, healthy, otherwise productive women every year," Miller says.

In the short timespan since the WHO backed the garment, 20 countries have purchased a lower-cost version of it called LifeWrap, produced by a manufacturer found by Safe Motherhood and the nonprofit PATH. "We've determined that these suits can be used at least 70 times," Miller says. "So we're looking at a life-saving device that costs less than a dollar per use."

Around the world, the Safe Motherhood Program continues to disseminate information on and provide training for using LifeWrap. In the wake of Typhoon Haiyan, which ravaged the Philippines in November 2013, the organization donated garments to midwives working in disaster zones, helping to save lives. More recently, Miller and her colleagues conducted training for Médecins Sans Frontières, also known as Doctors without Borders, and the Canadian Red Cross so they may implement the garment's use in African countries affected by Ebola. LifeWraps have also been provided for ambulances in East Timor and are being used increasingly throughout rural Tanzania.

Miller thanks the Space Agency for the critical role it played in getting the technology to this point. "We're taking this suit to the village, we're taking it to the hut, we're taking it to the poorest, most vulnerable, voiceless, powerless people grounded into the Earth, and making a difference for them," she says. "Thank you, NASA."

Miller also reports that some of the doctors and midwives she has met have voiced their own thanks for the garment that has taken so many names over the years: they like to call it the miracle suit. ❖



“We’re taking this **suit** to the **village,** we’re **taking it to the hut . . .** to the **poorest,** most **vulnerable, voiceless, powerless people . . .** and **making a difference** for **them.”**

— Suellen Miller, Safe Motherhood Program

The village of Gando, Burkina Faso, in subsaharan Africa.

Tool Kit Simplifies Development of High-Affinity Molecules

NASA Technology

As NASA sets its sights on long-duration missions deeper into the solar system, including a planned mission to Mars, astronauts will need access to health-monitoring technology. Of particular importance is the need for a diagnostic tool that could measure for biomarkers that indicate loss of bone density, or demineralization, which is a serious concern for astronauts, as living in a microgravity environment causes attrition in the bones and muscles.

But using antibodies, which are proteins commonly utilized to detect biomarkers in diagnostic tests, is problematic, says Dr. Thomas J. Goodwin, who manages the Disease Modeling and Tissue Analogues Laboratory and is lead scientist for Oxidative Stress and Damage research at Johnson Space Center. For one, antibodies in space are susceptible to degradation from radiation exposure. In any case, when refrigerated, antibodies remain viable for only three to six months—far short of the years required for deep-space missions. "Even if you did freeze them, after a couple of years you would have to question their viability," he notes. "Add to that the fact that you would have to build special storage units into a vehicle that has a lot of space constraints, and it becomes clear that we shouldn't use antibodies."

As a result, through the Small Business Innovation Research (SBIR) program, Johnson put out a call for a health-monitoring technology that could not only remain viable for several years, but also be produced simply. One company would contribute to that goal by improving on an alternative to antibodies that has more recently come onto the biotech scene.

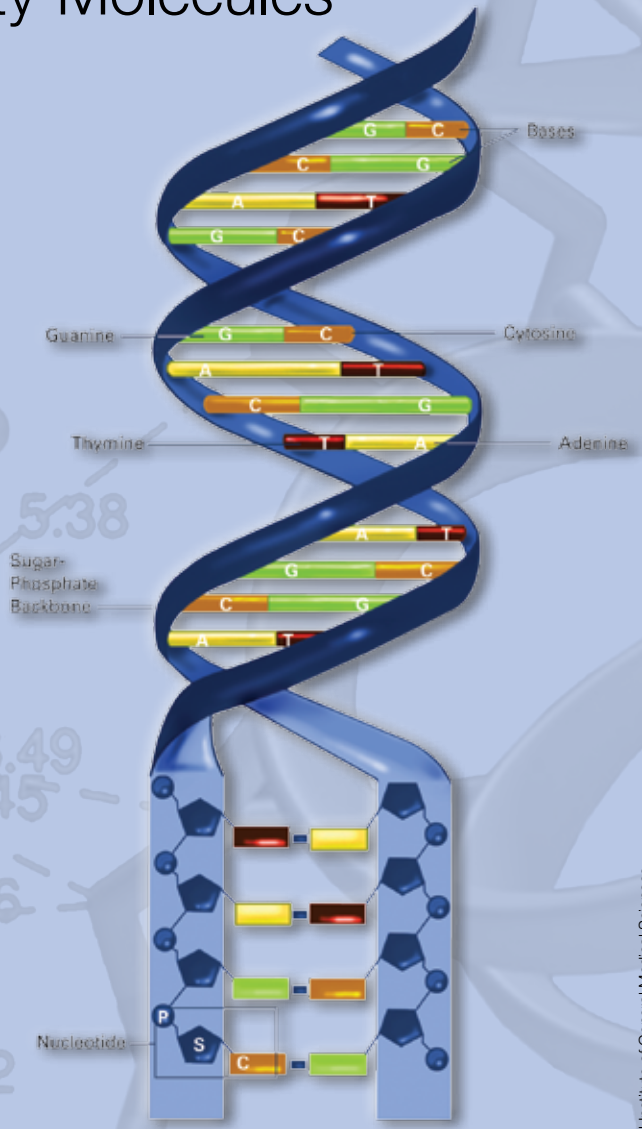
Technology Transfer

In the 1990s, researchers discovered through a process called systematic evolution of ligands by exponential enrichment, or SELEX, that short, single strands of RNA and DNA called oligonucleotides could fold themselves into three-dimensional structures that then bind to specific molecules. Called aptamers, they were found to have many potential advantages over antibodies for diagnostics. They can be stored at ambient temperatures without degrading, are impervious to radiation, and, unlike certain antibodies, they don't provoke a negative immune response in the body, which in extreme cases can be life-threatening.

However, the downside was that, at their stage of development, aptamers did not function as precisely as antibodies in tests, says Mark Shumbera, president of AM Biotechnologies LLC, based in Houston. "They didn't bind well enough—they weren't specific enough for their targets. Certain chemical modifications needed to be added to their DNA to make them work better."

The SELEX process, explains Shumbera, starts with an enormous library of 10^{14} random oligonucleotide sequences in solution, into which the target molecule is placed. While many sequences will not bind at all to the target, some may bind very well and others will bind weakly. Those sequences that bind are partitioned off and amplified, or copied many times over through a technology called polymerase chain reaction (PCR) in order to create another, smaller library of sequences. After 10 to 15 rounds of partitioning the sequences and amplifying them, only those sequences with the highest binding affinities will remain, and they are identified. While the enzymes used for PCR normally produce unmodified DNA sequences, it is possible to construct sequences that are chemically modified if one or more of the four nucleotides used during PCR contain chemical modifications. Those modifications may improve a sequence's binding affinity as well as other characteristics.

The problem with this process, says Shumbera, is that the number of chemical modifications possible using the PCR method is limited. Only those modifications the amplifying enzyme will accept can be used, and only a total of four different modifications are possible, since changes made to any nucleobase (adenine, cytosine,



DNA comprises two twisted chains of nucleotides, with each nucleotide containing one base (adenine, thymine, cytosine, or guanine), one phosphate molecule, and the sugar molecule deoxyribose. It was discovered that oligonucleotides—comprising multiple nucleotides—were able to fold themselves into three-dimensional structures called aptamers that, based on their makeup, bind to specific molecules. AM Biotechnologies developed a faster, simplified method for developing highly effective aptamers.

Image courtesy of the National Institute of General Medical Sciences

guanine, or thymine) are then made to every other base of its kind in the sequence. "But in reality, it's difficult to use that many," he says. "The PCR process doesn't work very efficiently like that, so typically people only use one, and maybe two modifications at a time."

Through NASA SBIR funding in 2007, AM Biotechnologies advanced what Shumbera describes as a bead-based method for developing aptamers that removes limitations associated with inserting chemical modifications during PCR while also simplifying the process. The technique had been conceptualized several years earlier by David Gorenstein, a chemist and now Associate Dean for Research and Distinguished Chair for Molecular Medicine at the University of Texas Health Science Center in Houston as well as chief science officer for AM Biotechnologies. Through the NASA funding, along with additional support from the Bill & Melinda Gates Foundation and the National Institutes of Health, the company was able not only to create next-generation aptamers with numerous chemical modifications, so-called X-Aptamers, but also to commercialize a kit so others could develop them on their own.

The process begins by utilizing a proprietary technology to synthesize a library of 10^{10} oligonucleotide sequences, both natural and heavily modified, on microbeads. "You can have 50 modifications in a sequence—there's virtually no limit," Shumbera says, compared to the limited capability of the PCR method. "This method allows for the DNA or RNA to be more chemically diverse, meaning there's a better chance of creating a molecule with a particularly high affinity and specificity for the target."

Each microbead has billions of copies of just one oligonucleotide sequence synthesized on it, and there is an enormous library of these beads. They're exposed to the desired target molecule in a solution, and the most promising sequences bind a large number of target molecules to their bead. Magnetic particles that attach to a label on the target molecule are then added to the solution so the beads containing a large amount of the target can be separated from the rest with a magnet. The sequences from those selected beads are cleaved, placed into a solution, and then exposed once again to the target. Shumbera points out this second step—culling the best binders from the solution—only needs to be carried out once because the sheer number of identical sequences on each bead makes finding the highest-affinity sequence easy. "Instead of taking weeks to find the right aptamer with SELEX, our method takes only a few days."

The sequences of the oligonucleotides pulled out of the solution by the protein target are identified using a next-generation DNA sequencer. "The DNA sequence acts as a barcode to go back to the original library, figure out where the chemical modifications are, and then we resynthesize it. That's the X-Aptamer," Shumbera says.

Benefits

After years of further research and development, AM Biotechnologies' X-Aptamer Selection Kit is now commercially available for any customer, including biotech companies and universities. Practically anyone with basic biochemistry lab skills can work with the technology. "We have university customers, our prototype users, who have had freshman undergraduates select X-Aptamers using our kit. The bead-based process simplifies aptamer selection tremendously," Shumbera notes.

Unlike the SELEX method, AM Biotechnologies' X-Aptamer Selection Kit is simple enough for freshman undergraduates to use and takes only a few days to achieve results.

Beyond their use as a medical diagnostic tool for disease, X-Aptamers can substitute for antibodies as targeting agents for drugs that treat everything from arthritis to cancer. "The X-Aptamer could carry and attach a chemotherapy drug to a tumor, which prevents other parts of the body from being impacted negatively by it," Shumbera explains, while noting that aptamers themselves can also be made into drugs for treating disease. One such aptamer is Pegaptanib, which is used to treat macular degeneration by preventing the formation of new blood vessels that would otherwise damage the retina.

As far as Shumbera knows, Pegaptanib is the only FDA-approved aptamer drug, and there don't appear to be many diagnostic tools based on aptamers currently on the market, either. He chalks that up to aptamers being a relatively new technology and their performance not being up to par until now. "The rule of thumb is that it usually takes 20 years for a new technology to really gain mainstream acceptance. It's been about that long for aptamers. In addition, the chemical modifications that are now being used in our X-Aptamers make them much more effective."

It's just the right time, Shumbera says, for something like the X-Aptamer Selection Kit to make its debut. "It has the promise of greatly simplifying the development of affinity-based molecules while also lowering their development cost. It could help usher in the next big revolution in terms of how we diagnose and treat patients."

For NASA, the X-Aptamer is one critical component for a space-worthy diagnostic tool. The Agency is working with other companies on the other component: a hardware platform that can perform the analysis in space. "No matter what platform or platforms we end up using, right now I think this technology is probably the best solution for the reagent side of the formula," says NASA's Goodwin. "X-Aptamers can step up and fill that niche when we're ready to use it. ❖

"Instead of taking **weeks** to find the **right aptamer** with **SELEX, our method** takes only a **few days."**

— Mark Shumbera, AM Biotechnologies

An artist's concept of a human mission to Mars. The area depicted is Noctis Labyrinthus, in the Valles Marineris system of canyons. AM Biotechnologies' X-Aptamers may be used as part of a health diagnostic tool for missions such as this, which can last for years. On Earth, X-Aptamers can also be used in the development of medicines that aim to treat a range of diseases, from arthritis to cancer.

Space-Ready Spectrometer Offers Terrestrial Advantages

NASA Technology

In the 1990s, Jet Propulsion Laboratory (JPL) scientist Joy Crisp oversaw an effort to get a cutting-edge, ruggedized, lightweight spectrometer on a lander to be carried by the European Space Agency's Rosetta comet orbiter. Conceived in 1985, the Rosetta probe launched in 2004 and finally encountered its target comet in August 2014.

Crisp's spectrometer of choice, however, was not on board.

The device NASA had selected before ultimately pulling out of the mission was a near-infrared, acousto-optic tunable-filter (AOTF) spectrometer built by Brimrose Corporation of Sparks, Maryland, under two Small Business Innovation Research (SBIR) contracts with JPL, both awarded in 1992.

The type of spectrometer Brimrose and Crisp worked with uses light, primarily in the near-infrared and visible range, to analyze the chemical composition of a target surface or substance. Every substance has its own "spectral signature," depending on the wavelengths it reflects, absorbs, or emits, and the spectrometer typically reads the signature of the transmitted, reflected or absorbed optical spectrum.

What made Brimrose's device different from a standard spectrometer was the AOTF technology the company had recently begun developing and which was relatively new at the time. Normally, a spectrometer isolates different wavelengths of light by rotating a grating or prism, explains Sudhir Trivedi, director of research and development at the company, adding that such devices require a mechanical leg to recalibrate themselves. An acousto-optic filter, on the other hand, is a crystal that responds to different pitches of sound. "By changing the frequency of the sound, you can diffract the light into bands," he says. "So the technology we have has no moving parts."

"This was a nifty way of making it rugged," says Crisp, who was the monitor for the two SBIR contracts. Aboard Rosetta's Champollion lander, the imager would determine the chemical makeup of samples from the comet, which could have implications regarding the origins of the solar system and the universe. A Mars scientist and a geologist by training, though, Crisp was especially interested in determining whether an AOTF spectrometer would one day make an effective tool for analyzing the surface of the Red Planet.

But in 1996 the United States withdrew from Champollion, opting to invest that money instead in another imaging device, the Hubble Space Telescope, which still needed extensive corrections.

"We thought if we could demonstrate the AOTF spectrometer, people wouldn't say, 'Ah, it's a new-fangled technology, why don't you use something more tried and true?'" Crisp says. "If it has no flight heritage, you have to make an incredible case and show you've done lots of testing."

Technology Transfer

The SBIR funding came at a time when the company was in the early stages of developing its AOTF technology, a pioneer in the field, says Jolanta Soos, Brimrose's chief technology officer. "It let us develop our fabrication procedures for the AOTF and its electronics."

NASA requirements also shaped the device in ways that would prove useful on Earth. It had to be able to withstand the extreme temperatures of space, as well as radiation exposure that would destroy most regular electronics, says Trivedi. It had to use a minimal amount of power.

"Whenever you have to send anything to space, weight is a great factor," he adds, noting that, while the company's earlier spectrometers had weighed two to five pounds, the designers got the version for NASA down to just over a pound by using lightweight metals and compact, light, digital electronics.

"All the harsh conditions of space—our systems we developed with NASA programs are capable of withstanding that," Trivedi says.

Benefits

In the years since Brimrose's partnership with JPL, the use of near-infrared spectrometers has exploded across numerous industries.

The pharmaceutical sector was one early adopter, using the devices to monitor ingredients in capsules and tablets for quality, uniformity, and compliance with

Brimrose's work with NASA made the company's solid-state, acousto-optic tunable-filter spectrometers rugged, small, and lightweight, able to withstand vibrations, radiation, and extreme temperatures. This one is about a foot long in its entirety.

> All the harsh conditions of space—our systems we developed with NASA programs are capable of withstanding that."
>
> — Sudhir Trivedi, Brimrose

regulations. The technology is used in agriculture to determine the quality of seeds and produce. Winemakers use it to analyze grape and wine composition. For oil companies, it can assess the properties of a batch of crude. In healthcare, it's used to map brain activity by tracking hemoglobin concentrations, to investigate tumors and muscular functioning, and to image the retina. In materials science, spectroscopy can measure film thickness or investigate optical coatings for telecommunications. An exhaustive inventory of applications for the technology becomes unwieldy.

What have given Brimrose spectrometers an edge in this burgeoning field are the sturdiness, small size, light weight, and energy efficiency that the company learned to incorporate into its designs during its work with NASA. These qualities led to the success of early models like the Luminar 3050 mini-spectrometer (*Spinoff* 2003). But the company has continued to build on this technology, recently introducing its Luminar 4060 Free Space Analyzer and Luminar 5060 Hand-Held Analyzer, both of which represent major advances in size and efficiency while retaining Brimrose mainstays like the absence of moving parts and the ability to scan at 16,000 wavelengths per second.

Soos points out that the compact, lightweight designs make it possible, for example, to attach a device directly to a blender that's mixing a pharmaceutical. "What our spectrometer is doing, in real time, is to measure the composition throughout the blend and stop it when it has the right blend," she says, adding that units might also be attached to robotics or other machinery.

Trivedi notes that lightweight, energy-efficient models are ideal for troops in the field, who might use them in medical devices and other applications. He adds that energy efficiency is attractive to all customers, saving them money, which is what commercial spectroscopy comes down to. "All our spectroscopy customers purchase the instruments to save money," Soos says. "Sometimes the cost of the instrument is paid back in a couple of months on the production line."

Brimrose now offers 14 different AOTF spectrometers, which have been modernized over the last dozen years to include touchscreens, longer battery life, a conversion to the Linux operating system, better manufacturing, and purer materials, in addition to increased efficiency and portability, says David Chaffee, the company's director of marketing communications.

The company has also adapted its rugged AOTF technology for other applications. In June 2014, it released a line of ultra-high-speed tunable light sources that use acousto-optic filters to narrow light down to a specific, adjustable wavelength. The technology is expected to find a market in the medical, microelectronics, and spectroscopy fields, among others.

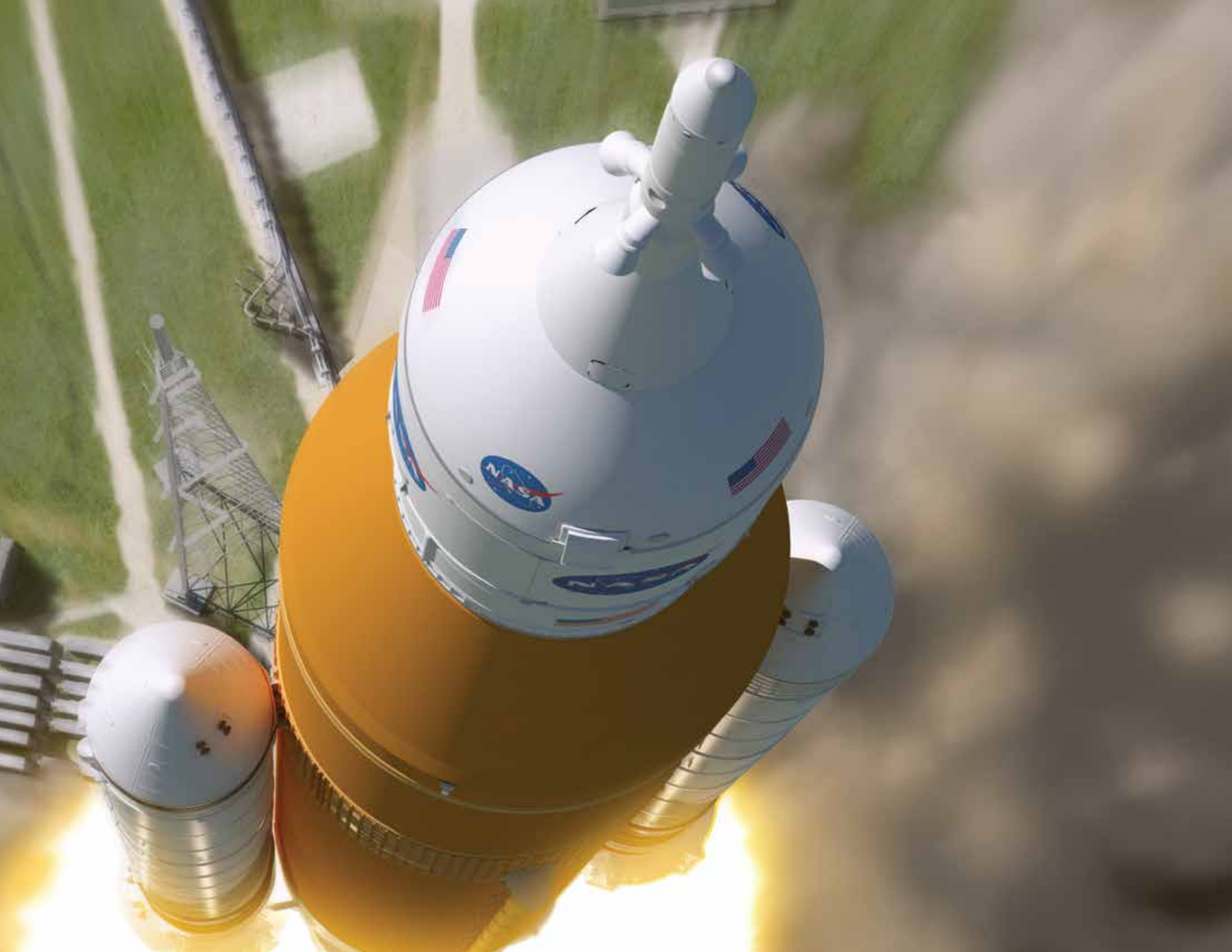
And in 2011, a piece of Brimrose AOTF technology was finally put to the space test when one of its acousto-optic modulators was one of two such devices that rode to the International Space Station (ISS) on the Materials International Space Station Experiment-8. The goal of this test flight was to see if the device could survive liftoff and function in the unforgiving conditions the company had in mind when working with JPL more than 20 years ago, says Narasimha Prasad, electro-optical sensor technologist at Langley Research Center, who worked with the company to have the device sent to the ISS.

Prasad says Brimrose was one of the companies selected to supply an AOTF device for testing because the company is a leader in its field and one of only a handful of acousto-optic developers in existence. He explains, "Something has to be done to make electronically tunable filters available for space applications." ❖

The pharmaceutical industry was an early adopter of spectroscopy, which can monitor ingredients to ensure quality, uniformity, and compliance with regulations. Winemakers use it to test the composition of both their grapes and their end product, and spectroscopy lets petroleum companies analyze the crude they unearth and the oil they sell.

Transportation

No one knows transportation better than the Agency that sent people to the Moon and back and safely lands complex instruments on distant planets. Meanwhile, a major part of NASA's mission is to transform the field of aviation on Earth, and its researchers are constantly developing new test beds and design software to push the boundaries of aerodynamics, efficiency, and safety, leading not just to higher-performance vehicles but also to lives and money saved.


NASA

Unmanned Research Aircraft Test Cutting-Edge Innovations

NASA Technology

Born out of a desire for aircraft to be able to take off and land capably at airports with shorter runways to alleviate congestion at the major hubs, the circulation control wing concept has been floated by the aeronautical community as a possible solution for decades. The technology calls for increased amounts of high-pressure air, derived from either the jet engines or separate compressors, to flow over the leading and trailing edges of the wings, creating greater lift. Given extra lift, an aircraft can take off and land at a lower speed, thus reducing the length of runway needed. Extra lift also enables increased weight-carrying capacity.

To test an idea that had yet to see flight time, in 2006 NASA's Dryden Flight Research Center (now Armstrong Flight Research Center) put out a call through the Small Business Innovation Research (SBIR) program for the design and manufacture of an unmanned, sub-scale test aircraft outfitted with circulation control wings that could fly with or without the technology.

"The goal would be, you fly the baseline aircraft and see how long it takes to take off and land, and then compare it to the new technology," says Armstrong aeronautical engineer Bruce Cogan. A host of other parameters would also be tested, including how the circulation control wing responded to aerodynamic stalling, whereby an aircraft simultaneously loses lift and altitude. "And since stalling cannot be modeled well in a wind tunnel or in a simulation, it's one of those areas where you have to get flight test data, and because this is a risky maneuver, unmanned testing is always better."

Technology Transfer

Area-I Inc., based out of Kennesaw, Georgia, garnered Phase I and II SBIR funding primarily for developing the aircraft's design, and the company used grants from the state of Georgia, along with its own money, to build a prototype. Nick Alley, Area-I's CEO, oversaw the circulation control wing project and finished constructing the aircraft in 2011.

Developed with NASA SBIR funding, Area-I's Prototype-Technology Evaluation Research Aircraft, or PTERA, was flown and tested in Georgia skies on three separate occasions in 2014. The aircraft, a 10-percent scale model of a medium-range twinjet airplane, can be used to test any number of aeronautical technologies, from advanced control algorithms to avant-garde wing designs.

> "PTERA is sitting there with an open source flight computer … In a matter of a year you can be up and flying."
>
> — Nick Alley, Area-I Inc.

In the intervening years, however, NASA had begun to focus on other aeronautical research, and two of the Agency's centers were soliciting SBIR proposals for the development of different research aircraft: Armstrong was looking for an economical, sub-scale baseline model akin to a medium-range, narrow-body, twinjet airliner for aerodynamics investigations; Langley Research Center, through the Aviation Safety Program, needed a regional-type, sub-scale airplane with a T-tail empennage and a rear engine mount. T-tail aircraft can have more severe stall characteristics, so Langley researchers wanted to fly a small-scale facsimile into extreme conditions and experiment with recovery maneuvers. The data gathered from those tests would be used to develop a model for a pilot-training simulator.

Fortuitously, the aircraft Area-I had constructed to test the circulation control wing technology was highly adaptable. "The unforeseen genius of the aircraft was that we inadvertently designed a platform that was reconfigurable in the way we designed the molds and the tooling," Alley says. "We could, for a minimal amount of effort relative to designing a whole new airplane from the ground up, reconfigure it and put a different type of wing on it or do a whole bunch of other things as needed." Banking on its versatility, he named his baseline aircraft PTERA, or Prototype-Technology Evaluation Research Aircraft, and applied for and received Phase I SBIR funding from both Armstrong and Langley to develop the pair of what Alley calls his "flying laboratories" in 2011. He received Phase II funding from both centers to continue work the following year.

In 2014, Area-I completed construction of both aircraft, in addition to another model similar to Armstrong's medium-range twinjet airplane that the company is keeping for commercial use. Armstrong's model is 10 percent the size of its commercial counterpart, while Langley's plane, which the center named PTERA GMA-TT, for

Generic Modular Aircraft T-Tail, is about 16 percent of full-scale and represents the flight dynamics of a mid-sized regional jet transport.

With their respective aircraft at hand, both centers see a lot of potential. In addition to improving pilot performance during stall, a secondary goal for GMA-TT would be to test related alerting and automation technologies, says David Cox, who is element lead for sub-scale testing at Langley. "We've explored some advanced control laws that would automatically pull an aircraft out of these situations, so that's another possible use."

Armstrong's interest in aerodynamics opens up numerous research possibilities using PTERA. Plans are in place to test wing tips made of shape-memory alloys, which can change their shape at certain temperatures to reduce drag or maximize control at various stages of the flight envelope. "We could test a number of other wing innovations as well, along with assorted sensors and promising algorithms," says Cogan. "The baseline PTERA is designed for experimenting on a range of technologies, so it's certainly capable."

Benefits

Building on its successful work with NASA, Area-I is developing other unmanned aerial vehicle airframes for the U.S. Navy and the U.S. Air Force and is also taking orders from universities and companies interested in using PTERA or other company-designed unmanned aircraft for testing aerospace technologies that may yet be too dangerous for piloted flights. "Maybe you need a dynamic environment where it makes the most sense to fly it on an airplane rather than use a wind tunnel, especially when you're developing advanced control algorithms," Alley notes.

Customers stand to benefit from the substantial work put into making the aircraft dependable. With Phase II funding from Armstrong, Area-I's baseline PTERA aircraft was flown and tested over Georgia on three separate occasions in 2014. As well as allowing engineers to refine the controller architecture and various flight software that Alley had developed on his own prior to the NASA contracts, the flight time proved valuable for dealing with the much-dreaded "gremlins"—those unforeseen problems that invariably show up when a newly built aircraft is getting off the ground. Alley says, "We've had the opportunity to work out those kinks—to kill those gremlins."

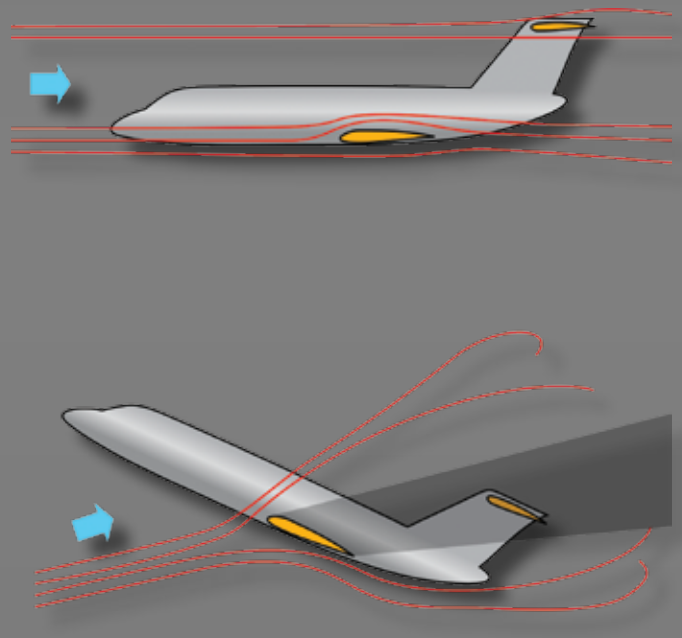
That means much of the challenging work has already been done. "Blood, sweat, and tears have gone into the design of this baseline aircraft, including the design of the system as a whole, from the ground control station to the onboard avionics to the airframe and its structures," Alley remarks. "You're already standing on the shoulders of a giant. It's helping you be one step ahead so you don't have to design the whole thing from scratch. PTERA is sitting there with an open source flight computer so that you can go in and load up everything you need. You can put your payloads in, we can build you new wings if you need to and other new things, and in a matter of a year you can be up and flying."

Flight time also allowed the company to build a performance database of the baseline aircraft, documenting its maximum speed, takeoff distance, and altitude, among other variables. Users can compare the benchmark data to whatever innovation they're working with and determine whether it's having the intended impact. "You can look at all of our previous flight tests and discover, for example, if your fuel burn is less on this flight," Alley says. "There's data, there's background, and there's history with PTERA, which will be very valuable later as we're evaluating new technologies."

Cogan says having flight data available like this is rare. "We can't release data owned by the Navy or Air Force because of ITAR [International Traffic in Arms Regulations], and companies have proprietary data that they don't want to share," he says. "But with PTERA, it's basically all Government-owned, nonmilitary data, so it's easy to distribute and publish."

PTERA's other benefit—one accounted for by all the blood, sweat, and tears that went into its testing and the development of modular construction techniques—is its cost. While comparable models sell for millions, if not tens of millions of dollars, a new PTERA can be purchased for about $250,000. "That's a pretty good price," says Langley's Cox. "We spend a fair amount of time making sure we won't lose it for the wrong reasons, but Nick [Alley] is down there with that price tag—it's possible for a quarter of a million dollars to dig your way out of that problem should it happen. That wouldn't be the case with a multi-million-dollar aircraft."

For Alley, the experience his company has gained from working on these sub-scale aircraft is priceless. "It's matured my young engineers. It's given them experience that they would never get in typical industry, which has made us a much better company," he says. "It keeps us young and flexible and keeps us doing the wild and crazy stuff as well, which makes this quite the dream job." ❖



An aircraft with a T-tail empennage in normal flight (top) versus when it's in a deep stall condition, whereby the wake created by the stalled wings blanket the T-tail, preventing normal recovery. One of NASA Langley Research Center's goals for its PTERA Generic Modular Aircraft T-Tail, or GMA-TT, is to flight-test stalls and recovery maneuvers in order to improve simulators used for pilot training.

Data Visualizer Enhances Modeling for Cars, Consumer Products

NASA Technology

Nearly 20 years ago, Pieter Buning was in the early stages of his career with NASA, working on an interactive graphics program called Plot3D. "Life was different back then," says Buning, an aerospace engineer and research scientist at Langley Research Center. "We didn't have all the fancy screens and interactive graphical interfaces. My motivation was to be able to see what was going on in the calculations and also to make it look physical."

He was working in the world of computational fluid dynamics (CFD), translating the movement and interaction of substances like air and water and solid surfaces. "Basically, what you get out of CFD is doing essentially what wind tunnel testing would do, but you're doing it on a computer," he says. "The idea is that it would be cheaper to use CFD than building a model and running a physical test in a wind tunnel. We're still pursuing that. But back in the 1970s, the claim was that CFD would replace all wind tunnels. That hasn't happened."

It might have been fun work, but mostly the time spent on graphics was a way to avoid working on his thesis, he jokes. Buning went on to work on a solver called OVERFLOW, teaming up with Rutherford, New Jersey-based Intelligent Light Inc. to provide post-processing and visualization capabilities.

Technology Transfer

NASA has been familiar with Intelligent Light since at least 1996, when the company received its first Small Business Innovation Research (SBIR) contract for the development of a CFD post-processor to create efficient visualizations of large, unsteady results (*Spinoff* 2003). At the time, the product, FieldView, was a visualization tool, and the contract was awarded for the company to develop transient data-handling capabilities and integrate them into the existing product. The company was successful and has secured a total of 13 additional SBIR contracts from NASA and other Government agencies, including 8 Phase I and 6 Phase II contracts, along with 3 Small Business Technology Transfer contracts, worth a combined $5.4 million since 1996.

To hear Steve Legensky, one of the founders and a general manager of Intelligent Light, talk about it, the FieldView product of 15 years ago is almost entirely different from today's model.

Intelligent Light was one of 11 companies that could do high-resolution, 3D-rendering animations using computers when the company started in the mid-1980s, and the goal was to help make complex mathematical equations easier to understand by making them visual. "If we could take the numbers, whether they were measured numbers in a wind tunnel or whether they were computed numbers from CFD, our philosophy was that if people could see these phenomena in a context that looked like the real object, they would more naturally be able to uptake it to the brain and the eye and understand it," says Legensky.

Some things are easier to visualize than others. A pebble tossed into a pond makes traceable ripples, but the air traveling through a heating and cooling duct is more difficult to monitor. Harder still is trying to determine the flow of fuel through a jet engine, says Legensky. This is why CFD modeling is needed, to better understand the dynamic conditions that occur whenever a fluid interacts with or manipulates something solid.

FieldView has evolved beyond those early visualization goals to allow companies to ask for specific information based on static or unsteady data, providing the user with detailed results for the task at hand. If an aircraft company wants to redesign a wing, instead of having an engineer in an office running calculations, that same engineer can input a series of parameters or constraints and allow the program to run simulations. In post-processing, which is where FieldView is used, the results are then analyzed,

Among the biggest commercial users of Intelligent Light's FieldView computational fluid dynamics post-processing tool are Formula One racing teams, which use the software to make minute and intricate changes to a car's structure to improve performance.

> “Our work with NASA is both with them as great customers, and as collaborators who push us while also teaching us about technology.”
>
> — Steve Legensky, Intelligent Light

and only the best-performing wings are presented for the engineer to review.

“Think about that broad stretch, from one guy waiting weeks for a calculation of a steady picture, to today, where the fidelity and magnitude of things that can be computed is so much greater. The problem has shifted over the years from handling the results in some way to extracting the knowledge from those results for it to be a meaningful endeavor,” Legensky says.

The data FieldView can return are not just what Legensky describes as “wide”—like the aircraft engineer looking at wing permutations—but also deep, he says. He’s been working on a project for the navy involving 45 seconds of a helicopter approaching, hovering, and landing on an aircraft carrier. “A customer came to us and said, ‘I need to measure forces and take pictures at a rate of 60 frames per second, so I have 2,700 sets of files.’ Each set is many gigabytes. But that’s one simulation that, because of the grid resolution for the length of time, is very, very deep.”

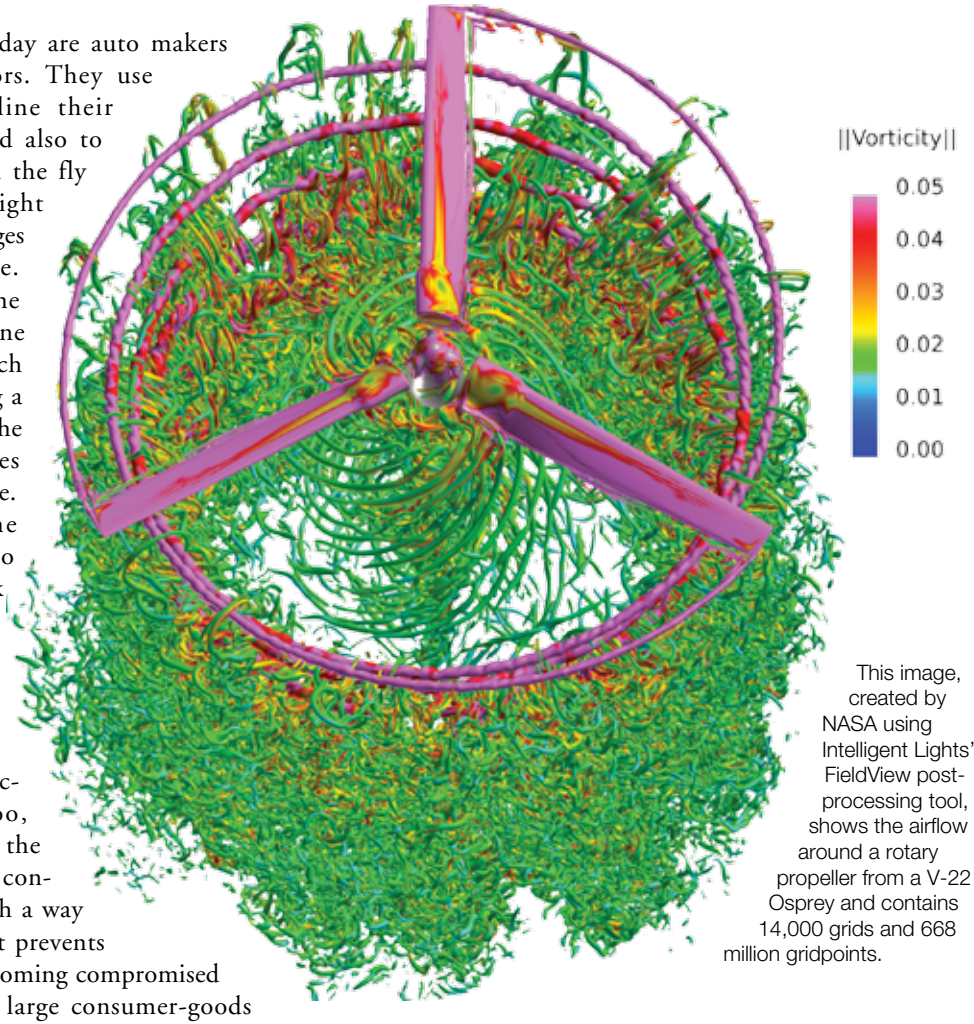
Benefits

Legensky compares FieldView’s user interface with the cockpit of a plane. In the first commercial airlines, dozens and dozens of dials, displays, and gauges alerted pilots to what was going on with the plane in flight. Now, cockpit displays are more streamlined, with only the most important information readily visible. The same is true for the computed data entered into FieldView—additional information is there if a user wants it, but only the most pertinent, best results are presented at first glance.

It’s not just aircraft designers who are interested in CFD results. Legensky says the two industries using FieldView the most today are auto makers and defense contractors. They use FieldView to streamline their workflow processes and also to make modifications on the fly and get real-time insight into which design changes will be most effective. He’s worked with some of the top Formula One racing companies, which are interested in making a change to vehicles in the few days between races to improve performance. “Some Formula One teams, I’ll venture, do more CFD per week than NASA does. They have budgets close to $350 million a year to field one or two cars at up to 20 races.”

There are more practical applications too, including determining the best way to fill plastic containers of yogurt in such a way that is not only fast but prevents the safety seals from becoming compromised or contaminated. One large consumer-goods manufacturer uses FieldView to calculate the best way to ensure encapsulated treatments or minerals are equally distributed throughout a batch of shampoo or lotion.

NASA still uses FieldView to help gain a physical understanding of airflows, and the speed at which the program can mine large amounts of data is crucial, Buning says. “We now do unsteady calculations like helicopters, new launch vehicles, or Mars landers. The amount of data coming from simulations just exploded. FieldView is a fantastic tool for analyzing our results and giving the user a real understanding of the calculation.”



This image, created by NASA using Intelligent Lights’ FieldView post-processing tool, shows the airflow around a rotary propeller from a V-22 Osprey and contains 14,000 grids and 668 million gridpoints.

Legensky credits NASA’s support and its challenges for much of his company’s success. “Our work with NASA is both with them as great customers, and as collaborators who push us while also teaching us about technology. These SBIR contracts from NASA are an indication that someone with a big brain is looking out over the horizon and saying this problem is going to have to be solved for us in the future, then turning to see if somebody in a small business is clever and able to solve the problem.” ❖

Lightweight, Ultra-Strong Nanotubes to Transform Industry

NASA Technology

In June of 1991, Japanese scientist Sumio Iijima had been studying fullerenes, man-made molecules made up entirely of carbon, when he discovered under an electron microscope a novel configuration—a honeycomb-like structure of carbon atoms connected by covalent bonds and rolled into a tubular shape. Because of its extended, uniform bonds, the nano-sized material (each tube's diameter measures a billionth of a meter) is the strongest ever discovered: ounce for ounce, it's at least 117 times stronger than steel and 30 times stronger than Kevlar. It also proved to be elastic, able to bend and then snap back into position, and it had a high degree of electrical conductivity.

BNNT LLC has developed the technology to synthesize 200 milligrams of boron nitride nanotubes per hour. The company is making the material available to researchers who aim to take advantage of its molecular properties, such as its strength and heat resistance, for a variety of applications.

While carbon nanotubes (CNTs) have since caught the imagination of a wide swath of industry, so has another, similar material with distinct properties. In 1994 physicist Marvin Cohen, a professor at the University of California, Berkeley, theorized that boron and nitrogen, two elements with comparable atomic sizes to carbon, could be formed together into the same strong, tubular structure as CNTs. The next year, his colleague Alex Zettl successfully synthesized the first boron nitride nanotubes (BNNTs) using an electric arc method.

The synthesis of BNNTs piqued NASA's interest because the molecules' additional benefits make them potentially valuable for protecting astronauts during space exploration. For one, BNNTs can withstand temperatures up to 1,650 °F, while CNTs start to degrade at 750 °F. What's more, BNNTs also absorb neutron and UV radiation, which are threats to spacecraft, electronics, and people traversing the solar system. For the Agency, acquiring a heat shield that has a layer of lightweight, powerful, heat-resistant, radiation-absorbing BNNT composite would be hugely advantageous.

But for all their promise, there was one major preliminary hurdle that had to be cleared: finding a way to synthesize BNNTs in sizable quantities.

"Researchers could make no more than a little fingertip of this stuff at a time," says Mike Smith, a former staff scientist at NASA Langley Research Center.

In 2001, Smith led a team of Langley scientists in experimenting with different methods for synthesizing the ultra-tiny, elusive nanotubes in greater quantities. In total, NASA and the Department of Energy provided several million dollars of support for research and development. In partnership with researchers from the National Institute of Aerospace (NIA), a nonprofit research and education institution, the team carried out its work at nearby Jefferson Lab. The facility houses the world's most powerful free electron laser, which played a role in producing CNTs in the early years of research.

At that point, finding a successful, reproducible method for creating any amount whatsoever of high-grade BNNT required another two years of experimenting. "We tried different laser frequencies, target materials, catalyst compositions, focuses and frequencies, and so on to find the optimum condition, with a thorough characterization of the product at each condition," says Cheol Park, a scientist in the Advanced Materials and Processing Branch at Langley. "This was a long and challenging process."

In 2008, the team tasted success when it produced the world's first sizable, high-quality BNNT sample. In short, their resulting winning formula requires that boron and nitrogen be present in a particular ratio to each other inside a highly pressurized chamber. A powerful laser is then fired into the chamber, causing the two elements to heat up and form a vapor cloud that, as Smith puts it, "self-assembles into these puffy, long mats of nanotubes that kind of look like cotton balls."

Technology Transfer

In the next few years, the team worked to fine-tune its formula, with special attention paid to increasing the rate

of production. Eventually, they were able to synthesize 20 milligrams of BNNT per hour, and managed to do so using a standard welding industrial laser.

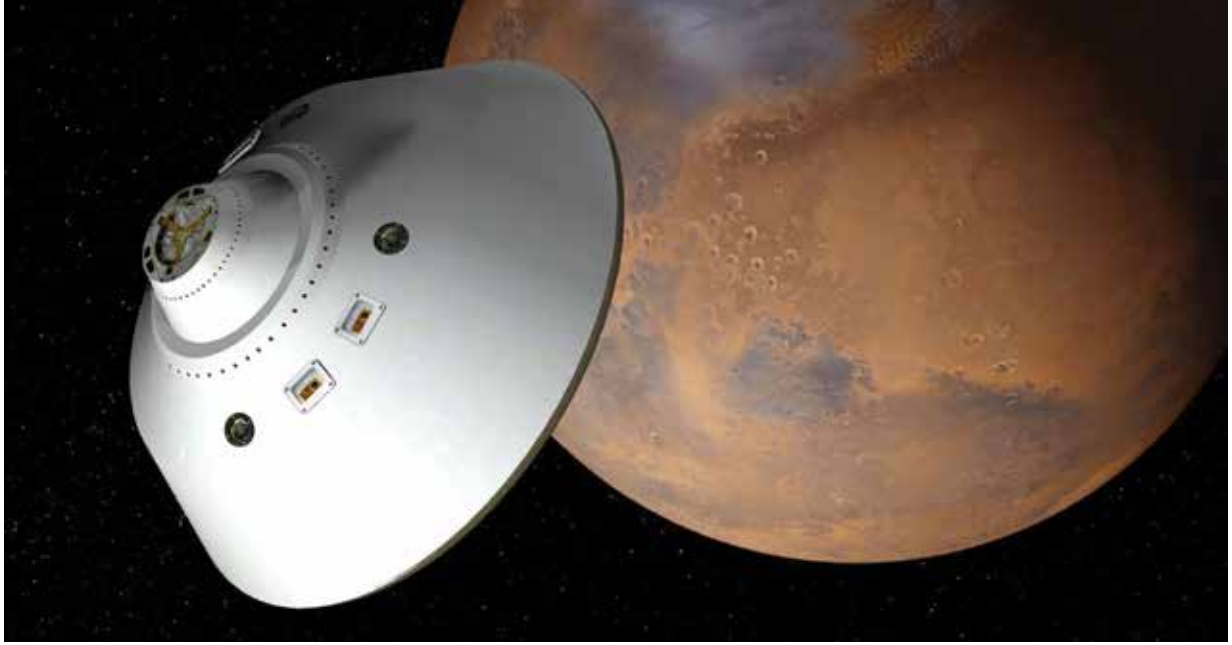
Recognizing the value of commercially synthesizing such an in-demand, novel molecule, several individuals involved in its development, namely Kevin Jordan, chief engineer of Jefferson Lab's free electron laser, and Roy Whitney, the lab's CTO, helped found Newport News, Virginia-based BNNT LLC in 2010. Smith, lead author on the BNNT synthesis patents the Agency, Jefferson Sciences Associates, and the NIA filed, followed suit in 2011 as he left NASA to become the startup company's chief scientist.

Having licensed NASA's patents, BNNT LLC's goal has been to continue improving the nanotube's production efficiency. As a result, in May 2014, the company announced it had further developed the foundational technology to the point that 200 milligrams of BNNT could be synthesized per hour. That July, the product was made commercially available to researchers for the first time.

Benefits

There has been a steady global demand for samples. Aside from NASA's aspirations to use the material for protective composite materials in spacecraft, numerous other potential uses abound, such as protective gear for first responders, electrical insulation (in contrast to CNTs, which are solely electrical conductors), and even soft-tissue cancer therapy. "BNNTs have a lot of subtle qualities that lend themselves to a variety of applications," Smith says, "and now that it's commercially available, people are itching to see what they can do with it."

Meanwhile, the Space Agency and BNNT LLC have maintained a close working relationship. Through a Space Act Agreement, in exchange for a steady supply of samples from the company, NASA Langley provides modeling and simulation analysis, as well as material characterization, on an ongoing basis. (A new BNNT synthesis rig—designed by NASA and NIA researchers and built at the NIA's laboratory—is being used for those purposes.) "It's about quality control," says NASA's Catharine Fay, who manages the BNNT program. "The goal is for us to help the company to continue optimizing the quality and quantity of the nanotubes."



An artist's concept of a Mars sample return mission. NASA scientists hope to utilize boron nitride nanotubes for various structural components of spacecraft. The material's ability to absorb neutron and ultraviolet radiation makes it an optimal choice for space exploration, and its strength and heat resistance can provide stability against the very hot temperatures associated with entering planetary atmospheres.

Another way they're working together toward that goal is by experimenting with other methods for BNNT synthesis. For example, the BNNT team is exploring the use of Langley's plasma spray as a heat source for the vaporization process. "The key is not using a laser, per se, but being able to heat the material very quickly," Park explains. "Lasers may not be the final destination. We may be able to find a cheaper method."

Decreasing the production cost would benefit both the private sector and NASA, which is dedicating considerable resources to structural composite development utilizing BNNTs. More than 20 researchers throughout the Agency, along with others at the NIA, are working on the technology, which could one day serve as either part of the heat shield or the entire hull of a spacecraft, protecting astronauts from temperature and radiation as they journey to Mars or some other celestial body.

In addition, BNNTs' lightweight, stable composition makes them ideal for eventually replacing ceramic and metallic engine components and rocket nozzles in spacecraft and airplanes. "We think boron nitride nanotubes can improve the structural and thermal properties for a variety of parts that can be exposed in extreme environments," Park says.

"There's no telling what else BNNTs will be used for in the future because it has such unique properties," Smith adds. "Now that we're unlocking more efficient methods for synthesizing them, at least now we'll be able to find out." ❖

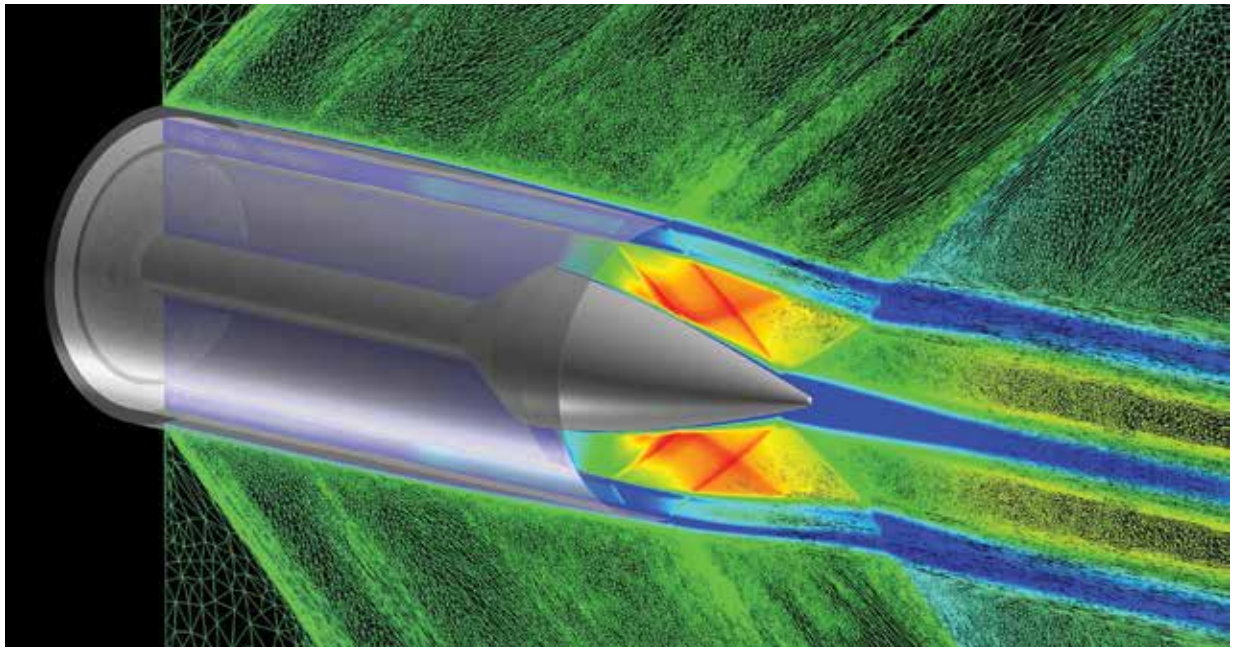
Multidisciplinary Software to Help Take Aircraft to the Next Level

NASA Technology

Consider any component of a modern passenger airplane, and you'll discover a remarkable amount of engineering complexity that went into its design. Turbofan engines rely on the harmonious combination of fans, compressors, combustors, turbines, shafts, and bearings. Airplane wing designs must consider two major but distinct disciplines: structural engineering, which analyzes the surface and interior makeup of the wing to minimize heft while avoiding structural failure, and aerodynamics, which studies how best to sculpt the wing's shape to optimize lift.

For decades, engineers and scientists have taken apart and reengineered various aircraft components to find ways to maximize fuel efficiency, reduce noise, and improve safety. And for many years, NASA has played a leading role in supporting advances through both in-house research and close, long-term collaborations with industry. For example, the Agency has partnered with aerospace manufacturer Pratt & Whitney to maximize the spin efficiency of both the turbine and the fan in its jet engines (*Spinoff* 2015), and also with Boeing to advance a manufacturing process for lighter-weight, cost-efficient composite wings (*Spinoff* 1998).

Advances in aircraft parts have come a long way, but many improvements have come from optimizing a single component in isolation. Major improvements are becoming increasingly difficult to achieve through this approach, according to Justin Gray, a researcher at Glenn Research Center's Propulsion Systems Analysis Branch. "It was pretty clear we're reaching the limits of what can be done one part at a time. Things need to be engineered more holistically, which means researchers need to consider the system-level effects of their technologies."



An optimization to minimize sonic boom impact from a jet engine nozzle, with the color scale showing the flow field Mach number, indicates that much greater reductions could be found by coupling the computational flow dynamics-based shape optimization with an engine design code. Researchers will be using OpenMDAO, developed by programmers at Glenn Research Center, to perform the complex analysis.

Technology Transfer

Making the next generation of aircraft more efficient requires a process called multidisciplinary analysis and optimization (MDAO). In MDAO, researchers from various engineering fields—structures, aerodynamics, propulsion, materials—work together to figure out how each component can best be coupled with the others to contribute to "an optimal design, which is not necessarily the sum of the optimal subsystems," Gray points out. "Everybody has to compromise to get the best answer."

But interdisciplinary cooperation of this sort is made difficult because combining all of these fields poses significant computational and mathematical challenges. Professor Joaquim Martins, who teaches aerospace engineering at the University of Michigan and works frequently on problems that utilize MDAO, says complexity is a given in this field. "You need at least 200 different variables to define just the shape of the wing, then you have the sizing of the skeleton, along with the internal structure, which brings in a few hundred more variables," he says. "And everything is coupled. Everything affects everything."

In order to facilitate such a complex design optimization process, in 2010 programmers from Glenn, with funding from NASA's Fundamental Aeronautics Program's Fixed Wing Project, began coding for a platform that would allow researchers to tightly couple their analyses without needing to be experts in MDAO. Later that year, the first iteration of OpenMDAO, a free and open source software framework, was made available to the public. The technology continues today under the new Transformational Tools and Technologies Program.

Engineers at Langley Research Center installed in its Transonic Dynamics Tunnel this semi-span, 15-percent-scale aircraft model equipped with a truss-based wing, taken from a Boeing design. Incorporating a truss—the diagonal piece attached to the belly of the fuselage and the underside of the wing—would make it possible to increase a wing's aspect ratio, which would improve fuel efficiency by a greater margin than advanced conventional wings. Through the Leading Edge Aeronautics Research for NASA, or LEARN fund, universities are using OpenMDAO to optimize the aerostructural design of aircraft fitted with the technology.

Benefits

NASA is currently providing support for a number of ambitious projects that use OpenMDAO. One is a multi-university effort—supported by the Agency's Leading Edge Aeronautics Research for NASA, or LEARN, Fund—to design a next-generation, truss-braced-wing aircraft. Such an aircraft, in theory, could burn 70 percent less fuel than a Boeing 737. While promising, Gray warns, "The risk is also high. If you don't account for the detailed interactions between the aerodynamics, structures, and propulsion early on, it could all fall apart," which is why OpenMDAO is playing a critical role in checking and building an integrated system model.

Martins, the principal investigator for the LEARN effort, will be taking advantage of the platform to optimize the aircraft's aerostructural design as well as its speed and altitude throughout flight. Then, in another complex move, he and his colleagues will figure out the best combination of flight routes for a family of these planes in order to increase fuel efficiency and reduce greenhouse gas emissions across an entire fleet. "It's very ambitious," he says, "but we're using OpenMDAO to tackle each of these problems. It's really designed to help us make sense of complex, interconnected systems like this."

> "OpenMDAO is unique because it's being designed to couple high-fidelity modeling tools."
>
> — Justin Gray, Glenn Research Center

Another project that's taking advantage of OpenMDAO is Texas A&M University's work with NASA to reduce the amount of noise created by slats: panels that deploy from the front of an airplane's wings to provide extra lift. The challenge there is that it's a tightly interconnected aerodynamics, structural, and materials problem, which is a "classic case" in the MDAO field, Gray says.

While the aeronautics industry stands to gain from the platform, so do others. The wind-energy community is actively using the technology to build multi-fidelity models of wind turbines that cost the least to operate per kilowatt of energy produced. And graduate students at the University of Michigan, working under Professor Jamie Cutler, used OpenMDAO not only to design a CubeSat (a miniaturized satellite) but also control it throughout its orbit. The CubeSat project used over 25,000 design variables. "OpenMDAO is unique because it's being designed to couple high-fidelity modeling tools and handle distributed data transfer among them," Gray says.

As industry and academia rely more and more on the platform for developing the technologies of tomorrow, NASA continues to work with partners to improve functionality through monthly software updates and a constantly expanding toolbox of plug-ins. The OpenMDAO Web site also hosts a forum where users can share ideas and trouble-shoot problems.

"OpenMDAO has got a lot of capability, but there's a lot more to do still," Gray says. "The goal is to have it help design real physical systems, so we're working hard to make the program as robust and as applicable to as many industries as possible." ❖

Orbital Trajectory Analyzer Takes Mission Planning to New Heights

NASA Technology

There's some wizardry involved in sending a rocket or other spacecraft beyond the oppressive reach of Earth's gravity. Long before the first missions were launched, complex mathematical calculations had to be worked out to determine the amount of fuel needed to propel a heavy vehicle skyward, the best way to reach the desired destination, and how all that would correlate to the planet's daily rotation.

Things have become a little easier in the intervening years thanks in part to experience, but also to engineering software that helps plot a course from launch pad to destination to maximize fuel efficiency, determine the best time for launch, and the optimal route to target.

More than a decade ago, a team of engineers at Goddard Space Flight Center began working on what's become the General Mission Analysis Tool (GMAT), a modeling program that specializes in trajectory optimization, allowing mission-control specialists to plot the best course for their craft.

"We have models of spacecraft, fuel tanks, thrusters; we have models of the solar system and how it affects the motion of spacecraft," says Steven Hughes, the project's manager. "We have things that are called solvers that let you say, 'My mission needs to be in an orbit that has these basic requirements, it needs to come within this distance of the Moon but it can't come any closer than this.' It has a lightweight, built-in programming language so you can customize your solution to meet the mission needs."

Before the development of GMAT, NASA had been using software called Swing By for mission calculations, but when the Agency began phasing it out in 2001, Hughes and his team started collecting requirements and spent two years designing an open source program customizable to meet the Agency's needs.

The GMAT team now has 11 active members, including five engineers, five developers, and one tester. The program was predominantly developed on Windows but runs on OSX and Linux as well, and it contains some 540,000 lines of C++ code. Extensive testing carried out over many years helped ensure all components worked properly before it was made available for operational support, Hughes says. Even now, some 12,000 tests are run each night to find glitches before they become bigger problems.

One of the first missions flown using GMAT was the Lunar Reconnaissance Orbiter, which launched from a United Launch Alliance Atlas V rocket in 2009 with a mission to gain information about the Moon's surface in the hopes of finding areas of high scientific value.

The first flight-qualified release came in 2013, the same year NASA launched the Mars Atmosphere and Volatile Evolution mission, whose team used GMAT in preparation for flight. But NASA also used GMAT while it was still in development as one of many tools for planning missions. GMAT was used to support the Lunar Crater Observation and Sensing Satellite in 2009; the Acceleration, Reconnect, Turbulence, and Electrodynamics of the Moon's Interaction with the Sun in 2005; the Lunar Reconnaissance Orbiter in 2009; the Magnetospheric Multiscale Mission in 2015; and it will be used for Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) in 2016 and the Transiting Exoplanet Survey Satellite (TESS), set to launch in 2017.

The program has extended the life of on-orbit missions through resource optimization, most notably helping the Lunar Reconnaissance Orbiter save fuel equivalent to an additional year of station-keeping.

"The TESS mission is using GMAT as the primary tool," Hughes says. "For OSIRIS-REx, they use it for launch-window analysis, and they used it for the verification of the OSIRIS-REx touch-and-go phase. A lot of Goddard missions have used GMAT in some way." GMAT has also been applied to nearly every NASA flight regime, including CubeSats and spacecraft designed for low- and high-Earth orbits, geosynchronous orbits, and interplanetary missions.

GMAT has also been used in connection with the 2018 launch of the James Webb Space Telescope, which will eventually settle into a Lagrangian-point orbit, or one that balances the gravitational forces of the sun and

Earth to stay in the same place relative to both bodies. Though useful for the mission, it is an unstable orbit, and small changes can have a big effect on maintaining the telescopes location, says Hughes.

Technology Transfer

Technology transfer is built into the GMAT development model. According to Hughes, "The private sector has been involved in all aspects of development, in fact, the system was designed by Thinking Systems, Inc. under contract with Goddard. GMAT employs a service model on an open source system to ensure active private sector involvement and to maximize transfer of Government-funded technology broadly and openly."

Thanks to its open source license, GMAT has been extended, integrated, and applied to problems well beyond those anticipated by the design team. It has been used by 15 universities and has seen contributions from 12 commercial firms, including large aerospace companies, among them The Boeing Company, Computer Sciences Corporation, and Honeywell Technology Solutions Inc., and smaller firms such as a.i. solutions Inc. and Emergent Space Technologies Inc. The system has experienced major industry adoption with more than 30 peer-reviewed publications citing analysis performed using GMAT. In academia, GMAT has been used for everything from orbit propagation to simulations, intercept maneuvers, collision avoidance, and trajectory verification and optimization. It has supported entries to Google's Lunar X-Prize and mission plans made by the Inspiration Mars Foundation.

The application and its source code have been downloaded over 49,000 total times over 5 releases, and the project's latest release is on track for a total of 12,000 downloads.

Other governmental agencies have also used GMAT. The system has been used by the Air Force Research Laboratory and commercial partners for satellite-interception and collision-avoidance simulations. International organizations using the software include the European Space Agency, the Korean Aerospace Research Institute, and EUMETSAT (the European Union's meteorological and climate agency).

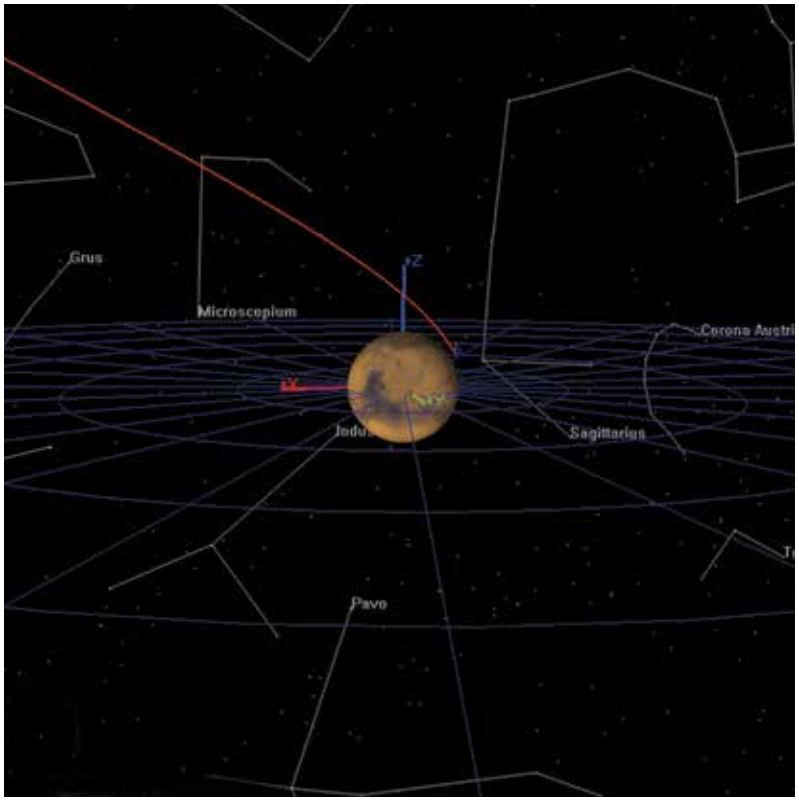
Benefits

GMAT is the only enterprise, multi-mission, open source space guidance, navigation and control ground software system. One of program's biggest fans is Hank Grabowski, chief technology officer and co-founder of Columbia, Maryland-based Applied Defense Solutions Inc., which worked with Goddard and the GMAT team to support the lunar orbit design for NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) when it launched 2013. It was the first mission in three decades to fly around the Moon's equator and, in planning the mission, the company and NASA wanted to know more about the uncertainties about the gravity model around the Moon.

"There isn't any literature for that," Grabowski says. "We were able to take GMAT and instrument the gravity model such that it would allow us to dump out all the types of statistical information we needed in order to come up with estimates for uncertainties on the gravity model for the Moon. LADEE was a very successful mission."

Applied Defense is a service vendor for companies in the space, national security, geospatial information systems, and other Government contractors. While clients sometimes want to use specific software tools for their mission, if a customer comes in without such a request Grabowski recommends using GMAT, especially if the customer wants to use open source technology.

"GMAT is the premiere open source trajectory design tool that's out there right now," he says. In addition to being free of licensing costs, GMAT has a community of users and technical support from which to draw support. The GMAT community is also able to contribute back to the project. "You can get the source code, you can send comments back to Steve's group and see if they can incorporate changes you've made to the tool as well," he says. ❖



The team responsible for launching NASA's Mars Atmosphere and Volatile Evolution (MAVEN) mission worked closely with GMAT's developers when plotting the spacecraft's flight before it launched in late 2013.

Open Source Aircraft Design Software Helps Industry, Hobbyists

NASA Technology

The old saying about the inability to build a better mousetrap could also apply to aircraft design tools. For years, the best, and maybe only, way to dream up a realistic new aircraft design was to use computer-aided design (CAD) software, an expensive and regimented class of programs accessible only to professional engineers or engineering students. Hobbyists and others were mostly left out, and even those who had access to CAD tools were limited in their ability to be creative, as some parameters of fuselage, airfoil, and engine concepts were difficult to represent and couldn't be modified without extensive re-work.

Silicon Valley programmer J.R. Gloudemans, professor at CalPoly San Luis Obispo Robert McDonald, conceptual aircraft designer Andrew Hahn, and Mark Moore, chief technologist for on-demand mobility, Hahn and Moore being at NASA's Langley Research Center, have developed an open source program that allows anyone with a computer, from NASA to hobbyists to the aircraft industry, to try their hand at designing aircraft.

Previously, all design analysis capabilities relied on building analysis-specific geometries that were distillations from the fully defined master that had to be recreated and tweaked if any one input was modified. But the people being asked to create these meta-geometries weren't specialists in this area, says Hahn. "Their job was to do computational fluid dynamics or structures. We wound up starting to do things like creating front-end interfaces for aircraft, but we quickly figured out we would need to have a different graphical interface for every single one of these things. That was just kicking the can down the road."

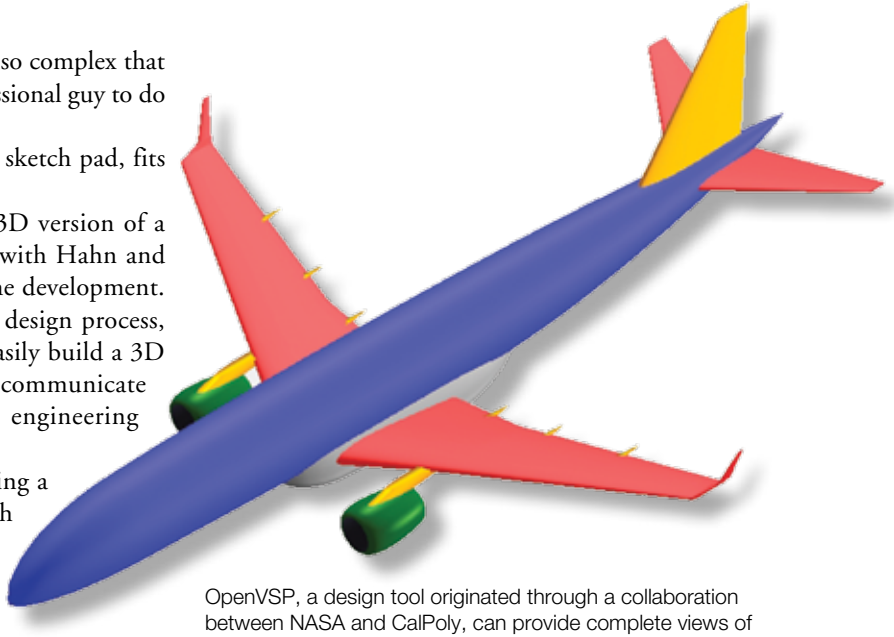
Hahn and Moore wanted to create something between CAD and having to restart the modeling process every time a change to the geometry or analysis method was made; something that was "generic and had enough flexibility to where we could generate a whole bunch of different geometries for analysis, but not so complex that it was hard to use and you'd need a professional guy to do just that," Hahn says.

Their solution, OpenVSP, or vehicle sketch pad, fits the bill.

"I like to think of VSP as sort of a 3D version of a napkin," says McDonald, who worked with Hahn and Moore on the software and now leads the development. "When you're in the early phase of the design process, you can very quickly and cheaply and easily build a 3D model that's not only good enough to communicate your idea but good enough to do real engineering calculations with."

A tutorial video shows how, by clicking a few boxes and moving a few sliders, rough shapes can morph into aircraft designs.

"You go in and very quickly build a 3D model that looks like the aircraft you have in mind, then go and run industrial-strength or research-strength calculations on it to figure out what's the lift and drag on the idea," McDonald says. And it's not just limited to aerospace: OpenVSP is surprisingly flexible, and McDonald envisions uses for buildings, vehicles, rockets, maybe even NASA's next crew vehicle.



OpenVSP, a design tool originated through a collaboration between NASA and CalPoly, can provide complete views of an aircraft design, like this isometric rendering of the Embraer ERJ190AR Regional Jet.

Technology Transfer

Uses and designs are only limited by the degree of effort expended by the user, Hahn says.

CAD programs were intended to mimic the process of machining in order to create something new, but their ability to render any idea in 3D comes at the cost of convenience. "The more arbitrariness you build in, the harder it is to actually build or modify whatever model you're creating," he says.

OpenVSP, by contrast, allows changes to be made throughout an entire design when a single parameter is modified. The program works best with general concepts or designs, rather than trying to recreate specific vehicles. Someone wanting to make a socket set, or wine glasses, for example, can define basic parameters that describe those items and then modify them to create something that will serve the same purpose but have a different look, based on the specific dimensions input.

"You can describe, not perfectly but pretty well, using just three parameters, pretty much any wine glass you've ever seen. That's how VSP works," McDonald says.

"The key is to have just a few parameters that let you make huge changes to the shape in a meaningful way," adds Moore. "Most people, if you show them a wing, they can recognize it as a wing. There are many different kinds of wings, but there are certain parameters that describe objects that all share that function. That's what we're doing. We're allowing people to change those relatively small number of parameters and be able to generate pretty much any wing that's out there."

What makes OpenVSP different isn't just its capability to change related geometries with a single modification but also the fact that it's free to download and use for anyone with an interest in it. NASA developed the basic program more than a decade ago, and since it was released as open source software in January 2012, it has been downloaded an estimated 50,000 to 60,000 times.

"Well, it is free," McDonald admits with a laugh.

He's become the new lead on maintaining the program and its user community, in part to ensure OpenVSP will be available to users after Hahn and Moore leave NASA.

"It's a wonderful situation from NASA's perspective, because we still get the benefit of this program continuing to evolve to meet our needs without it having to be done through strictly internal dollars and development efforts," Moore says.

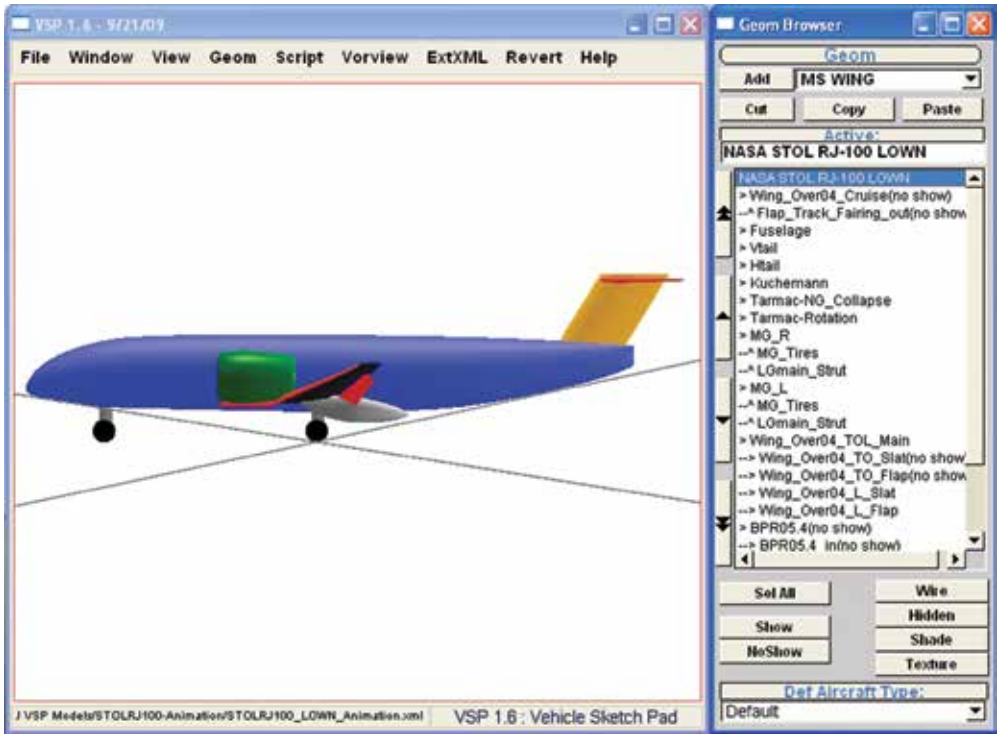
Benefits

For NASA, the benefit is obvious.

"I use it every single day and I simply would not be able to do my job without this tool," Moore says. But it's also "perfect for those garage innovators. Anyone can pick up this tool and, within an hour, put together a decent 3D aircraft model."

Most aircraft companies use commercial CAD packages to design their products. Some of those aircraft companies, including Boeing and Gulfstream, who sought competitive advantage from their conceptual design capabilities, developed their own proprietary CAD-free geometry software. Now a growing number of companies, universities, and Government agencies are leveraging these advantages in their own design processes, but are doing so with OpenVSP rather than their own homegrown solution.

Colin Johnson, chief commercial officer of Desktop Aeronautics Inc., an aircraft design software company in Palo Alto, California, that sells a rapid aerodynamic simulation tool called GoCart, based on a program developed at NASA called Cart3D, sees that OpenVSP is helping to change how the industry designs aircraft. The early phases of designing aircraft used to be just numbers on a spreadsheet, with imaging software coming in to play later in the process.



In addition to working through changes on existing aircraft designs, OpenVSP can be used on concept designs, like this NASA over-wing nacelle in landing configuration showing rotation tail-scrape and collapsed nose gear clearance angles.

"PhD students used to have to write their own crude modelers to do cutting-edge aerodynamic analysis," Johnson says, resulting in a "gap between what you do on a spreadsheet and what you do before" going into CAD.

Along the way, bigger players in aircraft design realized they could harness the power of shape optimization through parametric CAD-free geometry modeling tools, but those are often difficult to use for anyone other than the original developer, he says.

"OpenVSP opens up the capability of rapid 3D modeling to the entire industry without having to overcome the barrier of needing to create the tool yourself, dedicate months to learning how to use it, or spend significant resources to commission the tool's creation and maintenance," Johnson says. Further, the open source nature of the program "allows the entire industry to benefit from each incremental improvement that developers contribute."

He sees designers at places like Boeing who want to use GoCart going instead to OpenVSP because it's easier to learn and free to download and get started. Previously, these designers could not conduct performance evaluations on early designs because creating the 3D model was too complicated. "CAD was too generic for how these designers think, was not well-suited for optimization, and was too expensive," Johnson says. Boeing's internal software "might define shapes in terms that are intuitive to the designer, but OpenVSP does this as well with greater accessibility and ease of use."

Johnson says his company is a big fan of OpenVSP because it has "an enormous amount of capability. In some ways, you can think of OpenVSP as democratizing concept development across aerospace companies large and small. It's gaining its own momentum." ❖

Public Safety

Any agency that works with millions of pounds of thrust and puts people into one of the most hostile environments imaginable has to pioneer new safety measures. NASA spinoffs like surface-crack detectors that ensure structural safety or sensors that identify dangerous gas leaks are natural outgrowths of that concern, but other safety applications of NASA technology are more surprising, like software that uses satellite data for forecasting crop yields and preventing food shortages.

Rice Crop Models Stabilize Global Markets, Enable Efficient Irrigation

NASA Technology

When global food prices spiked dramatically in late 2007 and into 2008, with the costs of many basic dietary staples doubling or even tripling, protests and riots upset much of the developing world. Panicked governments stopped exporting food, aggravating the crisis. Almost as troubling as the widespread unrest and hunger, though, was the fact that it had taken the world by surprise.

Following the price spike, world leaders gathered to figure out how to foresee and avert such market instabilities in the future, and a major product of those meetings was the Group on Earth Observations' Global Agricultural Monitoring (GEOGLAM) initiative, carried out by a partnership of governments and international organizations in the G20 nations. The initiative relies primarily on satellite Earth-imaging data to improve projections of crop production and weather forecasting.

Making projections based on raw satellite data, however, is no simple task. "You have to be an expert to transform that data into useful information," says Nathan Torbick, a director at Applied GeoSolutions, based in Newmarket, New Hampshire, which has been researching various applications for Earth-imaging satellite data for more than a decade. As far as crop projections, the company decided it would leverage its ongoing work on rice, which is the world's most difficult major dietary staple to predict.

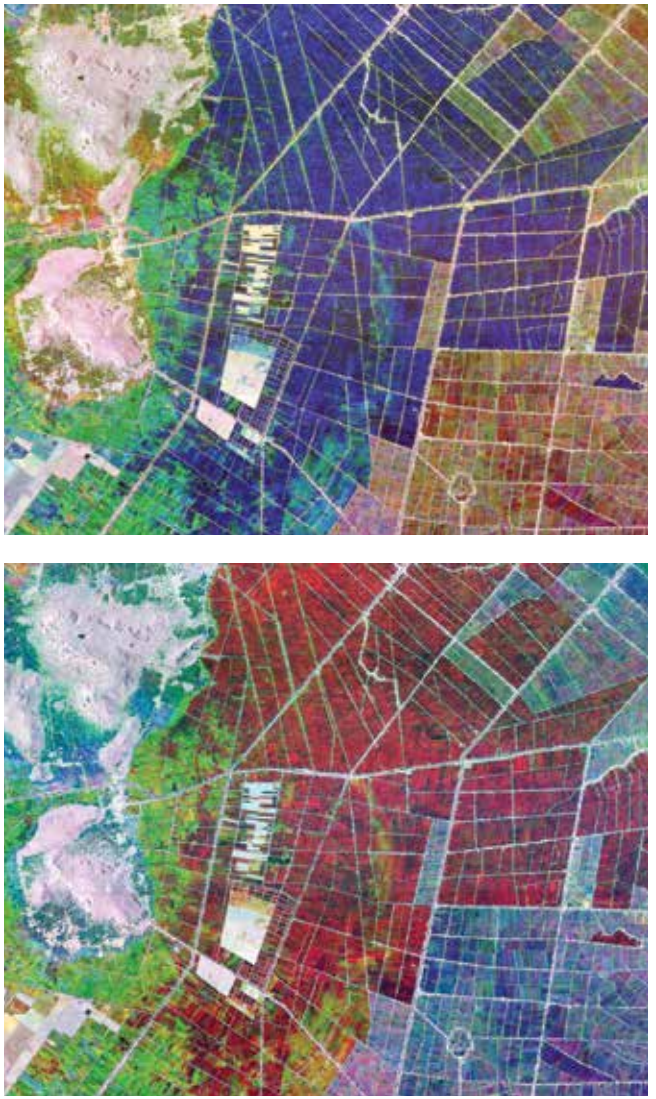
"There really is no rice futures market, relative to corn, soy, wheat, and beef," Torbick says, noting that this is because traders don't have reliable rice information or production forecasts on which to base such trades. This makes the rice market volatile, putting investors, producers, and, ultimately, consumers at risk. "If there's a big drought in Thailand or other parts of Southeast Asia, hundreds of thousands of people worldwide might starve," Torbick says.

Meanwhile, in the United States, parts of the country's two biggest rice-producing regions are running out of water. In the Sacramento Valley area of California, which is home to about half a million acres of rice fields, drought has become the new normal, Torbick says. And in eastern Arkansas, where about a million and a half acres are dedicated to rice production, areas like the Grand Prairie region sit on aquifers that have been pumped nearly dry. One solution is to use satellite data to plan water use more efficiently, Torbick says.

Among the satellites most popularly used for Earth-imaging data are the Landsat series, in orbit since 1972, and the Terra and Aqua satellites, equipped with the Moderate-Resolution Imaging Spectrometer (MODIS) instrument. Although NASA built the satellites, the U.S. Geological Survey operates each Landsat once it's in orbit.

Landsat 8, launched in 2013, covers Earth's surface every 16 days, capturing images in nine visible, near-infrared, and shortwave infrared bands, as well as two thermal infrared bandwidths. The thermal information is especially important for detecting crop stress and supporting crop predictions, as it reveals moisture and temperature on the land surface, in plants, and in the lower atmosphere. MODIS, meanwhile, maps Earth every one to two days in 36 visible and infrared bandwidths, providing the frequent visits needed to monitor changes in crop stages, plants' responses to weather, and farm activities such as irrigation or tillage.

In addition to moisture and temperature observations, the imagers can detect the greenness, biomass vigor, and leaf moisture of rice plants, and the presence and depth of surface water, all useful for assessing crop health and predicting crop outcomes. By using the satellite imagery, Applied GeoSolutions can assess large areas at far less cost than traditional field visits.



These two satellite images depict the An Giang Province in Vietnam's Mekong Delta, a major rice-producing region, at different times of year. Dark blue and black areas are inundated and have low biomass, while white and gray areas are other crops like row crops and trees. The differences in color indicate a change in the ratio between soil moisture and biomass.

Applied Geosolutions approached NASA with a plan to design Web-based software that would use current and archived data from Landsat, MODIS, and other satellites, incorporating measures of rice fields, yield modeling, and weather forecasts to generate information in real time about rice coverage, growth stages, deviation from normal, and expected yield around the globe, as well as calculate the statistical certainty of that information to address risks.

Technology Transfer

In 2012, Stennis Space Center granted the company Phase I and II Small Business Innovation Research (SBIR) contracts to create a Rice Decision Support System (RDSS), one that would inform rice-related decisions ranging from how to invest in rice futures to how to irrigate fields, where and when production risk exists, how to validate conservation practices, and when to buy, sell, or hold.

The system went into operation around the start of 2014.

In the United States, Applied Geosolutions predominantly uses Landsat and MODIS data, while in Southeast Asia it relies primarily on synthetic aperture radar (SAR) satellite data made available by governments and especially the Japan Aerospace Exploration Agency. In 2015 the company grew its use of the European Space Agency's (ESA) Earth-imaging Sentinel platform, in addition to continuing its work with the ESA's Phased Array Type L-Band SAR satellite and Canada's Radarsat-2.

The various imagers have different resolutions and operate in different parts of the electromagnetic spectrum, with the RDSS overlaying all that information. "You combine all the satellites to give you a complete picture of what's going on on the ground," Torbick says.

Abroad, the system is focused on pilot sites in Java, Indonesia, and the Red River Delta in Vietnam, as well as in Brazil, which has recently ramped up rice production and has begun to offer incentives for sustainable crop management styles. RDSS monitors which farms are using these practices. "Tools to help monitor and validate rice-management practices will be central to developing ecosystem-services markets that will improve transparency and increase efficiency while rewarding stewardship," Torbick says.

In Arkansas and California, Applied Geosolutions has paid partnerships with farmers and agencies to help them plan their growing season and manage resources, especially with regard to irrigation. As in Brazil, imagery gathered in the United States also proves which farms should receive incentives for using alternative irrigation methods.

The imagery from Southeast Asia is used primarily for supporting food security programs and commodity markets. In that part of the world, where rice is a major contributor to gross domestic

Rice is one of the most heavily produced food crops in the world, but it is one of the most difficult to predict, with yields often depending on weather. The Philippines' famed Banaue Rice Terraces, pictured here, dried up completely in 2010. Applied Geosolutions' Rice Decision Support System, which it developed with NASA funding, will use imagery from various satellites to make more accurate predictions, helping to stabilize the world's rice markets.

product and supports the livelihood and diet of hundreds of millions of people, Torbick says, agriculture faces major challenges in the coming decade due to increasing resource pressures, weather and climate change, population growth, shifting diets, and economic development.

Historically, global rice production has been difficult to predict because this region, where the overwhelming majority of the world's rice supply is produced, is too cloudy for conventional satellite imaging. SAR imaging technology helps overcome that problem, as it is able to detect vegetation structure and moisture content through cloud cover.

Benefits

Applied Geosolutions' system now supports the GEOGLAM initiative, helping it to supply producers, buyers, and investors around the world with more comprehensive information and projections about what was, as of 2012, the second-most produced crop in the world.

"GEOGLAM allows countries and regions to make a better assessment of what the harvest will be, so they can do things like put out the right loans and buy the food when they should," says Bradley Doorn, program manager for the Water Resources Applied Sciences program in NASA Headquarters' Earth Sciences Division. Waiting for a crisis drives up prices, while buying and storing beforehand can avoid disaster, he says. "When we're blind to what production will be, the market becomes speculative, and volatility prevails. This is not good for business, government, or consumers."

In these cases, the only ones who benefit are those who happen to guess correctly—usually not the farmers, he says. But with solid information, farmers can predict what prices will be and make sound decisions about when to sell. "It's that whole give and take of the market that it's going to support."

By reducing risk for investors and producers, Torbick says, the RDSS can help stabilize global rice markets and blunt future price upheavals. "It's really a risk-management tool."

"Adding the rice capability was huge, because it just has such an impact on the world and on the populace," says Doorn.

Image courtesy of Feed My Starving Children, CC BY 2.0

By making rice harvests easier to predict, Applied Geosolutions' Rice Decision Support System will bring stability to the rice market, blunting food shortages that tend to hit developing countries especially hard. The system could also help inform programs like the U.S. Agency for International Development's Famine Early Warning System, which can use the data to predict regional food crises and decide how much food aid will be needed and when and where to buy it.

The system could also be used to help inform programs like the U.S. Agency for International Development's Famine Early Warning System, which uses this sort of data to predict regional food crises and decide how much food aid will be needed and when and where to buy the food, he says. "They're making those decisions constantly."

Another reason Applied Geosolutions chose to monitor rice is that the crop is a major driver of greenhouse gases. The saturated soil of inundated rice paddies leads to anaerobic decomposition of organic material, which produces methane, a greenhouse gas 20 to 30 times more powerful than carbon dioxide. The company is doing some work in Vietnam, California, and Arkansas, in part supported by NASA's Land-Cover/Land-Use Change Program, to support alternative rice management strategies and to explore the possibility of wealthier countries paying developing countries to use environmentally sound farming practices.

Meanwhile, in the United States, a primary RDSS application is water management. "If we can help them reduce water usage, that's a big help because they're running out of it," Torbick says, noting that rice acreage in California dropped by 25 percent in 2014 due to lack of water, a trend the RDSS had predicted and mapped in real time.

In northern California, most rice fields are flooded prior to seeding, a process called wet seeding, but as water availability continues to decline, there's been increased need for conservation. Using satellite images, the company can determine whether a field needs to be watered, how much water it needs, and whether wet seeding is even necessary. "If you can do dry seeding without reducing your yield much, you could potentially offset yield costs by reducing pumping costs," Torbick says. "We can say where that might work, and we can model yield."

In Arkansas, the company is helping farmers implement a water-saving irrigation method known as alternate wetting and drying. "We can optimize watering by looking at weather, soil moisture, and crop conditions across Arkansas," Torbick says, adding that historical data, weather predictions, and measures of soil moisture let Applied Geosolutions tell a farmer pretty precisely how much water a field needs at a given time. Fifty farms there are partnering with Applied Geosolutions, letting Torbick use measurements from moisture sensors in their fields to calibrate data points from imaging satellites.

Torbick notes that techniques like alternate wetting and drying could one day be implemented in many locations around the world.

The company also helps to inform the U.S. Department of Agriculture's National Agricultural

Statistics Service, which publishes about 5,000 national statistical reports and thousands of state reports each year. "They have a big mission, so if we can help them do that in real time, with better sensors, that's great," Torbick says.

In the United States, the company is able to predict rice extent with 90 to 95 percent accuracy six weeks into the growing season, he says, adding that accuracy is about 85 to 90 percent at pilot sites overseas. "By mid-June, I'll tell you how much area is going to get harvested in September. We combine extent forecasts with yield predictions and statistical modeling from past conditions to manage risk."

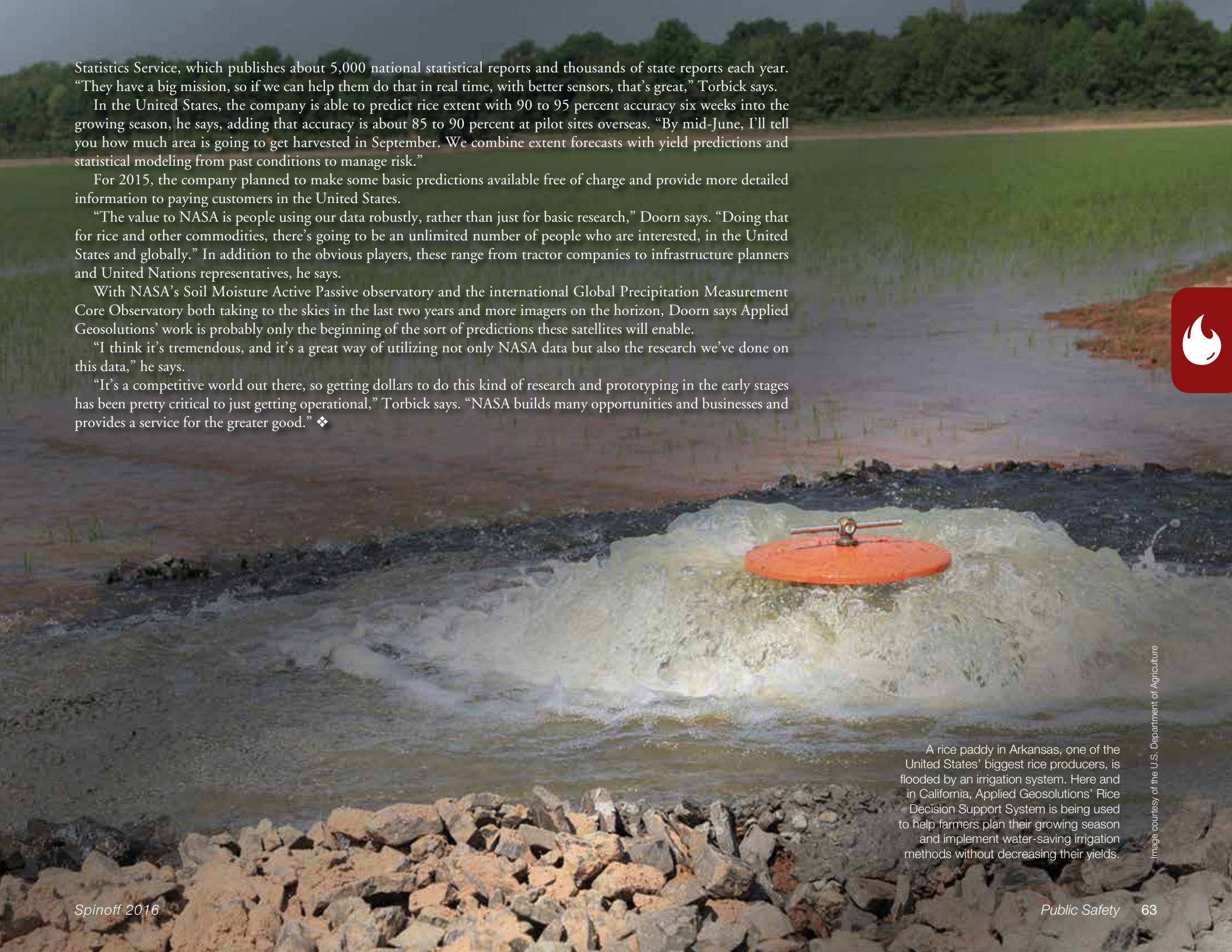
For 2015, the company planned to make some basic predictions available free of charge and provide more detailed information to paying customers in the United States.

"The value to NASA is people using our data robustly, rather than just for basic research," Doorn says. "Doing that for rice and other commodities, there's going to be an unlimited number of people who are interested, in the United States and globally." In addition to the obvious players, these range from tractor companies to infrastructure planners and United Nations representatives, he says.

With NASA's Soil Moisture Active Passive observatory and the international Global Precipitation Measurement Core Observatory both taking to the skies in the last two years and more imagers on the horizon, Doorn says Applied Geosolutions' work is probably only the beginning of the sort of predictions these satellites will enable.

"I think it's tremendous, and it's a great way of utilizing not only NASA data but also the research we've done on this data," he says.

"It's a competitive world out there, so getting dollars to do this kind of research and prototyping in the early stages has been pretty critical to just getting operational," Torbick says. "NASA builds many opportunities and businesses and provides a service for the greater good." ❖



A rice paddy in Arkansas, one of the United States' biggest rice producers, is flooded by an irrigation system. Here and in California, Applied Geosolutions' Rice Decision Support System is being used to help farmers plan their growing season and implement water-saving irrigation methods without decreasing their yields.

Image courtesy of the U.S. Department of Agriculture

GPS Sensor Web Helps Forecasters Warn of Monsoon Flash Floods

NASA Technology

In the American Southwest and in northwestern Mexico, more than half the annual rainfall often comes in the form of the torrential and unpredictable downpours of the North American monsoon. As in monsoon seasons across the tropics, a summertime reversal of winds carries streams of moisture from over the oceans or, in this case, the Gulf of California and Gulf of Mexico, and unceremoniously dumps them on the sunbaked land.

Perhaps the least understood and most erratic weather pattern in the United States, the monsoon brings precipitation that is vital to agriculture and the ecosystem, but it also presents serious threats to life, limb, and property. Severe flash-flooding is common. Roads are washed out. Miles away from the cloudburst, dry gulches become raging torrents in seconds. The storms are often accompanied by driving winds, hail, and barrages of lightning strikes.

"The monsoon is pretty nasty stuff, pretty ugly," says Ivory Small, science and operations officer for the National Weather Service at the San Diego Weather Forecast Office, noting a recent death during a flash flood in Mt. Baldy, just northeast of Los Angeles.

Small's office is one of two National Oceanic and Atmospheric Administration (NOAA) Weather Forecast Offices benefiting from the Next-Generation Real-Time Geodetic Station Sensor Web for Natural Hazards Research and Applications project, funded by NASA's Earth Science Technology Office. The four-year project, intended to develop a network of sensors to provide advance warning of potentially dangerous weather and seismic events, kicked off in mid-2012, and a year later, the San Diego and Los Angeles/Oxnard Weather Forecast Offices were benefiting from more accurate monsoon forecasting.

The project takes advantage of the fact that scientific GPS calculations have to account for any signal delays caused by humidity. "When we solve for position, we automatically have to solve for the delay caused by water vapor," says Angelyn Moore, research scientist with the Geodynamics and Space Geodesy Group at NASA's Jet Propulsion Laboratory (JPL). Moore, the project's co-investigator, introduced the idea of including a meteorological product alongside the project's seismological

"It definitely contributed to their **ability** to have **situational awareness** as to how **vapor** was **moving around** and to **predict flash flooding."**

— Angelyn Moore, Jet Propulsion Laboratory

North American monsoons such as this one in Ludlow, California, occur when summertime wind reversals carry streams of moisture inland from over the Gulf of California or the Gulf of Mexico. While bringing needed precipitation, the storms are violent, unpredictable, and dangerous.

Image courtesy of Will Wilkens

plans and got the National Weather Service Forecast Offices involved.

Other partners include the Scripps Institution of Oceanography, which is tracking seismological events like tremors and earthquakes, and NOAA's Earth System Research Laboratory in Boulder, Colorado, which has, since the early 2000s, provided half-hourly water vapor estimates from a nationwide GPS network to forecasters and for assimilation into NOAA's weather models.

Under the project, 37 GPS stations have been added to NOAA's meteorological GPS network in Southern California, outfitted with either onsite or nearby meteorological sensors.

The GPS stations calculate moisture indirectly based on how long it takes for the time-stamped signals from the GPS satellite network to reach them. The signals are sent on two frequencies, which interact differently with the troposphere, where moisture resides, and the ionosphere, where ionic activity can also delay signals. The charged ionosphere is dispersive, making the delay different for the two frequencies, whereas in the neutral, non-dispersive troposphere, the delay is the same for both. "Under the hood, when we do the calculation, we can tell the difference between the two sources of delay," Moore says.

Combined with temperature and pressure data also collected at each site, the results are used to calculate what are known as integrated precipitable water (IPW) estimates, which are broadcast every half-hour, and Moore says the team is working to get the interval down to five minutes.

Technology Transfer

"NASA wanted a technology developed by the Agency that's useful to somebody outside NASA," Moore says of the project's origins. She notes that NASA, and particularly the Earth Science Technology Office, has long worked to help the public predict and respond to natural hazards.

Image courtesy of D. Glen Offield, Scripps Institution of Oceanography

Thirty-seven GPS stations like this one on Mt. Soledad in San Diego have been added to the National Oceanic and Atmospheric Administration's meteorological GPS network in Southern California. Meanwhile, the Scripps Institution of Oceanography is outfitting the stations with accelerometers to enable early warning of earthquakes.

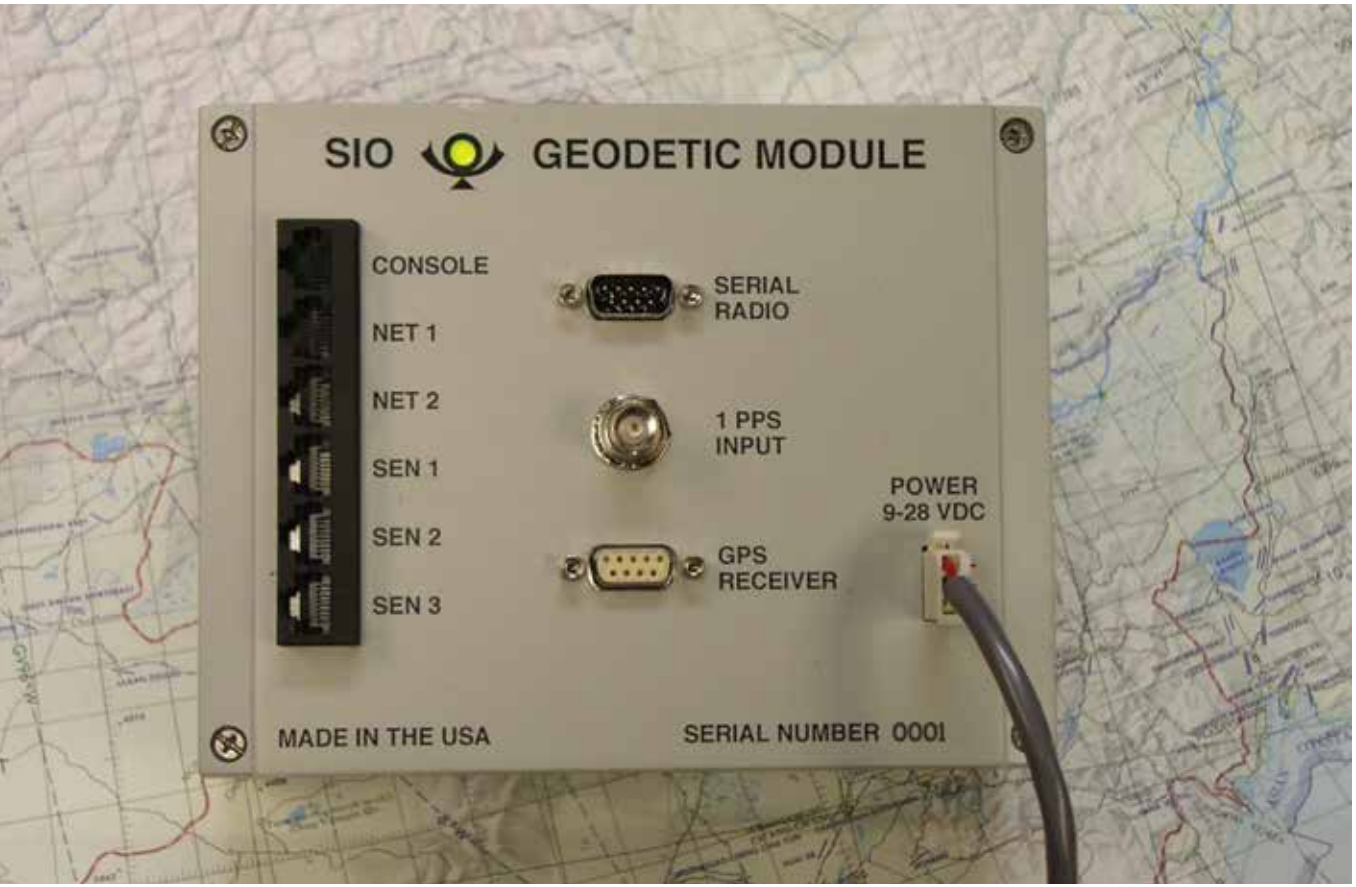


Image courtesy of D. Glenn Offield, Scripps Institution of Oceanography

Next-generation, real-time geodetic modules have been added to GPS stations across Southern California, enabling more accurate weather forecasting and, perhaps, early warning of earthquakes.

The entire project builds on a network of GPS stations installed in the 1990s for the study of seismic movement and later also used to gather some meteorological data. The geodetic modules developed by the team at Scripps calculate the IPW estimates onsite and transmit them, rather than sending raw data back to a central facility for interpretation. "Each site individually computes its location and water vapor and transmits that directly," Moore says.

The system is still considered a prototype and a test bed for developing and demonstrating the technology, which is likely to later be more heavily integrated into local forecasters' tools and NOAA's Advanced Weather Interactive Processing System.

Benefits

On the afternoon of July 18, 2013, weather balloon soundings indicated enough monsoonal moisture from the Gulf of Mexico had reached Yuma, Arizona, to cause heavy rains, but it had not, or at least not yet, arrived in San Diego. It was early in the monsoon season, which in Southern California runs from July until mid-September.

"In meteorology, we try to determine how much rain we can get out of the atmosphere by looking at how much moisture is in the atmosphere," Small says. "When we see IPW really start to go up on the GPS data, that's when we can make some decisions on how much rain we're going to get and if we should issue a flash flood watch."

Whether that moisture is coming from the Gulf of Mexico or the Gulf of California, there's little warning due to scarce meteorological observations in Mexico.

Before the Earth System Research Laboratory started incorporating data from the meteorological GPS network, forecasters in Southern California relied on data from four weather balloon sites in San Diego, Yuma, Phoenix, and Las Vegas, which report twice a day. Now, though, there were five GPS stations along the Mexican border between Yuma and San Diego, transmitting data every half hour.

By the morning of July 19, the balloon sounding at San Diego showed the moisture had arrived, but it would have been difficult to characterize its movement and extent because no data were available yet from Yuma. Using the GPS dataset, though, forecasters were able to track moisture distribution in real time. Water vapor content began to spike around El Centro, California, between San Diego and Yuma, to levels higher than at either of those other cities.

Based on the information, a flash flood watch was eventually issued for the area, followed, indeed, by several flash flooding events carrying large rocks into the roadway, including two that trapped about 30 drivers on Route 78 northeast of San Diego and another that strewed debris across Sunrise Highway, just east of the city.

“The monsoon is pretty **nasty stuff, pretty ugly.”**

— Ivory Small, San Diego Weather Forecast Office

Monsoon rains flood Highway 78 just south of Borrego Springs in San Diego County in late July 2013.

Image courtesy of the National Oceanic and Atmospheric Administration

“It definitely contributed to their ability to have situational awareness as to how vapor was moving around and to predict flash flooding,” Moore says.

Small says the enhanced density of sensor sites and frequency of reports has demonstrably helped the office with its most important public safety function of issuing flash flood watches and warnings during fast-changing and hard-to-predict events like monsoons. “We can let them know which days are not good days for hiking in the canyons and mountains in our deserts.”

The office’s warnings and forecasts go out to all local television and radio stations. “It’s a big hit with the forecasters,” Small says of the new system.

Forecasters are now working with the project scientists to refine the interpretation of data and develop tools to use it, including the IPW tools being planned for a revision to NOAA’s weather processing system.

Meanwhile, with the accelerometer sensors in the GPS network, which detect seismic motion, JPL and Scripps hope to demonstrate a technology that could save lives in the event of an earthquake. The ability to predict the arrival and intensity of the quake that follows a primary wave would leave between half a minute and a minute and a half, depending on a population center’s distance from the quake, to shut down elevators and gas lines, bring bullet trains to a halt, cease any surgical operations, and otherwise take potentially lifesaving precautions, Moore says. “There are a lot of things you can do if you have 30–90 seconds.” ❖

Analytic Tool Simplifies Metal Fracture Assessments

NASA Technology

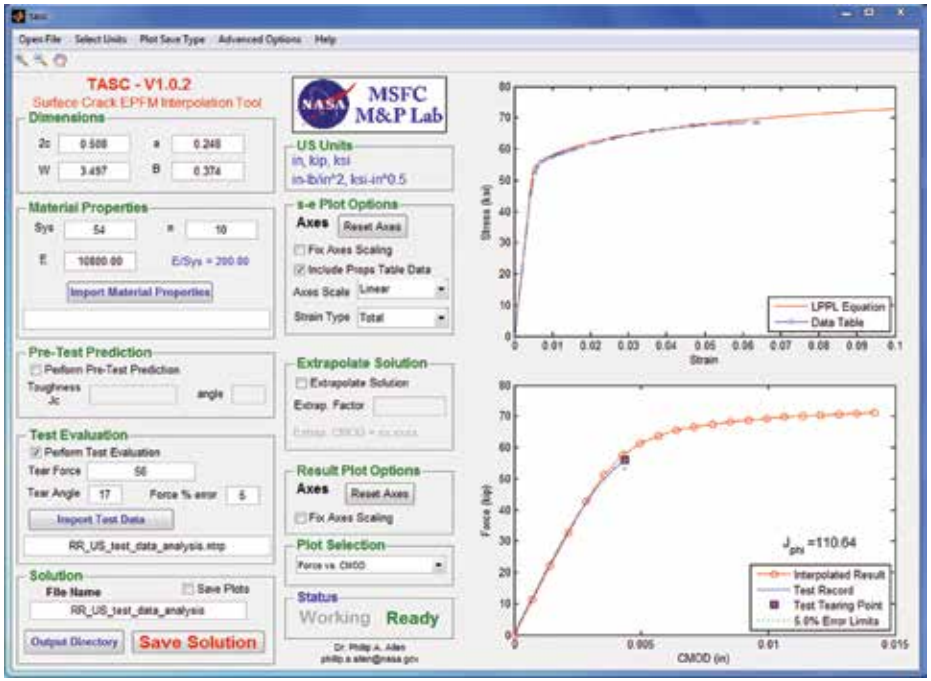
When NASA builds a spacecraft, materials engineers at the Agency have the important task of assessing the structural properties of the materials that comprise various hardware, whether it's the hull of a crew capsule or the external tank of a rocket. By knowing these properties, they can ensure that these spacecraft and structures are safe for flight, which means determining if existing defects, such as cracks, will cause structural failure. To perform such work, engineers first have to determine each material's fracture toughness—its ability to resist fracture when it contains a crack.

To derive fracture toughness for lightweight metals—aluminum and titanium alloys, for example, which are used in airplane and spacecraft hardware—plastic deformation must be taken into account. This is the amount of permanent deformation they can withstand without failing. (Even when cracked, depending on the circumstances, metals can continue to be used on flights before needing repair.)

Phillip Allen, a materials engineer and structural analyst at Marshall Space Flight Center, says to think of a paperclip. "If you bend it far enough, it won't straighten back out," he explains. "You've pushed it beyond its linear limit into the plastic regime, into permanent deformation. Then, if you cycle it back and forth enough times, it'll break." Contrast that with other materials like glass or some carbon-fiber composite materials that have basically a purely linear response. "They're very stiff and brittle in nature. Once you exceed their ultimate capability, they just splinter and fail rapidly."

To come up with the surface crack fracture toughness for plastic-deforming metals, engineers perform laboratory testing combined with what's called nonlinear finite element analysis, which requires expertise in several niche fields. "Traditionally, you had to have somebody specifically skilled in nonlinear fracture mechanics and material behavior, and he or she needs to run an analysis of that test, which takes a long time and costs a lot of money," says Allen, noting that it's typical for such an endeavor to take upwards of eight hours.

In early 2012, he decided to create a software program that could automate the process, which is based on the American Society for Testing and Materials (ASTM) standard for testing surface cracks, E2899, that he and fellow NASA Marshall engineer Doug Wells had developed and tested over a 10-year period. The standard is used not only by NASA but also by airlines for aircraft safety and by oil companies to protect against pipe leaks and explosions, among others. "I wanted to open up the standard to a whole new group of labs that can run these types of tests for these different industries," he says.



Marshall Space Flight Center materials engineer Phillip Allen developed the free, downloadable program Tool for Analysis of Surface Cracks, or TASC, to simplify determining a metal's fracture toughness. Such a measurement helps engineers assess the point at which a crack will begin to tear and fail structurally. The software cuts the time needed to perform an analysis from several hours to 20 or 30 minutes.

Technology Transfer

This project took Allen two years to complete, and it involved setting up scripts to automate the building of 600 nonlinear models and solutions, covering almost any metal one would ever use. He recalls, "Basically, it was a big bookkeeping problem." Afterward, he took those results and distilled them into data arrays that software he had developed would interpolate in order to arrive at the fracture toughness value for a specific-sized crack in a given metal.

After developing an easy-to-use interface for the program, in January 2014 Allen made his free and open source program, Tool for Analysis of Surface Cracks, or TASC, available for download at Source Forge, a source code repository Web site.

Benefits

Determining a metal's fracture toughness is relatively simple with TASC, Allen says. An engineer or a technician

runs a fracture toughness test according to ASTM E2899, where a machine applies force to the metal, which is shaped as a plate with a surface crack in it, and instrumentation measures the forces and displacements on the plate as it begins to crack further and, at some later point, fail. The measurements made at the point when the crack begins to tear, combined with the material's basic tensile properties (yield strength, elastic stiffness, and the strain-hardening exponent) and the resulting crack and plate dimensions (length, depth, width, and thickness), make up all the inputs needed to run TASC and acquire the metal's fracture toughness point when it will start to tear and fail structurally. "That's your limiting value that you would never want that structure to approach," he says.

With that information, engineers can evaluate the risk posed by actual cracks found during inspections as well as by cracks that might be overlooked. To perform a structural evaluation of a defect, they input its dimensions and prompt the program to run the problem backwards to calculate the force needed to reach the fracture toughness point. Sometimes a crack requires immediate attention, Allen says, while others are left untouched for months, if not years, before they get near a threshold where repairs are necessary. "Engineers perform fracture mechanics calculations and may determine that a crack won't grow to a size that would cause catastrophic failure during the time that passes before the next inspection," he explains. By extension, smaller cracks that may be missed during inspection are also deemed safe in the interim.

Many industries, such as petroleum companies, have to weigh the risks posed by cracks very carefully. "Losing a pipe or a pump to a catastrophe is bad, but taking them down too often for service costs millions of dollars as well," Allen says. "They invest heavily in fracture mechanics because they want to know with the greatest accuracy possible how long they can safely run their hardware."

Greg Thorwald, a consulting engineer with Quest Integrity Group, based in Boulder, Colorado, has worked with NASA as well as companies big and small throughout the gamut of industry, says the time saved by using the software is substantial. Whereas in the past, it took him four or five hours to perform such a material analysis, "Using TASC, once you know how to use the software, you could do it in 20-30 minutes," he says. "It's one of those tools that you've got on the shelf, so to speak, and just knowing it's there when you need it is pretty nice."

As of this writing, 670 users in 60 countries have a copy of TASC on their shelves, figuratively speaking, according to Allen, who checks the number of downloads from Source Forge periodically. Among the users are university professors and their students, who he presumes are learning graduate-level fracture mechanics. "You can run problems with the software, and you get a lot of insight and understanding in a hurry because you can play with the variables and instantly see how they change the final answer and the shape of the response curves."

The Agency is also busy using TASC, but for real-world applications, such as determining the fracture toughness properties of the metals comprising the core stage rockets and the solid rocket boosters of the Space Launch System, NASA's next-generation launch vehicle slated to take humans deeper into the solar system than they've ever been. Similar work was also done with SpaceX's Falcon 9 launch vehicle, which delivers supplies and experiments to the International Space Station.

In recognition of his work, Allen was one of two recipients of NASA's prestigious Software of the Year Award for 2014. Right now he's working toward what could be another success story: getting TASC designated as an official standard analysis tool for surface crack testing. "It will be the first ASTM mechanical testing standard that uses a computerized tool to get the answer. That would be cool." ❖

As of this **writing, 670 users** in **60 countries** have a **copy of TASC** on their **shelves.**

TASC has been used to determine the fracture toughness of the Space Launch System's core stage rockets, which will comprise four modified RS-25s—the engines used to launch the Space Shuttle. Here, an RS-25 undergoes a hot-fire test.

Image courtesy of Aerojet Rocketdyne

Mars Methane Detector Identifies Harmful Gas Leaks

NASA Technology

Residing inside the intestines of animals and in marshes, bogs, untreated sewage, ocean sediment, and other places devoid of oxygen are microbes called methanogens. These single-celled, primordial organisms arose more than 3 billion years ago, at a time when the atmosphere lacked oxygen but contained an abundance of carbon dioxide and hydrogen that the microbes metabolized. Their name is derived from the fact that, as a metabolic byproduct, methanogens produce and release methane.

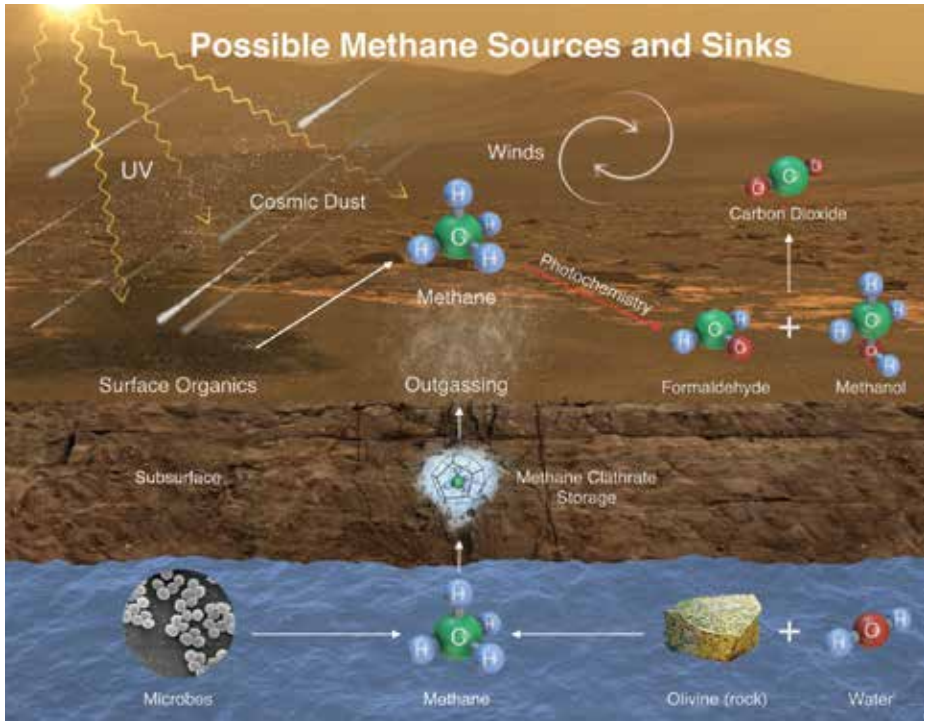
Their knack for thriving on the margins of habitability was on the minds of NASA scientists when, in 2003, plumes of methane were detected on Mars. While the gas could have been created through geochemical processes, confirming its presence on-site and determining how it got there could be a crucial step in figuring out if Mars is, or ever was, host to microbial life. In preparation for the Mars Science Laboratory, also known as the Curiosity rover, in the mid-2000s engineers at the Jet Propulsion Laboratory (JPL) started developing a device that could detect methane and its isotopes, along with carbon dioxide and water. The technology would become one of three gas-analyzing instruments that make up the Sample Analysis at Mars, or SAM.

Known as the Tunable Laser Spectrometer, or TLS, the device works by opening an inlet that lets in either the atmosphere surrounding the rover or gas evolved from solid samples it has acquired. Inside the TLS, mid-infrared laser beams interrogate the gas. Some of that light will resonate with gases such as methane, and, as a result, light will be absorbed. At the opposite end, the detector gauges the reduction of light intensity, alerting scientists to the gases present.

The technology was made possible through NASA investment in lasers and tunable laser spectrometers for Earth and planetary science. Previous room-temperature lasers used for detecting methane were less suitable, as they could only emit light in the visible and near-infrared spectrums. "Methane absorbs much more weakly at those wavelengths," explains JPL senior scientist Lance E. Christensen, who helped develop the TLS. He adds that, as a consequence, the instrumentation for such a laser has to be made that much larger to capture more signal, resulting in an apparatus that's very difficult to install on a rover, where weight and volume are at a premium.

As an alternative, the Agency made use of a technology the Microdevices Laboratory at JPL started developing back in the early 1990s called the interband cascade laser. By the time Curiosity's development got underway, the technology had matured enough for the center to advance a distributed-feedback version of the laser capable of emitting a mid-infrared beam at about 3.3 microns, an ideal wavelength for detecting methane. Its efficiency also allowed the resulting instrument to be made relatively compact.

Those features made it the perfect laser for the TLS, which made its way with SAM to Mars in 2012. As it turns out, the technology would also make an impact on Earth by improving on an important tool used in the energy sector.



The image depicts the ways methane might enter and be removed from the Martian atmosphere. Using its Tunable Laser Spectrometer, the Curiosity rover has detected fluctuations of the gas, which, as the illustration shows, could be created by either geochemical or biological means, or both.

Technology Transfer

Used as both a cooking and a heating fuel, natural gas consists primarily of methane, which, besides serving as a possible marker for the existence of microbial life, also has the dubious distinction of being one of the greenhouse gases responsible for global warming and its damaging impacts on Earth. According to the U.S. Environmental Protection Agency, methane is the second most prevalent and most potent greenhouse gas emitted in the country, and leaks arising from underground pipes supplying energy are a major contributor.

Industry does what it can to detect these leaks, but current methane-detecting devices have the same drawbacks that the interband cascade laser resolved for the TLS. For one, they are bulky—a problem for gas company workers, who have to carry them around for long stretches of time. "These men and women are out there in

> Employees feel really proud that they get to use technology used on Mars to help them do their jobs."
>
> — Hailey Wilson, PG&E

the hot sun walking these neighborhoods for much of the day," says Hailey Wilson, a spokesperson for Pacific Gas & Electric, or PG&E, a company that provides energy for most of northern California. The firm is responsible for monitoring its 48,000 miles of pipeline for safety and environmental concerns.

Second, their sensitivity isn't particularly strong, meaning a detector has to be fairly close to a leak for the alert to sound. A more sensitive instrument is available, but it's large and heavy enough that it needs to be attached to a car. "You can imagine it not being useful for leaks in yards and other places inaccessible to vehicles," Wilson says.

Those drawbacks, combined with efforts to further decrease greenhouse gas emissions caused by gas leaks, led the industry in 2013 to initiate a reimbursable Space Act Agreement between Pipeline Research Council International, a membership-based research organization for energy companies, and JPL to incorporate the interband cascade semiconductor laser into a handheld methane-detecting device. Firms such as PG&E, Southern California Gas Company, and Chevron also provided direct funding.

Over the next two years, JPL's Christensen utilized the TLS as a template for making a really small spectrometer. "Because I didn't need to use hefty space-qualified parts on Earth, it gave me more flexibility to shrink it even more," he says. The device was then tested by PG&E and went through a few iterations to optimize comfort and usability.

JPL senior scientist Lance Christensen tests the methane sensor he invented. Utility companies will use the device to detect gas pipe leaks, which are potentially dangerous and contribute to global warming.

At the close of 2014, Christensen finalized the handheld methane detector's design. The technology is now ripe for commercial use.

Benefits

The methane detector has made quite an impression on field workers from the get-go, says PG&E's Wilson. The device, which she says resembles a stripped-down metal detector, is being lauded for its easy handling. "It's extremely light compared to what they had before, which were shorter, heavier instruments that had to be held at strange angles to work," she says.

Then there's the sensitivity of the instrument, which is much greater than previous handheld versions. According to Christensen, traditional handheld detectors are able to identify about one part methane per million, whereas the NASA-derived tool's responsiveness is 10 parts per billion—a 100-fold improvement. The increased sensitivity makes it easier to find, for example, tiny leaks that arise from micro-fissures underground. "With this new technology, you can be standing 100 feet away from that kind of leak and it'll sense it," he says, "and you'll be guided to the source like a moth follows pheromones."

A key innovation developed during the prototyping stage—having a voice that reads the concentration aloud—also makes the task more efficient. That's in contrast to other models that produce beeping sounds upon sensing the gas. "We've found that people have an easier time responding to spoken data measurements," Christensen says. "And this method is also a better option for those who don't have sensitive enough hearing to make out changes in pitch and volume."

For PG&E, the technology is a win all around. "Our workers like the product, we find leaks more easily and quickly, which means safety is that much better, and it's going to help us reduce greenhouse gas emissions," Wilson says.

For the firm, supporting innovations such as this in the energy industry is an important goal. "This is not your grandfather's utility company," she adds. "We pride ourselves on being ahead of the times. Employees feel really proud that they get to use technology used on Mars to help them do their jobs." ❖

Hydrogen Detection Tape Saves Time and Lives

NASA Technology

From the Apollo missions through the Space Shuttle Program, NASA has relied on liquid hydrogen as a fuel source for the upper stages of its rocket launches. The reason is simple: Hydrogen is the most efficient propellant there is. Measure for measure, it provides more thrust than any other fuel source.

But harnessing that energy requires a great deal of technological know-how on the Agency's part. For one, keeping hydrogen in its liquid state means maintaining it at a temperature below -423 °F. The element must also be insulated from external heat sources during launch, lest it begin to evaporate. Then there's the persistent threat of leakage. As the smallest and lightest of atoms, hydrogen escapes through the tiniest of cracks. That makes it a hazard, as the element is highly flammable, to the point where high-pressure joint leaks can cause combustion. As a result, detecting leaks is a top priority, but it's also a challenge, because the gas—and the flame it emits—are odorless and colorless.

Given those stakes, imagine the task of having to monitor liquid hydrogen as it flows through a few miles of pipeline—which is what NASA had to do in preparation for every Shuttle launch, when hundreds of thousands of gallons were transferred from a holding tank to the launch pad for fueling. In the Apollo days, detecting a flame from one of those leaks was accomplished by using the "broom" method, whereby workers would take a broom and walk around with the head stretched out in front of them. If the head began to burn, there was a leak. Later, during the launches of the 1980s and '90s, they used ultraviolet sensors to detect flames; to find non-burning leaks they began utilizing electrochemical and combustible gas sensors.

But a major problem with those instruments is they can only offer up a general area for a leak. "Sometimes a sensor would go off and, because the leak is in an area with a lot of hydrogen transfer lines, they would have a hard time finding it," says Luke Roberson, a research scientist and principal investigator of the project in the Chemistry Branch, Materials Science Division at Kennedy Space Center. "So they asked us if we could develop a way of locating a leak visually."

Technology Transfer

It just so happens that, in 2003, not too long before that request, the Florida Solar Energy Center (FSEC) at the University of Central Florida (UCF), about an hour's drive from Kennedy, had received a grant from the Agency to lead a hydrogen research program. Robert Youngquist, head of Kennedy's applied physics lab, reached out to one of the grant's principal investigators, Dr. Ali Raissi, and a collaboration was struck between the two organizations and also the Polymer Science and Technology Laboratory to advance a new gas detection technology.

In order to detect hydrogen visually and passively, Raissi conceived of developing a chemochromic tape, meaning the tape would change color upon exposure to the element. To accomplish this, his team worked with a Japanese patent that utilized the palladium oxide (PdO) and titanium oxide (TiO_2) class of pigments. In short, PdO and TiO_2 are mixed together into a powder, and when hydrogen is present, the powder changes color. The problem with this particular recipe, according to FSEC chemist Nahid Mohajeri, who worked on the technology, was that the color change was slow and it didn't produce a noticeable enough change. "We had to do a lot of work adjusting the chemistry so that the color change is fast and visible to the naked eye."

Much of the adjusting was done to the TiO_2 mixture, which Mohajeri calls the "support," as the actual color-changing chemical reaction occurs between PdO and hydrogen. But the color of the support is important because it has to contrast with that of the reaction so a person can clearly see it. Also, in its various iterations, the support can either speed up or slow down the chemical reaction process. Therefore, the team had to develop an iteration of the pigment that had the right color contrast, supported a very fast reaction, and could be applied to a silicone-based tape, which provided the necessary encapsulation properties.

> "We had to do a lot of work adjusting the chemistry so that the color change is fast and visible to the naked eye."
>
> — Nahid Mohajeri, HySense Technology

After about two years, the pigment formulation was completed, at which point Kennedy worked to improve and advance the technology for a broad range of applications, including Shuttle launches, which required a more robust version of the technology, as the tape had to be stable in cryogenic environments, protected against flammability, and weather-resistant. To meet those challenges, Roberson, along with fellow NASA scientists and inventors Janine Captain, Martha Williams, LaNetra Tate, and Trent Smith, among others, devised an encapsulant made of Teflon and other matrices instead of silicone. They then tested the new iteration of the tape successfully on cross-transfer lines, fuel cells, and other NASA sites.

Its dependability assured, the technology was first implemented on STS-118, which, as it happens, had an incident where a leak developed at the launch pad. The area sensor technology detected the presence of hydrogen, but the tape enabled crews to pinpoint the exact location of the leak. Afterward, the tape was used for every launch up until STS-134—Space Shuttle Endeavour's final spaceflight and the program's penultimate mission.

As a result of developing the hydrogen-detection tape, the Agency and UCF filed for and were subsequently

Space Shuttle Endeavour arrives at launch pad 39A on August 9, 2007 in preparation for mission STS-118. A leak developed in the Orbiter Midbody Umbilical Unit, or OMBUU (inset), which loads liquid hydrogen and liquid oxygen into the spacecraft's fuel cells. A color-changing hydrogen-detection tape, seen in beige, which was developed by Kennedy Space Center and the University of Central Florida in the mid-2000s, was applied to the OMBUU and helped to detect the leak's source. The technology went on to be used for every subsequent Shuttle launch up until STS-134, the program's penultimate mission.

issued several patents. In 2013, the two organizations also agreed to bundle and commercialize the technology jointly; as a result, later that year Mohajeri founded Rockledge, Florida-based Hysense Technology LLC and began production and marketing of the product as Intellipigment.

Benefits

Hydrogen is one of the most widely used gases in industry. Oil refineries utilize the gas to turn crude oil into gasoline and diesel, and manufacturers mix hydrogen with argon to weld stainless steel. Chemical plants also use the element as a building block for creating ammonia, a key ingredient in fertilizer, and methanol, an important constituent in many polymers.

And just as NASA is keen on monitoring leaks from a safety standpoint, so is every other industry that deals with the highly reactive and flammable gas. Mohajeri says the traditional technologies that companies work with have their drawbacks.

"Stationary sensors have a shelf life and, depending on where they're located, they might not be able to detect every area that's susceptible to a leak," she explains. "And the handheld ones require technicians to walk around and listen for a beeping sound. What if there are two flanges near the beep that are very close together? It could be that one is leaking and the other one isn't, but the sensor can't make out the difference."

That's where the company's Intellipigment tape comes into play. "With this new technology, all they have to do is wrap the two flanges with the tape, and they'll directly home in on the source of the leak," she says, noting that it's easy to spot the problem area, as the beige tape will turn black.

As for how long it takes the tape to undergo the chemical-induced color change, if 100 percent hydrogen is being used, results come within 10 seconds. Mohajeri adds, "We also tested leaks that contain as little as 1 percent hydrogen, and we saw a reaction time of three minutes, which is very good."

Although the product has been commercially available for only a short period of time, and despite it being unlike any gas detection technology that came before it, a number of companies across the swath of industry have taken to using the tape, and many of them have already placed a second round of orders.

Adding to the technology's promise, in 2014 *R&D Magazine* awarded HySense, Kennedy, and UCF an R&D 100 Award for its development, and in that same year HySense won a $100,000 first-place award at the CAT5 Innovation Competition, which honors and supports early-stage companies that offer "powerful, disruptive" technologies.

"I'm very hopeful, as all the indications are telling me that this product will be a success," Mohajeri says.

The technology was also shown interest by the automobile private sector as the Space Agency carried out potential applications discussions with several car companies in their development of hydrogen and hydrogen fuel cell automobiles. NASA also contributed its expertise to the Hydrogen Highway project: an initiative led by the Department of Energy that aimed to proliferate hydrogen refueling stations in order to make such automobiles commercially viable.

According to Kennedy lead polymer scientist Martha Williams, public and private partnerships such as these, along with the technology's successful commercialization, play an important role in the Agency's overall mission.

"We're always thinking in terms of the big picture," she says. "As we solve problems for NASA, we're also figuring out the best ways to transfer the technology successfully. This detector tape is a great example of that." ❖

HySense Technology's Intellipigment hydrogen-detection tape will benefit oil refineries, steel-manufacturing and chemical plants, and other industries that check for gas leaks to ensure safety. The tape is easy to apply, and problem areas are easy to spot because of the sharp color change (inset). Intellipigment is sensitive enough to detect leaks that contain as little as 1 percent hydrogen.

Image courtesy of Flickr user ddatch54, CC BY-NC-SA 2.0

Single-Photon Lidar Maps Ground Features Quickly, Efficiently

NASA Technology

Taking topographic measurements with single photons in broad daylight means pushing the limits of precision, and this is what Sigma Space Corporation set out to do with its impossible-sounding single-photon lidar (SPL) Earth-imaging technology.

The result is an airborne device that splits a single laser beam into 100 low-power beamlets directed at different points on Earth's surface, firing at a rate of 32,000 pulses per second and then detecting individual photons reflected back to it, distinguishing them from a storm of sun-generated photons, and determining how long each photon's round trip took to an accuracy within about 20 picoseconds, or twenty-trillionths of a second. In this way, the lidar creates a 100-pixel, three-dimensional image with every pulse, which is then integrated into a contiguous, high-resolution image by an optical scanner matched to the aircraft's ground speed. Furthermore, the lidar uses a fraction of the energy typical of conventional imaging lidars.

A system with this sort of capability, however, was not born overnight.

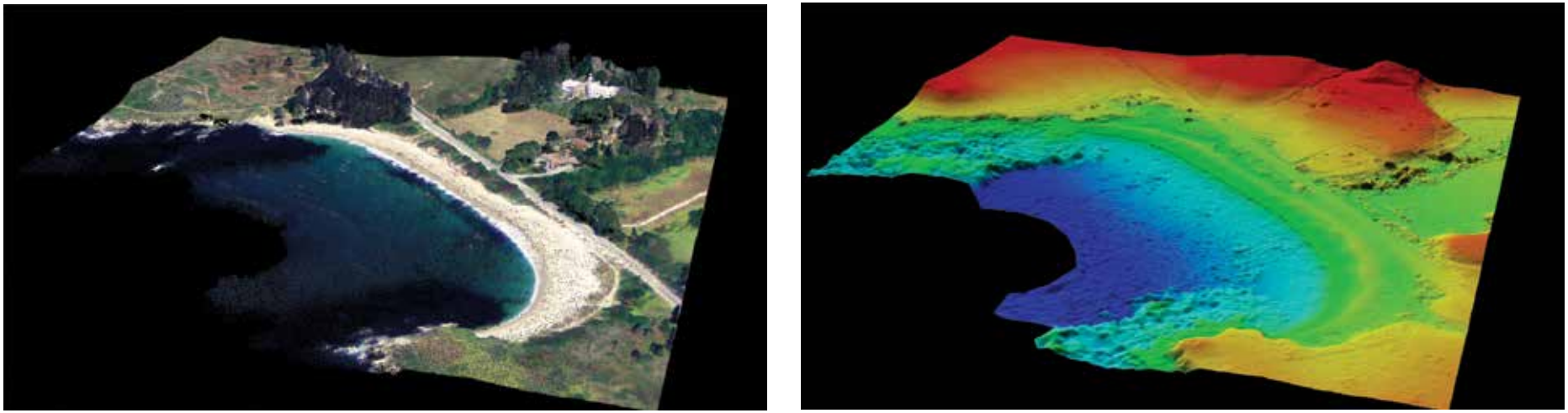
The technology draws heavily from a half century of satellite laser ranging, going back to 1964, when then-physics co-op student John Degnan, now the Lanham, Maryland-based company's chief scientist, arrived at NASA's Goddard Space Flight Center just in time to participate in the world's first laser satellite ranging experiment. The project successfully timed the round trip of laser pulses fired from Earth and reflected back from a satellite in low-Earth orbit to determine its location to an unprecedented accuracy of 10 feet.

Laser ranging accuracy quickly increased by orders of magnitude and became common practice around the world. In 1994, Degnan, still at Goddard, proposed the SLR2000 system, a single-photon-sensitive, high repetition-rate, eye-safe, fully automated satellite laser ranging system. SLR2000 later evolved into the Next Generation Satellite Laser Ranging System, the prototype for NASA's future international network of Space Geodesy Satellite Laser Ranging Systems. Both projects received support from Sigma and other private contractors.

Meanwhile, it occurred to Degnan to try reversing the direction of laser ranging. "If I can see the slope in that data for a satellite due to orbital time bias, why can't I see a slope on the ground?" he asked.

His ensuing proposal, funded by NASA's Instrument Incubator Program, bore fruit more quickly when NASA's Airborne Multi-Kilohertz Photon-Counting Microlaser Altimeter flew over the Eastern Shore of Maryland and Virginia in 2001. The experimental system, which Sigma also worked on, demonstrated the ability to map Earth's surface by catching individual reflected photons from a height of 23,000 feet and was even able to see forest floors through the canopy, as well as ocean depths down to a few meters.

"The fact that we could actually detect single photons in broad daylight—that had never been done before," Degnan says. "With single photons, we could do things a lot faster, with less energy and smaller instruments."



A lidar point cloud colored using simultaneously acquired photography by a Sigma Space imager shows the trees, grass, beach, and surf at Point Lobos in California. Meanwhile, a digital elevation model extracted from the data reveals the topography and bathymetry—that is, underwater elevations—of the same area, down to a sea depth of 13 meters.

“Instead of **using** a single, **powerful pulse,** now we’re **using** a lot of **weaker pulses** for the same **resolution** with **less stress** on **the laser.”**

— Anthony Martino, Goddard Space Flight Center

In 2010 Sigma provided components of Goddard’s airborne, photon-counting Multiple Altimeter Beam Experimental Lidar, which served as a test bed for the technology that will fly on the Agency’s Ice, Cloud, and Land Elevation Satellite 2. Sigma is contributing significantly to that vehicle’s instrumentation as well.

Technology Transfer

In 2003, Degnan retired from Goddard and started his work at Sigma, bringing four decades of NASA laser ranging experience with him. In the ensuing years, the company licensed two of his NASA patents—the Space Act Award-winning microaltimeter patent and a 3D-imaging lidar patent. Sigma was later awarded additional patents for improvements to the technology.

Under an SBIR contract with the U.S. Air Force, the company built on the NASA microaltimeter prototype to create the 100-beam Leafcutter, a low-altitude SPL imager capable of seeing underwater and through tree coverage for military reconnaissance. The instrument has a spatial resolution of 15 centimeters at an altitude of one kilometer.

With funding from follow-on contracts with the Department of Defense and NASA, as well as Sigma's own money, the High-Altitude Lidar and High-Resolution Quantum Lidar System (HRQLS) followed. These were designed to operate at 25,000 and 7,500 feet, respectively.

All the imagers are based on a similar design: 100 streams of laser pulses are sent out from a 10-by-10 array of emitters, with a matching array of ultrasensitive photodetectors picking up the returning photons. A 100-channel timing system records photon departure and arrival times at laser pulse rates up to 32,000 per second, allowing 3.2 million measurements every second.

Photons reflected from the surface can be distinguished from sunlight because they arrive more or less all at once, and the more uniformly distributed solar noise can be removed in post-processing, explains Roman Machan, Sigma's chief technology officer and creator of the systems' timers. "You're looking for structures, and all of those will return lots and lots of points next to each other."

Because the aircraft barely moves in the time it takes the laser pulse to reach the surface and return, the same gaps in tree canopy that allowed the photons to reach the forest floor also allow their return to the system's receivers, he adds.

The technology is able to penetrate water because it uses light in the green, 532-nanometer wavelength, rather than the near-infrared frequencies most other altimeters use.

A Sigma imager captured this high-density lidar point cloud of a forested area in Sierra Nevada, California, in a single pass.

Benefits

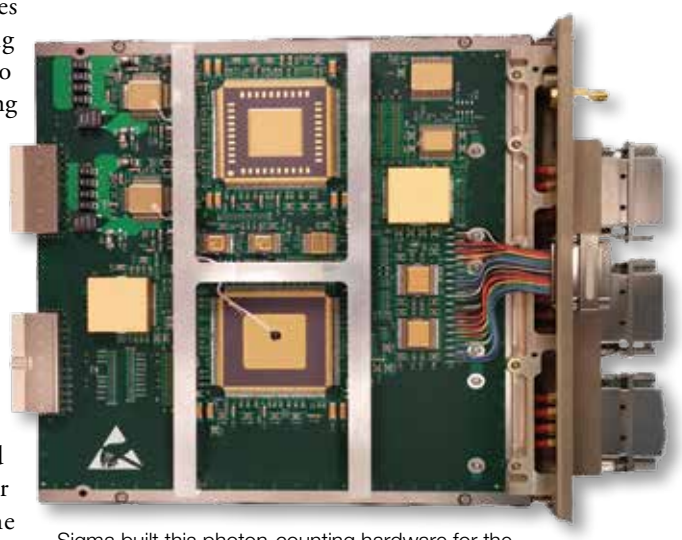
The ability to cheaply and accurately map surface features across large areas has a multitude of applications, even without factoring in the ability to see through water and tree cover. While the Air Force was interested in foliage-penetrating reconnaissance, and other agencies have worked with Sigma on a system for spotting underwater mines and submarines, HRQLS can also serve such civilian purposes as rapid, wide-area surveying or seeing whether train tracks are warped or trees are infringing on power lines.

By flying at high altitudes, the device can map swaths of up to a few kilometers, making surveys of broad areas faster and more affordable. While the company has built a number of systems for Government clients, Sigma is now more interested in selling its data-gathering services, which is why the highly flexible HRQLS system was built.

With a grant through NASA's Carbon Monitoring System, the University of Maryland recently worked with Sigma to map and quantify the forest cover, or biomass, of all of Garrett County, Maryland. The company was able to map the 1,700-square-kilometer area with a horizontal resolution of a few decimeters in about 12 hours, using half-overlapping flights.

"It's cost-effective now to do an entire state or to do a whole country because of improvements in how much area we can cover," Machan says, adding that this ability marks a paradigm shift for the lidar market, where current technology limits the size of such image collections due to high costs and low coverage ranges.

The company has been in talks with one agency that wishes to map an entire country in Africa. The work



Sigma built this photon-counting hardware for the Advanced Topographic Laser Altimeter System that will fly aboard NASA's upcoming Ice, Cloud, and Land Elevation Satellite 2.

would monitor tree coverage, ensuring compliance with arboreal cap-and-trade agreements, and would also be useful to oil companies and others who need to know the topography beneath that canopy to plan pipelines, roads, and other infrastructure.

"Once you have a 3D map, you can use it for any and all of the above types of things," Machan says.

Various states have talked with the company about having large portions or even the entirety of the state mapped, and one company approached Sigma with an interest in mapping the Chesapeake Bay. "We're just at the point where a number of commercial customers are interested in having us start flying over really large areas," Machan says.

The company still works closely with NASA. In 2010, Sigma provided components of Goddard's airborne, photon-counting Multiple Altimeter Beam Experimental Lidar (MABEL), a test bed for the technology—again, much of it provided by Sigma—that will fly on the Agency's Ice, Cloud, and Land Elevation Satellite 2 (ICESat-2).

"With photon counting, we're able to get the same resolution with much less light than we would with other methods," says Anthony Martino, instrument scientist for ICESat-2 at Goddard. The mission, scheduled to launch in 2017, will use multiple single-photon lidar beams to monitor changes in ice coverage at the poles, as well as watch tropical forest coverage. "The scientific goals of ICESat-2 are primarily to measure changes in the heights of polar ice sheets and thickness of ice in the polar oceans, and secondarily to measure the thickness of vegetation in lower latitudes," Martino says.

The new satellite's altimeter is known as the Advanced Topographic Laser Altimeter System (ATLAS).

This is a follow-on to the first ICESat mission, which flew between 2003 and 2010. The original ICESat altimeter had a single laser that used about 100 times the energy per pulse that ICESat-2's six beams will use together, until the laser failed, with the result that the device had to conserve laser life by operating just a few months each year. "Instead of using a single, powerful pulse, now we're using a lot of weaker pulses for the same resolution with less stress on the laser," Martino explains.

Among the many uses being contemplated for the single-photon lidar Earth-imaging technology Sigma Space Corporation developed from its NASA patents and know-how is the monitoring of logging in Africa and around the world to enforce logging cap-and-trade agreements. The technology can quickly image and calculate tree cover.

From an altitude of about 500 kilometers, ATLAS will fire its six beams around 10,000 times per second—as opposed to the original ICESat's 40 times per second—and 60 detector channels will register returning photons, creating an image by averaging the results of every 100 pulses or so. The price of a more reliable laser, Martino says, is the need for more complicated, difficult receiving and timing systems. Sigma was brought on board because, in addition to supplying the fundamental concept for the necessary photon-counting electronics, the company could demonstrate its ability to develop the intricate hardware and software to support the mission.

"It's the most complex single thing I've seen at Goddard in the electronics domain," says Greg Henegar, product design lead for ICESat-2's main electronics box, adding that Sigma's solutions were "extremely cleverly devised. It required a very efficient architecture of that electronics board just because of the sheer volume of data it's receiving."

"The Air Force paid for us to develop our own timer concept, and we were able to take that and give it back to NASA in the form of MABEL and ATLAS," says Machan. "That kind of completes the circle, if you will."

Not that the story ends there. While the company's SPL technology begins its break into the commercial market, Sigma also worked on a study with NASA regarding the feasibility of using a similar system to orbit and completely map three of Jupiter's moons, concluding that Callisto and Ganymede could be covered in two months each, while the smaller Europa would take just a month, all with better than 5-meter horizontal and 10-centimeter vertical resolution.

"John's claim has always been that a single photon is the most efficient use of energy," Machan says. "To have a tiny laser and a really sensitive detector is a nice solution for NASA instruments." ❖

Temperature Sensors Cement Integrity of Bridges

NASA Technology

When the White House calls, NASA answers. The Obama administration wanted to foster partnerships between the Government and small- to medium-sized manufacturers through its Strong Cities, Strong Communities Initiative, wherein Federal agencies around the country are asked to mentor local businesses. One of the communities selected was the Cleveland-Youngstown region of Ohio, resulting in a call to Glenn Research Center.

Glenn approached the city of Cleveland, Cuyahoga County, and the Manufacturing Advocacy & Growth Network (MAGNET) to brainstorm the best way to select worthy partners. Together, the Adopt a City program was launched, in which eight companies were identified to receive 40 hours each of assistance from experts and at Glenn. The companies also were eligible to receive low-interest loans through the program, now in its third session.

Given the variety of tasks and challenges faced by NASA scientists every day, the experts at Glenn were well-positioned to participate in the program, bringing both expertise from aeronautics and space missions and specialized equipment the companies couldn't otherwise access easily.

An independent report released on the project by MAGNET found Glenn's involvement with the Adopt a City program's first 14 companies resulted in the creation of at least 19 jobs, the retention of an additional 47 jobs, $2.7 million in revenue generated, and an additional $33.9 million in private money invested in the projects. "That's just the tip of the iceberg," adds Paul Bartolotta, a senior technologist at Glenn, as some of these projects had not been completed at the time of the report's publication at the end of 2014, and their economic impact is not yet fully realized.

The companies involved in the first round of Adopt a City varied greatly in their lines of work, from a company that produced vinyl records and another that turns garbage into energy (page 126), to one—Pile Dynamics Inc. (PDI)—that needed assistance making thermal sensors for concrete piles. Using an array of NASA experts to work on such a diverse set of challenges made sense, Bartolotta says. "We have the talent, we have the technologies, we have the facilities to solve their problems."

Image courtesy of the Ohio Department of Transportation

The Innerbelt Bridge in Cleveland has just been replaced, a $26 million undertaking. Contained within the cement piles that support the bridge are thermal integrity profilers built by Pile Dynamics Inc., a local company that used the profilers to ensure the structural integrity of the bridge by monitoring the temperature of the cement as it cured.

Technology Transfer

PDI needed an important solution to a pressing problem: the company had developed a commercialized version of a prototype created by University of South Florida professor Gray Mullins but needed a way to protect the thermal wire sensors within its Thermal Integrity Profiler (TIP) from both water and the caustic environment of curing concrete. Time was of the essence, as the company had just been tapped to work on the new Innerbelt Bridge on Interstate 90 in Cleveland.

Concrete warms as it cures, and TIP monitors the temperature within a concrete pile, or shaft, to identify whether it was poured properly or if any defects have occurred. PDI instruments a rebar cage with the sensors

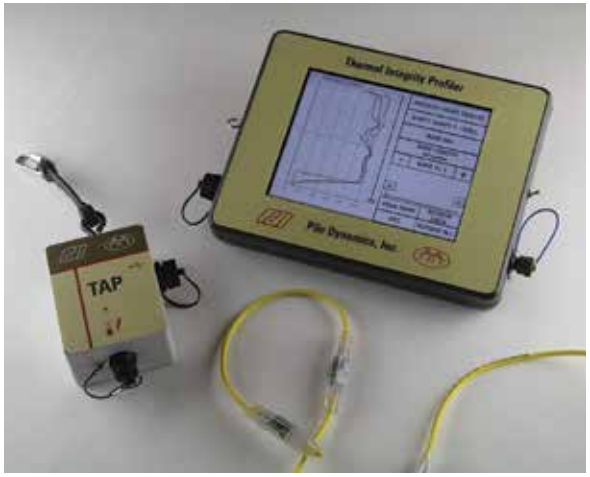
before it is installed in the shaft and filled with concrete. The temperature is collected for the first day or two after the concrete is poured, which allows the integrity of the pile to be monitored before the end of the 28-day curing process.

The company was using an extrusion process for sealing the sensors, but PDI's team of electrical engineers wanted to find something better. Needing to find a glue with the correct chemical properties that was available to do the job in a commercially feasible way, PDI applied and was accepted for the Adopt a City program's first round.

Their initial conversation with Bartolotta was encouraging, says Dean Cotton, one of the electrical engineers at PDI. Bartolotta had extensive experience in civil engineering and understood well the process of pouring a concrete foundation. "We were able to get right to the problem, that we were making these sensors and they have to go deep underwater and then be encased in concrete," he says. "We developed a plastic shell to mechanically protect our sensors, but needed a glue to put inside the shell to protect our circuit boards."

On Bartolotta's recommendation, PDI paired up with Sandi Miller, a chemical engineer at Glenn, who began reviewing her list of thousands of companies specializing in glues and epoxies. "Picking an epoxy out of the thousands of epoxies available was proving to be very difficult," she says. In the end, a representative for an adhesive company already working with PDI found a substance that had potential. PDI then asked NASA to change the direction of the project and brought some samples of the glue to Miller's lab for testing.

NASA's new role was to validate the strength of the seal the glue made inside PDI's shell and the strength of the bond between the shell and the wire used to transmit the temperature readings to an above-ground data collector. "We looked at the degree of cure of the epoxy, and we used optical microscopy and scanning electron microscopy to look at the cross-section between their epoxy and the wire," Miller said. "We basically sectioned their sample along the wire and also within the encapsulated material to make sure we weren't seeing any gaps between the wire and the epoxy." She also ran some strength tests



Pile Dynamics Inc.'s thermal integrity profilers track the temperature inside cement piles to ensure they were poured properly, thereby ensuring the structural integrity of the project. Data are collected for the 28-day curing period on the digital monitor, left above ground and later disconnected.

to see where a failure would occur and found the tensile strength of the bond was stronger than the wire itself.

She admits this was a different kind of project than she's used to undertaking, but "any time you're interacting with the greater community and you're learning what the needs are outside of our little box that we tend to focus on, it expands your knowledge base. It was a neat learning experience."

Benefits

Equipped with their NASA-validated glue, PDI got to work monitoring the concrete piles for the project right in their backyard, the $26 million bridge. The sensors have since been used in at least 40 different projects around the globe and, according to the company, are quickly gaining acceptance as a better alternative to existing testing methods.

Monitoring the temperature of concrete as it cures can indicate whether the concrete pile was poured properly. If temperature readings indicate a cooler spot, it suggests some of the concrete is closer to the soil or another defect in the shaft. If the rebar cage comes in contact with the soil and groundwater, it could eventually rust

The thermal integrity profilers designed by Pile Dynamics Inc. are affixed to a rebar cage, which is then installed into a shaft and filled with cement. The profilers monitor the temperature of cement as it cures, which can alert engineers to any problems with the structural integrity of the cement before it dries.

and threaten the structural integrity of the concrete shaft, Cotton says.

Thermal Integrity Profiling was standardized by the American Society for Testing and Materials in 2014. "This showed us the civil engineering world accepted this test method," Cotton says. "That was a big deal for us. It validates the method, and we have the equipment and sensors to commercially provide to the construction industry." The sensors have also been embraced as a standard tool by the Ohio Department of Transportation for bridge foundation projects, and were awarded the 2015 American Society of Civil Engineers Charles Pankow Award for Innovation.

There's a bit of personal satisfaction in the help NASA provided PDI, Cotton adds. "I grew up very close to NASA Glenn and still live close by. I drive by Glenn every day. It's great to know NASA is here and sharing technology to help the Cleveland area." ❖

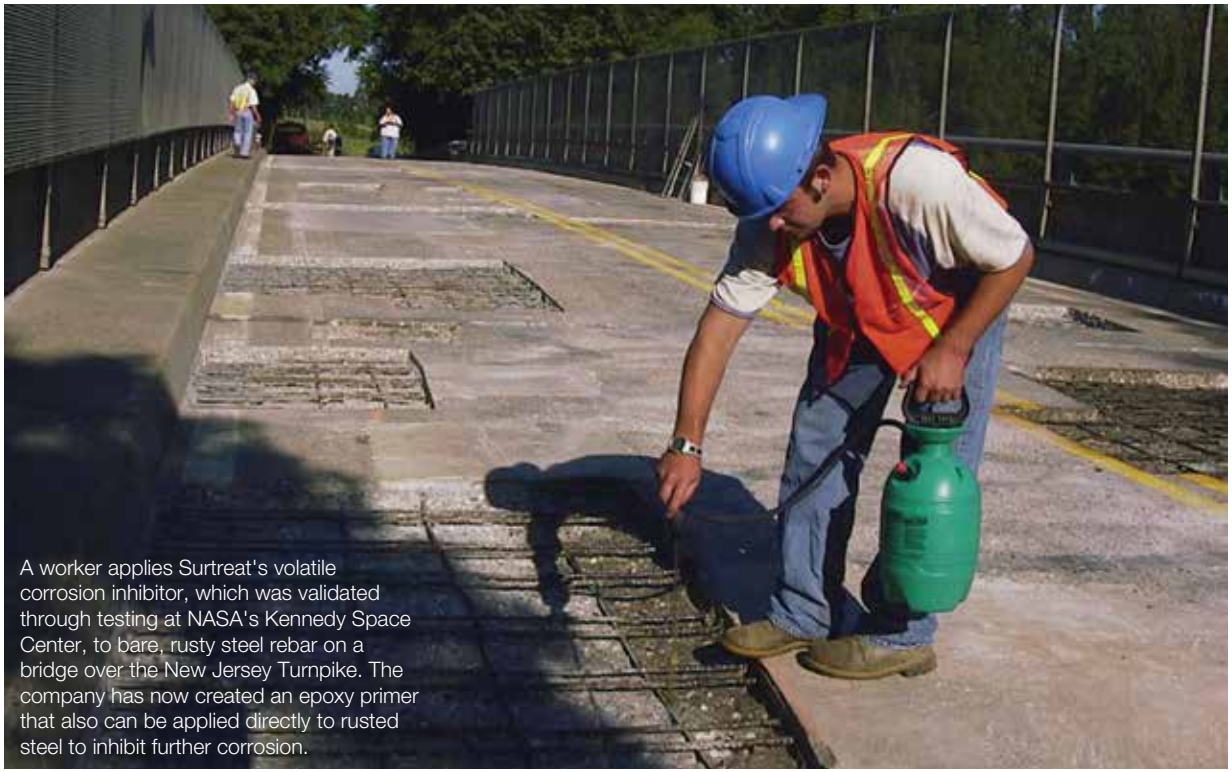
Primer Stops Corrosion without Requiring Rust Removal

NASA Technology

"The world is made out of bad concrete and rusty steel, and corrosion is the primary cause of deterioration of our infrastructure," says Bob Walde, vice president of technology for Surtreat Holding LLC. The problem, he says, is that engineers tend to try to stop corrosion by physical means that address the symptoms but not the underlying causes. "Corrosion is an electrochemical process, and it can be inhibited by changing the chemical environment around the steel."

To that end, in the mid-1990s Surtreat, based in Pittsburgh, developed two corrosion inhibitors that worked by chemical means and were designed to be applied to the surface of concrete, where they would migrate to the steel rebar inside. By 1996, though, the formulas still had not been formally tested and validated.

Meanwhile, of all the concrete in all of NASA's field centers, probably none has it harder than that in the structures at Kennedy Space Center. Not only is the seaside campus, located near Orlando, constantly bathed in damp, salty air, but some of its concrete is in and around the Cape Canaveral launch pad, where rocket boosters blast it with white heat, hydrochloric acid, and other hazards, while it's simultaneously sprayed with water for cooling. For these reasons, in February 1996, Kennedy entered into a Space Act Agreement with Surtreat to test its products (*Spinoff* 1998). Joe Curran, a NASA-contracted corrosion engineer at Kennedy, set up the testing.



A worker applies Surtreat's volatile corrosion inhibitor, which was validated through testing at NASA's Kennedy Space Center, to bare, rusty steel rebar on a bridge over the New Jersey Turnpike. The company has now created an epoxy primer that also can be applied directly to rusted steel to inhibit further corrosion.

One of the products validated during those tests has now led to a new epoxy primer that can be applied directly to clean or rusty steel to stop corrosion.

Kennedy spends considerable money on corrosion prevention, says Curran, who now does similar work for the Air Force at Cape Canaveral Air Force Station. "If there's a less expensive way to do it, you should think about doing that."

Rusting occurs as iron, the main ingredient in steel, loses electrons, he explains, noting that saltwater, which is highly conductive, accelerates this process. As rebar rusts, it expands, breaking up the concrete surrounding it.

One of Surtreat's early solutions was an inorganic compound whose ions would readily migrate through the concrete to the steel to form a corrosion-resistant surface. The other was an organic compound whose vapor would pass through the pores and cracks in the concrete and form a protective film on the steel surface.

During testing, Curran applied a number of different manufacturers' inhibitor products to several reinforced concrete "coupons" and assessed them by three different methods. Salt-fog chamber testing subjected them to a measured chloride concentration at a set frequency of salty fog for a set duration. Another test used a technique called electrochemical impedance spectroscopy to measure the rebar's resistance to corrosive current flow.

He also employed the American Society for Testing and Materials' widely used method for determining the effects of chemical admixtures on the corrosion of rebar in concrete. Curran waited until corrosion was taking place in the salt-laden test blocks, then treated them with corrosion inhibitors. After a period of time, he measured the macro-corrosion currents between the rods of rebar and determined that corrosion rates were reduced.

Of the several corrosion inhibitors he tested, Curran says, Surtreat's vapor-migrating inhibitor was a top

Image courtesy of the U.S. Navy

Far left, Surtreat's latest product, an epoxy primer with a volatile corrosion inhibitor, has been applied to a rusted abutment bearing under a bridge in Houston as part of a pilot project. The U.S. Navy is interested in the primer for ship maintenance, and the Federal Department of Transportation is considering using it, especially on bridges.

performer and was subsequently used on Kennedy's Launch Pad 39A and other reinforced concrete structures at the space center. Other private contractors used the Surtreat product to treat beachside condominium balconies and other structures in the Central Florida area.

Technology Transfer

"The NASA results showed that the inhibitors did migrate from the surface to the rebar and did inhibit the corrosion," Walde says. "That allowed us to go out and market these two corrosion inhibitors with greater confidence."

The products went on to be used on bridges, parking garages, military installations, power plants, condominiums, and other structures across the country and abroad.

In a 2007 partnership with the U.S. Army Corps of Engineers, Surtreat experimented with applying its products directly to the surface of corroded steel at two military installations in Okinawa. The work was successful, and in 2010 the Corps of Engineers commissioned the company to develop a pigmented epoxy primer that could be applied to rusty steel to inhibit corrosion.

Surtreat ended up using an organic compound similar tothe one that had been tested at Kennedy, known as a volatile corrosion inhibitor (VCI), whose vapor would migrate through the rust to the steel surface and form a protective film.

"We had to find a paint system that the VCI would be compatible with, where it wouldn't change any of the characteristics of the paint, and the paint wouldn't hinder the corrosion inhibitor," Walde says. The company developed a two-part primer, which was evaluated by the U.S. Army Corps of Engineers in 2012 and was found to be effective on rusty surfaces to the point that it offered 5–10 times the corrosion-inhibiting properties of the standard primer.

Surtreat filed for a patent that year and created VCI Coatings LLC to market the product.

Benefits

"We're still trying to get people to understand that if you have a problem of chemical deficiency, you might want to use a chemical solution," Walde says.

But people are beginning to come around.

The U.S. Department of Transportation has expressed interest in the new corrosion-inhibiting paint, mostly for use on bridges, and the Navy is interested in it for ship maintenance, Walde says, adding that by late 2014 a number of painting contractors had also used VCI Coatings' primer to protect everything from metal roofs to bridge cables, to the galvanized pans under a football stadium's walkway.

"We're quite optimistic about the commercial opportunity here," Walde says.

Other corrosion inhibitors require all rust to be scraped off a steel surface before they're applied, at a cost that Surtreat estimates at as high as $5 per square foot. That adds up quickly on a large structure. The new product costs about twice what a basic primer costs, but that expense is more than offset by the savings in surface preparation and the increased lifespan of the steel. The company calculates a cost of 57 cents per square foot per year over 10 years for a basic primer, as opposed to 10 cents a year over 20 years for its primer with the VCI agent. The primer can also be applied to new steel surfaces to increase their lifespan.

Walde says the company still credits the Space Agency with proving the effectiveness of this family of compounds.

"It was the work done by Joe Curran at NASA Kennedy Space Center that first defined the functionality of these corrosion inhibitors for migrating to a steel surface, which has evolved into what's now been incorporated into the primer," he says. ❖

Consumer Goods

NASA develops and funds such a wide range of technologies—often with broad applications beyond the space program—that its technical DNA often turns up in the most unexpected places. Temperature-regulating clothing and heat-blocking device cases might not be surprising places to discover NASA's influence, but you might not expect space technology in a coffee shop, microbrewery, or prayer mat—all spinoffs you can find in this section.

NODE+ Platform Integrates Sensors with Smartphones

NASA Technology

In 2007, when the Department of Homeland Security (DHS) issued a call for a sensor that could equip a smartphone with the ability to detect dangerous gases and chemicals, Ames Research Center scientist Jing Li had a ready response. Four years earlier, she led a team that wrote a paper on the use of carbon nanotube sensors for gas and organic vapor detection, which would later receive Ames' 2012 H. Julian Allen award for outstanding science and engineering papers.

She had been developing the use of single-walled carbon nanotubes that respond to various gases and compounds for use in NASA applications, such as evaluating planetary atmospheres, detecting chemicals around rocket launch pads, and monitoring the performance of life-support systems. Her proposal in response to DHS's Cell-All initiative was awarded funding through an interagency agreement in 2008. What she still needed was a way for the device to "sniff" the air for samples and a system that would allow it to interface with a smartphone.

Li approached George Yu of Genel Systems Inc. "Genel had the technology to provide a very small sample collection system," Li says, noting that the company was subcontracted shortly after funding was awarded. In the end, however, that sampling jet proved too noisy, and Li and her team settled instead on a tiny fan. Then a separate contract for the cell phone interface system fell through. "That contract didn't work out, so I asked George to do it—I know he is good at electrical circuit design," Li says.

The team settled on the iPhone, which was new at the time, and Li convinced the program manager at DHS that the sensor should be a module attached to the outside of the phone, rather than a system built into the phone's guts. "This is a very new technology, and there will be a lot of iterations. Making it interchangeable will make it easier to update," she explains.

This modular design not only will pave the way for future smartphone chemical sensors but also presaged the line of interchangeable, smartphone-savvy sensors Yu would commercialize a few years later, after founding Variable Inc. in Chattanooga, Tennessee.

Yu figured out how the sensor module could draw its power from the cell phone battery and use the phone to digitally process the data it gathered and transmit it to a central location, such as a cloud platform. Most of the design for the microprocessor, memory, communication protocol, back-end Web structure, data storage, and cloud technology he developed for NASA and DHS under a NASA subcontract would later appear in Variable's NODE wireless sensor platform.

Ultimately, Li's team outfitted each of 40 iPhones with a tiny chip containing 32 carbon nanotube sensors that react to potentially harmful chemicals, such as ammonia, nitrogen dioxide, hydrogen chloride, and chlorine, as well as volatile organic compounds, such as benzene and toluene. Most of the phones have been delivered to DHS and are being tested by technical first responders and trained personnel.

The NODE platform can be outfitted with an array of different sensor modules for detecting light, gases, temperature, motion, and more. It can store data or transmit it to a smart device using Bluetooth wireless technology.

The NODE+ platform, shown here attached to the bicycle handlebars in the bottom left, tracks motion with a gyroscope, accelerometer, and magnetometer. It can also let a whole host of other sensors—up to two at a time—communicate with smart devices.

"DHS wants to utilize chemical detection technology incorporated with a cell phone to do global or regional chemical detection," Li says. If firefighters arrive at a scene involving a toxic gas leak, for example, the device can let individuals know how far into the area they can safely go, and the collective data from multiple firefighters carrying the technology can map the extent and boundary of the chemical hazard. "Then they can make decisions based on the detection results at certain locations," says Li. All this is accomplished without requiring anyone to carry an additional device—in almost all cases users are carrying cell phones anyway.

"It became immediately clear that this integration of nanosensor technology in combination with a cell phone is extremely powerful," Yu says. To launch his commercial line, however, he began with simpler technology.

Technology Transfer

Building on the integration system he developed for the Cell-All initiative, Yu developed his NODE platform—a cylinder not much bigger than a man's thumb that can transmit data from sensors to a smartphone or other smart device and that also has its own memory port capable of storing data to be uploaded to any computer. Unlike the sensor developed for DHS, NODE operates independently of the cell phone and transmits the data to the phone or other device using Bluetooth wireless technology.

Variable converted off-the-shelf sensors, such as infrared thermometers, color referencers, motion sensors, and barcode readers, into interchangeable modules that can be snapped onto either end of NODE, so it can use two modules simultaneously. Echoing the Cell-All project, there is a module for carbon dioxide detection and another that senses carbon monoxide, nitric oxide, nitrogen dioxide, chlorine gas, sulfur dioxide, and hydrogen sulfide. Another module measures ambient light, room temperature, humidity, and barometric pressure.

"Using a common platform for multiple sensor modules, you save a lot of money through economies of scale," Yu says.

The product line went on the market in 2012, and by summer of 2014, it was already in its second generation,

The NODE Chroma color sensors let the user upload a custom color set and reference colors against a library of hues.

NODE+, which Yu says is faster, uses less power, is more durable, has more memory, and is compatible with Android devices as well as Apple smart devices.

Benefits

Yu says the sensors have found extensive use in the areas of supply-chain management, transport, and logistics.

An early adapter of the technology was the pharmaceutical industry. "Their packages are extremely high-value, and the cost of shipping penicillin across the country is so high that this type of sensing device is of huge value for them," Yu says, noting that a sensor embedded in a package can record temperatures and vibrations and then report that information to a smartphone.

A company that deals with paints or other color-specific products can use one of the Chroma sensors for quality control, just as one that deals with food can use the infrared thermometer or thermocouple probe for temperature assurance.

"As we started deploying this product, we got a huge amount of feedback from our customers," Yu says, adding that the response resulted in, among other developments, the suggested pairings of sensors on the company's Web site. Since each NODE can house two sensors, someone doing temperature control, for example, can take a temperature reading and then flip the device around to scan a product barcode that would show which product the reading applies to.

All the data can be automatically recorded on the accompanying smart device, saving time and cutting down on user error.

"Variable is also a solutions partner for the 'Internet of things,'" says Alex Lavidge, the company's vice president of business development and marketing. "We use NODE+ as a platform to gather market intelligence

from our clients and innovation partners. From these studies, we determine how we can integrate mobile sensor features in the future that add the most value for targeted segments in both the private and public sectors." Lavidge says a lot of these trials are currently centered around integrating sensors with wearable technology like smart safety goggles, as well as other sensor hardware concepts that can be integrated with big data analytics platforms to help end-users make "smarter decisions faster."

To solicit further input, in the summer of 2014, Variable held its international Hackanode challenge, offering a total of $16,500 in prizes in various categories to developers who build or integrate existing sensor functions with the NODE+ platform using their own apps. Among the 10 judges were Apple cofounder Steve Wozniak and Tom Suder, president of the mobile Government technology organization Mobilegov.

Even before the contest, independent developers had created numerous apps for the platform.

It has also received widespread attention within the computer and technology industries. *CNN Money* magazine called NODE the coolest gizmo found at the Consumer Electronics Show 2013, and the company was named Most Innovative Startup at that year's Southland technology and entrepreneur conference. NODE was a finalist in the Spark Awards' 2013 International Design Competition, the Made in the USA category of Walmart's 2013 Get on the Shelf competition, and the Tech for a Better World category at the 2014 Consumer Electronics Show.

Variable now has 25 employees, about a third of whom are manufacturers. The devices are built right in Chattanooga.

Yu says the company is now working to incorporate the sort of nanotube sensor technology he integrated with iPhones during his work with Li.

Li says she, too, hopes to develop her sensors to the point that the price can be brought down enough to make them viable consumer products.

"Hopefully we can continue this work, because this technology can be used for many application areas, like industrial, environmental, and in space," she says. ❖

NODE's Therma modules detect temperature at a distance and have proven popular in the food service, auto repair, manufacturing, and home inspection industries.

Precision Coffeemaker Adapts Brews to Beans, Taste

NASA Technology

Technology often takes circuitous paths. A magnetron developed for precision bombing during World War II led to the microwave oven, and a battery-powered drill created for collecting samples of Moon rock gave birth to the Dustbuster. Likewise, one student's NASA experience with cutting-edge, autonomous robotic vehicles has informed the creation of one of the world's most sophisticated coffee machines.

In 2006, Matt Walliser, now chief engineer at San Francisco-based Blossom Coffee Inc., took on an internship at the Carnegie Mellon Innovations Laboratory at NASA Research Park, part of Ames Research Center. He was a high school student at the time but continued his summer work at the lab and at Ames' Exploration Aerial Vehicles (EAV) Laboratory for the following three summers while working toward his mechanical engineering degree at California State Polytechnic University, Pomona.

The Blossom One Brewer draws heavily on Blossom Chief Engineer Matt Walliser's four summer internships at NASA's Ames Research Center, where he learned to work with the kinds of technology that enable the coffeemaker to hold brew temperatures steady and synchronize brewing with recipes stored in the cloud.

"I was mostly doing hardware support for a couple of robotics projects and a little electrical design work associated with that," Walliser says. He worked with the MAX 5A Unmanned Ground Vehicles and the EAVs, all test platforms for intelligent, autonomous robotic systems.

"Matt was unusually gifted at robotics, especially fast prototyping," says Corey Ippolito, flight data systems engineer at Ames, who ran both labs during Walliser's time there. "He designed mechanical structures, designed solid models in [computer-aided design], and would take these designs to a local machine shop and fabricate them. He was very good at embedded software development."

Since 2002, NASA has been collaborating through its research park with academic institutions, as well as nonprofit organizations and commercial companies, and Ippolito says working with students helps to keep NASA engineers tuned in to the latest research. "It's always good to have the students bringing ideas and to have us working with universities." The EAV Lab focuses on testing experimental autonomous control technologies on custom-made, scaled-down vehicles such as the EAV line and the MAX 5 rovers.

Technology Transfer

It was his work on one such class of control systems—proportional-integral-derivative (PID) controllers—that laid the foundation for the key component in Blossom's coffeemakers, Walliser says.

Ippolito describes PID control as a classical control technique that continually monitors and corrects the output of a controlled system through error feedback. The technology is common on rockets, missiles, and other aircraft, he says.

"It's used pretty heavily in industrial robotics and any kind of precision system," says Walliser, noting that he was introduced to PID systems on the MAX 5, where, for example, they keep the rover moving at a constant speed even as it traverses rough, uneven terrain. In Blossom's coffeemakers, the technology is used to hold temperatures constant in both the water boiler and brew group.

The Ames laboratories also provided Walliser with his introduction to embedded communications, the frameworks that allow different components within the same device to communicate with each other, chip to chip. Ippolito says the technology is common in the EAV Lab's systems.

"It was my first exposure to that kind of intersection between electrical systems and software," Walliser says. "Certainly, what I did at NASA exposed me to a lot of these concepts of embedded development I used for Blossom." In the coffeemakers, which are Wi-Fi-enabled, embedded communications are used to synchronize brewing processes with recipes stored in the cloud. Walliser also used this knowledge base to write his own stripped-down operating system for the machines, one that he says is faster and more reliable than Android.

"At NASA I did a lot of repairing and debugging of other people's work," he adds, noting that troubleshooting electrical systems is also fundamental to his current work.

The internships at Ames were not NASA's first influence on Walliser's career, though. In high school, he participated in the NASA-sponsored Botball Educational Robotics Program. "I already knew I would go into engineering, but Botball really let me challenge myself to learn new things," he says, adding that this was where he learned C programming language and developed core engineering skills.

The Blossom One Brewer is Wi-Fi enabled, and brewing processes can be synchronized with recipes stored in the cloud.

Benefits

Blossom Coffee was formed in 2011, after now-president Jeremy Kuempel approached Walliser with the idea for a high-end, precision coffeemaker. "It seemed interesting, it played to my strengths, and it hadn't really been done before," Walliser says.

The main problem to solve was temperature control. Coffee made from the same beans can taste significantly different when brewed at different temperatures, Walliser says. "Most coffee machines will control the temperature within 5 to 10 degrees, but the average coffee drinker can tell the difference between coffees brewed as little as 2 degrees apart."

Blossom's machine, called the Blossom One Brewer, controls the average temperature to within one degree. It also keeps all the coffee grinds within 10 degrees of each other, regardless of their place within the brewing basket, a temperature gradient significantly narrower than in most coffeemakers, and it automatically corrects heating and fluid delivery for altitude, barometric pressure, and ambient temperature. All this is accomplished using the PID control-loop technology Walliser learned at Ames.

Tight temperature controls allow the user to consistently produce the same brew. They also let the machines change temperature from one cup to the next within a few seconds. Recipes for different beans can be shared and downloaded via Internet and implemented more or less automatically.

Walliser calls the coffeemakers "semiautomatic," noting that, while they control temperature and extraction time, the grind and the stirring time are in the hands of the barista, making the brewing process flexible. "It's still a craft product, and you still need training to use it, but it takes over the things that are difficult to control by hand," he says.

The first prototype Blossom Limited machines went on sale in 2013 for $11,111. By early 2015, the company had set up production in Japan and was offering the Blossom One for about half the price of the prototype. The current product is a single-cup brewer marketed to cafés and coffee shops, but Walliser says the company hopes to offer a home version in the future.

Ippolito says Walliser isn't the first intern who's gone on to apply skills learned at Ames to entrepreneurial efforts. "I'm seeing this more and more often lately," he notes.

Walliser credits the freedom interns have while working in the NASA labs. "Being able to do engineering in a self-directed manner isn't an experience you usually get in high school, or even college," he says. "Having that kind of real-world experience really allowed me to excel in school and build the skills I have today." ❖

CO_2 Recovery System Saves Brewers Money, Puts Bubbles into Beer

NASA Technology

Building on work he and his companies did with Johnson Space Center's In Situ Resource Utilization (ISRU) team, Robert Zubrin has developed and commercialized technologies that could prove revolutionary in their Earth applications, such as a system that could extract millions of barrels of oil from defunct oil wells around the world and another that can harness all the natural gas currently burned off as waste at many oil drilling rigs (*Spinoff* 2015).

But when he's not working to change this world or colonize others, the president of Pioneer Astronautics, Pioneer Energy, and the Mars Society enjoys a good microbrew. Now, he's applied some of that same technology to cut costs for craft breweries that produce anywhere between 3,000 and 300,000 barrels per year.

Beginning in the mid-1990s, as a NASA contractor and then as founder of Pioneer Aeronautics, Zubrin worked with Johnson's ISRU team to develop technology that could break down elements that are abundant on Mars and turn them into essential resources for exploration missions. Early work devised means to capture the carbon dioxide (CO_2) that comprises more than 95 percent of the thin Martian atmosphere and turn it into oxygen and fuel. He built systems that could, for example, collect and separate CO_2 from other gases, raise its pressure by two orders of magnitude, combine it with hydrogen to make methane and water, break the water down into oxygen and hydrogen, and remove water vapor from the resulting oxygen before it was stored.

Some of this technology, such as systems that manipulate temperature and pressure to liquefy and store gases or to strip water from a gas, as well as the technology that allows such systems to run autonomously, has found its way into Lakewood, Colorado-based Pioneer Energy's latest creation, the CO_2 Craft Brewery Recovery System.

Image courtesy of Quinn Dombrowski, CC BY-SA 4.0

While major breweries have long had systems to capture the carbon dioxide generated during fermentation for reuse in carbonation and other functions, the technology has not been available on a smaller scale, forcing the more experimental microbreweries to buy carbon dioxide. This is the niche Pioneer Energy aims to fill.

Technology Transfer

"When you ferment beer, the process that produces alcohol also produces carbon dioxide," Zubrin explains, noting that CO_2 is also necessary later, to carbonate the beverage.

Major breweries typically have systems that capture the carbon dioxide produced during fermentation for use in carbonation and other functions, such as purging process tanks. These are high-capacity, multimillion-dollar systems, however, and don't make sense for a small craft brewery. "They don't have the capacity to liquefy the carbon dioxide that comes off their fermenters to put it into the beer," Zubrin says. Instead, microbreweries are left to release the gas from fermentation and buy carbon dioxide from an outside vendor.

Pioneer's CO_2 recovery system fills that gap. "We made a system that would produce about five tons of carbon dioxide per month," Zubrin says, adding that this is enough for a brewery that generates up to about 60,000 barrels per year, and units can essentially be stacked to increase that capacity. "Two of my key engineers, Andy Young and Matt Lewis, saw the need, and together with the rest of the team, created a flexible system that works like a charm."

"We've taken our general technology acumen, which we developed under NASA, and applied it here," Zubrin says. "If you want to get CO_2 from the Martian atmosphere, you want to compress it, and you want to liquefy it." With some modifications, the same technology can put the bubbles into beer.

On Mars, carbon dioxide would more likely be frozen, at least initially, rather than liquefied, says Gerald Sanders, chief ISRU engineer at Johnson. But the products made from it would be stored as liquids. "The types of technologies Bob is talking about to liquefy carbon dioxide are similar to technologies we would use to liquefy and store any oxygen or methane we produced

on Mars," he says. "It's a similar process. It requires things like mechanical compressors and cryocoolers."

Liquid CO_2 could also come in handy on the Red Planet, as some NASA researchers are looking into the possibility of using it for washing clothes during a Mars mission, Sanders says. "What Bob has done could fall into that realm if we decide to go that route."

Another commonality is the use of devices like desiccant beds, which Sanders says would be used on Mars to remove any remaining water molecules from final products before storing them. "Before you liquefy oxygen or methane, you have to strip water out of it."

"The fermenters in breweries have water in them, and you've got to keep it out of the carbon dioxide, or it will freeze in the lines and block them," says Zubrin, noting that this is where desiccant beds enter into Pioneer's CO_2 recovery system.

"None of this is really new physics, although we do use our own blend of refrigerants, which is new," he continues.

Any system for mixing and matching molecules on Mars would also have to be fully automated using techniques Zubrin worked out during his years of ISRU work. "Typically, for the missions to Mars we've been considering, we would send the return vehicle 26 months before the crew even leaves," Sanders says, noting that systems on the vehicle would produce resources for both the mission and the journey home before the astronauts arrive. And they couldn't even be controlled remotely in real time, as there is a communication delay of around 4 to 24 minutes each way, depending how far apart Mars and Earth are at the time.

In the case of a brewery CO_2 recovery system, while the device may save a couple thousand dollars a month, it wouldn't be economical to hire an employee to run it, Zubrin says. "On a smaller scale, this thing's got to be totally automated, too. The robotic control you would need for a system on Mars is key to this."

Pioneer Energy's CO_2 Craft Brewery Recovery System can recapture about five tons of carbon dioxide per month, enough for a brewery that generates up to about 60,000 barrels per year, and units can be stacked to increase that capacity.

"Even if it's not 100 percent something we would use on Mars directly, there's a lot of synergy between what he's done in the past and what he's doing here," Sanders says.

Benefits

Carbon dioxide typically runs about $200 to $300 a ton, although costs can be much higher depending on the distance from a source, Zubrin says, noting that, while the price is currently around $300 in Denver, breweries in Durango 300 miles away are paying $600 a ton. A typical brewery producing 60,000 barrels a year and paying $300 a ton for CO_2 would save around $15,000 a year by using Pioneer's recovery system, he says. The units are priced to pay for themselves within two years or so.

Quality is another advantage the system offers. The carbon dioxide brewers buy is typically a byproduct from ammonia and urea plants and may not be entirely pure, Zubrin says. "Here, you're getting it pure from the fermenter, so it's high-quality CO_2, without even the slightest trace of industrial contaminants. We have tested it, and it is free from air contamination as well."

And, of course, the technology allows reuse of a greenhouse gas that would otherwise be released into the atmosphere.

By June 2015, the company had taken at least a dozen orders, and the system went into production late last year. Pioneer also has a unit that it brings around the country for demonstrations. Zubrin says the technology has already received a lot of interest. He notes that microbreweries have proliferated over the last decade, a trend that continues today. "Within the United States, there are several thousand breweries that would be targets for this, and probably 20,000 worldwide."

He credits his NASA work with the money and greenhouse gas emissions he plans to save breweries around the world.

"The intellectual capital being developed in NASA's research and development programs is playing out across the economy, and this is just a small example," Zubrin says. "The intellectual capital is the big spinoff." ❖

Space Blanket-Inspired Cases Protect Expensive Devices

NASA Technology

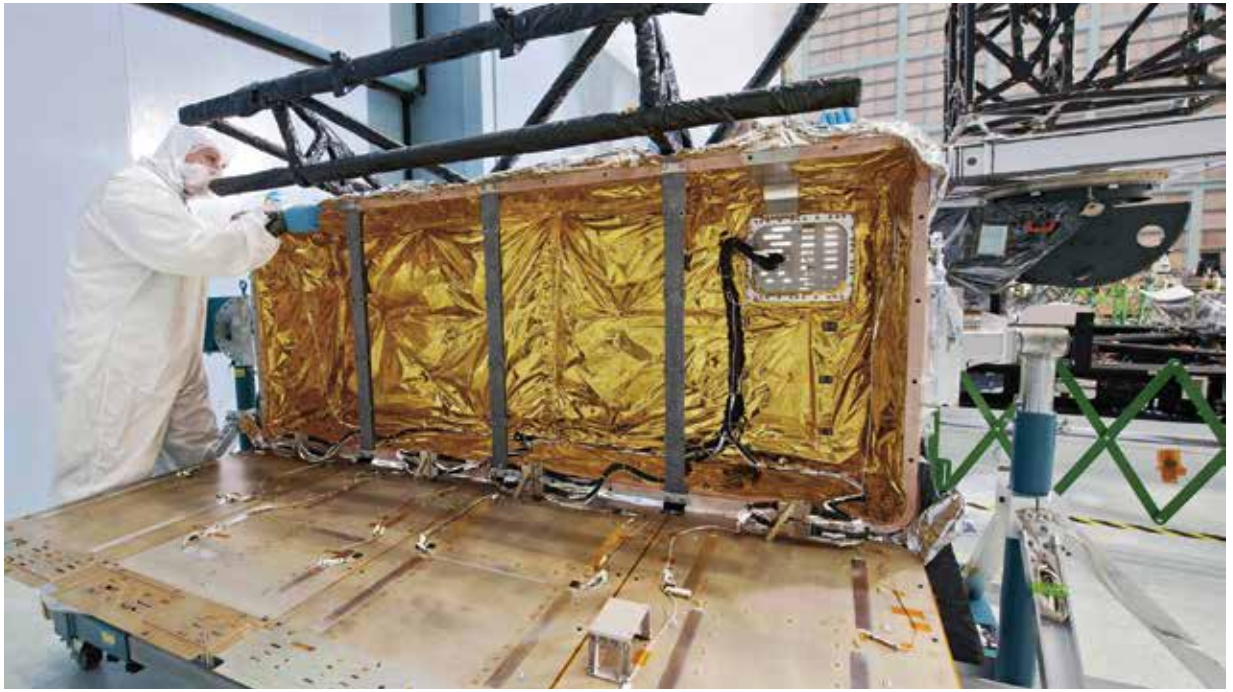
Nick Blanton spends a lot of time outdoors, skiing in the winter months and hiking when the weather's warm. All of this takes a toll on his electronic gadgets, which are sensitive to temperature fluctuations and can be damaged after exposure to extreme hot or cold conditions for long periods of time.

With a little luck and some elbow grease, coupled with Eagle Scout ingenuity and the assistance of a NASA-developed material, Blanton has created a line of cases designed to protect iPads and iPhones from the heat of Death Valley, California, and the frigid cold of a ski slope in the Rockies.

In the 1960s, NASA was preparing for early forays into space and worked to devise thin, reflective, metallic material to protect spacecraft from the dangers of solar radiation. This material, metallized polyethylene terephthalate (MPET), is strong and not only reflects radiation but also serves as powerful insulation to protect electronics from large swings in temperature.

NASA's use of MPET has included nearly every mission to and beyond Earth orbit. The importance of its function was especially apparent when, in the mid-1970s, Skylab's heat shield was found to have been damaged during launch, resulting in internal temperatures reaching 130 °F. The material is also still used in astronauts' spacesuits to protect them from the radiation and heat of the sun while on spacewalks.

The flexible, highly efficient, and plastic material had already been back to Earth as a main component of the lightweight "space" blankets used by runners to maintain their body temperature after finishing a race, among the others uses (*Spinoff* 2006).



A scientist at Goddard Space Flight Center examines the thermal blanket that will protect the Integrated Science Instrument Model's Electronics Compartment of the new James Webb Space Telescope.

Technology Transfer

As a child, Blanton grew up curious about and in awe of space and NASA's exploration work. When he was a Boy Scout, his camping packs always had a few thermal blankets made from MPET.

"I've carried around space blankets with me, particularly during survival situations, since I was a kid," Blanton says, citing two-week backpacking trips at the Philmont Scout Ranch in Cimarron, New Mexico. "We learned how to use it to redirect heat from a fire pit around an emergency shelter made of space blankets and plastic draped over a log, and also how to use it to reflect the heat of the New Mexico sun away from us for cooling."

As he grew up, the blankets came in handy following cross country meets, and "after seeing the dramatic effect this thin material had at filling the shelter up with heat and the cooling effect it could have, I guess it stuck with me," he says.

Blanton was snowboarding and using his iPhone one particularly cold day when, to his surprise, his phone froze. He wondered whether someone had already made a protective case for such electronics, which are sensitive to temperatures due to liquid crystals enclosed in them, but was unable to find anything that met his expectations on the market.

A few months later, he was outside on a hot day when his iPhone displayed a temperature warning alert, which got him thinking. "I had the 'aha' moment and thought a thermal shield like a space blanket could help in this situation," he recalls. He contacted an inventor friend about his ideas, and together they brainstormed what kinds of materials might best protect the increasing array of gadgets vulnerable to heat and cold. They purchased

> Who better to go to than NASA?"
>
> — Nick Blanton, Salt Cases

some sample materials and began working on cases that would shield electronics from temperatures in excess of 95 °F or below 32 °F, conditions in which batteries also become compromised and can decrease usability.

Among the materials he considered were thermoelectric Peltier devices, a solid-state heat pump that transfers heat from one side of a device to another electronically, in addition to phase-change materials and flexible insulation aerogels, but nothing was quite right until he tried the blankets from his camping trips.

After sewing up some initial prototypes using a variety of materials and sending them off to friends in various parts of the United States for testing, the best results came from the cases made using MPET. "I decided to go with the space blanket technology after getting one and cutting it up and putting my phone inside and testing it on the dashboard of a car or while going out hiking and snowboarding," he says.

The cases are designed with three layers to protect phones and tablets. The first layer redirects the thermal radiation, reflecting it away from the device in the summer and holding in heat during the winter. The second and third layers provide additional insulation to limit the conduction and convection of heat. A micro-suede fabric lines the interior of the case to prevent the screen from scratching.

Benefits

Protecting iPhones, iPads, and MacBooks means a user is less likely to have to replace a product due to electrical malfunctions during an epic run on the slopes or when a device is left sitting on a car seat during a long, hot day, Blanton says.

His company, Salt Cases, based in Portland, Maine, started a Kickstarter fund in late 2014, raising more than $28,000 for an initial production run. "We're doing great," he says. "We're selling lots of cases. We've been written up in CNN, Business Insider, and we're getting lots of traffic and lots of sales. We're doing even better than we expected."

The cases have been certified by the Space Foundation as well, Blanton says. The company's profile on the Space Foundation's Web site notes that, during field testing, an iPhone was left in a car that reached 126 °F after just 10 minutes, which put the device at risk for permanent damage. When the protective shield was attached to the back of the iPhone, heat was reflected away and the temperature quickly dropped to 90 °F.

Thanks to the popularity of Apple products—a line of cases for Samsung products is in development—orders for the cases are coming in from around the world. "It gets cold in a lot of places but it gets really hot more often," he says. "We've had some people contact us from Dubai and other locations in the Middle East where everyone, it seems, has iPhones. They need a case because it gets to 120 °F there during the day and drops down to being really cold at night."

He's getting some interesting emails from customers in the United States as well, including one from a person who volunteered, when placing an order, that he eats his lunch in a freezer. Blanton says his target audience, initially, was young adults who spend a lot of time outdoors, "the more extreme-sports type of people. The unforeseen market ended up being Government workers who have to leave their phones in their cars during the day for security reasons. That hadn't even occurred to me."

Blanton says he's happy to have NASA technology protecting his devices after protecting him from the elements as a scout. "Who better to go to than NASA? They clearly have to put a lot into everything they do. They're going to know the most about thermal capacities." ❖

Inspired by his adventures as a Boy Scout and fascination with NASA, the founder of Salt Cases based his protective cases for electronics on heat sheet technology developed by the Agency to protect astronauts and spacecraft.

Antimicrobial Agent Updates Ancient Industry of Prayer Mats

NASA Technology

Although it is one of the most abundant organic compounds on Earth, chitin is not among the best understood. For example, chitosan, a derivative of chitin, has been used in agriculture since the 1980s and is credited with boosting plant immunity, increasing resistance to insects and fungi, stimulating nutrient uptake and germination, reducing fruit and vegetable decay, and protecting against freezing. In humans, it has been said to battle obesity and high cholesterol, increase immunity, prevent cavities, and speed blood coagulation.

Not all these benefits have been proven, but NASA, particularly interested in the potential for hardier crops and augmented human immunity, has investigated chitosan and demonstrated at least a couple of its benefits.

A nitrogen-containing polysaccharide, chitin is the primary ingredient in the exoskeletons of arthropods, such as insects, spiders, and crustaceans, and possibly doubles as a first line of defense in these organisms' immune systems. Its molecules carry a positive charge that attracts the negatively charged membranes of bacteria, trapping and possibly killing them, and also initiates red blood cell clotting.

In 1997, NASA researchers aboard the Mir Space Station and the Space Shuttle used chitosan to protect adzuki bean plants and found the treated plants yielded more biomass and showed greater resistance to pathogens than the control group. With an eye toward long-term, deep-space exploration, the Agency has had an interest in space farming since its inception. Aboard a spacecraft, plants not only provide food but, as they do on Earth, also filter carbon dioxide from the air, replacing it with oxygen, and they can process and eliminate waste by feeding on it.

The researchers found that chitosan increased levels of beta-1, 3 glucanase enzymes in their bean plants' cells, making them more resistant to fungal pathogens, and they determined the substance would have the same effect on Earth.

Ten years later, Johnson Space Center, in collaboration with the Department of Defense, undertook an experiment on NASA's Cell Culture Module aboard the International Space Station (ISS) to determine chitosan's effects on human immunity.

Previous studies had shown many bacteria become more virulent in microgravity, where it is easier for some types to spread out and minimize competition for resources, and where they can more easily form hardy biofilms. Some even express their genes differently and become more infectious. Meanwhile, for reasons not completely understood, the human immune system is weakened during spaceflight. NASA's interest in boosting it was clear.

Results of the 2007 study on the ISS were also unambiguous. Human white blood cells—the warriors of the

Incorporating a NASA-inspired antimicrobial layer, among other features, the TIMEZ5 Prayer and Meditation Mat is the first significant upgrade to the ancient industry of prayer mats.

immune system—injected with both an endotoxin and chitosan-arginine survived the trip and made it back to Earth, while those injected only with the endotoxin were wiped out.

Technology Transfer

The ISS experiment on white blood cells took place right about the time Nader Sabry and his crew began research that would result in the first significant update to an ancient industry—prayer mats.

"We did a lot of research into antimicrobial agents and discovered this technology NASA had tested and proven well enough that we decided to look into it," says Sabry, now the founder and CEO of TIMEZ5 Global Inc., self-proclaimed purveyor of the world's first physiological prayer mat.

The company brought on Lloyd Starks, now president of Chemco Technologies, as a consultant. In the course of several unrelated partnerships with NASA, Starks had learned of the Agency's two chitosan studies and seen the report on the ISS work, published by NASA in 2009. He was already working with the Centers for Disease Control (CDC) to use the substance to develop the world's first antimicrobial film. While chitosan had been used in medicine as a blood coagulant for decades, Starks says, the NASA studies were the first he knew of that demonstrated its effectiveness as an antimicrobial agent.

"NASA identified, tested, and documented it as an antimicrobial, and I took it from there," he says. In his work with the CDC, he developed a method for using the steam of a chitosan solution to sterilize a surface and form a film that prevents microbes from returning. This technique was used to apply the substance to TIMEZ5's prayer mats.

The final product, the TIMEZ5 Prayer and Meditation Mat, became available in 2012. The mat has five distinct layers, with chitosan applied to the lowest. Micro-holes that run through the mat let traces of the substance pass through to the surface, keeping all the layers microbe-free, Sabry says. "When you put pressure on it, it will push air through those holes from the bottom upward."

In the middle of the mat is a thin transfer grid of tiny cones that manage the weight ratio between a weight-absorption layer above and a weight-bearing layer below, both of which are made of a viscoelastic gel foam. The top layer is a microfiber designed to give the surface a soft, pleasant feel, and on the bottom is a micro-grip surface. "Quite a few people have injuries while meditating because their mats move," Sabry notes.

The surface design, created with the help of a psychologist, is as unorthodox as the rest of the mat, eschewing traditional darker colors and opting instead for tones that better convey "purity and clarity," Sabry says.

The TIMEZ5 Prayer and Meditation Mat includes layers for weight distribution, comfort, and safety, as well as an antimicrobial layer informed by NASA's research on chitosan, a derivative of the primary ingredient in the exoskeletons of arthropods, such as insects, spiders, and crustaceans.

Benefits

In researching its product, the company found that minor respiratory problems are not uncommon among users of prayer mats, a result of dust and tiny organisms that accumulate in them, aided by heat and humidity. Also, Muslims wash before prayer, which can add moisture that fuels the growth of organisms, Sabry says. "Usually these fabrics would collect dust and mold, they would have bacteria and other microbes that collect over time," he says, adding that he even saw cases of foot fungus possibly contracted from prayer mats.

He says the company settled on chitosan to address these problems after testing showed the substance was able to kill more than 99 percent of the bacteria, fungi, and mold it encountered. The researchers were also impressed by its longevity. "Obviously, it doesn't last forever, but it works a lot longer than other solutions we looked at," he says.

Due to the NASA-inspired addition to the design, the TIMEZ5 mat became the first Muslim-oriented product to be recognized by the Space Foundation, which certifies consumer products as having origins in space technology.

While Muslims in the area of the Persian Gulf are the largest segment of the company's market, TIMEZ5 has customers of all faiths in 35 countries, from Russia to the Americas and especially East Asia, Sabry says. "Our key markets are what we call floor-bound cultures—those who go to the floor to meditate."

Thanks to its product's antimicrobial and ergonomic properties, he says, the company has claimed a slice of that industry in the three years or so since its debut and is now selling thousands of mats each month.

TIMEZ5 employs about 125 people in production and about 20 more in operations and research and development. While its headquarters is in Calgary, Alberta, and its international distribution center is in Dubai, the company is working to develop a presence in the United States as well, Sabry says.

He says he's pleased to have introduced NASA-tested technology to the Middle Eastern culture that produced the first written observations of space. "We used space technology to disrupt an industry that hasn't innovated in 1,400 years." ❖

Heat-Reflecting Material Regulates Body Temperature

NASA Technology

From its beginnings, the U.S. X-Plane Program has delivered big on its objective: to advance aviation science and technology through the use of experimental aircraft. On October 14, 1947, Chuck Yeager flew into the history books as the first person to break the sound barrier when he piloted the program's first test plane, the Bell X-1.

Fast-forward several decades, and past a multitude of other accomplishments, to the 1990s, and NASA was now looking into the feasibility of using rocket planes to reduce the cost of launching payloads into orbit. As a result, two experimental, unmanned aircraft were slated for development. Lockheed Martin's X-33 was to be a single-stage-to-orbit, reusable launch vehicle that could reach speeds greater than Mach 13 and climb 60 miles above Earth; Orbital Sciences' X-34 would also be a reusable launch vehicle—although it would be launched in mid-air while attached to another airplane—and capable of reaching a similar altitude.

But as with any spacecraft destined for return to Earth, their hulls would need to withstand scorching temperatures during reentry into the atmosphere, caused by intense friction with the air due to their speedy descent. NASA Ames Research Center scientists supplied the solution by inventing Protective Ceramic Coating Material (PCCM), which can be applied as a light, paper-thin coating on virtually any surface. The keys to the technology's success are the high-emissivity, or heat-radiating agents contained in the mixture that decrease the amount of heat traveling to the underlying material. In addition, PCCM is resistant to mechanical damage and abrasion. Being that it's water-based and doesn't contain solvents, it's also environmentally friendly.

Orbital Sciences' modified L-1011 takes off with the NASA-funded X-34 Advanced Technology Demonstrator under its belly for the first captive-carry flight on June 29, 1999. Designed to launch from mid-air, the X-34 program was initiated by the Space Agency to test low-cost, reusable launch systems for putting payloads into space. Scientists at Ames Research Center developed Protective Ceramic Coating Material, or PCCM, to protect the spacecraft from the scorching heat of reentry into Earth's atmosphere.

Technology Transfer

Although funding for the X-33 and X-34 ended in 2001, Blacksburg, Virginia-based Emisshield (then Wessex Incorporated) had seen potential in PCCM and obtained a partial-use license for the technology from Ames in 1996, followed by an exclusive license in 2001 (*Spinoff* 2001, 2004, 2011). With help from the Center for Adhesion and Sealant Sciences at Virginia Polytechnic Institute and State University (Virginia Tech), the coating's shelf life was increased, and it was optimized for metal and adapted for use with a spray gun. The technology has since been incorporated into more than 20 products. "It will work just about anywhere there is heat—from electricity to manufacturing glass and plastic bottles," said Emisshield CEO John Olver in 2011.

Among its most popular uses is coating substrates in combustion processes such as hydrocarbon and chemical processing, resulting in energy savings, increased productivity, and less maintenance. Power generators such as

biomass boilers, natural gas boilers, and steam generators reap the same benefits in addition to reduced air pollution. Furnaces that manufacture glass products also run more efficiently because of the heat savings. PCCM is even applied to commercial ovens for better heat distribution, improving the quality of baked breads.

More recently, the NASA invention has made its way into yet other markets. In 2014, Mooresville, North Carolina-based Trizar Technology licensed the PCCM innovation from Emisshield and is adapting the temperature-regulating technology for use in clothing and furniture.

Benefits

Brad Poorman, Trizar's CEO, explains a simple truth about people's general preferences during the hot and cold seasons. "In the summer, you want to reflect the sun away so you stay cooler, and in winter you want to absorb the heat that your body's producing and maintain it so you stay warmer longer." He says he's using PCCM to accomplish just that.

To understand how the technology works in hot weather, Poorman says to consider suntan lotion, which uses similar materials as PCCMs to reflect the ultraviolet (UV) light away from the skin, preventing burn. "But UVA and UVB light rays are very different from heat, so our coating, which goes on the outside of the fabric, addresses all those wavelengths by using different sizes and types of materials so that you can get a higher-UPF [Ultraviolet Protection Factor] fabric and also deflect heat, which keeps the temperature of your clothes lower."

For cold-weather garments, the coating is applied to the inside lining, where it will deflect outgoing heat, sending it back toward the body. It's in thermal attire that the company is making its first impact. Wyoming-based rainwear and winter adventure apparel company Cloudveil and the European Penguin brand have incorporated the technology into their clothing lines. South Korean firm Kolon Sport is also using PCCMs for its down jackets. "Both the down and our technology help you to keep your own body warmth, so there's two types of protection at work," Poorman says, adding that 300,000 jackets are slated for production in 2015.

Since its development, PCCM has been incorporated into many products that require heat management. For the technology's latest incarnation, Trizar Technology is working with clothing companies to develop apparel that keeps people comfortable in hot and cold weather. This ski jacket, made by Wyoming-based outerwear company Cloudveil, is lined with PCCM in order to retain body heat that might otherwise escape into the air.

> "Approaching companies with a product made and used by NASA gets you so much further, faster, because of the credibility."
>
> — Brad Poorman, Trizar Technology

For its latest venture, Trizar is also working with companies to apply the technology to patio furniture. Poorman says we've all experienced it: sitting on an outdoor bench or chair so hot it burns. The same goes for children's car seats. Tests have shown that when a coat of PCCM is applied to an object's surface, it will remain at the ambient temperature, he says. "If it's 90 degrees out, your furniture stays at 90 degrees, versus 140 degrees if you don't have the coating."

No matter where the technology is headed next, a source of pride for Poorman is that the PCCM concentrate, as well as the PCCM-woven fibers and yarns the company is currently developing, is made in the United States. "Normally, in textiles a lot of the manufacturing is done in the Far East, but by making it here we can control the intellectual property," he notes. "It pays for it to be made in the USA."

The fact that it's NASA technology is also paying off. "Approaching companies with a product made and used by NASA gets you so much further, faster, because of the credibility," Poorman says. "It beats walking in the door with another technology and saying, 'Trust me.' They've heard of the Agency, and they just get it." ❖

Modified Monitor Provides Glasses-Free 3D for Pilots, Gamers

NASA Technology

When flying the increasingly crowded skies, pilots need to have an arsenal of information at the ready: altitude, airspeed, fuel level, distance to their destination, the location of other planes in the sky. All of this information is presented in a series of two-dimensional instruments, panels and readouts, meaning the pilot has to mentally assemble the information and translate that into the three-dimensional world to better understand the relationship between air, ground, and traffic.

NASA has long been interested in making it as easy as possible for pilots and astronauts to have the best information available to ensure safe flights, knowing that humans are imperfect creatures.

Kyle Ellis is an aerospace research engineer in the Crew Systems and Aviation Operations Branch at Langley Research Center and spends a good deal of time analyzing pilot feedback to determine which tools and alarms best capture pilots' attention during flight.

"We'll look at their eye tracking and their brain activity to see what the state of the pilot currently is," he explains. "Let's say they haven't looked at the airspeed indicator in the last five minutes and the autothrottle has been disconnected and the plane starts bleeding off speed. The plane is always monitoring what's going on, but it also makes the assumption that the pilot knows what's going on as well."

Alarms and flashing lights are used to draw the pilots' attention to gauges to signal when something's amiss, but if it were possible to monitor what kind of alert worked best, new tools could be developed to further boost pilots' awareness of their conditions and better ensure safe travel. "We can do a traditional blink, like we do for a warning, or we can do a 3D blink, have it pop out of the screen at them," Ellis says.

Unfortunately, the ability to install a 3D monitor or other device in the flight deck has been limited. Fighter pilots have head-up displays that require the head be within in a certain space, also known as a head box. This is similar to what is traditionally required for 3D monitors and is easier for fighter pilots to maintain for the duration of their short flights because they're strapped into place and don't move around much, Ellis says. Commercial aviation pilots, however, who spend hours in their seats, move quite a bit more, and would often fall outside any head box into which a 3D image might be projected. The technical barrier of the limited head box has thus far made 3D displays non-viable in commercial operations.

NASA has been working with Dimension Technologies Inc. on the development of a 2D/3D switchable display that could be used to help pilots better understand their position relative to other planes in the sky. This NASA flight simulator, where the display will be tested before it becomes available for use in commercial airliners, shows how the displays might be positioned.

Technology Transfer

For years, NASA has been working with Rochester, New York-based Dimension Technologies Inc. (DTI) to develop a 3D monitor that would not only provide a vivid image (*Spinoff* 1995, 2002) but could track the pilot's eye movements, all without requiring glasses.

The ability to track and follow movement without losing resolution is DTI's latest advancement in this technology and could be key to helping pilots. "Pilots need to be immersed in what they're doing," Ellis says. In the earlier iterations of the monitor, there were limits to the technology that prevented a pilot from having the kind of full immersion needed when attempting to use 3D displays. "They had a wide field of view with multiple little head box areas, so while it gave you a good image, the depth of field wasn't as large."

Earlier iterations of the technology couldn't be considered for installation in airplanes because the images did not have the ability to move with the viewer, meaning pilots would have to stay perfectly still or risk losing a clear image.

Through a series of Small Business Innovation Research (SBIR) contracts, the most recent of which was awarded in early 2014, DTI has been working on monitors that can switch between 2D and 3D imaging. By modifying the backlighting system in any LCD monitor and incorporating a forward-facing camera, targeting the eyes of the person looking at the monitor, the display is able to follow the movement and position of the viewer in real time without compromising resolution or depth of field, explains DTI CEO Arnie Lagergren.

"Ideally, both the pilot and the copilot can see each other's monitors," he says. "They'll be able to see with real depth."

Benefits

A sample of the scenarios DTI has been testing is a loop of flight traffic data provided to the company, showing a swarm of red, yellow, and white airplanes massing along the Eastern Seaboard of the United States, with each color indicating whether a plane was landing, taking off, or in mid-flight. In standard display mode, the planes appear and blink off the map in real time.

"What you've got is an incredible beehive of data that doesn't serve the pilot too well, nor the copilot, in terms of quick, intuitive understanding of what they are facing," Lagergren says.

But switched into 3D mode, the clustered information is sorted and clarified. It's possible to determine whether one yellow plane is flying at a higher altitude than another, and whether two planes might be using the same runway at a busy airport.

The 3D capability without glasses, thanks to eye-tracking technology, should help NASA ensure pilots have all the information they need to navigate increasingly busy airports, which are already struggling with higher demand for runway space, Ellis says.

"Traffic densities are going up by three or four times, projected, in terms of air travel, in the next 20 years or so. That causes a lot of problems. How do we take four times the amount of aircraft we have now flying into Chicago-O'Hare, Boston-Logan or Reagan National in Washington, DC," he says. "You can't build another Reagan because DC's pretty densely populated. The only thing you can do is improve the efficiency of it."

DTI isn't only thinking about pilots with this glassless 3D technology.

Already the displays have been presented at two large digital visual arts conferences—Immersed in Toronto and SIGGRAPH in Vancouver—to rave reviews. At Immersed, DTI set up a console with the action role-playing game *Skyrim*, which features mountains, rivers, fields, and animals, including dragons and woolly mammoths. "We had these woolly mammoths walking over the terrain, up and down the mountain, into valleys, and it seemed like you could see forever," Lagergren says. "People were awed by it."

The successful demonstration earned the company an invite to several technology conferences to show off its monitors. DTI also took its displays to the NVIDIA GPU Technology Conference and Emerging Companies Summit, in 2015, which highlights applications that are breaking new ground and pushing the boundaries of visual computing.

Games built to be played or viewed in 3D rely on glasses, or players must remain in a "sweet spot" to get the full effect, but DTI has eliminated both those constraints, he says. "Now you can walk around and the monitor will track you and keep the 3D at your eyes. There's no loss of resolution or brightness, no restriction in head movement, and it works for two players."

DTI's latest display, sold commercially as the DTI Mission Critical 2D/3D monitor, has also been met with enthusiasm from 3D animators, including James Stewart. His award-winning stop-motion short film, *Foxed!*, is among the clips used by DTI when demonstrating the monitor.

Finally, there's been interest from car manufacturers as well, which could lead to 2D/3D displays as part of the center console, driver instrument cluster, and backseat entertainment packages.

"This thing is starting to take off," Lagergren says. "The market's ready to accept it." ❖

The 2D/3D display from Dimension Technologies could be used in space someday, providing better and more detailed information to help spacecraft dock on the ISS.

Energy and Environment

The agency responsible for powering interplanetary sojourns and gathering data on alien worlds naturally has a keen interest in developing technologies that also fuel operations on Earth and examine our own globe. In fact, Earth observation has been one of NASA's key functions since before it produced the first image of our home from space. The results benefit everyone from farmers to firefighters, while new energy solutions harness resources that might otherwise be wasted.

Flock of Nanosatellites Provides a Daily Picture of Earth

NASA put its PhoneSat 1.0 nanosatellite through a high-altitude balloon test, replete with a mock mission, to ensure its suitability both for launch and for operating in a space environment. Started in 2009, the PhoneSat project set out to prove that affordable, off-the-shelf commercial parts could be used to build satellites, which have traditionally come with very expensive price tags.

NASA Technology

Because of their expense, building and operating satellites has long been the purview of large companies and Government agencies. Having to manufacture unique electronic components that are hardened against radiation exposure and resistant to extreme temperature ratchets up their price tags, to say nothing of the astronomical fees associated with launching these often heavy objects into space.

Take NASA's advanced sun-monitoring satellite, the Solar Dynamics Observatory. Launched in 2010, it weighs 6,800 pounds and cost roughly $850 million to build and put into orbit. Even satellites built under NASA's Discovery Program, which supports the development of low-cost spacecraft, require budgets far beyond the affordability of smaller companies and educational institutions. One such satellite, the sun particle-collecting Genesis, although modest, still ran up a hefty $164 million in expenses.

In recent years, however, NASA has done much to advance a new generation of satellites that have less sticker shock but still perform valuable scientific work. In 2010, the Agency, in cooperation with the U.S. Department of Defense, successfully launched the Fast, Affordable, Science and Technology Satellite, or FASTSAT. Weighing in at just shy of 400 pounds and equipped with instruments to carry out six scientific experiments, the $10 million spacecraft proved it was possible, as its name suggests, to build a lower-cost and quick-to-assemble spacecraft.

But one former NASA Ames Research Center contractor was going to help make satellites much smaller—and a great deal less expensive yet.

Chris Boshuizen, an Australian physicist, made his way to the United States in 2007 by accepting a leadership position with Singularity University—a technology innovation school situated at Ames' Moffett Field. The following year, he accepted a job at Ames as a space mission architect, charged with, among other things, overseeing technical improvements to an Agency-funded lunar lander spacecraft known as the Hover Test Vehicle (HTV). Afterward, through a Space Act Agreement, Boshuizen worked on behalf of NASA to transfer HTV-related technologies to companies participating in the Google X Lunar Prize, whose grand prize of $30 million will be awarded to the team that can land a robot on the Moon, move it at least 500 meters, and have it send back high-definition video of its surroundings, all by the December 31, 2016 deadline.

That experience—working as a liaison between Government and industry—gave Boshuizen "a look under the hood" of the space industry, as he puts it. "Helping these teams crack their own problems gave me exposure to inefficiencies in the market, technological gaps, and even misconceptions that were holding people back," Boshuizen says—"things like fear, accepting the status quo, or just not believing in what could be done, or thinking space was harder than it was."

Pete Klupar served as NASA Ames' Director of Engineering during Boshuizen's tenure there. Klupar had this shtick, Boshuizen recalls, where he'd pull out a Government-issued BlackBerry from his pocket and tout how a smartphone has more capabilities than many satellites, as it has a bigger computer and better sensors. He'd follow up by asking why satellites are so much more expensive, then slip the phone back into his pocket and carry on.

One day, Bolshuizen took Klupar's words, and what he had learned from working on the lunar-based projects,

In February of 2014, Planet Labs Inc. released its first commercial constellation, or flock, of Dove nanosatellites into space. Shown are two shoebox-sized Doves being ejected into low-Earth orbit from the ISS. The company's goal is for these nanosatellites to take a high-resolution snapshot of Earth every 24 hours.

to heart. He, along with longtime collaborator Will Marshall, who also worked on several Moon-related missions for NASA, interjected. "We said, 'Pete, don't put that back in your pocket,'" Boshuizen recalls. "'We're going to make that into a satellite.'"

Led by the pair, a small team started with testing smartphones in cold vacuum chambers to determine whether they could withstand the frigid temperatures of low-Earth orbit. Next, to test their ruggedness, they attached a few of them onto sounding rockets that were carrying other science payloads. A hole was drilled into the side of the rocket so the smartphone's camera could snap photos; in addition, its built-in accelerometer would provide physics-related data. (Most smartphones have accelerometers to adjust the screen's orientation in response to how it's being held.) During the first test, the rocket split prematurely and hit the ground hard. Everything inside was completely destroyed, except the phone. "We were able to get the memory card out, and it had actually recorded data," Boshuizen says. "Maybe we got lucky, but what that really showed us was that smartphones are tough and they could work."

With its ruggedness demonstrated, it was on to the next step: testing a smartphone's functionality in an actual space-like environment. First, they needed to integrate the smartphone into a carrying satellite called a CubeSat. Roughly four inches on each side, weighing less than three pounds, and comprising off-the-shelf electronic parts, CubeSats, also called nanosatellites, were cheap to build, making them the perfect pairing for a smartphone. Apart from installing larger batteries and a radio beacon and writing some software for it, the phone was unaltered before being nestled into the tiny satellite. (On future spaceflights, however, smartphones would be taken apart and repackaged into CubeSats for maximum efficiency.) Afterward, they tethered the CubeSat onto a balloon and lifted it to an altitude of about 100,000 feet—the edge of space. From a ground station, the team was able to execute a mission. "After that, we knew we were good to go," Boshuizen says.

The moment finally arrived in April 2013, when three aptly named PhoneSats, which cost less than $7,000 in materials to build, were launched into space. Once in orbit, they took photos, stored them in data packets, and transmitted them back to the ground stations. Those data packets were then put together to produce a few hundred images of Earth. The project was a success, and under NASA's Small Spacecraft Technology Program, more PhoneSats have been launched, with each successive generation building on the capabilities of the last. In addition, the Agency has also introduced the CubeSat Initiative to support nanosatellite technology advancement, and the CubeSat Launch Initiative, which propels

educational institutions' nanosatellites into orbit by hitching them onto major mission launches.

Technology Transfer

That nanosatellites could carve out a niche in a historically big business- and government-dominated market wasn't lost on Boshuizen and Marshall. Together with Robbie Schingler, also a former research scientist at Ames, in 2011, not long after their balloon test with the CubeSat proved successful, the trio left their respective jobs at the Agency and founded their own Earth-imaging satellite company called Planet Labs Inc.

Working out of a garage in Cupertino, California, they made use of cheap, off-the-shelf commercial parts—a laptop battery for power and smartphone semiconductors for the electronics, for example—and continuously iterated on their satellite designs, tweaking and improving them as they went. It's a practice Boshuizen refers to as agile aerospace, a play off of a management method popular in Silicon Valley called agile project management, where software and hardware technology development is accomplished through incremental goals, making room for constant flexibility, collaboration, and feedback. "Instead of doing it the old-school Apollo way with a lot of system design and analysis and then building the thing at the end, we decided to do it the software way, which is building a minimum-viable prototype first just to show that we have a working model, then going on from there," he says.

Using agile aerospace, the three quickly developed the base prototype for what would become their Doves—nanosatellites tasked with snapping continuous three- to five-meter-resolution images of Earth, sharp enough to make out the canopy of a tree. Impressed by how quickly they were able to produce a viable product, venture capitalists started investing in them. The money allowed the company to hire engineers so they could mass-produce

Planet Labs' Dove nanosatellites captured this image of the Sabina wildfire in Riverside County, California, on July 23, 2014, just 10 minutes after it was reported. The photo reveals the fire's size, the path it had burned, the wind direction, and its exact location. Timely and accurate information is essential for wildfire teams in safely containing a blaze, the company says, explaining one of the technology's many uses.

Doves, improving them with every iteration until they were ready for flight.

That time came soon enough. In April 2013, Planet Labs, now based in San Francisco, successfully launched into orbit its first test satellites, Dove 1 and Dove 2, onboard Orbital Sciences' Antares rocket and the Russian Soyuz rocket, respectively, followed by another two testers brought up by the Russian Dnepr rocket that November. (Because of their light weight and small size, they can be launched as secondary payloads alongside much heavier and larger spacecraft.)

In February 2014, the company dispatched its first commercial "flock" when 28 Doves were released from the International Space Station; another 28 were placed into orbit that July. The goal was to have a constellation of over 130 fully operational Doves circling Earth, enabling the company to provide full coverage of the planet on a daily basis.

Another image captured by Planet Labs' Dove nanosatellites, this one on July 13, 2014, depicts agricultural lands abutting the Yellow River in Pingluo County, northern China. The company notes that a desertification control project is under way to preserve farmland in the area, and that progress can be monitored by examining the landscape as the imagery changes over time.

Benefits

A high-resolution snapshot of Earth every 24 hours will be a game-changer, Boshuizen says. "We're going to be gaining insight into the changing planet in a way no one's ever gotten before." And the company sees that insight benefiting a number of humanitarian, environmental, and commercial agendas.

The private sector is desirous of fast-refreshing snapshots of the globe for any number of reasons. Insurance companies can verify homeowner damage claims by examining before-and-after images of properties, and commodities traders can track agricultural crops to forecast yields. Oil and gas companies can monitor pipelines to ensure integrity and safety. Mobile-phone companies want fresher satellite imagery to improve their map applications on smartphones.

One of the company's core missions is to provide technology that adds environmental and humanitarian value, fostering positive change. With access to frequently updated images of the globe sharp enough to discern tree canopies, scientists and government agencies will be better equipped to handle a range of issues, from tracking natural disasters to improving farming practices and detecting overfishing. It would even be possible to stop unlawful deforestation.

"If you're able to plot tree logging in an area where no one is supposed to be logging trees, then you'd be able to do something about it," Boshuizen explains. "We have the vision of turning insight into action, and what that means is being able to see things and stop them before they become a problem."

The technology has already proven valuable for fire detection, he notes. In the summer of 2014, by using incoming satellite imagery, Planet Labs spotted a forest fire only 10 minutes after it had started. The team later learned that local television stations initially reported the fire's location erroneously by placing it in the wrong county. Boshuizen says, "In the future, we could provide a huge utility for the public by recognizing and accurately locating major events before anyone else. There's a huge potential to save lives."

Others have become believers. Buoyed by further investor support and positive feedback from a range of industry and academia, the company has grown to employ around 70 people while lining up millions of dollars in contracts for supplying imagery once the constellation is fully operational.

Boshuizen says he hopes Planet Labs, with its beginnings in a garage and a starting budget of less than $10,000, pushes others to dream big as well. "We need to keep going down this road of democratizing access to space and space technology. And we're in a time and place where we can make that happen." ❖

Multispectral Satellite Imagery Shows Farmers' Fields in New Light

NASA Technology

Lanny Faleide founded his Agri ImaGIS company, now called Satshot Inc., in 1994 on an idea that may have given offense to the day's tillers of the earth: the idea that farmers didn't really know their fields. Not, at least, in the intimate detail that a multispectral imaging satellite, having passed over their farmland hundreds of times, recording images in the visible and infrared spectra over the course of years, knew them.

His first difficulty, however, wasn't winning converts but gathering such imagery in sufficient quantities and, especially, distributing it. The Internet was in its infancy and lacked the capability to transmit or share such huge datasets. They had to be physically sent on floppy discs or other storage devices. With few high-definition satellites in orbit, Faleide used imagery from the French company Spot Image.

But he and his young, Fargo, North Dakota-based company found a solution to the problem of distributing data in the University of Minnesota's (UMN) Department of Forest Resources in 1999.

Five years earlier, a group of faculty and students there and in the university's Computer Science program had won funds from Goddard Space Flight Center through NASA's Public Access to Remote Sensing Data program to develop ForNet (short for "forest network"), a set of applications that would let the Minnesota Department of Natural Resources use satellite imagery and geospatial data regarding the state's forests in its day-to-day business. But they had run into the same problem Faleide had.

"We went into ForNet thinking our main task would be to build these applications using existing technology, but it didn't exist," says Thomas Burk, who was a professor in the department at the time and oversaw the project's development.

Satshot's various apps offer satellite images of farms in a variety of spectral bands. Often, a quick visual scan can alert a farmer to a problem such as a faulty seeder or irrigation system, but the programs also offer in-depth analyses and allow a tractor to be programmed to deposit seeds and resources according to the fertility of soil in different parts of a given field.

What the team needed was a server that could process raster and vector data and would allow data products to be placed on the Web, searched for, and accessed. "We just sort of assumed, 'Well, certainly somebody's going to develop that capability, and we'll just use it to develop these solutions,'" Burk says. "But nobody did."

A mix of forestry and computer science graduate students ended up working on the effort, which became almost entirely a software development project. What the team produced, though, was a wildly successful open source development environment known as MapServer, which is still used by thousands of active Web sites today, including Satshot's.

Technology Transfer

Faleide discovered MapServer after approaching TechLink, an organization at Montana State University that was, at the time, funded by NASA, with the mission of transferring the Space Agency's technology to the region's private sector.

"He was definitely ahead of the technology and ahead of his time," says Will Swearingen, who is still the organization's executive director, although it is now primarily funded by the Department of Defense. "No one was using the term cloud computing, but he was thinking along those lines."

So was the MapServer team, which had recently made their server operational and had finally started work on forestry applications. Agri ImaGIS "seemed like it would be a really good fit for extending MapServer from just forestry to agriculture in general," Swearingen says.

He introduced the two, and Faleide became MapServer's first commercial user (*Spinoff* 2000).

"We never would have been able to do this without the MapServer core we started using back in the '90s," Faleide says, noting that, thanks to the NASA-funded technology, his company had an online map delivery system three years before even Google had such a thing.

Benefits

Satshot has benefited from major advances in Internet and imaging technology since the turn of the millennium, as well as an increasing number of commercial imaging satellites, but the basic idea of precision agriculture through remote sensing remains more or less unchanged. Images captured with different spectral bands, particularly in the visible and near-infrared range, reveal crop density throughout a field, creating a sort of "biomass map."

Pointing to such an image of an 80-acre field of his own, Faleide notes that greener areas indicate heavier plant production, while a yellow region represents a more sparsely vegetated hilltop. In this particular field, about 75 percent of the yield comes from just 35 to 40 percent of the area. "We want to try to increase yield in the really good areas and quit feeding too much crop input into the poorer areas," he explains.

This means depositing a higher seed population where the soil is able to handle it, laying down more fertilizer in these areas, and, since denser populations are more prone to disease, spreading more fungicide.

By targeting resources rather than using a "blanket approach," Faleide says, farmers not only save on resources but also reduce the amounts of chemicals and fertilizers that run off into watersheds.

The images can also reveal mistakes and problems that could be fixed in the future. Showing a shot of another field, he points out that the dark circle of vegetation fed by the farmer's pivot irrigation system is streaked with rings of yellow, indicating a problem with the sprinkler heads. "Anything linear, straight, or in a pivot is human error," he says. "Whenever we see a field that's not uniform, it means there are problems. Some of them you can manage, some of them you can't."

An image of a 300-acre field in the Canadian province of Saskatchewan reveals straight, perpendicular lines crisscrossing the entire area, with the horizontal traces more obvious. "When this farmer saw this field, he literally jumped out of his chair," Faleide says. The wings of the farmer's air seeder were uneven, with part of the device set about half an inch too shallow, resulting in lines of thinner vegetation.

The "biomass maps" Satshot provides allow tractors to deposit more seeds, fertilizers, and pesticide in the most fertile areas of a field while allocating fewer resources to soil that can't support dense vegetation. This targeted approach saves up to 20 percent on resources and also prevents excess fertilizers and chemicals from running off into the watershed.

Image courtesy of MDA Information Systems

Among the various satellites that provide Satshot's images are the five orbiters of BlackBridge's RapidEye fleet. The company also relies on imagery from Airbus, Geovantage, Landsat 8, and Planet Labs to maintain a rich, up-to-date collection.

Since the crops are already planted and growing when the images are taken, the pictures are generally used to plan changes for the following year, Faleide says. "That you learn from your mistakes is basically the concept here."

But with more and more private-sector satellites taking to the skies, he says, the imagery will soon be useable on more of a real-time basis, for example, to schedule irrigation. Multispectral imaging can also reveal plant health and water content, but acting on that information requires frequent, high-resolution monitoring.

Satshot currently uses imagery from a handful of private companies—RapidEye's five satellites, Airbus' two Pleiades orbiters, and GeoVantage's fleet of planes—as well as the NASA-built Landsat 8 satellite. Each features different resolutions and imaging capabilities. The company already has agreements with startup Planet Labs, which is partnering with NASA to put dozens of small-scale Dove satellites into orbit with the goal of producing high-resolution imagery of the entire planet on a daily basis (see page 104). With that capability, Faleide says, a cloud-free image of any given field can be virtually guaranteed on at least a weekly basis, which is enough that the data can be used to schedule irrigation economically.

Planet Labs also has a partnership with Faleide, who has leased the company a piece of his farm in North Dakota for the installation of two large receiving stations.

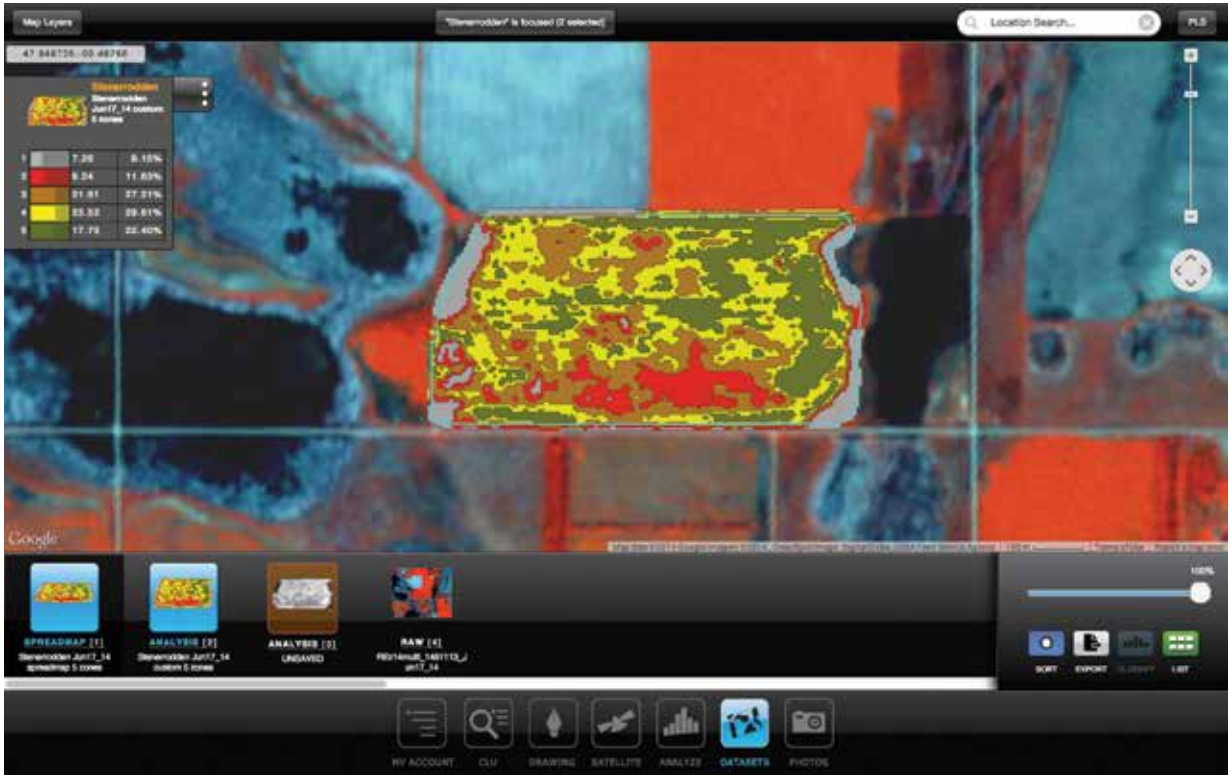
Just as he was 20 years ago, though, he is still waiting for technology to catch up. Only about 5 percent of irrigation pivots in use today have the capability to adapt to schedule changes, he says. "They've got to get their technology up to date, and we've got to provide more consistency."

The advent of smartphones and other "smart" devices has allowed the company to make its products more accessible, for example via its Landscout app, which allows mobile image analysis, and its iCue app that lets customers know every time a picture is taken of their fields and automatically analyzes images according to custom settings.

Satshot is also working with farm equipment giant John Deere to integrate computer systems on tractors with the Satshot image archive. The application will allow the machines to automatically adjust the rate of seed, fertilizer, and pesticide application based on vegetation indices, saving up to 20 percent on these resources, Faleide says, adding, "Environmentally, it's very sound practice."

The company is able to provide images of any field in the United States and Canada and counts among its customers thousands of individual farmers, crop consultants, agricultural dealers, and corporations employing many dealers.

"Since 14 years ago, we've increased our exposure by at least 10 times," Faleide says, adding that revenues have increased four- or five-fold. "We're growing at a pretty



In this shot of one of Satshot President Lanny Faleide's fields, as it appears in the company's Mapcenter app, low vegetative cover on a hilltop shows up in red, while the densest crops appear dark green. It's the NASA-funded MapServer platform that has allowed Satshot to host and distribute its massive collection of satellite images like this one.

rapid rate now, because the precision agriculture industry has really matured in the last three or four years."

And at the heart of the company's technology, bringing images from orbit to end-users, is the MapServer platform, which UMN updated between 2000 and 2006 to allow data processing and image analysis as part of the TerraSIP project, also funded by NASA, and which has subsequently undergone several more iterations.

"We've used a tremendous amount of open source technology provided by NASA to get where we are today," Faleide says. "The NASA research into the basic technologies has been so instrumental in bringing this to fruition."

Minnesota's Department of Natural Resources, the only client originally planned, also remains among the server's users, running applications such as one that allows it to track the spread of wildfires. UMN still holds the MapServer license, but the software is part of the larger Open Source Geospatial Foundation.

Burk says he never expected the platform to become so widespread. "Since this was not our original plan, we had no aspirations of making a big deal of this or bringing in other clients," he says, noting that the server started to take on a life of its own when his team decided to agree to requests that it be developed in an open source format, which led to contributions from developers across the world.

"It went well beyond what we ever envisioned," Burk says. ❖

With more Earth-imaging satellites taking to orbit every year, companies like Satshot can offer images of a given area that are current and loaded with information. These are a boon to farmers, as well as crop consultants and agricultural dealers.

Software Helps Restore Fire-Ravaged Habitats

NASA Technology

Idaho is a nature-lover's dream. Forests there blanket swaths of terrain, from the glassy lake regions of the northern Panhandle to the famous trout-fishing streams of the southeast. Rangelands—drier regions that are home to native grasses, shrubs, woodlands, and wildlife—sprawl like carpet on the open country.

Such landscapes are beautiful, but during the summer they transform into veritable tinderboxes. On sunbaked days, a mere spark from a train car's wheel can ignite dry grass or leaves, which, in firefighting parlance, serve as "flash fuels"—or kindling—that start a wildfire.

Periodic blazes considered natural fires are healthy for these ecosystems. For instance, low-intensity ground fires burn away litter while also releasing nutrients in the soil that nourish the seeds of the ponderosa pine, one of the Pacific Northwest's iconic conifers. But more often than not, wildfires, the vast majority of them human-caused, wreak havoc on established habitats by destroying mature plant communities, inducing erosion, and making it possible for invasive plants to take a stranglehold over the landscape.

The Department of the Interior's Bureau of Land Management (BLM), in addition to coordinating firefighting efforts on federally held lands, is also responsible for the post-fire restoration process that's meant to limit the harmful fallout. Such measures include stabilizing erosive soils through the placement of berms and other features to prevent the contamination of nearby streams, replanting native grasses in severely burned areas to reestablish the natural ecosystem, and mitigating the damage caused by bulldozers used in fire suppression.

By law, before the Agency can commit to restoration work, it first must submit what's called an Emergency Stabilization and Rehabilitation plan, or ESR, which lays out the proposed course of action along with the estimated costs. But producing such a document, and within the mandated period of 14 days after a fire is extinguished, is a tall order considering the formidable amount of work involved.

"We have to survey multiple Web sites for information on soil layers, plant species composition, burn severity mapping, and other data," says Gregory Mann, a fire ecologist with the BLM. He adds that the act of collecting the information takes time. "When we're dealing with large fires, it's extremely difficult, and that's not taking into account occasions when we have multiple fires going at the same time."

A wildlife biologist by training and founding director of the Geographic Information Systems (GIS) Training and Research Center (TReC) at Idaho State University, Keith Weber has used various sources, including NASA satellite data, to examine wildfires' impacts on ecosystems, with a particular focus on rangeland habitats. With funding from the Space Agency, Weber has also worked with the BLM on a number of pre-fire and long-term post-fire recovery research projects. "One of the things we hadn't yet done was help the fire managers make better-informed decisions immediately following a fire," he says. That was about to change.

One day, not long after NASA's Applied Sciences Program put out a call for wildfire abatement-related proposals through its Research Opportunities in Space and Earth Science, or ROSES, announcement, Weber recollected conversations he had had with BLM staff on the sheer amount of information that needed gathering in order to prepare an ESR. They ran the gamut from endangered species habitat and elevation data to soil composition and vegetation indices.

"I began thinking of geospatial datasets 1, 2, 3, 4, 20," Weber recalls, intimating his familiarity with the array of source material. "I said to myself—a lot of that data could be staged and prepared for them."

As a result, Weber drew up a proposal for developing a GIS-based software program that quickly pools requested information and then presents it through a simple Web-based map interface. He formed a partnership with John Schnase, an ecologist and senior computer scientist at Goddard Space Flight Center who, in addition to his work on climate research and ecosystems, had also worked with Weber on fire-related projects. In turn, Schnase tapped his NASA colleague Mark Carroll, an expert in wildfire ecology and remote sensing technology, to join in on the effort. In 2011, after the trio was granted ROSES funding, the scientists led their respective teams in developing the software.

> The BLM [Bureau of Land Management]—both the staff based at incident command and the firefighters on the ground—found RECOVER useful not only for post-fire recovery efforts but also for assisting in active fire containment.

Following more than a year of programming and logistical work, they completed the first iteration of NASA's Rehabilitation Capability Convergence for Ecosystem Recovery, or RECOVER system.

Technology Transfer

RECOVER utilizes Amazon Web Services' cloud computing technologies to wrangle the requested data from a multitude of sources, whether it be the U.S. Geological Survey's Landsat, NASA's Moderate Resolution Imaging Spectroradiometer datasets, the U.S. Department of Agriculture's soil surveys, or any other publicly available database available on the Web. Once compiled, they are converted into an easily understandable visual interface that's accessible on a standard Web browser.

The system underwent its first field testing during Idaho's exceptionally active wildfire season of 2013. Once a wildfire was contained, the BLM, the Idaho Department of Lands, or the U.S. Forest Service (which has a plan

similar to the ESR called a Burned Area Emergency Response) would provide Weber with coordinates for the fire's extent, and Weber and his students would then plug those coordinates into the cloud-based software program, which he says acts "like a cookie cutter, clipping out all of 20 layers for that spatial extent," then stores them in a folder held in the cloud. That data was then sent back to GIS TReC at Idaho State University, where it was assembled into a RECOVER client Web map and delivered to the requesting agency through a URL link.

Today, the entire process, from request to map delivery, takes all of five minutes.

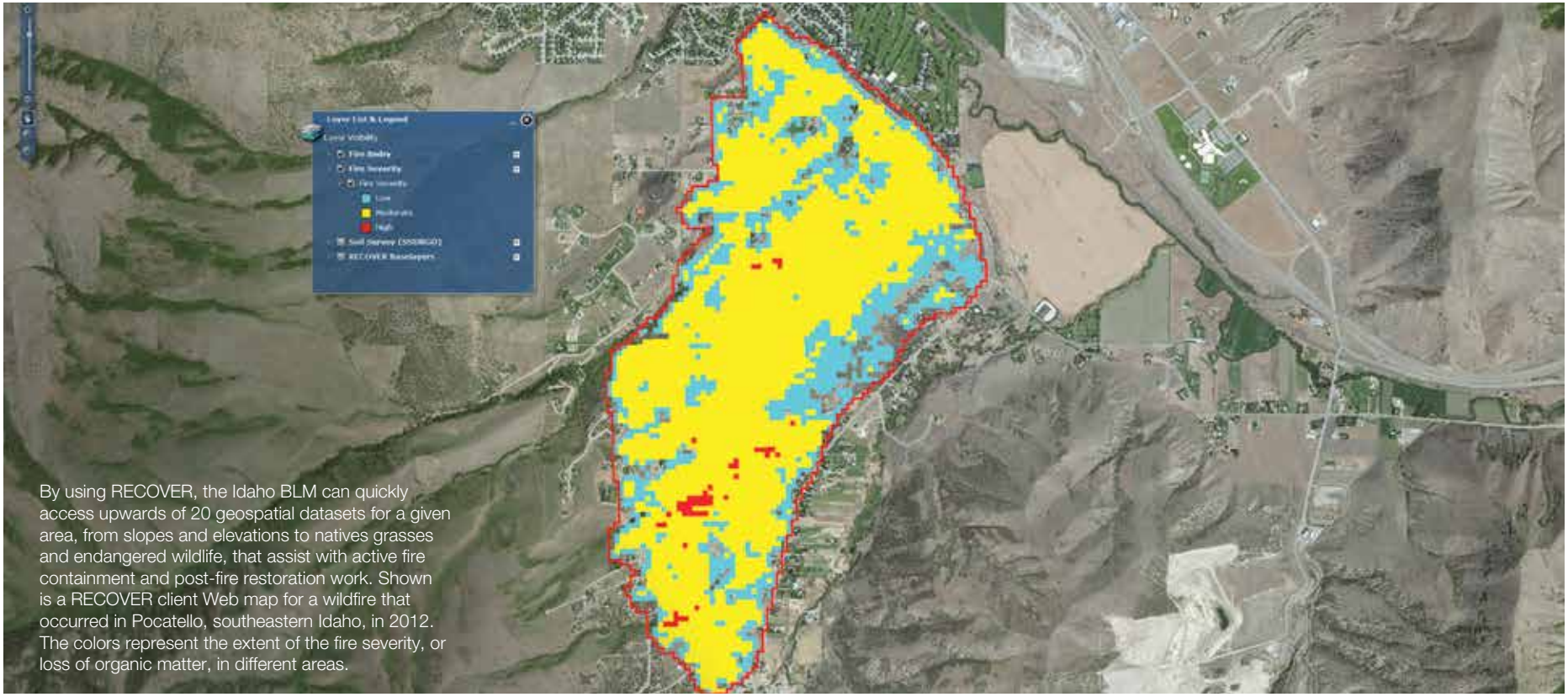
Benefits

RECOVER's speed impressed the BLM, which used the technology to prepare ESRs for five large wildfires that season. "We can get all the information in one place in a very short turnaround," Mann says. "It can save us valuable work time, which is extremely helpful when you're in a constant time crunch."

But the BLM—both the staff based at incident command and the firefighters on the ground—found RECOVER useful not only for post-fire rehabilitation efforts but also for assisting in active fire containment. Knowing where fires would spread based on identifying adjacent vegetative areas, for instance, helped crews to steer safely away from potentially dangerous locales.

The software's unexpected application in active fire management spurred Weber and his colleagues to develop smartphone- and tablet-friendly versions of the program that can be accessed with ease by firefighters in the field. What's more, the app's latest iteration allows fire crews to map hazards in real time using GPS technology. For example, a firefighter would be able to note the site of a weakened tree that's at risk of toppling. The information is then available on the map interface for all users to see. "Now when their fellow firefighters are in that area, they can look at the Web map on their phones and know to

NASA's Moderate Resolution Imaging Spectroradiometer, aboard the Aqua satellite, captured an image of multiple wildfires raging across Idaho in the summer of 2012. In addition to containing active wildfires, the state's Bureau of Land Management (BLM) also conducts post-fire restoration work on disturbed habitats. To simplify and speed up the planning process, Keith Weber, a Geographic Information Systems expert at Idaho State University, teamed up with scientists at Goddard Space Flight Center and, with NASA funding, developed the Rehabilitation Capability Convergence for Ecosystem Recovery, or RECOVER, system.



By using RECOVER, the Idaho BLM can quickly access upwards of 20 geospatial datasets for a given area, from slopes and elevations to natives grasses and endangered wildlife, that assist with active fire containment and post-fire restoration work. Shown is a RECOVER client Web map for a wildfire that occurred in Pocatello, southeastern Idaho, in 2012. The colors represent the extent of the fire severity, or loss of organic matter, in different areas.

avoid that tree, whereas in the past they may not have had any idea of the danger," Mann says.

RECOVER's feature-mapping capability will also prove useful in other ways. Consider the use of bulldozers in active fire suppression: they play an important role in clearing vulnerable areas of brush and other fuel sources to create a fire break, but they also impact the landscape. As such, dozer lines must be noted so remediation measures can be taken to restore those areas post-fire. By being able to track where the heavy machines are working in real time, fire suppression crews can utilize them in a more effective manner. Additionally, they will no longer have to go back to the field afterward to gather that data, saving time and money.

Weber points to another use for the technology that's already being implemented: fuel reduction. During the off-season, agencies take stock of areas where wildfires are likely to spread to and take proactive measures, including carrying out controlled burns or trimming understory growth, to decrease the potential for fires. "They can use RECOVER to locate these susceptible areas and mark areas they've already worked on," Mann explains.

Weber, along with Schnase and Carroll at Goddard, have received additional funding to continue their work over the next few years. Besides fine-tuning the smartphone- and tablet-supported software, which, if all goes as planned, will be fully functional for use by the BLM and the U.S. Forest Service during the upcoming wildfire season, another goal is to automate the process so that, instead of making a request to Weber, an agency can access RECOVER directly. "We'll probably have a Web interface where you'd enter the coordinates or use your mouse to draw the fire area on a map, then just wait a few minutes for the new Web site to be created," Schnase explains.

Another objective, given RECOVER's early successes in Idaho, will be to expand the technology's use by Federal agencies to the entire western United States. "We have a lot of interest from fire managers in Arizona and California, and they'll also soon have access to the technology," says Weber.

Mann believes the program will be well received. "I can really see this program being used nationally. It's a good tool for land managers to use to help make the best informed decisions on the ground." ❖

In the off-season, fire management agencies operate controlled burns and trim understory growth to reduce the potential for fires. Workers are using RECOVER to locate those vulnerable areas and then, after they're done, mark them as completed.

Buildings for Manipulating Magnetism Revolutionize Magnetometers

NASA Technology

In a corner of Ames Research Center in California stand a pair of rather unusual buildings, where mere mortals can control magnetic fields.

The Magnetic Test Facilities, identified on a map as N-217 and N-217A, are located at the outer edge of the facility, on the southern end of San Francisco Bay. Housed in a 12 by 12-foot section of N-217 is a chamber designed for calibrating magnetic sensor systems, determining the amount of metal in a magnet, and testing the low-frequency electromagnetic radiation of small objects measuring up to 3.3 feet in any direction. Next door, in N-217A, a facility with a 20-foot coil accommodates larger objects and is capable of duplicating the strength and direction of the planet's magnetic field as measured anywhere on Earth, in orbit, or in deep space.

"Originally, those buildings were put out there for testing space probes that had highly sensitive magnetic instruments on them," says Robin Orans, technology partnership manager at Ames. The magnetic fields could be altered as needed by electrifying Helmholtz coils, which helped determine how objects that responded to Earth's magnetism would fare in space.

By the end of the 1990s, however, NASA wasn't using the buildings very often. The Agency considered tearing them down, but one engineer fought to preserve them.

Ernie Iufer, a research scientist specializing in magnetics at Ames for many years, argued that the buildings should be maintained in case NASA needed them in the future, or for outside companies that could require testing in such rare conditions.

"Ernie came to me and said these buildings are going to be torn down, all the instrumentation will be taken away," Orans recalls. Instead of allowing that to happen, he found a possible tenant with its own special needs.

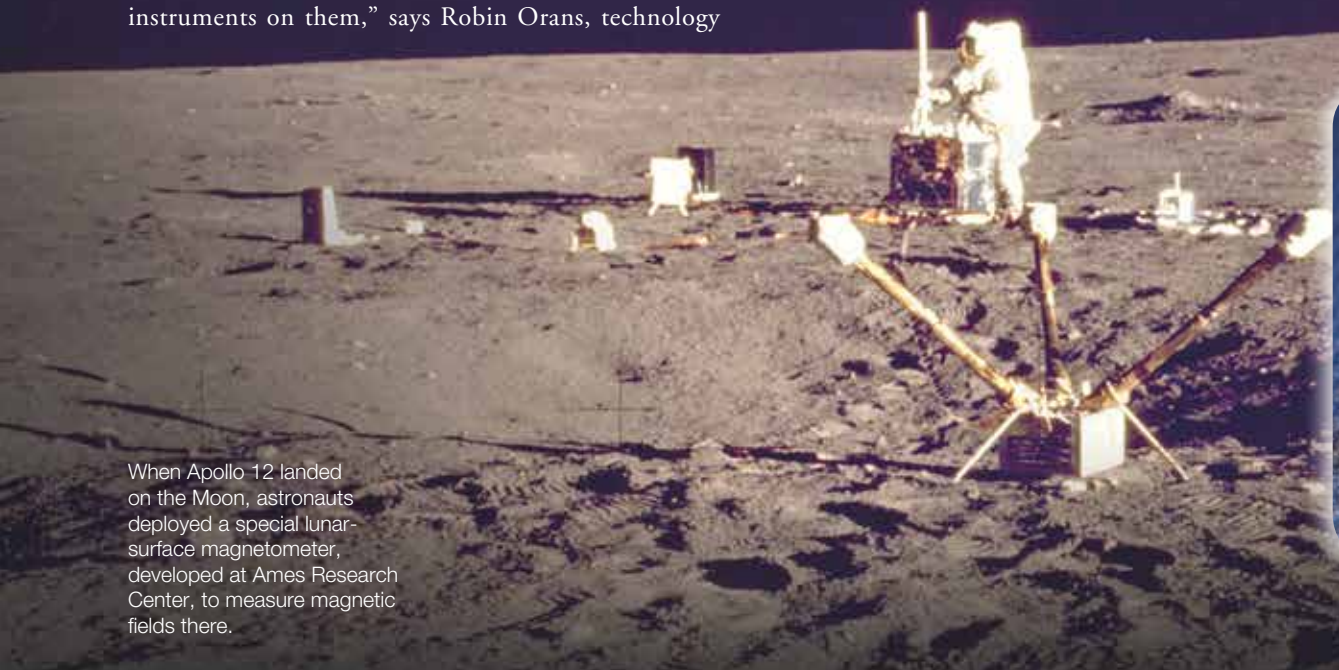
Geometrics Inc., from San Jose, California, was looking for a facility to test its magnetometers, devices used to measure magnetic fields. Iufer brought the company to the attention of Ames officials, noting that the company would agree to use the facilities on a noninterference basis: the buildings would be in use and maintained by Geometrics, but NASA would have priority if the Agency needed to conduct testing.

Technology Transfer

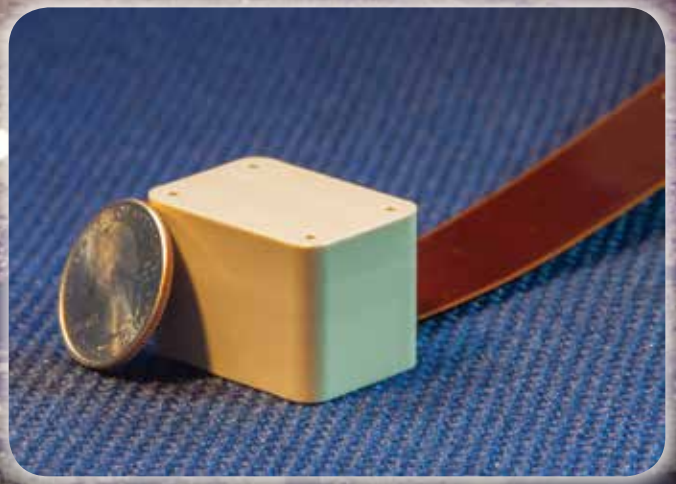
"The NASA buildings are instrumental to us in testing the products we manufacture," says Ron Royal, vice president of operations for Geometrics.

Magnetometers can't be tested in just any facility, as interference from traditional building materials, including rebar and nails, could skew test results or otherwise provide inaccurate readings. Upon learning of the facilities at Moffett Field, constructed with wood and nonaluminum nails, Geometrics leapt at the opportunity and negotiated a Space Act Agreement to lease the buildings.

Early spacecraft were found to respond to Earth's magnetic field while in space, says Raul Mhaskar, a senior



When Apollo 12 landed on the Moon, astronauts deployed a special lunar-surface magnetometer, developed at Ames Research Center, to measure magnetic fields there.



Geometrics' micro-fabricated atomic magnetometer, a prototype of which is shown here, has been optimized for miniature deployment platforms thanks in part to the use of special buildings at NASA's Ames Research Center.

One of two specially designed and equipped facilities at Ames Research Center where magnetic fields can be manipulated. Geometrics used the buildings to help develop their magnetometers, used to detect irregularities in magnetic fields.

scientist at Geometrics. "When they were sent out to space, the spacecraft itself acted like a compass needle and would start wobbling."

While NASA built N-217 and N-217A to determine how spacecraft would work in orbit and to eliminate as much "wobble" as possible, the facilities were just as adept at simulating conditions on Earth.

"The Helmholtz coils, when electrified, either add to the magnetic field or subtract from it, so you can test the full range of what you might encounter anywhere on Earth," Royal says. Locations closer to the poles have a stronger magnetic field than those closer to the equator, for example.

Benefits

Geometrics began making magnetometers in 1968, when the space race was in full swing. Since then, as technology has evolved, so too has the look of the company's devices, previously the size of a gallon jug but now roughly the size of a soda can. Soon, the company hopes to make devices even smaller, shrunk down to a one-inch cube.

"That represents an improvement in size and power, more than a factor of 10 lower than the existing magnetometers," Mhaskar says. "We expect this to be a revolutionary change in magnetic field testing, and we're relying on the NASA facility for it."

Magnetometers work by reading the magnetic signatures found in soil, water, or other substances to determine what's there, he says. Miners might be able to determine where a large core of diamonds can be found by using a magnetometer to get an image of what's buried underground. The diamonds themselves don't have a magnetic signature, but the ground around them does, and the magnetometer would register an anomaly.

The devices can also be used to calibrate underground drill rigs or to find buried objects. One was used to help a police department find a car that provided important evidence in a decades-old murder trial, says Royal.

A new and increasingly important use for magnetometers can be seen in the North Sea, where wind farms are becoming a major provider of energy.

During World War II, Germany landed aircraft in the area near the North Sea and "jettisoned their bombs as they landed in the North Sea itself, along the shoreline," Mhaskar says. "Now we have these million-dollar windmills being positioned in the same area as thousands of unexploded ordnance along the sea bottom."

Magnetometers are being towed out into the sea by boat and are used to determine where it's safe to install a windmill and where bomb extraction is needed, he says, based on the amount of iron found in the vicinity.

Another use for magnetometers is in the medical field, as they can be used to detect the electrical activity produced by the human heart.

"Along with the EKG signal that you typically see with electrodes, you can see the magnetic signature of the heart," Mhaskar says. "There are lots of things that you cannot see from an EKG. The brain, for instance, also produces a tiny magnetic signature, but that is also what's called magnetoencephalography," used to determine long-term effects of a stroke or brain damage.

Helmholtz coils like this are used to manipulate magnetic fields. Two buildings at Ames Research Center helped test how Earth's magnetic pull would interact with components of early spaceflight vehicles.

The military has an interest in magnetometers for finding IEDs or other explosive devices, as do the security and oil-drilling industries.

"All of our products are used to look under the ground or sea without having to dig it up," Royal says. "You map the magnetic field from above, and a geophysicist makes some kind of determination about what's below, saving time and money."

Mhaskar says the company is using NASA's facilities as it develops the next generation of magnetometers. "We use these buildings to make sure that the sensor has the properties we expect it to have throughout the range of operations, something we cannot test at our location in San Jose."

The company's next generation of magnetometers is being developed in partnership with Texas Instruments. These new, smaller machines will use silicon technology and incorporate microelectromechanical systems processes.

"Those tests will also be conducted at NASA," he says. "That facility is critical to making sure this technology matures." ❖

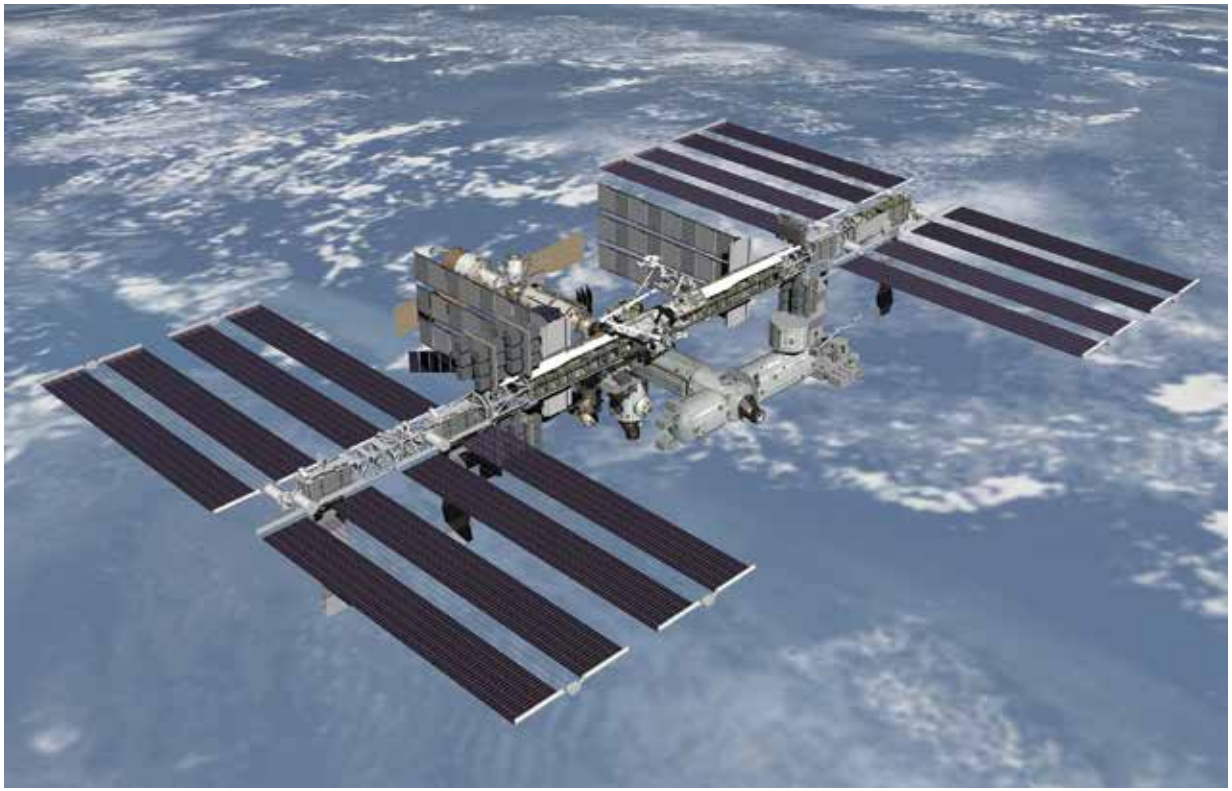
Cost-Saving Method Yields Solar Cells for Exploration, Gadgets

NASA Technology

It's expensive to fly to low-Earth orbit, let alone Mars and beyond. Engines are still propelled primarily by burning liquid fuel, but future missions by NASA could utilize alternative sources of space propulsion, such as solar-electric propulsion driven by high-power solar arrays.

Some vehicles and satellites, as well as the International Space Station, already are equipped with large solar arrays, which come with hefty price tags due to the high cost associated with space-qualified solar cells. NASA currently works with two primary manufacturers of solar cells, and the market could soon be expanding to include new players with modified production techniques as the demand increases.

"Lately we've had a lot of Small Business Innovation Research (SBIR) contracts looking not just at advanced cell technology, but also at maintaining low costs," says Mike Piszczor, chief of the Photovoltaic and Electrochemical Systems Branch at Glenn Research Center. "A typical cell that's four by eight centimeters is $400–$500 apiece, and that's because they go through flight qualification in addition to the manufacturing process used. It saves in the long run, because even with that very expensive cell technology, it's so efficient that it saves in overall system cost."



Solar arrays like these, attached to the ISS, will be increasingly important to NASA as the Agency works to travel deeper into space.

Most space solar cells have a conversion efficiency of about 30 percent, meaning that amount of incident sunlight is absorbed by the cell and turned into electrical energy. The greater the efficiency, the smaller the solar cell area needed for a particular job or mission.

The price for these cells has remained steady for quite some time, Piszczor says, and with the traditional space focus on efficiency and high reliability, there's little incentive for the technology or the cost to change.

However, one company is experimenting with a new method of growing cells using a reusable substrate that could shake up the industry.

Technology Transfer

MicroLink Devices Inc., based in Niles, Illinois, has been awarded multiple SBIR contracts from NASA to focus on cost reduction and improved cell performance. Most have gone toward developing a new method for growing inverted metamorphic multi-junction (IMM) solar cells using a substrate of gallium arsenide, and a process for reusing the substrate that could ultimately result in less expensive but more flexible and lightweight photovoltaic cells.

The cells might be slightly less efficient now than the majority of IMM solar cells on the market, but it's an enticing concept, Piszczor says. "What's nice about IMM is it's very thin, so you save on mass and the supporting array structure, and it's flexible as well," he says.

As NASA looks at the possibility of putting larger solar arrays in space, building on current solar array sizes of 10 to 15 kilowatts in the hopes of producing arrays with hundreds of kilowatts, the current method of manufacturing space solar cells may be cost prohibitive.

"That's where MicroLink comes in," Piszczor says. "MicroLink has developed technology that is very similar to what the current space cell vendors have, but what they do is reuse the substrate. In terms of solar cell cost, for a

Troops in desert regions already are using MicroLink Devices' flexible, lightweight solar arrays as a source of portable, renewable energy. The panels attach to a backpack and are capable of charging military batteries, eliminating the need to carry extra ones.

typical state-of-the-art space cell, that's about 40 percent of the cell material costs."

A lightweight, flexible, space-qualified solar cell with a substantially reduced price would make it more likely for NASA to achieve the goal of developing solar arrays capable of producing up to several hundred kilowatts, the kind of power needed for some solar-electric propulsion missions, he says.

MicroLink's cells are similar to the current space-rated options used by NASA in that the cells are triple-junction, meaning the sunlight is split into three ranges of wavelengths that are captured by each corresponding material layer to improve the overall conversion efficiency of the device.

The cells may not have the same efficiency as other cells, but that might not matter in the long run.

"MicroLink can achieve efficiencies in the 28 to 30 percent range, but there is also the potential to get the efficiency up close to what the other solar cell vendors are doing," Piszczor says. "Even if we don't, if MicroLink's cells are significantly cheaper, it might work out to be more beneficial at the system cost level. If a solar cell is a lot cheaper, I don't have to buy a 34 percent cell, I can buy a 30 percent cell and still save money, even if you need more of them."

MicroLink uses an epitaxial lift-off (ELO) procedure to make the cells, which doesn't damage or deplete the gallium arsenide substrate in the same way traditional cell-making processes do, explains Chris Youtsey, MicroLink's director of fabrication. "Our work was really focused on developing this technology for terrestrial applications—these cells can go into concentrator systems—but since it's a similar technology to space cells, we started interaction with NASA, and we've been working with them for the past five years."

Benefits

MicroLink originally was developing these flexible cells for other Governmental departments.

"We started this work in 2007 with some funding from the Department of Energy" from another SBIR contract, Youtsey says. In addition to off-Earth applications, the cells can be used in concentrator systems, "where optics focus the light down on a very small cell, increasing the focus of light by maybe 500 or more times" than if the cells were placed individually.

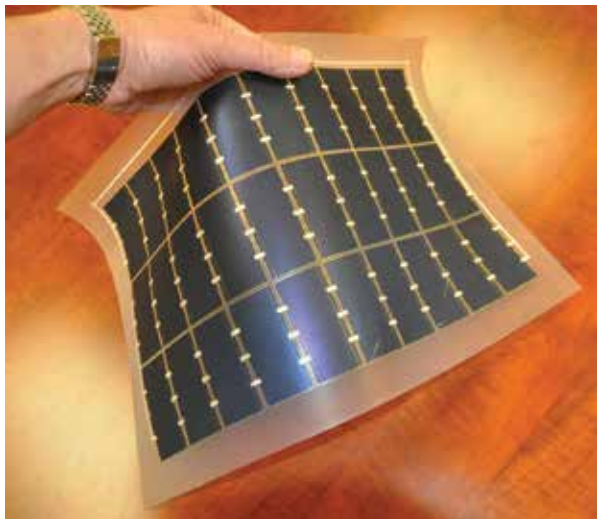
Already the military is benefiting from MicroLink's work. Rao Tatavarti, MicroLink's technology director, points to a solar array troops carry when out on patrol, which collects sunlight and is used to recharge batteries. This frees up space and weight for other mission-critical items, such as ammunition or food, instead of extra batteries.

In 2014, the magazines *Popular Science* and *Popular Mechanics* both featured articles about these panels, with *Popular Mechanics* lauding the U.S. Naval Research Laboratory's Marine Austere Patrolling System developed by MicroLink as its 2014 Breakthrough Award for Innovation. A similar panel made in partnership with the Naval Research Laboratory and the Marine Corps Expeditionary Energy Office was featured in a March 2014 issue of *Information Week*.

"It used to be they just had a radio with a battery" to carry in their equipment packs, Youtsey says. "Now they have all kinds of electronics. They have to carry more and more batteries, so there's an interest in developing lightweight, high-efficiency solar panels they can carry to provide power in the field. The characteristics of our cells are attractive because they're high-efficiency, you can make a small panel that produces a lot of power, and they're rugged because they're flexible."

Additionally, Youtsey says MicroLink has been working on incorporating panels into unmanned aerial vehicles.

"We've had several programs with the U.S. military to put these things on the wings of small and large UAV planes to help power them during flight. That's an exciting area that's emerging for us." ❖



Thanks to an innovative process that incorporates a reusable substrate, MicroLink Devices has created thin, flexible solar cells and arrays that could be used to help power exploration in space.

Wide Area Thermal Imaging System Brings the Landscape into Focus

NASA Technology

Finding a forest fire can be more difficult than some would expect. Seeing smoke in the distance indicates a problem, but determining the exact location where the fire started or has spread can be an inexact science, and mapping large areas with high resolution is time-consuming and expensive.

Government agencies have used various sensors and airborne cameras for fire monitoring, but the sensors could not always give an accurate read on the situation.

"NASA and a few other agencies had sensors that detected fires, but they all had a major flaw, and that was saturation," says Jim Brass, chief of the Biospheric Sciences Branch in the Earth Science Division at Ames Research Center. "The fire's signal was so intense it would overpower the sensor, and all we'd get, in most cases, was a big white blob."

To best devise a plan for fighting fires, NASA and the U.S. Forest Service, among other agencies, needed to be able to detect fire lines and the amount of energy being expelled by the flames. "We scratched our heads and looked at satellite sensors, we looked at aircraft sensors and finally went over to our instrument folks and said we have the requirements for a sensor, but we're not sensor builders," Brass says. NASA used internal discretionary funding for a new sensor and devised the Airborne Infrared Disaster Assessment System (AIRDAS), a scanner that flew for the better part of a decade, monitoring the forests of Canada, Mexico, Brazil, and the United States.

After that time, NASA was interested in updating AIRDAS with newer technology for better data, so the Agency turned to industry for help. "Industry usually does it better and cheaper than we do and more than likely faster than the Agency could develop and test new technology," Brass says.

There were a handful of companies that responded to NASA's initial request for ideas, including Daedalus Enterprise, a Michigan-based company that specializes in airborne sensors. At the time, John Green was an engineer at the company, working on its Airborne Hyperspectral Scanner in addition to the MODIS Airborne Simulator for Ames and the Daedalus Airborne Multispectral Scanner operated by the U.S. Department of Defense.

Green says he had an idea for a sensor that would fit NASA's fire detection needs, taking thermal infrared imaging and refining it to provide both a wider field of view and greater detail.

"One day, the idea popped into my head while I was mowing the lawn," he says with a laugh. "It's a big yard."

Technology Transfer

NASA has a long history of Earth observation, including MODIS, or Moderate Resolution Imaging Spectroradiometer, an instrument that was first launched on the Terra satellite in 1999 and is capable of observing and mapping the entire planet once a day. In fact, one of MODIS's first applications was fire detection, Green says.

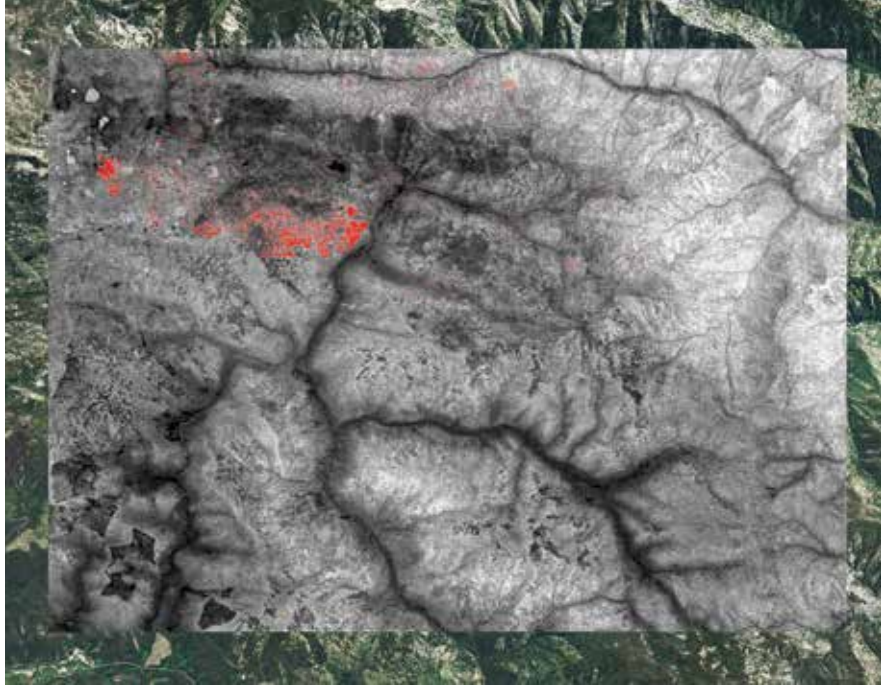
MODIS uses a line scanner, also known as a "whisk broom scanner," for the foundation of the sensor. The scanner moves back and forth as the satellite orbits the planet, collecting data from the Earth's surface one pixel at a time. "For thermal imaging, the line scanner was the only way to get a really wide field of view," he explains. The problem is, the resolution isn't as great as it is when using a camera, which has a narrower field of vision but collects more pixels at once, and in greater detail.

Putting the two tools together, Green developed a thermal infrared imager that uses the best attributes of both line scanners and cameras.

"We came up with the idea to put a mirror in front of the camera. We take a picture, move the mirror, take another picture, move the mirror," he says. "The result is, we have the high resolution of a camera and the wide field view of a line scanner. If you do it that way, simply, it's faster, it can run at a higher altitude and cover more ground, so we end up with improvement in efficiency over the existing system of somewhere around a factor of three or four."

The camera used in the new system, a quantum-well infrared photo detector, or QWIP, was originally developed at the Jet Propulsion Laboratory, Green notes.

Working with NASA, and in particular the Earth-science specialists at Ames, including Brass and Vincent Ambrosia—associate program manager for wildfires in the Agency's Applied Science Program—helped Green understand exactly what kind of tool would best address the needs of the Agency and the Forest Service, part of the U.S. Department of Agriculture.



Combining elements of both a line scanner and a digital camera, Xiomas has developed an aerial scanner that can pinpoint the presence and location of a forest fire from a great distance and indicate its intensity.

"They bring a ton of application knowledge," Green says of his NASA colleagues. Meanwhile, Brass and Ambrosia say Green's got a knack for successfully developing and designing sensors to meet NASA's needs, pointing to a list of at least five Small Business Innovation Research (SBIR) contracts from NASA alone, not to mention other contracts from the Department of Defense and USDA.

As a result of his success with SBIR applications, the first of which was awarded in 2008, Green spun off his work at Daedalus and created Xiomas Technologies, based in Ypsilanti, Michigan.

"We consider him to be on the cutting edge of the entire multispectral technology industry, which we don't have the luxury of being," Brass says. "Where we've pushed Xiomas recently is that we want the instrument in a smaller package, with a smaller power requirement—but we still want the resolution."

There are other companies in the marketplace that work in sensing technology, including a few specializing in infrared thermal scanners, but "none are really oriented toward the calibration of the measurement space that we want to look at, the high-temperature discrimination," says Ambrosia.

Benefits

The Wide Area Imager (WAI) aerial scanner made by Xiomas is capable of taking several kinds of images at once and overlapping the information onto a single output.

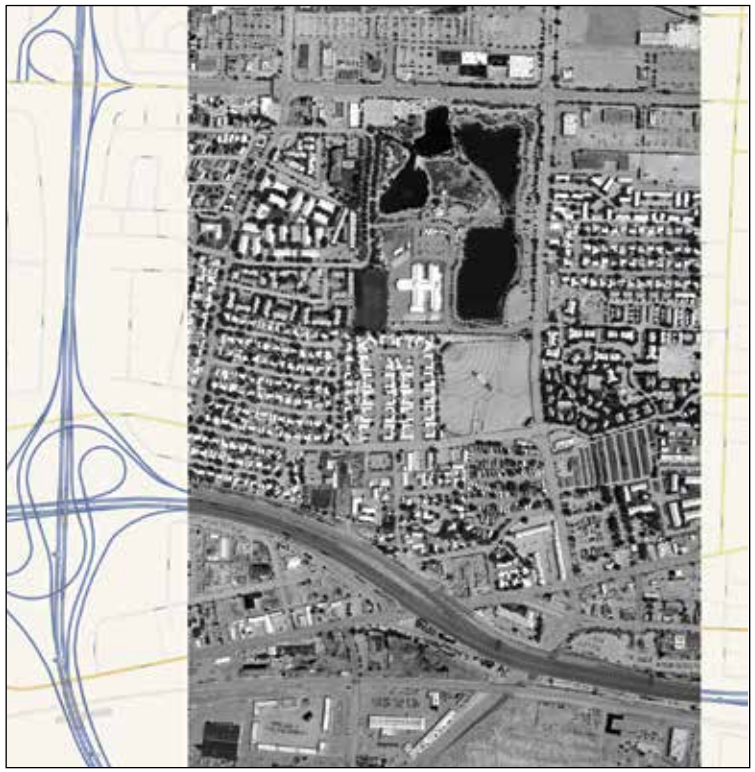
"When the Forest Service goes out to map a fire, they'll take the long-wave infrared thermal image, a single-band image in black and white, which provides a specific location for the blaze," says Green. The sensors also provide mid-wave infrared information, which is very sensitive to high temperatures. "By using the two bands, you can eliminate false detections from large, warm objects which look similar to small, hot objects," he says. That allows a user to detect fires as small as three inches while also distinguishing between fires and, for example, a hot road in the summer.

The imager has other uses as well, and at least a handful of counties have contracted Xiomas for other aerial work. Jefferson County, Kentucky, for instance, had Xiomas use the WAI to map the county's metropolitan sewer district in 2013. In one image obtained by the WAI, it is possible to detect liquid of some kind flowing from an industrial facility directly into a river in two different locations along the bank, Green notes.

The county also uses the Xiomas WAI thermal imagery to map groundwater flows, as thermal imaging also is capable of finding broken pipes leaking water, or bypassed septic systems.

Additionally, as the scanner is capable of imaging a larger amount of terrain in a shorter amount of time with greater detail than a typical line scanner or thermal camera, it is able to scan an entire county at a reasonable cost. Whereas aerial infrared photography might need 8 to 10 days spread out over a month due to weather constraints to fully capture a geographic area, the WAI can complete it in a few evenings.

"With the next version of the WAI, we'll be able to do a whole county in one night," Green says. ❖



Xiomas has combined the resolution of a digital camera with the depth of field offered by "whisk broom scanners" capable of photographing large geographic areas in shorter periods of time with greater detail than previously available.

Photocatalytic Water Splitter Stores Energy as Hydrogen

NASA Technology

At a glance, the surface of Mars appears to offer little in the way of natural resources. Scenes captured by the various rovers exploring the planet depict a desolate, dusty landscape, messily strewn with rocks and punctuated by occasional craggy outcrops, stretching to meet the rusty sky in all directions.

Researchers are still working to determine the composition of the Red Planet's geology, but analyses by NASA's rovers in recent years have confirmed the long-suspected presence of significant amounts of water—one of any Earthling's most precious resources—frozen in its surface. The find was significant to those planning missions to Mars, not just because of water's inherent life-giving properties, but also because of its constituent parts: oxygen, that other most precious resource to Earth fauna, and hydrogen, NASA's rocket fuel of choice.

In anticipation of interplanetary missions, NASA has long worked to find the most efficient ways to separate and recombine molecules such as water in order to make the most of whatever scant resources may be available on an extraterrestrial body. Such technology also has other space applications. For example, oxygen generators aboard the International Space Station create breathable air by separating oxygen from water using an electric current, a process called electrolysis. This method can also be used to purify water.

When John Guerra, president and CEO of Cocard, Massachusetts-based Nanoptek Corporation, and his team set about creating a semiconductor that could use sunlight to harvest hydrogen from water, though, they were also thinking of earthbound applications, like storing energy for backup power and running hydrogen fuel cell vehicles.

Japanese researchers had discovered decades earlier that titanium dioxide, or titania, could function as a photocatalyst to split water molecules when illuminated with ultraviolet (UV) light. However, Guerra says, "The limitation that it only responded to UV light made it inherently inefficient in sunlight." Only about 4 percent of the photons in sunlight have wavelengths in the UV range or shorter, while the sun's strongest output is in the lower-frequency visible range. Ultraviolet light also takes more energy to produce artificially than visible light.

Scientists had worked to push titania and other semiconductors to respond to visible light, but their techniques, such as doping the substances with ions, tended to make them less stable such that they would break down in an electrolyte solution. Water in this application is typically combined with an electrolyte to make it conductive.

Shortly before applying for their first NASA Small Business Innovation Research (SBIR) contract in 2002, Nanoptek's scientists discovered a way to push titania's responsiveness into the realm of visible light without altering its stability. Instead of ion doping, they stretched the material's molecules.

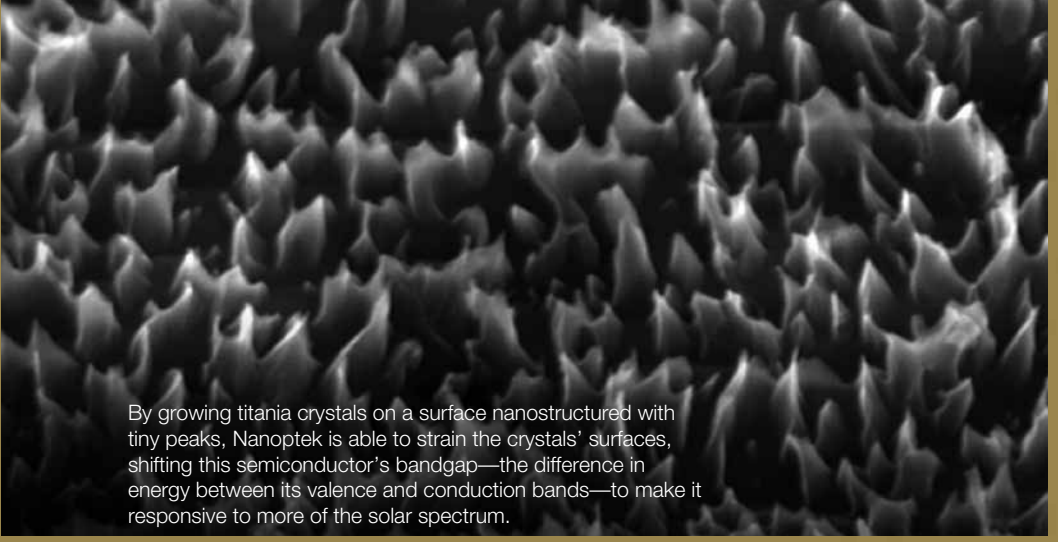
Making titanium dioxide an electrically active semiconductor when exposed to visible light meant shifting its bandgap—the difference in energy between the valence and conduction bands in the semiconductor. In its natural state, titania responds to electromagnetic wavelengths of around 400 nanometers or less, frequencies beginning at the upper end of the visible spectrum. Only these relatively high-frequency, high-energy photons deliver enough energy to cause its electrons to jump from the valence band to the conduction band, creating a charge pair. But the visible light that constitutes the sun's most abundant output has wavelengths between 400 and 780 nanometers, meaning most of it is lost on titania.

That the properties of a semiconductor can be altered by tensile stress was already known to industry, largely as a problem, but Nanoptek's scientists recognized this "weakness" as a potential tool to engineer the bandgap. The problem was maintaining a high enough level of stress without the substance bursting apart. The company's solution was to grow the titania crystals on a surface that was nanostructured with tiny peaks. As each successive layer of the crystalline lattice is added, the strain on its surface increases. "It's going to grow in such a way that it stretches to line up with the lattice below it," Guerra explains. At the same time, the nanostructures provide additional surface for the titania to adhere to.

"If you tried it on a flat surface, you could only get up to a few megapascals of strain before the whole thing explodes off the surface," he says. "Now we can develop extremely high strain, into the gigapascal range." A gigapascal translates to a force of about 145,000 pounds per square inch. It took years to get from the company's discovery to the development of a durable surface that could maintain this kind of pressure and could be mass-produced economically, but the work began in earnest with the company's Phase I and II SBIR contracts with NASA's Ames Research Center.

"For Nanoptek, that funding was incredibly important, not only in economic terms but also from the

With the long-term goal of sending astronauts to Mars, NASA has an interest in any technology that might be able to use sunlight to split water molecules from the Martian soil into oxygen for life support and hydrogen for rocket fuel.



By growing titania crystals on a surface nanostructured with tiny peaks, Nanoptek is able to strain the crystals' surfaces, shifting this semiconductor's bandgap—the difference in energy between its valence and conduction bands—to make it responsive to more of the solar spectrum.

Nanoptek designed this small electrolyzing panel for use in gas chromatography in the field.

standpoint of validation," Guerra says. "When you're at that stage, you're not going to find private funding. The SBIRs allowed us to hire people, expand our lab, and explore the parameters of what we had discovered."

Technology Transfer

The contract also helped keep the company focused on developing a product that not only worked but was commercially viable, bearing in mind factors like cost and marketability, Guerra says. "That was our goal anyway, but it was very helpful to have the funding entity have that point of view."

During its SBIR work, the company molded polycarbonate discs with nanostructured surfaces and then applied titanium dioxide, a process that allowed it to explore nanostructures of different sizes and shapes and to verify the effectiveness of the strained semiconductor surface. The work succeeded in lowering the titania's bandgap to the point that it was activated by light at frequencies of 529 nanometers and higher, well into the visible spectrum. It now made use of 29 percent of the sun's light, as opposed to the 4 percent that activates ordinary titanium. But the surfaces only lasted about half an hour in the solution of water and hot electrolytes.

Following the NASA work, Nanoptek went on to win funding from the Department of Energy and the state of Massachusetts and then subsequently from private investors, allowing the development of a less expensive, more efficient, and more durable product. Now the nanostructures are etched cheaply into less-costly commercial-grade titanium, and the titanium dioxide is formed through thermal oxidation, which is also inexpensive. More importantly, thermal oxidation causes the titania crystals to grow down into the metal, as well as upward. "You're sending roots into the substrate, as well as leaves into the electrolyte," Guerra says.

The result is a surface so durable the only way to remove it is through grinding.

Nanoptek's scientists also found that straining the semiconductor's molecules not only lowered its bandgap but had the unexpected effect of increasing the mobility of positive charges in the material, which allows more time for the positive and negative charges activated by sunlight to do the work of splitting water atoms rather than recombining prematurely. Also serendipitously, it brought the electron voltage of the material's conduction band above the hydrogen evolution potential—the voltage required to cause hydrogen to separate from water molecules spontaneously. This makes hydrogen production more efficient, causing it to occur in sunlight with no added electrical charge.

"But we choose to add electricity because it's more important to make a lot of hydrogen cheaply," Guerra says.

To split water simply by running a charge through it requires two to three volts, depending on the electrolyte and properties of the electrodes, Guerra explains. But

“It was really the **NASA funding** that **financially** got us **off the ground.”**

— John Guerra, Nanoptek

In hotter parts of the world, the batteries used to store energy from solar panels often have heat-related performance issues that a tank of hydrogen stored for energy would not. What’s more, Nanoptek’s photocatalytic panels become more efficient the hotter they get. The company envisions solar power plants for communication towers in the developing world scaled to also provide reliable power to microgrids for local communities.

the hydrogen harvested in this way would only generate something like one-half to 75 percent of that energy. When illuminated, Nanoptek's titania photoanode requires less than one volt to produce an equivalent amount of hydrogen, and so is two to three times more efficient on an electrical energy basis. To maximize return on capital, though, Nanoptek's go-to-market model uses both a titania photoanode and a conventional anode, which operates on 1.8 volts at 82 percent efficiency. The two anodes can be run during sunlight simultaneously to produce a blended efficiency of 97 percent, and the conventional anode can continue to produce hydrogen through the night with low-cost, nighttime grid electricity or with wind electricity, which is typically stronger at night.

Benefits

For any grid based on intermittent power sources—which describes most renewable energy sources, such as wind and solar power—the ability to store excess energy for times when there is no wind or sun is crucial. Nanoptek's technology efficiently converts excess power at any time of the day into hydrogen and stores it. "Then, by using a fuel cell, you can convert that hydrogen back to electricity in an on-demand way," Guerra says.

It's the first electrolyzer to be competitive with batteries and even provides some advantages. For example, unused alkaline batteries lose energy over time, whereas a cylinder of pressurized hydrogen gas will keep virtually indefinitely without losses. Batteries also lose energy to heat if power is drawn from them rapidly, which is not the case with hydrogen fuel cells. At telecommunication towers in remote parts of Africa or India, which are often powered by solar energy, batteries have performance issues due to the heat. "Our panels love heat," Guerra says. "The hotter the electrolyte, the more efficient they get."

Nanoptek envisions power plants for communication towers in the developing world scaled to also power microgrids for local communities, using the company's technology to maintain a constant energy supply. "It's a way to leapfrog an unreliable grid and deliver reliable, low-cost power to people in those parts of the world,"

Image courtesy of the U.S. Navy

As automakers and governments begin to turn their attention to hydrogen fuel cell-powered vehicles, Nanoptek hopes its technology will become integral to the new, hydrogen-based transportation infrastructure.

he says. "The R&D part for us is largely done, and the challenge now is to find funding to scale up manufacturing so the technology can be deployed and start positively impacting people's lives."

By the end of 2014, the company was taking its first orders and gearing up for production. For now, the technology is being marketed to businesses for large-scale operations. Companies whose trucks or forklifts run on hydrogen fuel cells generally have plenty of roof space for a set of Nanoptek's photocatalytic panels to power their fleets, Guerra notes, adding, "There are also a lot of companies out there that use hydrogen in their manufacturing processes, and a lot of them are interested in having a cost-efficient way to make the hydrogen on site."

The number of panels can be scaled up or down according to needs.

He points out that automakers and governments are beginning to turn their attention to hydrogen fuel cell vehicles, with car companies beginning to unveil their first hydrogen-powered production models and California building hydrogen filling stations. He hopes Nanoptek's technology will prove integral to the new, hydrogen-based transportation infrastructure. "Our success depends on the success of other companies, but their success depends on a low-cost source of hydrogen, and that's where we come in," he says.

The systems are not yet economical or safe for residential use, as the compressor and dispenser required for home refueling are still too expensive for an individual homeowner, but Nanoptek envisions the first residential use being in planned developments where a cluster of homes could be outfitted with panels. Homeowners could chip in for a shared compressor and dispenser, using the system to power hydrogen cars.

Guerra also predicts the technology will one day circle back to the Space Agency that first funded it, where it will be used for planetary exploration. "Our devices, with sunlight and local water on an extraterrestrial body, will be used to make hydrogen fuel for rockets and oxygen for habitats," he says. In fact, for each kilogram of hydrogen the system produces, it can make about eight kilograms of oxygen.

"It was really the NASA funding that financially got us off the ground and also established the validity of the technology," he says. Whether that technology will one day get NASA rockets off the ground of extraterrestrial bodies remains to be seen. ❖

Recycling Technology Converts Plastic Waste to Energy

A landfill located in Buckhorn Mesa, Arizona. According to the Environmental Protection Agency, only 9 percent of plastic waste generated in 2012 was recovered for recycling. According to Jim Garrett, president of Vadxx Energy LLC, a major reason for the low number is that many plastics either contain additives and fillers that make them incompatible with current recycling technologies or are contaminated with paper or ink. The company's recycling technology overcomes those limitations as it converts many types of plastic into light crude oil.

NASA Technology

Glenn Research Center has always been in the business of perfecting engines. During World War II, the center, then called the Aircraft Engine Research Laboratory, developed a cooling system for the B-29 Super Fortress—a four-engine, propeller-driven heavy bomber that saw action in East Asia—and also investigated carburetor icing issues in preparation for aircraft flying over the Himalayas into China. In 1945, well before the dawn of the Space Age, trailblazing rocket scientists there began investigating the use of liquid hydrogen as a fuel source, culminating in the development of the Centaur rocket, which would become the Nation's first upper-stage launch vehicle. Since the mid-1960s, Centaur has propelled into space numerous weather probes, communications satellites, and planetary explorers, such as Surveyor, Pioneer, Viking, and Voyager.

While Glenn has continued to flex its rocket-science muscles by improving ion propulsion technology for deep space missions and helping to mature additive manufacturing for rocket engines, the center has also shown its versatility by helping one Cleveland company improve, of all things, an innovative plastics recycling technology.

Technology Transfer

As good as it feels to throw plastic items into the recycling bin, the fact is most of that plastic goes unrecycled, according to Jim Garrett, a veteran of the oil and gas industry. "Of all the stuff my wife makes me sort on a weekly basis, most of it ends up in a landfill," he says. "It's a dirty little secret in America that 90 percent of our plastic ends up there, if not in our oceans."

The reason for the low rate of recycling is that many plastics contain additives and fillers that make them incompatible with current recycling technologies, while others are contaminated with paper or ink. "Recycling companies take in the clear water bottles, but most of the other stuff is not recycled," Garrett says. But as the old adage goes, one man's trash is another man's treasure. In 2009 Garrett met petroleum geologist and geochemist Bill Ullom, who had in mind a technology that could make use of all this unwanted plastic in order to strike oil, or at least manufacture it.

In 2005 Ullom happened on an expired patent for a thermal depolymerization process that could convert plastic back into its original form: light crude oil. The technology works by sending plastic feedstocks, as well as tires and car interiors, through a shredder, where rotating cutters shred the material before sending it through an extruder/kiln combination, where the feedstock is incrementally heated, producing vapor. At the exit of the process path, the vapor is released and condensed into liquid form and distilled into derivatives of light crude oil, namely fuel gas and diesel additive. The last and only solid byproduct of the process is inert char, which can serve as a strengthening agent in rubber products, among other uses.

Ullom began making improvements to the process that allowed the technology both to run nonstop and to accept contamination from materials such as wood and cardboard. After meeting Garrett, who had the business acumen to get the idea off the ground with investors, he founded Cleveland-based Vadxx Energy LLC and became its chief technology officer, with Garrett filling the role of CEO.

Things moved quickly from there, as the fledgling company initiated public-private partnerships with city and state agencies to receive technical guidance and acquire low-interest loans. Fortune 500 company Rockwell Automation also lent both its technical and plant construction expertise to Vadxx, and the nonprofit Manufacturing Advocacy and Growth Network, or MAGNET, also provided logistical and technical support.

Even so, by 2012 the company still needed help optimizing the kiln's design, which, according to Stan

Prybyla, Vadxx's vice president of technology, would be a complex task. "A proper solution to the problem would have to involve the kiln's geometry, tilt angle, and rotation speed, along with the polymer's thermodynamic and physical properties, during standard processing timescales," he says. "The problem was quite challenging, to say the least." Yet that's the type of work that falls right in Glenn's wheelhouse.

While one wouldn't necessarily think NASA has much in common with a trash-recycling technology, Paul Bartolotta, a senior technologist at Glenn, says the Agency's work on rocket propulsion makes it especially adept at analyzing such a process. "We have scientists who for decades have been studying the kinematics of oil decomposition for turbine engines and kerosene rocket engines," he says. "It's still looking at oil—it's just that, in this case, we're extracting it out of waste plastics."

Glenn's collaboration with Vadxx was made possible through Cleveland and the greater Cuyahoga County's Adopt a City Program, itself a product of the Obama Administration's Strong Cities, Strong Communities Initiative, whereby Federal agencies are asked to team up with local governments to provide technical assistance and other expertise to area businesses. Bartolotta, who wears many hats at Glenn, managed the program on NASA's end.

In May 2012, Vadxx was one of eight companies that qualified for the program (another being Pile Dynamics Inc., featured on page 80), which came with 40 hours of pro bono consultation. As a result, within the span of a few weeks, a team of four scientists from Glenn's chemistry kinematics group "created a kinematic model where Vadxx could put in the diameter of the kiln, the feed rates, and the viscosity of the polymers, and it'll optimize the process," Bartolotta says. "They'd be able to maximize the output of the oil byproduct."

The model proved to be a success, says Prybyla. "We were able to incorporate what we learned into the making of our first full-scale commercial kiln."

Benefits

With a cash infusion from Liberation Capital, Vadxx is building that kiln in nearby Akron, with Rockwell Automation leading construction and engineering efforts. When fully operational, it will be able to process some 20,000 tons of waste per year to produce 100,000 barrels of petroleum product that will be sold to distributors and marketers. While Vadxx will operate that facility, its expansion plans center around licensing the technology to other entities. The company estimates there's enough feedstock in the United States to build 1,500 Vadxx units, which would decrease the Nation's oil imports by 7 percent.

Vadxx president Jim Garrett speaks with President Barack Obama about the company's plastics recycling technology at the Manufacturing Advocacy and Growth Network, or MAGNET, Innovation Center in Cleveland. The president visited the town on March 18, 2015, to learn how businesses were benefiting from working with MAGNET, which helped Vadxx connect with NASA Glenn Research Center through the Adopt a City Program, itself a byproduct of the Obama administration's Strong Cities, Strong Communities Initiative.

And all those units would be environmentally friendly, according to Garrett. No hazardous byproducts are created, and, unlike most companies that flare off excess fuel gas, which contributes to global warming, Vadxx recycles that gas to provide 80 percent of a unit's heating needs. "From both an economic and environmental standpoint, it's a winner," he says. "The EPA [Environmental Protection Agency] classifies our unit as only a minor emitter, equivalent to a hospital boiler. And the key there is we're not burning feedstock but melting it in a vessel. It's not like we're building a new refinery where it takes 10 years to get the approval."

The future looks auspicious for the company, as the technology has generated enormous interest from waste disposal companies and large manufacturing facilities, which stand to gain by paying less money to truck material to a Vadxx unit than to the landfill. What's more, each unit is projected to make $8 to $12 million per year in revenue for its operator and provide 18 full-time jobs.

Besides the technical leg-up NASA gave the company, Garrett says there was another, more indirect benefit of having partnered with the Agency: credibility. "We'd kind of brag to people that we worked with NASA, and they say, 'Really? I may be interested in investing.' The NASA name has that kind of impact." ❖

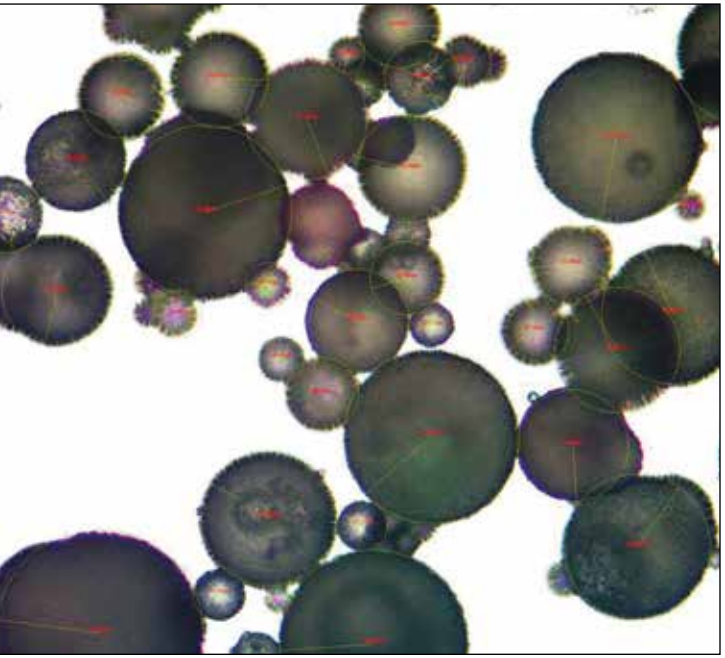
Tiny Capsules Enable a World of Possibilities

NASA Technology

Big opportunities sometimes come in the smallest packages.

In the early 1980s, NASA engineers and researchers from the Jet Propulsion Laboratory (JPL) and Marshall Space Flight Center were trying to devise a way to create hollow, spherical, latex microcapsules capable of containing live cells to use for time-released antibiotics or targeted doses of medication. The U.S. Army Institute of Dental Research had asked NASA for assistance in developing the capsules.

NASA found it nearly impossible to grow consistently spherical microcapsules larger than 10 microns on Earth due to gravitational interference, so instead the Agency turned to space. A team of scientists, led by chemist Dale Kornfeld from Marshall, created a machine that operated in microgravity, allowing the capsules to grow spherically instead of oval-shaped. The experiment, carried out on multiple Space Shuttle missions, proved capable of consistently growing larger spherical, latex microcapsules, up to 30 microns in size compared with previous spheres measuring 3 microns or less. The spheres became the first product made in space and sold on Earth, and the quality was so consistent that the U.S. National Bureau of Standards recognized the spheres as a national reference material for measuring 10 micrometers.



Microcapsules made from beeswax are a safe, natural way to enhance the flavor of a product such as grape juice.

Eventually, Kornfeld and his colleagues were able to create uniformly spherical microcapsules on Earth by incorporating a gentle stirring mechanism in their machine to prevent the latex spheres from sticking together, an innovation he patented.

Technology Transfer

In the mid-1980s, Joe Resnick had completed his undergraduate work at the University of Pittsburg and moved on to the Military College of Vermont, now Norwich University, where he studied on a NASA fellowship. He received a call from his mentor, Paul McWilliams, director of the NASA Industrial Application Center at the University of Pittsburgh, offering the opportunity to go to Florida and help the Agency formulate a new external coating for the wings of the Stealth Bomber.

It was during his time there that Resnick met Kornfeld and his team, and he began working to flesh out an idea he had for microcapsules made using beeswax, building on Kornfeld's work in space. Resnick obtained a license for Kornfeld's machine and began modifying it.

The system he developed forms the spheres out of liquefied wax using low-frequency sound waves, which break apart the stream of wax at regular intervals using a timer chip. Resnick's modified device also uses a proprietary method to counteract the effect of gravity on the liquid—think of the way soap bubbles always have a slightly heavier side when they break free from a bubble wand—keeping the capsules it forms perfectly spherical. Now up to 150 microns in size, the hollow capsules can be filled with live cells, powders, gases, or other materials. Resnick filed for a patent for his system in 1986, the first of 26 he'd go on to secure.

After patenting the device, Resnick teamed up with Pittsburgh-based Petrol Rem Inc. to market the Petroleum Remediation Product (PRP), beeswax capsules filled with a variety of yeast capable of breaking down hydrocarbon bonds in oil. The capsules repel water and absorb oil, which is consumed by the yeast and turned into water and carbon dioxide. When the internal pressure becomes too great, the capsules explode and release the harmless byproducts into the environment.

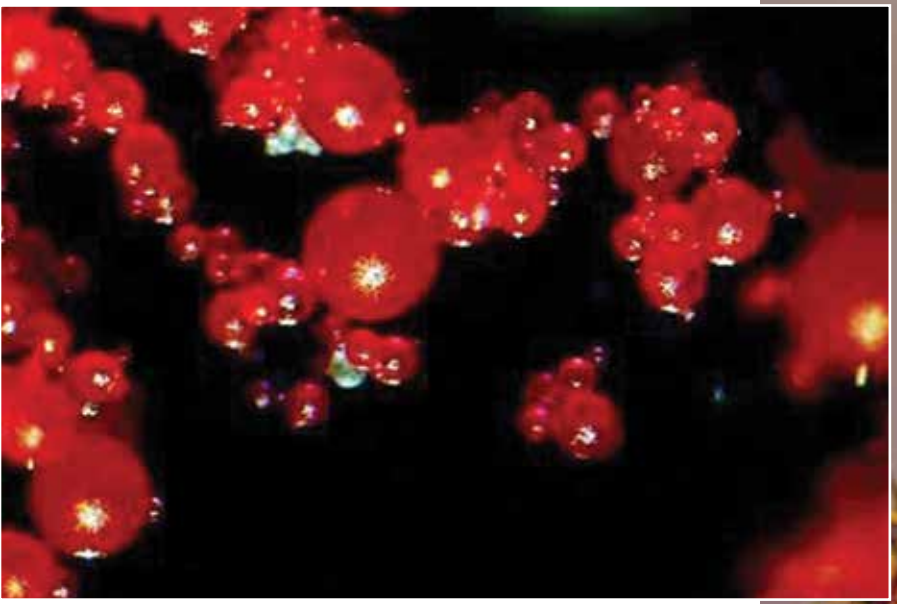
First used to remediate water in Prince William Sound in Alaska following the Exxon Valdez spill, PRP was later used to clean up the Gulf of Mexico following the Deepwater Horizon spill in 2010. Spun off into a series of products, including Bio-Sok, BioBloom and the Bio-Sok Bilge Maintenance System, PRP was inducted into the Space Technology Hall of Fame in 2008 (*Spinoff* 1994, 2006).

Resnick later started his own company, Lenoir, North Carolina-based RMANNCO Inc., to continue developing the microcapsules. Thanks to the availability of stainless steel tubing in ever-smaller diameters, the capsules can now be made in sizes ranging from 1 to 8,000 microns, or from one-fiftieth the diameter of a human hair to the size of an average ladybug.

Benefits

Being able to make the capsules smaller has increased their possible uses, Resnick says.

NASA had envisioned using microcapsules for time-released antibiotics, and Resnick has worked with medical companies on products incorporating microspheres that achieve that goal while also increasing the proportion of received medicine or vitamins that are available for use



NASA developed a method for making spherical, uniformly shaped microcapsules. Joe Resnick, a scientist and inventor, built on NASA's research and now works with companies to incorporate microcapsules into products ranging from foods and beverages to cosmetics, like these capsules used in lipstick to refresh color after application.

One new use of RMANNCO's microcapsules, made from beeswax, is a hybrid pollen made from wax and extract from the stevia plant. The pollen clings to the bees better than regular pollen, and the honey the bees make can be sold commercially for people who cannot consume regular honey.

by the body. The more efficiently the body can process a dose of medication, the more active ingredients in each dose can be reduced, he says, thereby decreasing the amount of medicine wasted and potentially shortening treatment time.

Resnick's improved microspheres can also be manufactured to adhere to substances, a feature that's attractive to food manufacturers. As he points out, food salted at the table tends to taste saltier than food prepared with an equal amount of salt, because the seasoning is on the surface of the food, rather than mixed in, and therefore hits the tongue first. Working on the same principle, Resnick has partnered with the North Carolina AgBiotech Center, located in Research Triangle Park in Raleigh, and Flavor Sciences Inc. of Lenoir to use the capsules to create new flavor enhancers. The ability of the capsules to preserve ingredients and stick to the food reduces the amount of ingredients wasted through aerosol or powder applications.

He's also worked with cosmetics manufacturers to incorporate the wax microcapsules in lipsticks. "Microcapsules are produced to enable microencapsulation of the basic tint used as the primary color or shade," he explains. "Once applied, the wearer can refresh the color simply by pressing her lips together, breaking the microcapsules open."

Most recently, Resnick has used his NASA-derived microspheres to develop a new supplemental food supply for the *Melipona beecheii* variety of stingless honeybee. Through research conducted in both the United States and Malaysia, Resnick has developed a hybrid pollen using waxy microcapsules—which cling better than natural pollen to the bee's bodies—filled with a synthetic stevia solution that can be used as a source of food for the bees during the winter and monsoon seasons, when other sources of pollen and nectar are scarce.

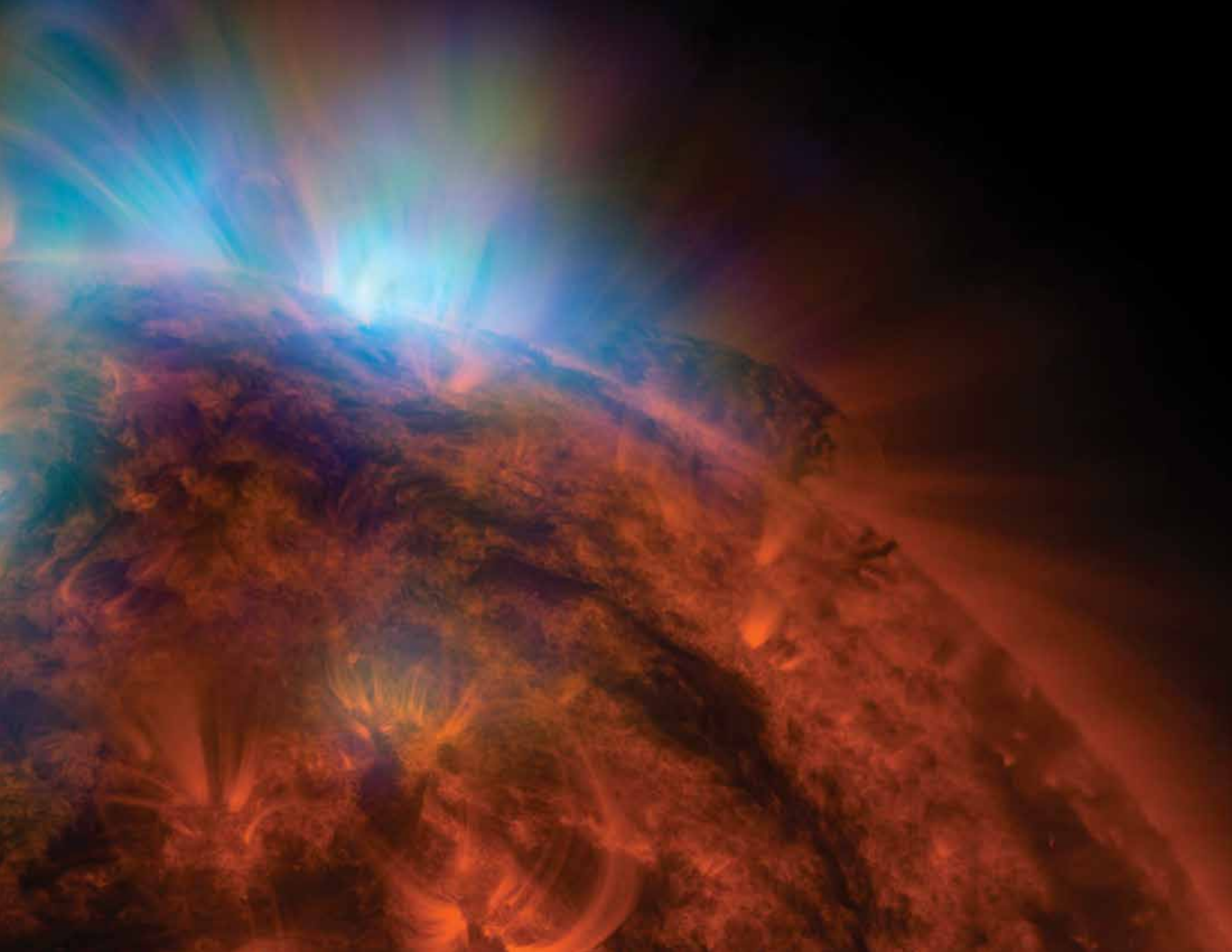
"Using the microcapsules as the delivery system, I can place any physiologically compatible substance into the microspheres and feed it directly to the bees," he says. Later, when the hive's honey is harvested, it could be packaged and sold as a specialty honey that, thanks to stevia's use as a food source for the bees, is suitable for consumption by people with diabetes.

Finally, Resnick also has been working on a treatment for working and military dogs injured in the field. The product, called Poochie-Peds, is made from beeswax microcapsules containing essential oils and antiseptics, and it works in just seconds to seal injuries to the sensitive pads on the bottom of dogs' feet, which can be fatal if left untreated for too long.

He credits NASA and his original partnership with the Agency for much of his success. "I just can't say enough good things about NASA," Resnick says. "I know firsthand the opportunities NASA innovation provides: for 30 years, I've worked with everything from monomers, isomers, and oligomers to oils, powders, sprays, and the heaviest gas in the universe, and I don't see an end to it." ❖

Information Technology

Whether monitoring mechanical systems worlds away, analyzing the dynamics of Earth's climate, designing vehicles that push the limits of sturdiness and efficiency, or modeling the behavior of air around vehicles in flight, NASA has a constant need for innovation in software and information systems. The products of these endeavors might find use in anything from optimizing wind turbines and predicting engine failures to cloud computing and targeting online advertising.



System-Health Monitor Predicts Failures before They Happen

NASA Technology

A young engineering and technical services company is betting that NASA teams at the Mission Control Center in Houston, aboard the International Space Station (ISS), and in Ground Support at Cape Canaveral—just about all of the Agency's Hollywood roles—will set a trend that explodes across private-sector industries.

In an era of "smart" devices capable of interacting with one another and developing an awareness of and reacting to their environments, what's still absent is any self-awareness in these technologies, says David Cirulli, engineering vice president and cofounder of Phoenix-based CEMSol LLC. The company name is shorthand for Comprehensive Engineering Management Solutions, which perhaps sounds a bit nebulous, but that may be due to the breadth of its software's potential reach.

"In the future, there's going to be an integrated system-health engine as part of every system out there, and it will be able to interface with other systems and components," Cirulli says. "That's missing today."

He equates system-health monitoring programs with the human ability to verbalize symptoms to a doctor.

The first version of what became CEMSol's Integrated System Health Management (ISHM) software was developed in 2003 at Ames Research Center to monitor an experimental hybrid rocket engine test bed that ran on both gas and solid fuel. Traditionally, this would have been accomplished by building models and running simulations.

"It's hard to build models of some things, so we figured, let's see if we can do it with the data automatically," says David Iverson, computer engineer with the Intelligent Systems Division's Data Sciences Group at Ames. To do that, he created what came to be called the Inductive Monitoring System (IMS).

Any system an engineer might want to monitor has sensors measuring factors such as temperature, pressure, fuel flow, voltage, and other vital signs, Iverson explains. The IMS program collects data from all those sensors and, by mining an archive of such data samples, determines relationships between these various factors and establishes a baseline and parameters for normal system behavior. Deviations from that norm suggest a problem and a possible failure in the near future.

"Our technology allows you to determine and detect known and unknown relationships and anomalies in any system," as Cirulli puts it. He notes that a human can understand the interrelationship of five to seven entities at most, while the data-mining software can see how hundreds of systems relate to each other.

The engine test bed was just a chance to test this new method, Iverson says. "It works for just about anything where you have data collection and some sort of normal baseline."

During a test launch of the Orion Crew Vehicle in December 2014, the Inductive Monitoring System (IMS) that CEMSol licensed to create its Integrated System Health Management (ISHM) software was used to monitor electrical systems on the space capsule.

“In the **future, things** will **be** much more **reliable, durable,** and **dependable,** because **they’ll** have a much **better understanding** of their **own behavior.”**

— David Cirulli, CEMSol LLC

The NASA-developed IMS that was the precursor to CEMSol’s ISHM software has been used since 2005 at the Agency’s Mission Control Center in Houston, where it now monitors more than a dozen different systems in real time.

Around 2005, a group at the Mission Control Center responsible for regulating spacecraft orientation—known as attitude control—selected IMS as a technology that might help sort out problems with a failing gyroscope. Iverson's group managed to enable the software to monitor the gyroscopes in real time, and the effort was a success.

By the time Mission Control started developing its own IMS models in 2012, Iverson's team had helped to apply the program to about a dozen systems there.

Now, the software is being integrated into the next-generation launch control systems at Kennedy Space Center, and it monitored electrical systems on the Orion capsule during its December 2014 test launch. It's also been applied to the F-18 fighter jet and the Black Hawk helicopter engine.

Also in 2014, a demonstration paired IMS with NASA's Hybrid Diagnostic Engine to let astronauts aboard the ISS monitor the carbon analyzer that ensures the safety of their drinking water. The project is preparation for deep-space missions, Iverson says. "The goal is to help the crew so that when they're a long ways away and have a long delay for communication, they can do more on their own of what's done on the ground now." He says the demonstration has so far been successful.

Technology Transfer

Seeing this sort of system-monitoring technology as the way of the future, in 2012 CEMSol licensed the program, which NASA had patented in 2008. Along with it, the company also licensed the Outlier Detection via Estimating Clusters software that Iverson developed as an extension to the IMS algorithm, along with the graphical user interface Ames had created.

CEMSol enhanced the program's presentation and developed two software packages—one as a desktop application and another as a software developer's kit. The desktop version uses a set of predefined functions to

The IMS that CEMSol licensed from Ames Research Center to develop its ISHM software has also been applied to the Black Hawk helicopter engine.

Image courtesy of the U.S. Navy

periodically import datasets and analyze them, charting data points and highlighting any that are outside the norm. The software developer's kit, meanwhile, can monitor systems constantly in real time. "It's a library of functions the programmers can choose from to perform whatever system-detection analysis functions they want to use," Cirulli says.

Having laid the groundwork for a final product since 2008, the company first offered its ISHM software for sale in late 2014. By then it already had its first major contract, with DSI International preparing to integrate the software into its eXpress system-health management application.

The integration of eXpress and ISHM provides a combination of model-based diagnostics and empirical diagnostics. Model-based diagnostics are based on engineering data for a system's design and are particularly good at identifying uncommon, first-time, or early failures that have not had sufficient empirical history. On the other hand, empirical diagnostics, because they're based on observation of previous problems in an existing system, are especially good at identifying issues that fall outside model-based diagnostics or finding trends that fine-tune the engineering analysis.

Benefits

In 2012 CEMSol teamed up with Ames and Lockheed Martin to try ISHM on the Lockheed C-130 Hercules military transport plane, which tended to have problems with the bleed valve that switches air flow between engines during start-up. Datasets were taken from start sequences for 16 of the planes over four years, including starter-system failures. These were fed into the program, which was subsequently able to predict a start-up failure three starts before it occurred.

By this method, the manufacturer doesn't have to redesign the part or introduce a new computer system, and the operator doesn't have to schedule a backup plane or wait for the valve to fail and then find another plane, Cirulli points out.

Lockheed Martin invested $70,000 in the test and quickly recouped 10 times that amount in reduced maintenance costs and mission delays.

"The reason it's so powerful is that it can detect subtle early-warning signs well in advance of a failure,"Cirulli says.

But he still sees ISHM as just a first step toward near-universal self-monitoring in everything from cell phones to medical devices, and from refrigerators to automobiles and snowmobiles. The company has even successfully used the software to analyze weather systems and predict snowstorms, thunderstorms, and dust storms. "So far, we haven't found any system it hasn't been able to work on," he says. He plans to feed several years' worth of data from his own blood work into the software to begin to determine if it could use patient data to predict health problems before they arise.

He compares the coming improvements in safety and reliability to the revolution in automobile quality that Toyota brought about in the 1980s, prior to which drivers were happy if a vehicle survived 70,000 miles.

"Historically, system-health management has been an afterthought," he says. "In the future, things will be much more reliable, durable, and dependable, because they'll have a much better understanding of their own behavior."

He credits Ames with contributing to this shift not only through its invention of the IMS software but also through the assistance it provided his company in turning it into a commercial product. "I can't tell you how good an experience this has been in terms of the support we received," he says, commending the "significant contribution and cooperation of the NASA Ames team in deploying this technology." ❖

Image courtesy of the U.S. Air Force

In 2012, CEMSol teamed up with Lockheed Martin to see if the company's ISHM software could predict failures of the bleed valve that switches air flow between engines on the C-130 Hercules during start-up. Lockheed Martin invested $70,000 in the test and recouped 10 times that amount in reduced maintenance costs and mission delays.

Algorithm Predicts and Evaluates Storm Surges

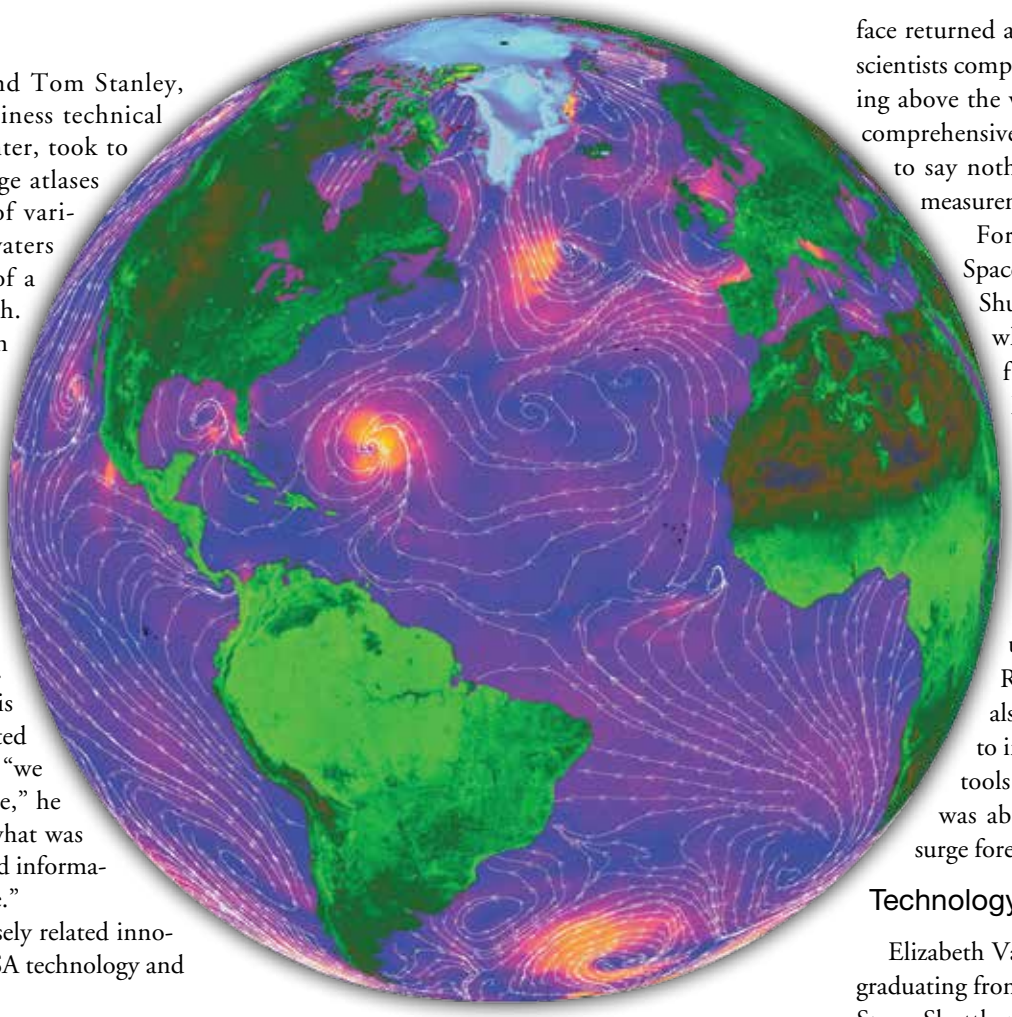
NASA Technology

It was sometime in late 2004, and Tom Stanley, technical monitor and small business technical advisor out of Stennis Space Center, took to studying newly completed storm surge atlases of the Gulf Coast. They consisted of various scenarios predicting how high waters would rise in areas during a storm of a certain strength and angle of approach. He zeroed in on his house, located on the central coast of Mississippi. "Hey, if we get a good Category 4 storm, we're going to have a 13- to 14-foot storm surge heading our way," he recalls saying to himself.

The following August, Hurricane Katrina made landfall, bringing with it a menacing storm surge. Based on what he had seen in the atlas, he knew he had to evacuate. Stanley was right. An 18-foot storm surge pummeled his region—and while his home was situated 12 feet above the ground, on pilings, "we had about six feet of water in the house," he recalls. "The good thing was I knew what was going to happen because I had very good information about for the potential storm surge."

The storm surge atlas and other closely related innovations have some of their roots in NASA technology and funding.

Around the turn of the millennium, NASA embarked on two missions that would have a large impact on Earth science. To facilitate research on global weather patterns and abnormalities, in 1999 the Agency launched the Quick Scatterometer, or QuikSCAT. The satellite's task was to send out radar pulses that would hit the ocean's surface before returning to its antenna; a rougher surface returned a stronger signal, while a smoother, calmer surface returned a fainter signal. The resulting data helped scientists compute the speed and direction of winds swirling above the world's oceans. QuikSCAT was far more comprehensive in collecting data than ships and buoys, to say nothing of its ability to provide continuous measurements regardless of weather conditions.



NASA's Quick Scatterometer, or QuikSCAT, was launched in 1999, and for 10 years it recorded ocean wind patterns, helping scientists to improve weather forecasts and glean more data on changes in vegetation and ice extent over land and in the polar regions. This false-color image is based on QuikSCAT measurements taken on September 20, 1999, with white streamlines indicating wind direction. Hurricane Gert is shown off the coast of Florida.

For NASA's second act, the following year Space Shuttle Endeavour undertook the 11-day Shuttle Radar Topography Mission (SRTM), which, at the time, resulted in the world's first near-global topographical map of Earth, detailing close to 80 percent of its land surface. The data would go on to be used in everything from navigation tools and wildfire management to simulation-based video games.

Advances brought by these datasets and other developments compelled NASA, under its Small Business Innovation Research (SBIR) program, to solicit proposals from companies that could utilize them to improve weather forecasting and evaluation tools for disaster management. One company was about to do just that by improving storm surge forecasting and post-storm analysis.

Technology Transfer

Elizabeth Valenti began working at Stennis soon after graduating from college in the late 1980s, working first in Space Shuttle main engine testing, then for remote sensing applications development. In 1997 she took a lead engineering job on center with User Systems Enterprises, a company specializing in the application of radar-based remote sensing products and services. She wound up purchasing the weather-related portion of the company in 2000, rebranding the firm as WorldWinds Inc. The company remained on the Stennis campus, setting up

Using NASA SBIR funding, WorldWinds drew on newly available observational data to develop StormWinds, a program that can provide accurate storm surge simulations as well as hindcasts, which remodel the winds and storm surge in the aftermath of a tempest. StormWinds created this pictograph showing the peak storm surge water levels caused by Hurricane Sandy in areas of New Jersey and New York in late October 2012.

shop at a small-business incubator called the Mississippi Enterprise for Technology.

From the onset, it was her goal to take advantage of all of the new data being made available by NASA and other government agencies to improve atmospheric and oceanographic forecasting and analysis. So when the 2003 SBIR call came out asking for ideas, Valenti and WorldWinds' chief scientist Pat Fitzpatrick already had one in mind: to advance storm surge forecasting through improved wind-field modeling and better terrain information.

Developed in the early 1990s by the U.S. Army Corps of Engineers and researchers at the University of North Carolina at Chapel Hill and at the University of Notre Dame, the Advanced Circulation and Storm Surge Model, or ADCIRC, is open source software that Federal Emergency Management Agency (FEMA) and other Federal outfits utilize for disaster preparation. One of its strengths, according to WorldWinds' senior meteorologist Benjamin Jelley, lies in its ability to assess terrain near the coast, which affects how a storm surge behaves. The

feature could be anything at all, from hills and trees to seemingly minor manmade infrastructure. "Take a railroad bed," he says. "In a coastal town, it acts as a berm or a levee that either piles up water or redirects it, protecting people and property on the other side."

The program's other strength, Jelley says, and one that he says separates it from other Earth science models, is that ADCIRC "allows for orders of magnitude-varying resolution." In other words, he explains, it can simultaneously compute complex urban areas, which contain changing terrain that is more computationally challenging, and uniform regions such as the waters off the Gulf of Mexico, which require fewer computations.

ADCIRC's abilities make it a powerful tool for predicting the damage that would be caused by a hypothetical hurricane's wind strength and surge, but WorldWinds, with the help of NASA SBIR funding in 2004, took advantage of the influx of new data to increase its capability even further.

First, they used topographical data derived from NASA's SRTM mission—data better than anything that had been available—as an ADCIRC input to increase the resolution of the terrain, which helped to provide greater accuracy for modeling storm surge water height, the result being the flood atlas that Tom Stanley gained insight from before Hurricane Katrina visited his home.

Their second task was aimed at creating an input for ADCIRC that took advantage of all the available wind-related data for a storm that had already occurred, creating what meteorologists call a hindcast. If it's a good hindcast, it's able to precisely remodel the winds and, because it's wind-driven, the storm surge, in any given area of a storm's path. (At the time, ADCIRC took advantage of some wind-driven data, but not all.)

For accurate wind and flooding hindcasts, WorldWinds needed exact data that reflected all the dynamics involved, specifically the wind speed and direction. "In a real storm, the winds vary depending on their location within it," explains Valenti. "Having lived through many storms on the Gulf Coast, we know that the strongest part of the storm is the eye wall and the northeast quadrant, which usually has higher winds than the rest of the storm. All those little details have to be taken into account."

> "We're very proud that we're able to tell people what actually happened [after a storm]. We like to say we're in the truth business."
>
> — Elizabeth Valenti, WorldWinds Inc.

The company formulated an algorithm that draws on a multitude of modern wind measurement-gathering sources, including National Oceanic and Atmospheric Administration buoys, airport observations, university wind stations, and real-time data from NASA satellites, including QuikSCAT (although Marshall's Short-Term Prediction Research and Transition Center now provides that input). With those overlapping streams of data, they were able to develop an algorithm capable of "depicting all of the vagaries of a storm over time, as it crosses the ocean and makes landfall," says Jelley, adding that it can log the impacts of wind at very high resolutions every 15 minutes.

Benefits

Having successfully tested their proprietary wind-based algorithm, in 2007 WorldWinds announced a new product called StormWinds, which takes advantage of the firm's 852-processor cluster (equivalent to 2,000 desktops strung together) to assist with a number of critical storm-related issues. For one, the company can run the program ahead of landfall to help local officials minimize the impacts to their communities.

Image courtesy of the U.S. Navy

The tool is also helping homeowners know whether water or wind caused damage to their home and which insurance claim to pursue: Federal flood insurance or private homeowners insurance, which covers wind damages. "There's always the debate of wind versus water," Stanley says, adding that the issue boiled over a few years ago when the Federal flood insurance program was going bankrupt. What typically has happened after a storm,

U.S. Navy air crewmen survey the damage inflicted by Hurricane Katrina, the costliest storm in the Nation's history, en route to Stennis Space Center. Using its StormWinds application, WorldWinds provided complimentary "Wind vs. Water" profiles for homeowners along the Gulf to help them settle claims for flood and wind damage.

he explains, is a lot of confusion about what specifically caused damage to the home. "The private insurance companies and the Government want to pay for their share of the damage, as long as they can calculate the right payment allocation for flood loss versus wind loss."

WorldWinds provided complimentary "Wind vs. Water" profiles for homeowners along the Gulf Coast after Katrina and other major storms. As far as Valenti is aware, these reports were accepted 100 percent of the time by insurance companies to settle the homeowner's claim.

As for how the analysis is received by Federal and private insurance organizations, everyone recognizes that the ADCIRC storm surge model and wind profile information is Government-sanctioned, and that all these scientific details are included in their reports. "We're very proud that we're able to tell people what actually happened. We like to say we're in the truth business," says Valenti.

But they're also in the disaster planning business. For the past five years, the company has been working as a subcontractor to three FEMA prime contractors and assisting with redrawing the storm surge maps for both the Gulf and the East Coast. The maps, which show the potential for flooding in areas based on various storm characteristics, are used by the National Flood Insurance Program to determine flood insurance rates and by officials to decide on evacuation procedures and on where they should focus their preparation efforts.

Valenti says the local government in Slidell, Louisiana, comes to the company a day or two before a storm to receive a briefing on which areas of the city are likely to flood. In 2012, before Hurricane Isaac made landfall, officials, after seeing the simulations, discovered there was going to be storm water inundating U.S. Highway 11 in south Slidell. In response, they closed off the highway with a line of Hesco baskets filled with sand to keep the storm surge from Lake Pontchartrain from inundating homes. The move proved successful, as it prevented the water from overtaking roads and property.

That kind of result makes Valenti proud. "We know that we make a difference," she says. ❖

Mars Rover Work Spawns PDF Collaboration Software

NASA Technology

Like satellites in orbit, some spinoffs just keep spinning.

Alliance Spacesystems, founded by a handful of engineers from NASA's Jet Propulsion Laboratory (JPL) in 1997, has become a major supplier of satellite flight hardware and other high-tech composite structures. But a tool the company's engineers designed just to make their own lives easier has successfully spun off into a completely different line of work.

Among Alliance's first projects were the robotic arms for NASA's twin Mars rovers, Spirit and Opportunity. The company, which had fewer than 20 employees at the time, had two years to design, build, and deliver the arms.

"Having engineers coming from JPL who are all very bright and talented, when they're under a lot of pressure, they get creative," says Richard Lee, CEO of Bluebeam Software, the company that arose from that creativity.

Former Jet Propulsion Laboratory Engineers at Alliance Spacesystems created the first Bluebeam software to help them meet tight deadlines for designing the robotic arm for the twin Spirit and Opportunity Mars rovers in the late 1990s. The engineering-geared PDF reader soon spun off into its own company and popular product line.

Alliance wanted to become more efficient in mundane tasks like reviewing, marking up, and circulating documents and drawings, as well as converting information from computer-aided design (CAD) software like AutoCAD into PDF format. This would free up more time for actual engineering.

"We were significantly challenged as a small team trying to get a large amount of work done in a short time," says Brett Lindenfeld, the former JPL mechanical engineer who was Alliance's project director for the robotic arms. "We just didn't have the months to do it and didn't have the people—that's the bottom line."

Lindenfeld is now vice president of operations for Motiv Space Systems, yet another company that spun off from Alliance.

Adobe Reader was already popular in those days, but no one had developed a PDF program to meet engineers' needs, he says. "We just weren't happy with the way we had to create those PDFs or the way they came out." As computer-automated machining became more popular, the machine shops making the parts Alliance designed wanted three-dimensional CAD models, as well as two-dimensional drawings. But these were often degraded when they were converted from one program to another, resulting in models and drawings that didn't quite match.

So Lindenfeld and some of the company's other engineers built technology that would later lay the foundation for Bluebeam's first product, Pushbutton PDF. With the click of a button, the plug-in would convert CAD models into high-resolution, scalable drawings. The evolution of the software has brought enhancements such as the ability to view, manage, and mark up rotatable, three-dimensional models while including data describing parts and materials, any other relevant properties, and hyperlinks for easy document navigation.

"Basically, that PDF is embedding all your data, and you don't have to worry about it getting separated or lost between the two," Lindenfeld says.

The creators saw opportunity in what appeared to be a neglected market.

"We were focused on ourselves as engineers, but it looked like there were other markets that could use this," Lindenfeld says. Lee, a friend, was brought on board to help turn what had begun as a way to meet a NASA product delivery deadline into a product in its own right.

Technology Transfer

Bluebeam Software Inc. was founded in 2002 and cultivated a customer base not just in engineering but also in industries like architecture, construction, and oil and gas. Pushbutton PDF was followed by Revu, an application focused on the technical review process. Revu allows and tracks symbol-based document markups from multiple parties simultaneously or separately. This allows real-time collaboration between the field and the office, or among multiple offices around the world.

"In the construction business, for example, you have literally hundreds of people running around with iPads and adding comments to drawings," Lee says.

Bluebeam's current primary offering, Revu also includes other tools for PDF creation and markup, as well as project management, in one cloud-supported application. Its most advanced edition, eXtreme, allows users to include features like batch processing, PDF form creation, and redaction among other functions. Bluebeam Vu, meanwhile, is a high-speed PDF viewer that the company offers for free download.

Bluebeam Q automates PDF production from source files, bFX is a protocol that allows integration of Revu with document and data management systems as well as third-party software, and Studio Enterprise allows collaboration behind a firewall in a locally hosted environment.

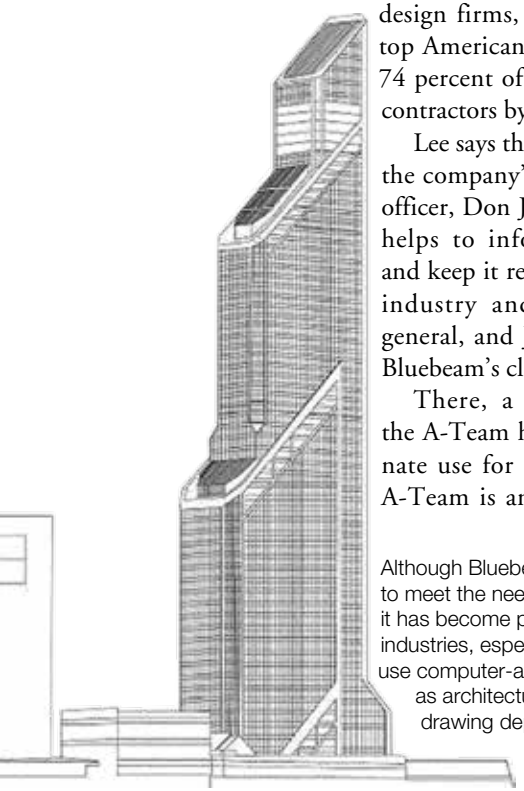
Lee says the company's largest client base remains in fields where AutoCAD is dominant, but it has also found a place in government and business, where the software reduces paper waste and increases efficiency.

Benefits

Bluebeam has steadily grown by about 50 percent every year, and in October 2014, German software provider Nemetscheck bought the company for an even $100 million. By then, Bluebeam claimed more than 650,000 users in 96 countries, and it employed about 150 people in four office locations. By the company's numbers, Revu was used by 58 percent of the top international design firms, 64 percent of the top American design firms, and 74 percent of the top American contractors by revenue.

Lee says the 11-year span that the company's chief technology officer, Don Jacob, spent at JPL helps to inform the software and keep it relevant to the space industry and engineering in general, and JPL is also among Bluebeam's clients.

There, a group known as the A-Team has found an alternate use for the software. The A-Team is an ad hoc group of specialists from different backgrounds that holds sessions for brainstorming or feasibility studies to address NASA's priorities. It's actually a different group with each iteration, depending on the topic at hand. Around mid-2013, systems engineer and space architect Raul Polit-Casillas, an A-Team core member, and A-Team lead John Ziemer were tasked to come up with a better way to facilitate these discussions. Polit-Casillas had seen Revu advertised in a magazine, and it wasn't until much later that he learned of the software's NASA origins.



Although Bluebeam was created to meet the needs of engineers, it has become popular in other industries, especially those that also use computer-aided design, such as architecture. This AutoCAD drawing depicts the Mercury City Tower in Moscow.

Image courtesy of Edvard Wlodyga, CC BY-SA 3.0

Rather than use Revu to allow collaboration by parties in multiple locations, the A-Team primarily uses it like a sort of endless whiteboard to facilitate meetings. "Bluebeam was not meant to do this, but it's worked very well, to have many people working on a document in a collaborative way," Polit-Casillas says. From their tablets, participants can add text, tags, images, links, diagrams, and other material for all to see, and each can flip back or forward through the material. Actual electronic whiteboards and other devices can also be tied in. The team calls this approach "A-Language."

"With all those things together, it's kind of like a living document," Polit-Casillas says.

Lindenfeld says aerospace, where the software originated, is a natural birthplace for such innovation, as it's a field that constantly requires creativity to overcome complex engineering challenges. He is especially pleased that the software he helped to pioneer has also become a major tool for the construction and architecture industries.

"It's really neat to see industries that have historically not been able to immediately capitalize on available technology being propelled forward by advancements from an industry that has to innovate," Lindenfeld says. "I don't think it was happenstance that this started with NASA work." ❖

One of Bluebeam's earliest and most important features is the capacity to convert three-dimensional computer-aided-design models into high-resolution, scalable PDF drawings.

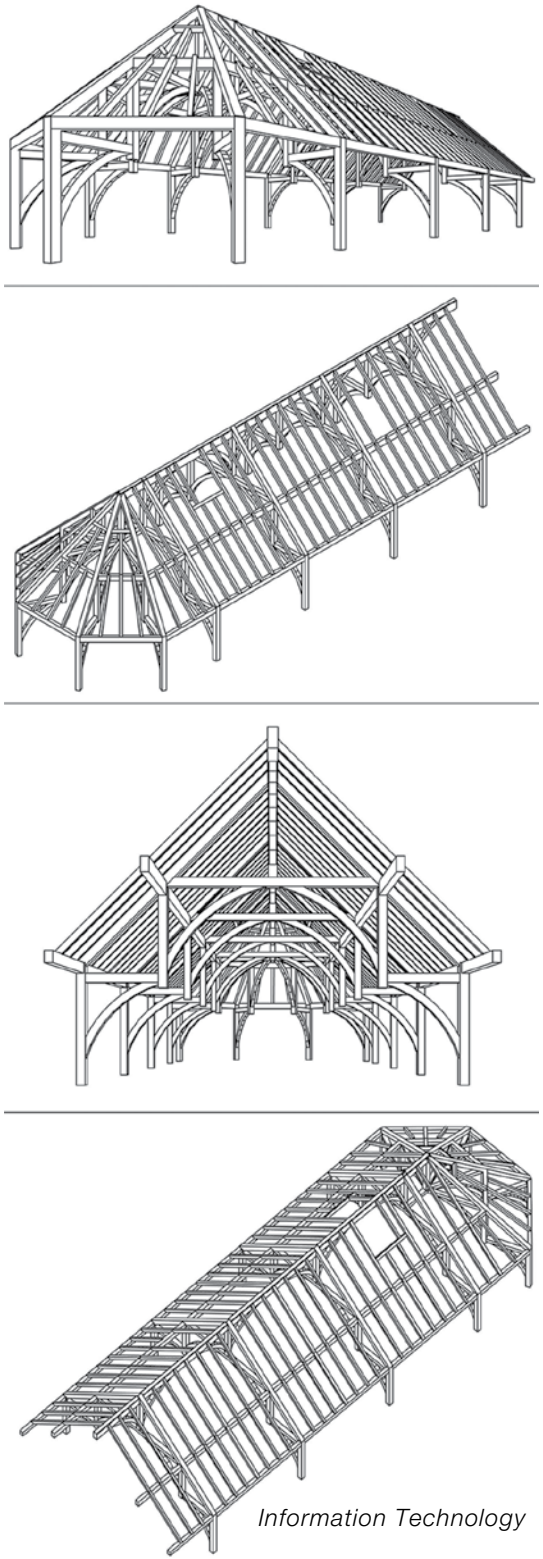


Image courtesy of Vermont Timber Works, CC BY-SA 3.0

Open Source Tools Popularize Infrastructure for Cloud Computing

NASA Technology

When a small group of NASA software developers met with representatives of Rackspace Inc. at a Thai restaurant in early 2010, few would have predicted that the unassuming partnership they formed would change the face of an entire industry. Just a few years later, however, OpenStack—the open source cloud-computing platform they created—is living proof that it did. The software's diverse user base, for example, includes CERN, Europe's research organization famous for its particle-smashing colliders; Walmart's entire online shopping operation; and the Wikimedia Foundation, which runs Wikipedia, one of the world's most visited Web sites.

Cloud computing came into its own as a technology starting at about the end of the 2000s. As the metaphor implies, it signifies the centralization of hardware and software resources (in the "cloud") apart from individual devices that utilize them. There they can be more easily secured, efficiently managed, and frequently upgraded.

In 2009, when NASA determined it needed a cloud-computing platform for internal Web services, the industry landscape was dominated by a few large players, all of whom were offering proprietary solutions. NASA's team of developers believed that an open source alternative could potentially address the needs of a broad and very large community, encompassing everyone from academic and government researchers to large and small businesses. As there didn't exist any such alternative in the market, they set out to create it themselves.

It was an ambitious goal, and the developers' open source idealism caught the attention of Rackspace engineers, who were attempting a similar project on their own in order to bolster the company's core business of hardware sales and services. Representatives of the company reached out to the Space Agency in 2010, and within a couple of months NASA and Rackspace's collaboration was born, resulting in OpenStack and later followed by the formation of the independent nonprofit OpenStack Foundation to foster its development (*Spinoff* 2012).

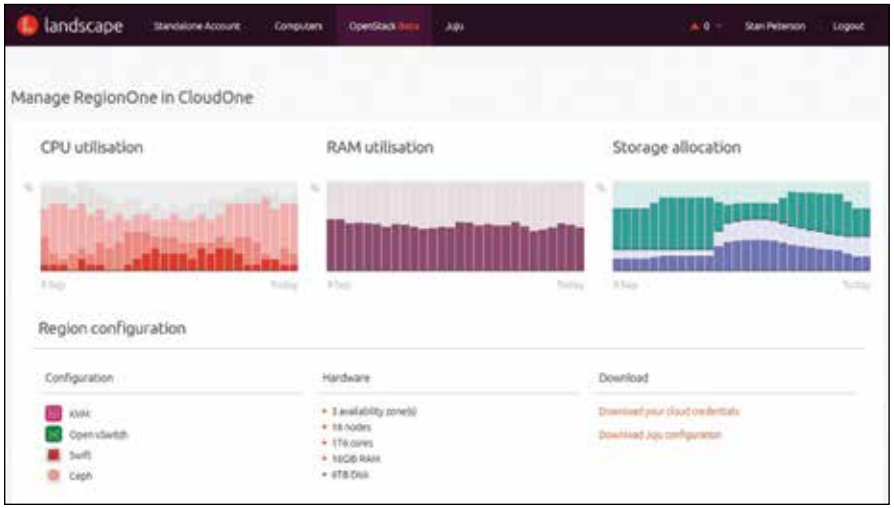
Technology Transfer

Among those at Rackspace who participated in the partnership was, coincidentally, an engineer who had recently held another job working on cloud technologies at Canonical Ltd., an international organization based in the United Kingdom with offices in Boston. The company is best known for Ubuntu, a Linux-based operating system found in desktop computers, mobile devices, high-powered machines such as servers and supercomputers, and public cloud infrastructure like that run by Amazon Web Services. Like NASA and Rackspace, Canonical was at the time exploring cloud computing, with a particular interest in fostering open source development within that space.

"In 2009, Ubuntu was very focused on Amazon Web Services and pushing hard into providing tools to allow people to create Amazon-compatible cloud infrastructure," explains Mark Baker, cloud and OpenStack product manager at Canonical. "We're by far the most popular operating system on Amazon."

Canonical's early foray into this area, a technology called Ubuntu Enterprise Cloud, was actually used by NASA as the Agency's developers created what would become OpenStack. By 2011, however, OpenStack's development had outpaced that of its alternatives, and Canonical executed a transition to make OpenStack the engine for Ubuntu's in-built cloud-computing platform. It began by integrating OpenStack's software packages into Ubuntu's repository, where anyone could download them, says Baker. "But it soon became clear that, in order to get businesses that aren't focused on technology to understand how they could benefit from using OpenStack, we needed to create a polished product that is easy to deploy, use, manage, and scale."

"Early adopters of OpenStack were technically savvy and had the depth in engineering to make it happen," adds Arturo Suarez, a product manager at Canonical. "Big names like AT&T, eBay, and Hewlett-Packard. As recently as 2013, using OpenStack meant manually coordinating a dozen pieces of technology and getting



Early adopters of OpenStack were typically big companies that could devote entire engineering teams to making it work smoothly. Canonical's free and open source distribution of OpenStack combines the platform's power with ease of use. Users can progress from downloading the files to a completed installation within a few mouse clicks, and Canonical provides intuitive, graphical interfaces to control every aspect of its cloud resources.

them to talk to each other across many servers. Even installing it was beyond most organizations."

In the fall of 2014, Canonical announced a new evolution in its distribution making OpenStack available to the masses: a suite of software known as the Canonical Distribution of OpenStack, which delivers an automated and integrated means of deploying, scaling, and operating OpenStack in conjunction with third-party technologies.

"The tool we've developed allows people to go from downloading OpenStack to building a functioning cloud in around four clicks," says Baker. "We provide a simple but intuitive dashboard that gives you control over how much storage and compute you're allocating out of what's available, as well as tools to add or remove capacity."

Baker and Suarez are quick to note that, for companies looking to push the limits of scalability and performance, the Canonical Distribution is not yet a replacement for a smart team of engineers. "It's great for that part of the market wanting to build and operate OpenStack in conjunction with third-party technologies," says Suarez.

Benefits

Even before the announcement of the Canonical Distribution, Ubuntu was by far the most popular operating-system layer beneath OpenStack deployments worldwide. According to a user survey conducted by the OpenStack Foundation in November 2014, Ubuntu underpinned 64 percent of deployments, more than three times the share of its closest competitor. With its new product, the company hopes to see instances of Ubuntu-based OpenStack deployments increase still further.

Among the software tools paired with OpenStack in the Canonical Distribution is a graphical dashboard for monitoring and managing hardware, computing resources, software upgrades and patches, and any disruptions to service. The software allows remote control over, and even the automation of, processes that until now required engineers to visit a data center to manually work on physical machines. It can also configure and integrate applications running in the cloud and coordinate how those applications are delivered to the outside world.

But more than providing polish and enhancements to OpenStack, the Canonical Distribution serves as the heart of a tightly integrated and expanding set of services that the company now offers.

For bigger companies with demanding scaling and performance needs, there is Canonical's service called Extreme OpenStack. "We have helped very large businesses implement OpenStack," says Suarez, noting that the company's resulting portfolio demonstrates that it stands ready to help still others push the limits of the software's capabilities.

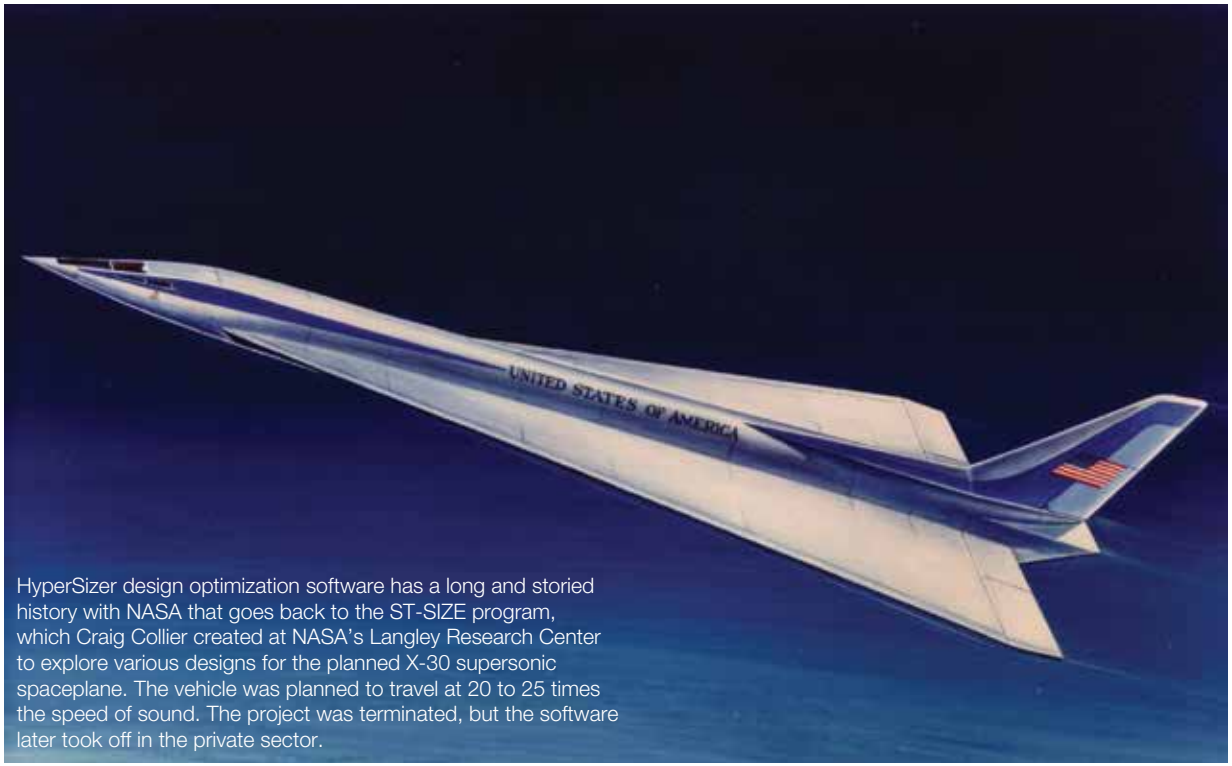
Businesses with more typical requirements can purchase a full-service cloud deployment, built and managed by Canonical, for a standard monthly fee. Called BootStack, the service lasts as long as the client needs someone to manage their cloud for them, but as soon as they are "ready for us to hand over the keys," says Baker, Canonical will train the client's staff to take over and ensure a smooth transition.

For those sitting on the fence, Canonical offers training in classrooms or onsite at the client's place of business, as well as flexible pricing plans to let customers try out the technology. The company can then decide whether to run its own cloud, purchase Bootstack services to let Canonical run it, or just abandon it altogether without investing additional resources. "We try to make it easy for our customers to analyze the cost of the specific services they are running and make educated decisions on where to run them," says Suarez.

Now a billion-dollar technology in its own right, OpenStack continues to evolve and develop at a furious pace. "It's fair to say that OpenStack is just getting going," says Baker. "There are a lot of places it can go, and a lot of us in this space are aiming to make it more broadly accessible to organizations over the next few years." ❖

The Canonical Distribution manages and even automates many tasks that until now have required engineers to visit data centers.

Software Optimizes Designs from Spaceships to Wind Turbines



HyperSizer design optimization software has a long and storied history with NASA that goes back to the ST-SIZE program, which Craig Collier created at NASA's Langley Research Center to explore various designs for the planned X-30 supersonic spaceplane. The vehicle was planned to travel at 20 to 25 times the speed of sound. The project was terminated, but the software later took off in the private sector.

NASA Technology

Sharing computer code with the private sector has become a major component of NASA's Technology Transfer Program, with the Agency's latest software catalog including more than 1,000 programs available for free. NASA also licenses some of its most successful programs, but when Craig Collier was developing the ST-SIZE computer program for Langley Research Center in the late 1980s and early '90s, the Agency had never before issued a software license.

Collier was part of a team working on the National Aerospace Plane, known as X-30. This was to be a "single-stage-to-orbit" vehicle, capable of flying into low-Earth orbit at 20 to 25 times the speed of sound and returning for a runway landing. An unconventional vehicle required unconventional designs, and the ST-SIZE software was created to help determine the best materials and configurations to keep the spaceplane as light as possible. "We had to have a tool to be able to very rapidly estimate how much it was going to weigh," Collier explains.

Budget cuts resulted in the termination of the X-30 program in 1993, but NASA has continued to have an influence on the development of later iterations of what became a widely used design tool. Recently, engineers at the NASA Engineering and Safety Center, also located at Langley, used a version of the program to create alternate designs for the Orion Multi-Purpose Crew Vehicle and its heat shield carrier. A number of features were added to the software to facilitate the design of a capsule that would careen back into Earth's atmosphere at almost seven miles per second, reaching temperatures of more than 4,800 °F and finally smacking into the ocean surface.

While the spaceplane may never have taken off, ST-SIZE did, under a new name.

Technology Transfer

Following the cancellation of X-30, Collier went on to found the Newport News, Virginia-based Collier Research Corporation, which, in 1996, obtained a license for ST-SIZE, becoming the first company to license NASA software. "I just wanted to keep working on the code," he says. "You're young, and you're bold, and you're fearless, and I had always desired to be able to create something as a tool-builder."

He says, "I was looking for new applications for the code at the time, but I didn't really have a practical sense about how to take a code made for a hypersonic vehicle and apply it to more practical purposes." At a time when industry had little interest in even supersonic vehicles, considerable alterations had to be made to the program.

Retooled and repackaged as HyperSizer (*Spinoff* 1997, 2003, 2009), the program was marketed as a design optimizer, one that could calculate the weights of different vehicle configurations based on their materials and also suggest design changes according to the loads a structure needed to handle. Beginning in 2005, Langley and Glenn Research Center funded improvements to the software through the Small Business Innovation Research (SBIR) program that would make it more versatile and better suited to design alternate crew capsules.

In its current form, HyperSizer can tell the user how laminates should be stacked, how thick the metal should be in a given area, how thick flanges need to be, how far apart stiffeners should be spaced, and other structural details. Thanks to a 2010 NASA SBIR contract, it is also able to alter designs for manufacturing ease, minimizing

Beginning in 2007, NASA engineers used HyperSizer to design the Orion Composite Crew Module, a carbon-graphite alternative to the original aluminum-lithium capsule. In 2012, HyperSizer was again employed to design a lighter heat shield carrier for Orion. Both projects resulted in significant improvements to the software.

"This tool allowed **us** to **explore** many **more** different **options** in **the time** we had **available."**

— Mike Kirsch, NASA Engineering and Safety Center

the number of ply cuts, ply drops, and layers of laminate and the number of starts, stops, and turns the factory's tape head will have to make when cutting the parts for the body.

"We optimize to create very large pieces to eliminate all that specialized cutting," Collier says, adding that the program now includes a slider that allows the user to prioritize weight versus ease of manufacture, to varying degrees. "What we put into the designer's hands is the ability to find his balance for his product."

Previously, the software was normally used in conjunction with the Nastran finite element modeling program, which models static load distribution. To allow modeling of the brief, jarring impact of the capsule's splashdown, Collier's company equipped HyperSizer to import data from the LS-DYNA program, which models dynamic load distributions.

The work on the capsule and its heat shield carrier also resulted in other capabilities being added to the software, such as the ability to analyze for plasticity and snap-through buckling, Collier says.

Benefits

"This tool allowed us to explore many more different options in the time we had available than we could have otherwise," says Mike Kirsch, deputy director of the NASA Engineering and Safety Center, whose team used HyperSizer to help explore alternate materials and configurations for the Composite Crew Module. Years ago, he says, the work would have required a multitude of spreadsheets, databases, and hand calculations.

The original capsule was designed with an aluminum-lithium pressure vessel, but NASA leadership was curious how a carbon-graphite alternative might perform. When Kirsch's team members undertook to design the alternative vessel in 2007, they didn't think it would be feasible, but using HyperSizer, he says, "We were able to get some data to say we could overcome those concerns."

HyperSizer recently found its first terrestrial application in helping to design blades for wind turbines. In 2014, Collier Research Corporation signed a contract with the country's largest wind turbine manufacturer.

Image courtesy of Scott Tere12sl, CC BY-SA 2.0

In 2012, he led another team in an effort to design an alternate heat shield carrier for the Orion Multipurpose Crew vehicle that would shed 800 pounds from the original 3,100-pound carbon-graphite design. They ended up with an all-titanium configuration that weighed just 1,600 pounds. "It was the HyperSizer code that allowed us to come up with that," he says. "It allowed us to compare all different varieties of configurations. We could compare and select the one we thought had the best advantages."

Jim Jeans, president of Structural Design and Analysis Inc., who was contracted as technical lead for the projects, says he resisted HyperSizer when he was first introduced to the software. Now, he's not only adopted it for use in his company but he's also become a reseller for the program. "I've come full circle," he says. "I think it's a great program, and I see a huge market out there."

Jeans says it would be hard to imagine redesigning the heat shield carrier, with its approximately 20,000 analysis zones, without the program's help. "I'm not sure we could have done it any other way," he says. "And I think it enabled one person to do the work of what used to take a pretty good-sized team."

NASA is far from the company's only client, though. Collier notes that Boeing, SpaceX, and just about every other American company designing space transport vehicles uses HyperSizer, as do many commercial aircraft companies. It has helped to design Bombardier's Learjet and Global 7000/8000 planes and Virgin Atlantic's GlobalFlyer. In all these applications, the company, whose motto is, "20 percent lighter structures in 20 percent of the time," has saved its clients untold time and money, from the design process to manufacturing and vehicle efficiency.

The program has also found an additional use lately: "What's happened in the last, say, five years, is that our software can also be used to automate the analysis necessary to get certification of flight-worthiness," Collier says. HyperSizer is able to generate the reports that show the Federal Aviation Administration how a user evaluated a structure's integrity.

Image courtesy of JetRequest.com, CC BY-SA 3.0

Bombardier's Learjet is one of several commercial planes designed with the help of Collier Research Corporation's HyperSizer software.

And, most recently, the software has found an entirely terrestrial application. "We have been successful in taking the software and having it applied to wind turbines in a big way," Collier says, noting that the company recently signed a contract with the largest wind turbine manufacturer in the country.

There is a general consensus in the wind industry that turbine blades, particularly the increasingly large ones, are not as reliable as they should be, Collier says, adding that structural integrity and weight are major factors that HyperSizer can improve. "That's very satisfying, to bring our product into an industry we didn't grow up in."

He says the company is also making efforts to expand its presence in the automobile, rail, and shipbuilding industries.

Already, though, NASA's first licensed software earns an estimated annual revenue of around $4 million and is used by companies in 20 countries around the world. ❖

NASA Climate Analytics Support Biological Research

NASA Technology

Every few seconds, NASA's satellites transmit more than a gigabyte of data back to Earth. By 2030, it's estimated the Agency will have amassed 350 petabytes of climate-change data alone. In consumer speak, consider that a single petabyte is roughly equal to the digital storage space taken up by 100,000 high-definition movies.

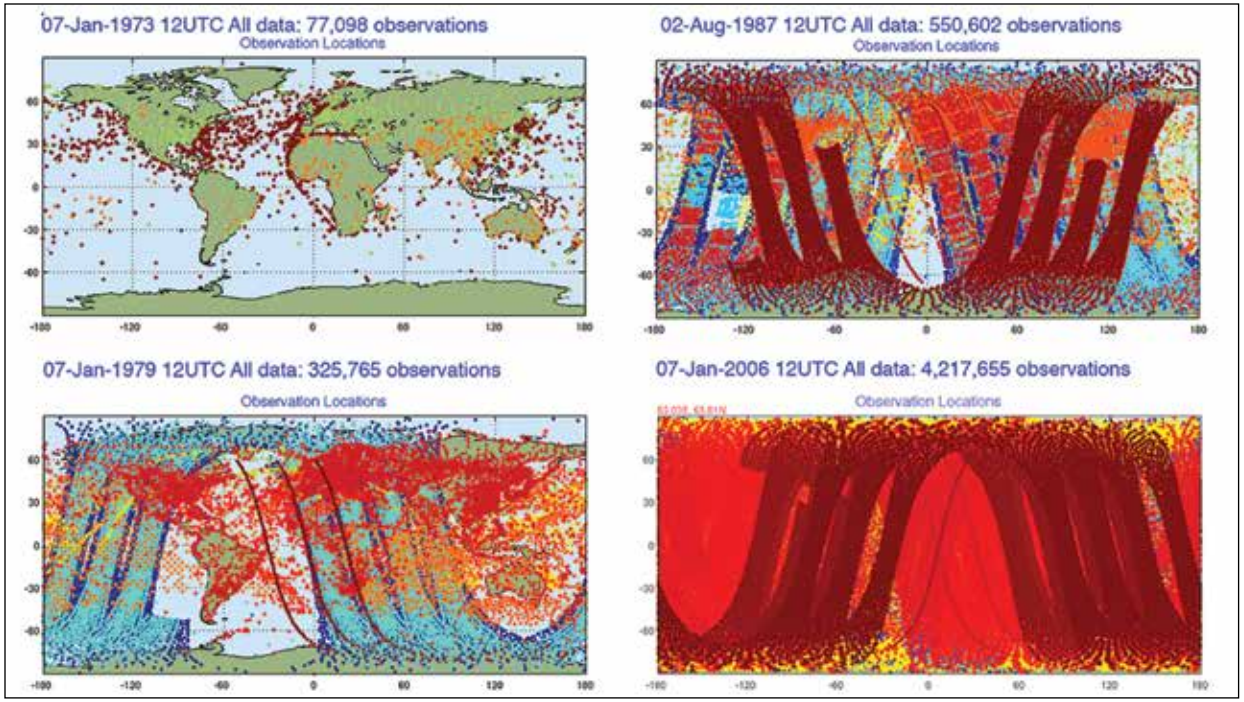
As NASA continues to accrue more satellite data, so do various programs that utilize them. One of those is MERRA, shorthand for Modern-Era Retrospective Analysis for Research and Applications. Run out of Goddard Space Flight Center's Global Modeling and Assimilation Office since its inception in 2008, MERRA integrates data from a variety of satellite systems into numerical models to recreate a synthetic data record of the weather.

MERRA so far has generated about 200 terabytes' worth of what climate scientists call reanalysis data, with another 2 or 3 terabytes being added each day.

"The models attempt to capture the physics that describe the atmosphere," explains Goddard senior computer scientist John Schnase. He says about 120 observation types, including satellites, radiosondes, aircraft, balloons, ship and ocean buoys, and land surface observations, provide input for MERRA. "MERRA provides global coverage. It takes the whole world and divides it up into grids and layers from the surface all the way through the stratosphere and then computes the physics going on—the heat transfers and the pressures and the moisture content."

Through this reanalysis, MERRA outputs 400 variables roughly every six hours. And it provides those results on either a worldwide or a regional level for any given timeframe from the beginning of the satellite era, in 1979, up to today.

The utility of all that data cannot be overestimated. Suppose a researcher wanted to figure out why corn yields in Nebraska were so low in 1983, Schnase posits. He or she might want to use MERRA data to examine various environmental conditions during that time, such as wind speed, temperature, and humidity. "It could turn into a very challenging data-wrangling exercise in order to come up with those values independently," he says, "but MERRA provides a single place to go to find those values quickly."



As the pictographs show, throughout the last several decades NASA has been accruing an ever-increasing amount of observational data. Run out of Goddard Space Flight Center's Global Modeling and Assimilation Office since its inception in 2008, Modern-Era Retrospective Analysis for Research and Applications, or MERRA, can integrate the data to not only recreate a synthetic record of the weather dating back to 1979 but also compute climate projections.

Beyond looking at past weather conditions, climate models are adept at computing climate projections, which are playing an increasingly important role as Government and industry attempt to prepare for a quickly and dramatically changing planet. Scientists can tweak certain variables to see how, say, temperature swings or moisture content will affect Earth 10, 20, or 100 years out. "Reanalyses like MERRA smooth out the differences we see in various measurement systems and give us physically consistent data across all climate variables," Schnase says. "They let us calibrate forecasting systems to improve our climate projections, and they give us a unique type of data important to many other applications."

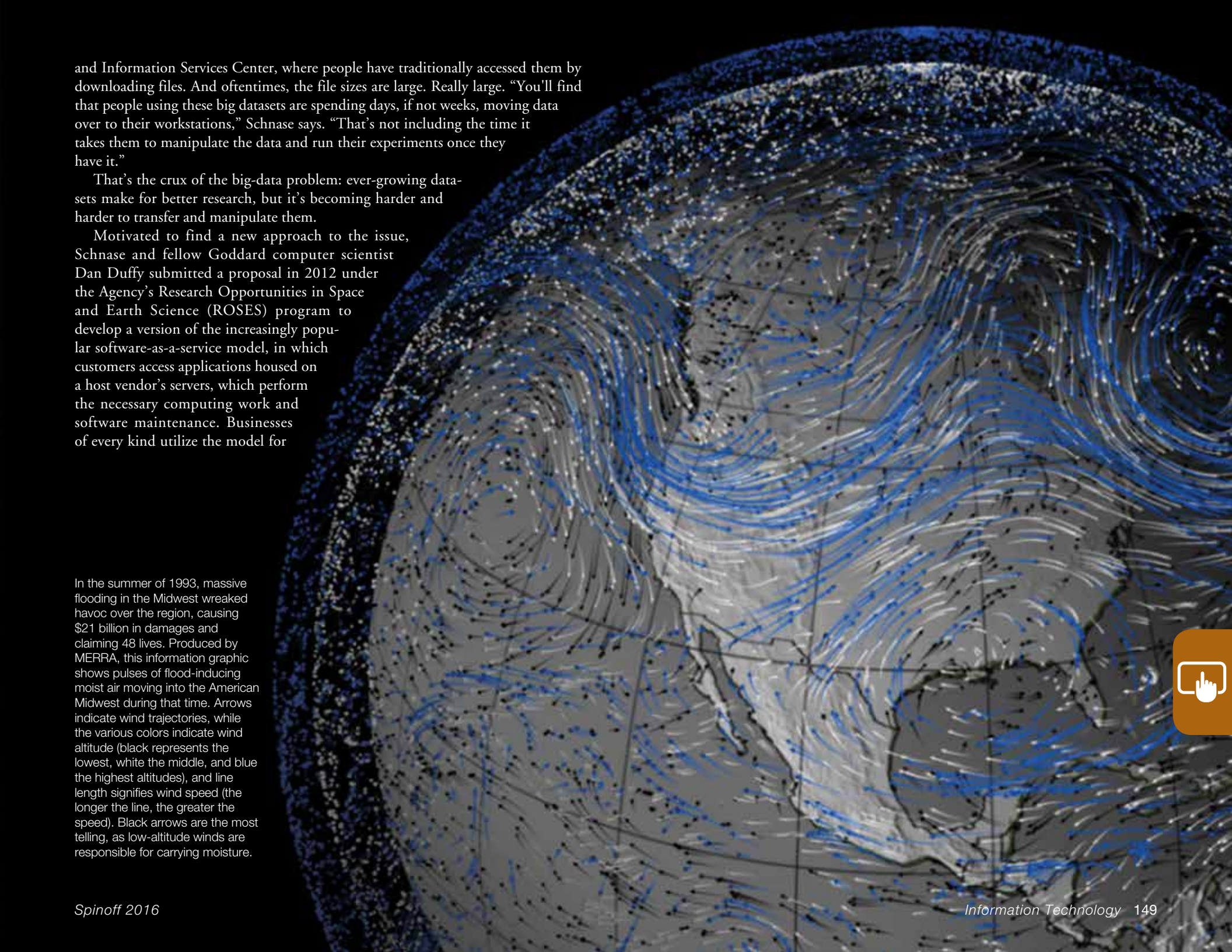
Technology Transfer

Because of their versatility, reanalyses are in high demand by outside researchers. MERRA, for example, is made available through Goddard's Earth Sciences

and Information Services Center, where people have traditionally accessed them by downloading files. And oftentimes, the file sizes are large. Really large. "You'll find that people using these big datasets are spending days, if not weeks, moving data over to their workstations," Schnase says. "That's not including the time it takes them to manipulate the data and run their experiments once they have it."

That's the crux of the big-data problem: ever-growing datasets make for better research, but it's becoming harder and harder to transfer and manipulate them.

Motivated to find a new approach to the issue, Schnase and fellow Goddard computer scientist Dan Duffy submitted a proposal in 2012 under the Agency's Research Opportunities in Space and Earth Science (ROSES) program to develop a version of the increasingly popular software-as-a-service model, in which customers access applications housed on a host vendor's servers, which perform the necessary computing work and software maintenance. Businesses of every kind utilize the model for



In the summer of 1993, massive flooding in the Midwest wreaked havoc over the region, causing $21 billion in damages and claiming 48 lives. Produced by MERRA, this information graphic shows pulses of flood-inducing moist air moving into the American Midwest during that time. Arrows indicate wind trajectories, while the various colors indicate wind altitude (black represents the lowest, white the middle, and blue the highest altitudes), and line length signifies wind speed (the longer the line, the greater the speed). Black arrows are the most telling, as low-altitude winds are responsible for carrying moisture.

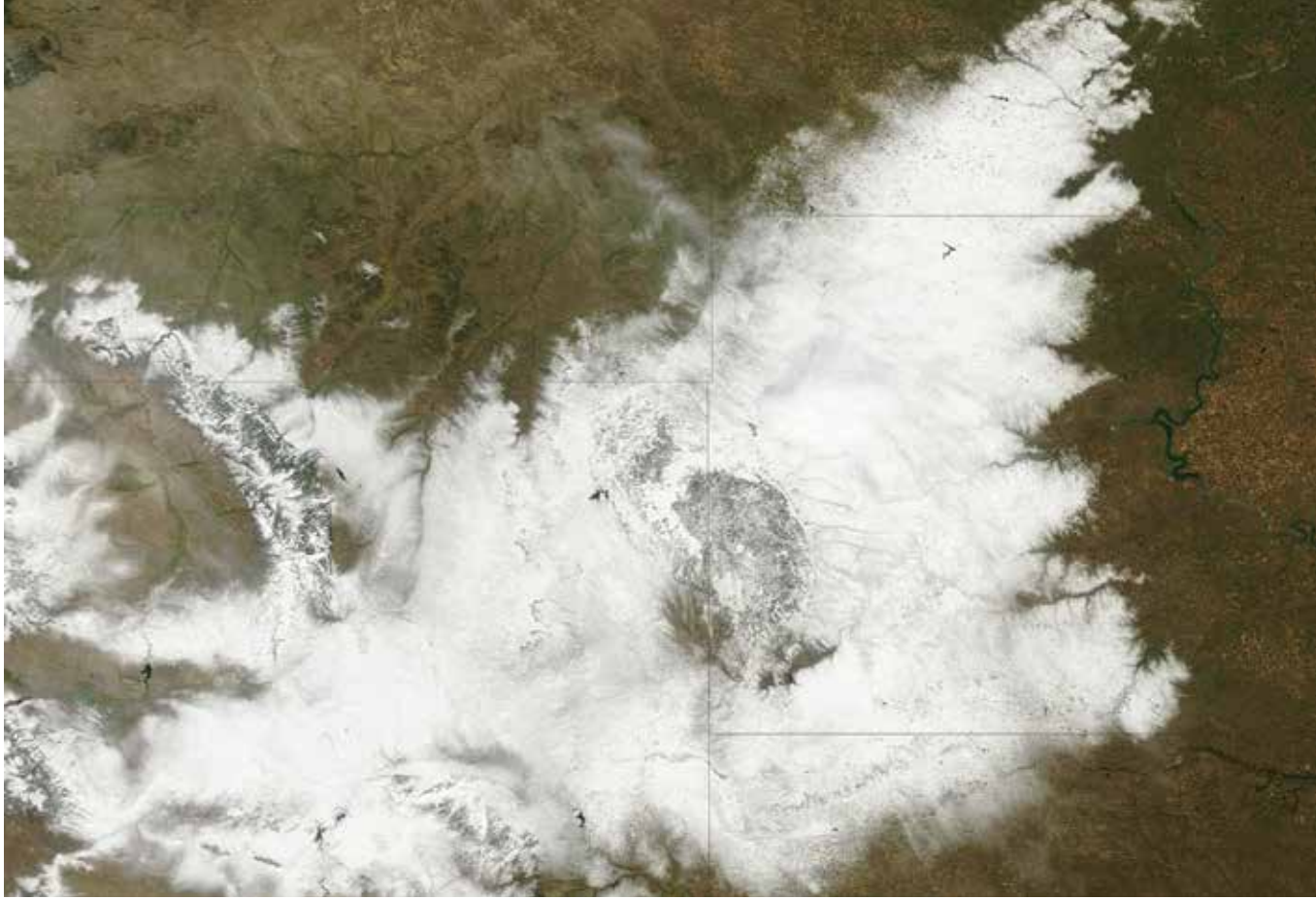
Web site hosting, graphic arts programs, and IT services, among other applications.

After receiving ROSES funding in 2012, over the next few years, Schnase, Duffy, and other colleagues at Goddard's Office of Computational and Information Sciences and Technology worked to build a MERRA analytic service where outside users could employ Goddard's high-performance computing capabilities to create useful data products. As they did so, they broke the MERRA dataset up into an array of files and stored them on a storage cluster—36 servers in an arrangement that facilitates parallel computing, allowing for vast amounts of climate data to be operated on simultaneously.

For the processing program, Schnase and his team adapted an open-source program called Hadoop MapReduce, originally developed by Google as a retrieval system that allows for those near-instant search results on the tech giant's Web site. The team modified it so it would work with binary scientific data rather than text.

After those tasks were completed, and after a series of basic operations was programmed into the system, Climate Analytics-as-a-Service, or CAaaS, was born. The program was made available for beta testing in fall of 2014 through NASA's Climate Data Services application programming interface (API), which is, in essence, a programming library and set of instructions that tell software developers how to access the service. They can also use the API to design graphical interfaces that make the service user-friendly.

One of the first organizations to utilize the new technology is the iPlant Collaborative, which was established by the National Science Foundation in 2008 to develop cyberinfrastructure, including supercomputing access, to support life-sciences research. By working with NASA's API, iPlant developed a graphical interface for CAaaS that's now available to member scientists in the organization's Discovery Environment platform, a fitting name considering it houses other big data research enterprises, such as genomic sequencing. Discovery Environment currently hosts three CAaaS-supported applications: Analyzed State, Meteorology Instantaneous Monthly, and Land-Related Surface Quantities. The first two are geared for direct climate studies, and the third focuses on the weather's impacts on terrain, such as snow cover, soil moisture, temperature, and vegetation.



NASA's Moderate Resolution Imaging Spectroradiometer captured an image of an uncommonly early blizzard that blanketed northeastern Wyoming and western South Dakota from October 3-5, 2013. The cattle hadn't yet grown their thick winter coats that allow them to survive winters, resulting in the deaths of about 15 to 20 percent of South Dakota's herds. By using the Agency's Climate Analytics-as-a-Service, or CAaaS, researchers could run projections to determine what regions may no longer be suitable for raising cattle in the future due to climate change.

iPlant senior coordinator Martha Narro says the programs will be an important tool for biological scientists, as "One of the grand challenges is understanding how the interplay between an organism's genetic repertoire and environmental factors results in particular characteristics being expressed in the organism."

Benefits

Currently, CAaaS is set up so that MERRA can be called on to run commonly used operations for determining the minimum, maximum, or average values for variables such as temperature, humidity, wind speed, rain and snow precipitation, and evaporation. Calculations can be made on global and regional scales and can account for either a static point in time or a specified duration.

What's key is that all of the storage and computing occurs on NASA's end. Rather than moving large amounts of data to their workstations and perform these operations themselves, users only have to move the results—and those products are much smaller. CAaaS can reduce the data-wrangling time from days and weeks to minutes and hours.

"MERRA's engine does the extraction for these basic operations so they're ready to be put into more high-order analyses by the user," Schnase says, while adding that future applications using CAaaS may also contain more complex analytic functions. "One of the things we're trying to do is get scientists, nonscientists, and the private sector all using this data and making the system more robust by contributing to the development of the API."

That's just what iPlant has done by introducing visualization tools for its Discovery Environment. For example, temperatures across a region can be clearly displayed through color-coded variations on a map, Narro says. "Data like this is often stacked in layers of interrelated spreadsheets, so they are much easier to wrap your head around if you can visualize them."

Paired with those new tools, Narro envisions iPlant's applications as being able to expand research opportunities for members whose work involves planning for climate change. For one, scientists could perform crop simulation models to project where plants will grow best, given different weather conditions. Other studies may look at how projected climate changes would impact the health of livestock. "If your cattle are suffering from high temperatures, it can impact their productivity and growth," she says.

Schnase sees CAaaS being utilized in yet other ways, particularly as more types of climate model data are made available. Insurance companies will eventually be able to utilize CAaaS to fine-tune risk assessments for potential natural disasters, and urban planners can prepare cities for the impacts of climate change by developing infrastructure to counteract rising sea levels and changing weather patterns.

"This is a different approach for accessing these huge datasets, and I think it's in line with the paradigm shift that's happening in terms of how big data challenges are being addressed," Schnase says. "We're excited to see how this takes off." ❖

CAaaS

[Climate Analytics-as-a-Service]

can reduce the **data-wrangling** time from **days** and **weeks** to **minutes** and **hours.**

In this image shared by NASA's Earth Observatory, Minnesota's farmlands look like a patchwork quilt. By utilizing CAaaS, researchers can run climate projections to investigate where crops would grow best, given different scenarios.

Artificial Intelligence Targets Advertising by Understanding User

NASA Technology

A couple of years ago, AJ Abdallat went online and bought a bracelet from a major department store as a gift for his wife. He wasn't happy with the product, he says, but to this day, he continues to receive online advertising based on that one negative purchasing experience. "Every time I log into Yahoo, they're pushing ads for this store to me," he says.

This is the kind of ham-handed online advertising that Abdallat, CEO of the new startup Beyond Limits Corporation, based in Thousand Oaks, California, says is soon to become a thing of the past. The company has licensed two artificial intelligence programs from NASA's Jet Propulsion Laboratory (JPL) that will enable Beyond Limits to target digital marketing with far greater precision.

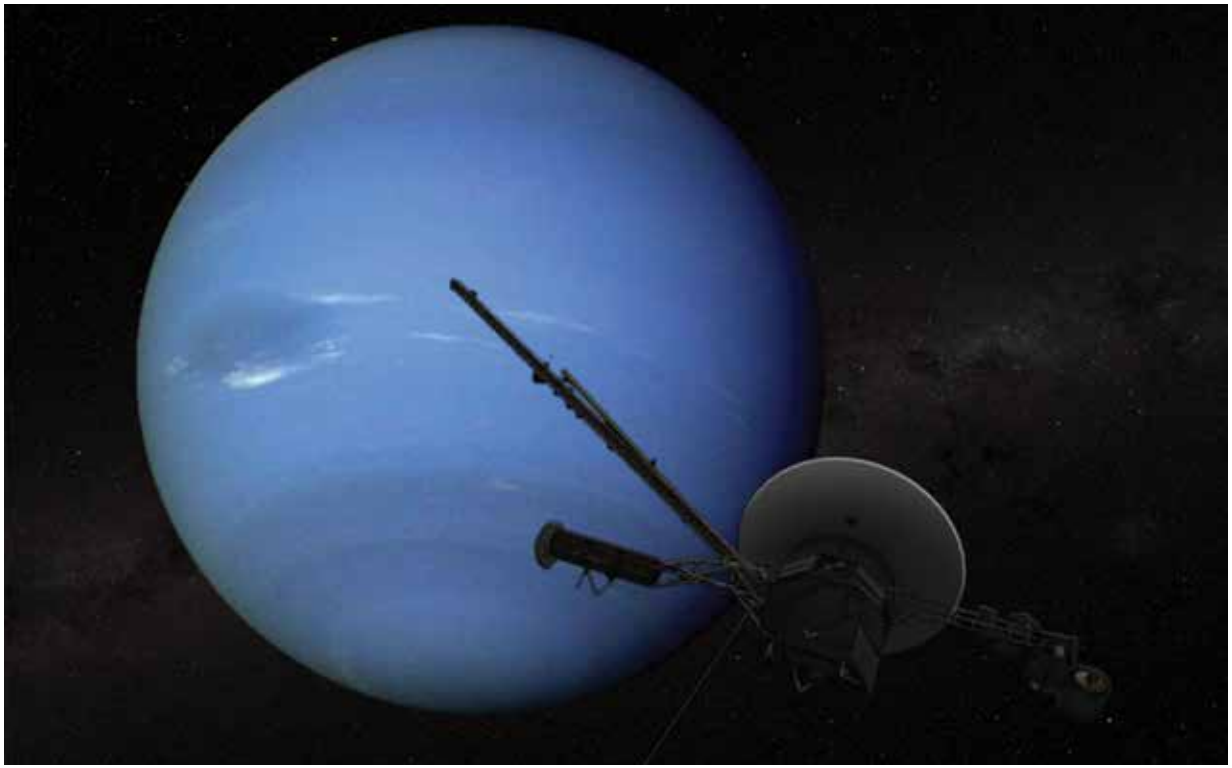
The creator of both those programs is Mark James, scientist with the Reasoning, Modeling, and Simulation Group at JPL. He and colleague David Atkinson created the earliest version of the Spacecraft Health Inference Engine (SHINE) back in the 1980s. "It was designed because, in the early days, spacecraft had very little computational power," James recalls.

Traditional expert-system software, which simulates the knowledge and judgment of a human expert in a given field, uses a vast knowledge base to process input and relies on a large mainframe computer or server to execute. It would include a general-purpose reasoning system that would repeatedly interpret the rules of its knowledge base. SHINE, by contrast, compiles the same knowledge base into a compact representation, which can natively be executed on the user's computer much faster, and which it uses to synthesize a lean, custom solution for each problem presented. It's as if, rather than calling in an entire 100-member advisory team to solve a given problem, one sends for just the two specialists needed to address the specific issue at hand, James explains. "The other 98 people can go away, and you can get the problem solved much quicker and in a smaller space."

A number of years ago, SHINE and C Language Integrated Production System (CLIPS)—a popular expert-system tool also created by NASA—were benchmarked executing the same test knowledge bases. CLIPS executed about 40,000 rules per second with a 20-megabyte memory footprint, while SHINE executed the same knowledge base at 100 to 300 million rules per second with just a 20- to 30-kilobyte memory footprint, demonstrating "tremendous performance improvements over anything else out there," James says.

> "This is a market where artificial intelligence capability is taking a major role."
>
> — AJ Abdallat, Beyond Limits

SHINE was designed to monitor the health of spacecraft systems, and the inference engine first proved itself when it discovered an anomaly in the Voyager spacecraft's telemetry system just before the craft's encounter with



The Jet Propulsion Laboratory's Spacecraft Health Inference Engine (SHINE) first proved itself when it discovered an anomaly in the Voyager spacecraft's telemetry system just before the craft's encounter with Neptune in 1989. Since then, the software has been used to monitor the health of a host of NASA systems.

Neptune in 1989. Had SHINE not made this discovery, mission progress could have been impeded. Since then, it's been used on many other NASA missions. For example, SHINE was used on the ground to perform telemetry analysis for the Galileo and Magellan missions, and it performed diagnostics and prognostic monitoring for the Extreme Ultraviolet Explorer mission and the NASA Deep Space Network, which maintains communications with spacecraft. It's also found a host of other applications in most military branches.

All along, it's been continually improved to make it faster and smarter. James says SHINE has been used to solve problems in cybersecurity, has been embedded in appliances, and has performed diagnostics for instrumented systems, robotics, and security systems, among others.

The other program Beyond Limits licensed is also powered in part by SHINE. Hunter is a natural language-understanding system James developed about six years ago. "It differs from other systems by allowing you to define models for what you wish to know and being able to extract that content from poorly structured text," James says. Whereas other language-understanding approaches use either template-matching or grammar-based solutions—comparing text with preprogrammed example phrases—Hunter can take a single representative statement and come up with hundreds of ways to paraphrase it because it hunts for intention rather than trying to parse everything using a traditional grammar.

Technology Transfer

Beyond Limits was formed in 2012 and licensed a suite of software programs and two patents from NASA the following year. The company set to work, making improvements to the software, especially SHINE, and figuring out how to use it to target online advertising to individual users.

Rather than simply remembering that a user once bought something from a particular store or pushing content based on words a user has typed, the software seeks to understand a person's intent at a given time and push relevant content, Abdallat says. He notes that this information can be combined with any demographic information that might be available, as well as individuals' Internet history to refine inferences about their intents and interests.

SHINE, an artificial intelligence program NASA designed to monitor the health of space systems, is now being used to determine the intent and sentiment of Internet users to better target advertising.

"Clearly, artificial intelligence, rule-based systems, and natural language understanding were the natural tools and building blocks for this capability," he says.

Benefits

The software makes its inferences beginning with the assumption that an Internet user's intent and sentiment are uncertain and change from day to day, Abdallat says. Someone looking at toy-store Web sites might not be a toy collector but simply looking for a baby-shower gift, for example. Using Hunter, the programs can determine not just what Web sites were visited but the subject matter of specific content that was read.

Abdallat notes that companies like Amazon and Netflix are spending tens of millions of dollars annually to improve their recommendations to users, with mixed results. In 2014 Google spent $400 million to acquire Deep Mind, a company that hadn't even created a product yet but employed some of the world's foremost experts in a cutting-edge field of artificial intelligence known as "deep learning."

"This is a market where artificial intelligence capability is taking a major role," Abdallat says of the online media and advertising business. Companies are losing interest in billboards and print advertisements, and the only advertising sector that's growing is digital marketing.

"With mobile devices, social networks, apps, that's where consumers are now getting information, especially the highly coveted 18- to 32-year-old demographic," he says. "And brands are demanding higher and higher return on investment." Nonetheless, online advertising only averages around one click out of a thousand views. The surest way to boost that number is through better-targeted advertising, Abdallat says. "It's an area looking for a solution because the industry is changing. We think the NASA technology can make a significant difference here."

Abdallat says the work was only made possible by the considerable funding, research, and development on NASA's part to create the original software. By early 2015, the company employed eight people and was just beginning its first commercial endeavors. "We have a product, and we're working with three big companies to implement our capabilities into their solutions," he says.

But NASA has also benefited from the partnership. According to the licensing agreement, the Agency is entitled to any improvements Beyond Limits makes to the software, and James says the company has made upgrades, particularly to SHINE, making it significantly more sophisticated.

"Their enhancements allow us to solve much more complex problems and pursue work we were previously unable to do," James says. ❖

Modeling Software Helps Rocket Scientists Go with the Flow

NASA Technology

Rocket science and simplicity don't normally go hand in hand, but that's what NASA had in mind when the Agency developed the Fastrac turbopump in the mid-1990s.

Turbopumps are responsible for sending propellant from the tank to the combustion engine with a high enough pressure to generate the needed thrust, which is accomplished by drawing in low-pressure propellant and compressing it before it's injected into the combustion chamber. The Space Shuttle main engine turbopump was considered one of the most sophisticated reusable engines of its kind. It used a staged-combustion cycle, meaning some of the propellants—liquid oxygen and liquid hydrogen—were burned in preburners to create hot gas to power the turbines and turbopump. The liquid propellants were then injected into the combustion chamber. In addition to requiring four pumps to pressurize the gases, the hydrogen needed to be kept at ultralow temperatures to remain in its mandatory liquid state.

Designed for smaller, less expensive spacecraft, Fastrac was made to run more efficiently and with simpler plumbing and fewer parts. Instead of liquid hydrogen, it uses a highly refined kerosene called Rocket Propellant-1, or RP-1, which is cheaper and easier to handle. The staged-combustion cycle was replaced with the less complicated gas-generator cycle, doing away with the complexities inherent in having to inject exhausted gas from the preburner to the combustion engine.

The goal was to come up with a simpler turbopump, but getting there still required rocket science know-how, namely computational fluid dynamics (CFD), which involves three disciplines: thermodynamics, fluid mechanics, and heat transfer. They're applied to resolve a number of thorny issues, from figuring out how much coolant is needed and ensuring that enough pressure is being generated in the turbine to making sure the RP-1 and liquid oxygen, separated by shafts mere inches apart, do not mix anywhere other than in the combustion chamber, lest an explosion occur.

NASA ushered in an era of simpler, more efficient turbopumps with the invention of Fastrac in the 1990s. To minimize costly test stand launches, the Agency created the Generalized Fluid System Simulation Program, or GFSSP, to analyze computational fluid dynamics. SpaceX used Fastrac as a blueprint for developing its Merlin family of rocket engines for the Falcon 9 launch vehicle, which is responsible for delivering payloads to the ISS.

It's better to iron out most of the kinks by using analytic software rather by than firing up imprecisely designed turbopumps on the test stand, says Marshall Space Flight Center aerospace technologist Alok Majumdar. Aside from the very real potential for major accidents, tests are also expensive. "A single test of the Space Shuttle main engine cost a million dollars, just for a couple minutes of firing," he says. "You still need tests, but if you can use your analytical tool to model the performance of the rocket engine, instead of 10 tests, maybe you can limit it to 2 or 3. It's a big cost savings."

But NASA was at a disadvantage because the Agency did not have access to a general-purpose code for performing such analyses. Aerospace companies created their own proprietary software and, understandably, kept the technology close to their vests. "They would say, 'Give us a contract, and we'll use our tool to give you the numbers,'" Majumdar says. "Our designers wanted a tool so they could make hundreds of runs. They didn't want to depend on somebody from the outside."

Technology Transfer

To meet that need, in 1994, just as Fastrac was getting underway, Majumdar began developing the Generalized Fluid System Simulation Program, or GFSSP, which was first used by the Agency's analysts in October 1996. NASA employees used the software for the Fastrac turbopump, and even though the program was cancelled in the early 2000s, the turbopump became the predecessor for others like it, such as SpaceX's Merlin rocket engines,

An artist's concept showing Virgin Galactic's LauncherOne spacecraft just after stage separation. Engineers are designing LauncherOne to be able to launch small satellites in space and are using GFSSP for tank-sizing and pressurization analysis.

which power the company's Falcon 9 commercial launch vehicle.

In the late 1990s, NASA made GFSSP available for free to other Government agencies and to Government contractors. Meanwhile, turbomachinery design company Concepts NREC, based in White River Junction, Vermont, licensed the technology and now sells the code as part of its own software package.

Benefits

GFSSP started out as a basic program, capable of computing only steady-state fluid models, but numerous functions were, and are still, being added and released in newer versions. For example, Majumdar and his team have developed code for analyzing solids via heat conduction, radiation, and the convective heat transfer between solids and fluids. Evaluating multilayer insulation for the tanks so gases are kept cool enough to remain in liquid form is another application, as is the ability to analyze mixtures that contain different liquid components.

Among its current users is Virgin Galactic, which is in the midst of developing an affordable rocket, called LauncherOne, aimed at the small satellite market. Kim Betker, a propulsion systems engineer with the company based in Mojave, California, says the software has proven useful for tank-sizing and pressurization system analysis, among other stage-level designs. "It's sometimes hard to figure out a spec for a component until you can see how it affects the other parts it's connected to," she says. "GFSSP has been really good about letting us put a bunch of components in a series to see how they all work together. That lets us figure out a good operating envelope for each component."

Even a mining company is making use of GFSSP. "They wanted to remove methane from their mine shafts and needed to figure out the types of compressors needed to get the gas to an acceptable concentration so it didn't pose an explosion risk," Majumdar says. "Basically, it's looking at flow distribution through a network. That you can use a rocket engine code to do mine ventilation is very striking to me."

Aside from its versatility, Majumdar says GFSSP is relatively easy to use compared with other CFD codes that require expertise in various programming languages. "We do not expect that only a highly sophisticated numerical analyst will run this code," he says, adding that any engineer who has some basic knowledge of thermo-fluid dynamics can use it.

Even though GFSSP won NASA's Software of the Year award back in 2001, Majumdar and his team show no signs of letting up on enhancing its capabilities. In addition to improving pre- and post-processor speeds, the program's next iteration, version 7.0, will include a separated phase model, which looks at mixtures of gas-liquids that move at different speeds, instead of assuming them to be homogeneous mixtures where all phases move with the same speed.

The classic case for this sort of problem-solving, Majumdar says, involves hydrogen rocket propellant. As liquid hydrogen travels from the tank to the turbopump, as soon as it makes initial contact with piping it turns to vapor because of the rise in temperature. As the pipe is cooled, the vapor will become a mixture of vapor and liquid before it returns to a full liquid. "Once it becomes a full liquid, you don't have any problems, but when there are two phases with cryogenic propellant, they don't move at the same velocity," he explains. "You need to have a modeling technique that can tease out what effects that will have on the overall system."

Such an analysis will be another big step for software that continues to impress nearly 20 years after its inception.

"It's such a complex process, and you're solving so many equations, which are coupled with each other and are highly nonlinear," Majumdar says. "But over the years we have done a lot of work on our solvers, and we now have the confidence that our solvers can handle these complexities." ❖

Electro-Optic Ceramic Creates High-Speed Fiber-Optic Networks

NASA Technology

By 2002, Corning Applied Technologies had developed a new electro-optic ceramic material, one that promised efficient, effective, rugged, low-cost optical components for a variety of uses. That year, however, Corning Inc. shut the subsidiary down before its new OptoCeramic could be tested and proven. The management and technical team formed its own company, Boston Applied Technologies Inc. (BATi), and in the same year, a contract with NASA's Langley Research Center allowed the new business to demonstrate the technology that soon became the basis for some of its major product lines.

The Small Business Innovation Research (SBIR) contract with BATi, based in Woburn, Massachusetts, was for an electro-optic Q switch for an all-solid, portable lidar system that would be used to monitor the atmosphere.

A lidar is an object-detection system similar to radar that uses light instead of radio waves, sending out laser pulses and then catching their reflections. Specialized versions can calculate atmospheric composition and even temperature by measuring how the pulses are absorbed or backscattered.

A material is electro-optical when its refractive index can be changed with an applied electric field. According to the voltage applied to it, it can alter the color, polarization, and intensity of light. For electro-optic Q switches and other components, the material traditionally favored by industry has been single crystals such as potassium dihydrogen phosphate and lithium niobate.

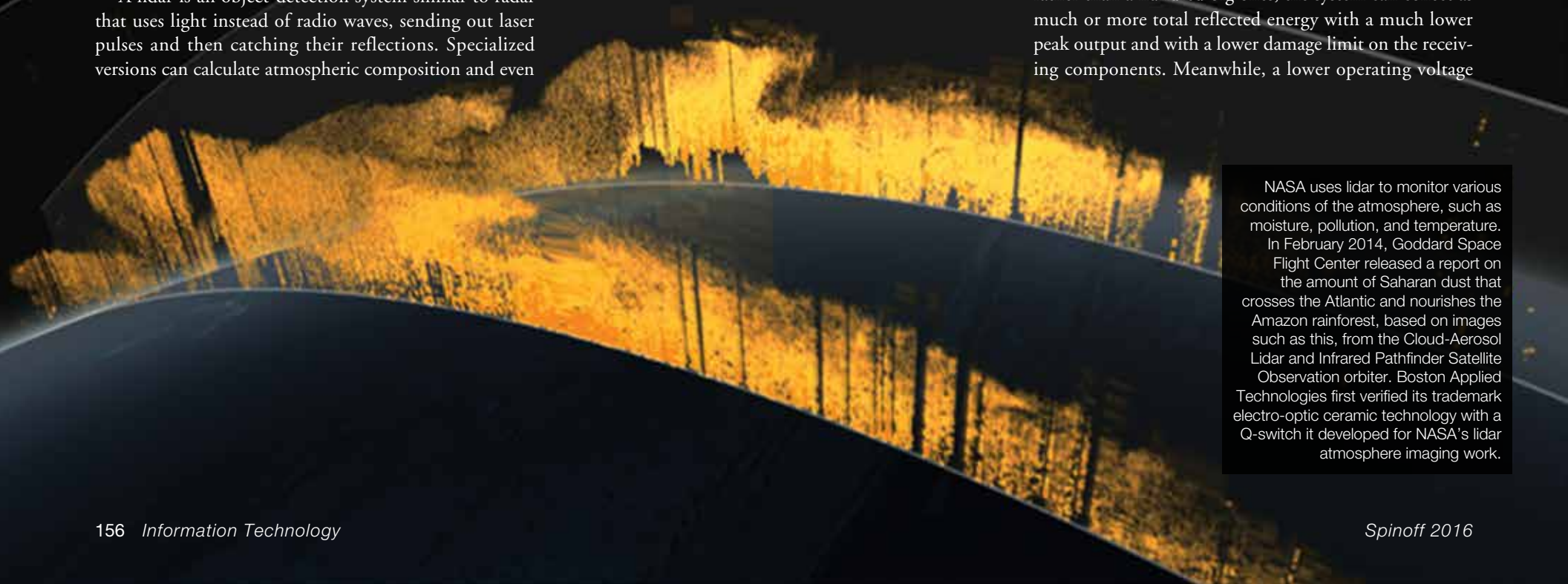
Before it shut down, Corning Applied Technologies had been experimenting with its second-generation OptoCeramic material, known by its chemical name of lanthanum-modified lead magnesium niobate titanate or, more conveniently, PLMNT. This refined ceramic had the potential to offer better performance than its predecessors.

Its high response speed and large electro-optic effect—nearly 100 times higher than that of lithium niobate—were key to the lidar Q switch created under the SBIR contract, which was to offer an improved signal-to-noise ratio by sending up to a million pulses per second on a power supply as low as 100 volts.

In the Q switch application, which turns a laser beam into pulses, the electro-optic absorber is placed inside the laser's resonator chamber. There, it rotates the polarization of the light to absorb and release the laser beam in pulses. One advantage of electro-optic Q switches in general is that they generate faster and more powerful pulses than a traditional Q switch.

Michael Krainak, head of the Laser and Electronic Optics Branch at Goddard Space Flight Center, explains the significance of a high pulse rate for lidar: "What you're trying to do is get as much total lidar signal return energy as you can over a fixed integration time. You can get the same energy that way, but with a lower peak-power laser. This reduces the chance of laser damage."

By sending and receiving a million small laser pulses rather than a hundred big ones, the system can collect as much or more total reflected energy with a much lower peak output and with a lower damage limit on the receiving components. Meanwhile, a lower operating voltage



NASA uses lidar to monitor various conditions of the atmosphere, such as moisture, pollution, and temperature. In February 2014, Goddard Space Flight Center released a report on the amount of Saharan dust that crosses the Atlantic and nourishes the Amazon rainforest, based on images such as this, from the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation orbiter. Boston Applied Technologies first verified its trademark electro-optic ceramic technology with a Q-switch it developed for NASA's lidar atmosphere imaging work.

Boston Applied Technologies manufactures a variety of products, such as the high-speed, fiber-optic switches and free-space, mid-infrared Q switch cores seen here, using the electro-optic ceramic it first verified under an SBIR contract with Goddard Space Flight Center. Electronic control circuits like the one on the right drive the optical switches.

makes the system more reliable and efficient and less expensive, Krainak says.

"Because we have this material with a high electro-optic coefficient, we have the capability to reduce the voltage and make the laser much smaller and more compact," adds BATi cofounder Kevin Zou.

Technology Transfer

"The NASA project, for sure, financially got us off the ground and verified the concept that got our electro-optic switch business growing," Zou says. It was the new company's first contract, and although NASA didn't fund a Phase II SBIR contract, he says the project demonstrated that the ceramic worked as intended. BATi ran with what it had learned, using PLMNT to expand its line of various products, mostly for fiber-optic communication networks, into the high-speed optical switch business.

"Most of our commercial products are based on this OptoCeramic technology," Zou says.

Among these are Eclipse variable optical attenuators, Acrobat polarization controllers, Equinox dynamic optical filters, and Nanona fast electro-optic switches. Other BATi products based on OptoCeramic technology include large-aperture tunable optical filters and polarization imagers. All these devices can be used in telecommunications, lidar, remote sensing, and other applications.

Benefits

In most photonic systems, speed is critical, Zou says. "If you compare them to similar products, nobody's switches are as fast as ours."

When a line goes down and the signal has to switch to a backup line, for example, "The faster the switch, the less data is lost," he says. "When a high data-rate system is down, switching in nanoseconds or milliseconds makes a big difference."

In tests, devices made with the company's OptoCeramic materials have been proven reliable and rugged, surviving high humidity and repeated cycles of temperature swings from -40 to 70 °C (-40 to 158 °F) without degraded performance. Because the ceramic requires only a small electric field to change its optical properties, the devices are compact and easily controlled.

As an added advantage, being polycrystalline ceramics, the materials can be made by hot-pressing, a process much cheaper and easier than growing crystals such as lithium niobate.

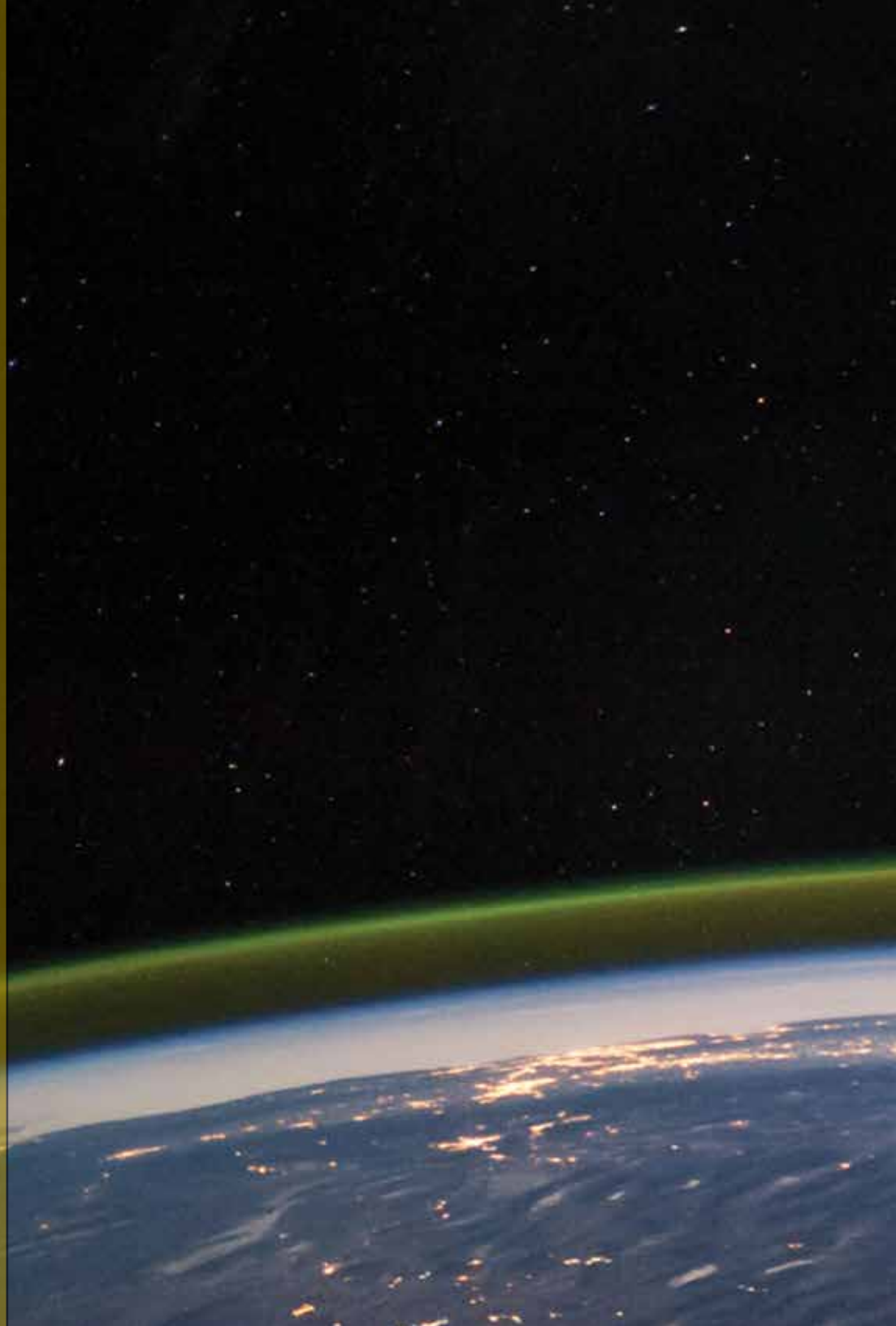
In addition to telecommunication companies, BATi counts among its customers defense contractors, universities, and research institutes, and the company is planning to turn its electro-optic ceramics to the medical imaging business. Under two Small Business Technology Transfer contracts with Johnson Space Center in 2004, the company worked on a polarization imaging device for cell and tissue analysis and diagnostics that has been awarded two patents.

The device works by understanding how different substances alter the polarization of light differently, with each having its own "polarization signature" that can be used to identify it, Zou explains. Central to the medical imaging device, which BATi developed in cooperation with Catholic University of America and Georgetown University, is a fast-tunable phase retarder made of electro-optic ceramic. The company hopes the technology will prove useful not only for commercial medical applications, from early detection of diseased cells to microscopic tissue analysis, but also for industrial material research, target acquisition and identification for astronomy and defense, and NASA's work in biological and medical molecular studies in microgravity.

All this from a substance BATi demonstrated for a NASA lidar system. "That contract gave us the initial push to get into electro-optical switching," Zou says. ❖

Industrial Productivity

NASA's various missions have spawned groundbreaking advances in industrial applications as varied as predicting machine lifespans, transmitting power in new ways, and producing both extreme temperatures and materials capable of surviving them. These and countless other innovations have steadily found their way from space applications into terrestrial industry, helping to keep American businesses at the forefront of efficiency and productivity.



DigitalClone Software Predicts, Extends Machine Life

NASA Technology

Medical scientists have made great progress in recent years toward understanding how genetic factors play a role in an individual's susceptibility or resistance to various diseases. Meanwhile, the engineers at Sentient Science have been hard at work trying to do similar predictive analysis for machine systems and components.

"What we set out to do was really hard," says Ward Thomas, president and CEO of the Buffalo, New York-based company. "We set out to decode the material genome."

The potential payoff is significant. Just as researchers hope to use DNA analysis one day to help patients choose lifestyles that maximize health, Sentient could suggest ways that machine owners and operators could maximize the life spans of their systems. Moreover, such knowledge would allow manufacturers to design systems for the longest use possible with the lowest energy consumption.

In 2001, the company accepted its first Federal funding from the Defense Advanced Research Projects Agency to work on a tool to predict the life span of a machine component with the aim of giving U.S. industry and Government a competitive advantage. Following a long string of Small Business Innovation Research (SBIR) contracts, a handful of which came from NASA's Ames Research Center, a validation test at Glenn Research Center proved Sentient had finally cracked the code.

The company had assembled mountains of data on material performance from manufacturers, researchers, the military, and its own testing. The engineers had fused this data with theoretical models of the physics of surface fatigue and built on previously existing analytical and computer models to process the information. To test the product, named DigitalClone, they needed a component that had a long and well-documented history.

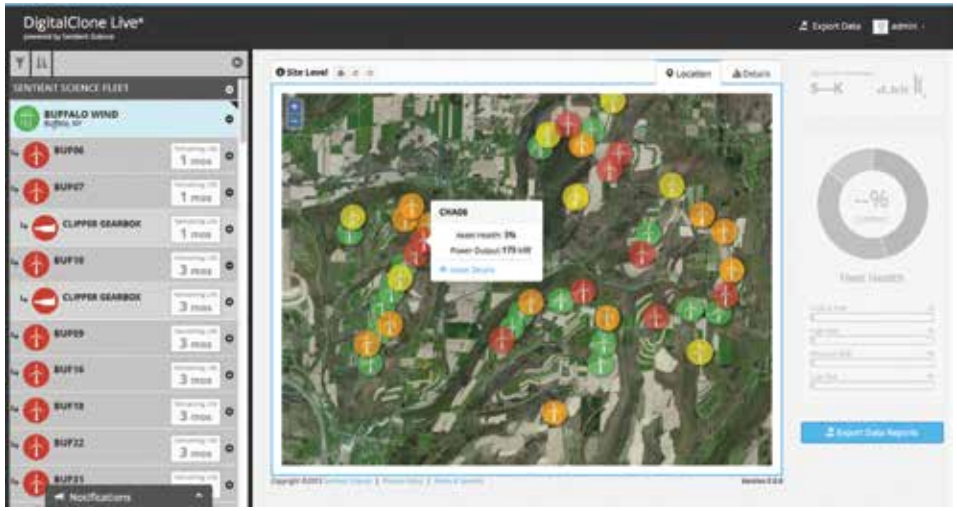
In October 2010, Tim Krantz, a mechanical components engineer at Glenn, was presiding over a database of test results regarding gears with various shapes, materials, lubrications, and processing parameters. One gear design—a spur gear used for helicopter drive train research—had 25 years' worth of data gathered at significant cost and was selected as the test subject.

"We're trying to help make better helicopters for the general public, and in the helicopter world, gears are very important," Krantz says, noting it can be difficult to obtain comprehensive performance data on such components because the companies that test them often keep the information proprietary. "This NASA gear performance database is pretty unique."

Sentient won an SBIR contract from Glenn to validate its software against the center's gear data.

Technology Transfer

As its name suggests, DigitalClone uses input data to create a high-fidelity digital twin of a component or system. Based on what it knows about the physics of friction, lubrication, and wear, the software then predicts its subject's future performance, life span, and failure.



Sentient Science's DigitalClone Live product builds sensors into wind turbine gearboxes and uses live data to update performance and failure predictions in real time. DigitalClone Live had its first sale in mid-2013, and by late 2014 it was in use on more than 5,000 wind turbines from eight operators in North America.

To validate this prognostic competence, the company's engineers first used the software to create a digital model of NASA's chosen spur gear. They input various materials, surfaces, and working conditions and compared the resulting predictions with the historical performance data NASA had gathered on the gear.

What they especially wanted to foretell was the component's "pitting life" under various conditions—the point at which pockets would begin to form on the surface of its teeth, Krantz says. "That's the life-limiting factor for aerospace gears, and a lot of other gears, too."

After about three months of running models, they had their answer. "When the results came, and the correlation was so good, the company president got very excited about what his guys had been developing," Krantz recalls.

"It perfectly matched Tim's database, so that was a complete game-changer for our company and our future customers," Thomas says. Not being an engineer himself, he had been attending grad school while the program was being developed. After hearing of the test results, Thomas quit school to take Sentient into the commercial realm.

"Prior to that date, we were a research-only company," he says. "That was the inflection point for us to go from being research to commercial, and it really happened overnight."

After the work with NASA, Sentient carried out 11 paid validations with companies such as Boeing, Sikorsky, and General Electric. It also continued developing its DigitalClone Live product, which builds sensors into a gearbox and uses live data to confirm and update performance and failure predictions for machinery in the field. DigitalClone Live saw its first sale in June 2013, when the wind energy company First Wind signed a deal to have the gearboxes of 218 of their wind turbines outfitted with the technology. By late 2014, Sentient had been contracted to provide prognostic and life-extension services to more than 5,000 wind turbines from eight operators in North America.

Benefits

The response to Sentient's new approach to predicting and extending machinery life, using computation rather than physical testing, was swift and enthusiastic.

DigitalClone was first validated on a helicopter spur gear at Glenn Research Center and, in the following years, came to be used on several military aircraft, including the Super Stallion, pictured here.

Image courtesy of the U.S. Marine Corps

"Instead of running physical tests for a year and getting three test points, we can give you thousands of test points in days," Thomas says. "You will have the world's most tested products, which will run in the field at the lowest cost to operate."

By late 2014, the technology was in use on the Hubble Space Telescope, the new Joint Strike Fighter F35, and the Blackhawk, Apache, and Super Stallion helicopters, among other Federal programs. The medical device company Zimmer had used it to analyze its hip implants. Of the 45 wind turbine operators in the country, 8 were customers, including giants such as NextEra Energy and Clipper Windpower.

A partnership with the State University of New York at Buffalo allows the company access to an 8,000-processor, cloud-oriented infrastructure to support its modeling and simulation software, and it offers clients the options of a one-time service or licensing for the software.

The company is currently focused on helicopters and, especially, wind turbines, where opportunity is abundant. With funding and incentives from the Recovery and Reinvestment Act of 2009, wind turbines multiplied across the country, but they experienced widespread mechanical problems, Thomas explains. "All of a sudden, they were sitting there like a '57 Chevy on your friend's lawn, up on blocks because you can't buy parts."

Wind energy was running 11 cents per kilowatt hour, compared to 1 or 2 cents for nuclear power and around 4 cents for coal and gas. Now, thanks in part to improvements due to Sentient's software, he says, wind energy is down to about 3.5 cents per kilowatt hour. "This technology is doing as much to make renewables economically viable as the Federal Government's provisional tax credit."

In August 2014, the U.S. Small Business Administration awarded the company the Tibbetts Award, the Government's highest recognition of outstanding technical and commercial achievements under the SBIR and Small Business Technology Transfer programs.

Since the technology's validation with NASA data, Sentient's staff grew from 10 to 26 by 2014, and annual revenues rose from $1 million in 2010 to $3.5 million in 2013. The company plans to go public in 2016 or '17 and is currently raising capital to break into more industries, such as aerospace, medicine, and automotive manufacturing. "That capital is to expand to other industries here in the United States, to give American manufacturers and operators a competitive advantage," Thomas says.

"We're so grateful to NASA for showing up at the time they did." ❖

Cryocoolers Fuel Exploration in Space and on Earth

NASA Technology

Studying solar flares and particle acceleration requires cool heads and lots of intricate planning. When NASA was preparing to launch the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), it needed a special kind of cryocooler that could operate in the extreme temperatures of space for a long period of time without breaking down. Cryocoolers have many uses in space and on Earth, and NASA was looking for one to keep the detectors aboard RHESSI at a steady temperature of -324 °F, or just 75 K .

To save time and money, the Agency wanted to leverage what was already available on the commercial market. To that end, it quickly became interested in cryocoolers made by Athens, Ohio-based Sunpower Inc.

What impressed NASA most was the efficiency of Sunpower's devices, which are powered by a set of thermodynamic processes known collectively as the Stirling cycle. The cycle works by taking advantage of the shifting pressures created by heating and cooling an enclosed gas to move pistons back and forth, ultimately transferring heat away from the cooler and, in the case of a spacecraft like RHESSI, radiated into space.

Attractive too was the durability of Sunpower's devices. Previously, to achieve long lifespans, NASA relied on custom-made cryocoolers that cost millions of dollars. In other applications, the Agency would save on costs by using less expensive but short-lived tactical coolers. Sunpower's off-the-shelf models cost a little more than their inexpensive competitors but are also rated by the company with a design life of at least 5 years—with their current mean time to failure clocking in at 200,000 hours, or 23 years.

Finally, the company's coolers included multiple other design features that lend themselves well to meeting some of the challenges posed by RHESSI's environment. For example, the pistons in Sunpower's cryocoolers don't use liquid lubricants, which would freeze in space and become useless. Instead, the device keeps its pistons centered in their cylinder bores by using gas bearings, which act in a similar fashion to the air jets on an air hockey table. The company's space-rated coolers are also fabricated using high-vacuum compatible materials, which do not allow the working fluid, in this case helium gas, to leak out—a difficult task considering the small molecular size of the element.

"We often joke that there are two moving parts in these machines. How difficult can a machine with two moving parts be?" says Stuart Banks, a senior cryosystems engineer in the Cryogenics and Fluids Branch at Goddard Space Flight Center. "When you put on all the constraints and conditions these machines have to operate under, they're a real challenge."

Technology Transfer

The Agency purchased some commercial cryocoolers from Sunpower for testing and then worked with the company to qualify them for space. When RHESSI launched in February 2002 aboard a Pegasus XL rocket, it carried a Sunpower M77 cryocooler. And while the primary mission was slated for just 2 years, RHESSI has carried on for an additional 13.

In total, the company has been awarded 18 Small Business Innovation Research (SBIR) contracts by Goddard and Glenn Research Center for the development of at least a dozen coolers for space applications. SBIR work since RHESSI's launch has included efficiency improvements to the Stirling engine and the incorporation of thermoacoustics—the use of sound waves to transfer heat—to further reduce moving parts.

Astronaut Tracy Caldwell Dyson, an engineer with Expedition 24 on the ISS, uses the General Laboratory Cryogenic ISS Experiment Refrigerator (GLACIER), which uses a Sunpower cryocooler.

Sunpower's CryoTel CT-F cryocooler has made more than 30 launches into space and is capable of reaching and maintaining temperatures ranging from 39 °F to -301 °F.

> "If you make NASA happy, you're going to make 99 percent of the rest of potential customers happy because they have such high standards."
>
> — Jimmy Wade, Sunpower

Among the company's cryocoolers built to NASA specifications are at least a dozen currently used on the International Space Station (ISS) for scientific experiments at cold temperatures. The cryocoolers are incorporated into a refrigerator-like product that "looks like a little dorm fridge," says Jimmy Wade, Sunpower's business development manager. Of course, no dorm fridge is capable of reaching 40 K.

Benefits

While somewhat of a niche product, Sunpower's cryocoolers have a solid base of customers. Most cryocooler applications are for various kinds of detectors. "Infrared detectors on high-end telescopes use our cryocoolers to cool them," Wade says. "There are also scientific, commercial, and military applications that need high-end detectors, multispectral or hyperspectral detectors, nuclear detectors, or germanium detectors and require our coolers."

Another use is in high-temperature superconductivity (HTS), for materials that act like superconductors at temperatures ranging as high as 100 K (roughly -280 °F), a balmy environment compared to the more traditional operating temperature of superconducting materials, which is closer to 4 K. There is currently significant research and development exploring HTS materials which may soon produce commercial HTS products such as bearings, levitating trains, and engines that would be used in large applications such as wind turbines and ships. Wade says, "There are a few technical challenges remaining, but several companies are investing heavily to make HTS products a reality."

Generally speaking, cryocoolers are used just about anywhere liquid nitrogen is used, including nuclear-magnetic resonance instruments needed by scientists who conduct research in cold sciences. Wade says Sunpower is in a good place for dealing with such niche applications when it comes to commercial or space-oriented cryocoolers and credits NASA for both the development of Sunpower's products and the boost in reputation that comes from having a product on the ISS.

"It's definitely helped make our product better," he says. "If you make NASA happy, you're going to make 99 percent of the rest of potential customers happy, because they have such high standards. That's helped improve our product. Of course, the ability to say we have a cryocooler orbiting the Earth for the last 12 years is helpful, too."

Sunpower's CryoTel cube is a ready-to-use cryogenic cooling solution used on the ISS but also on Earth for astronomical telescopes, nuclear magnetic radiation, infrared detection, gas chromatography, and medical uses.

He's also happy that Sunpower is helping improve life on Earth.

"Our products are made in Appalachia," he says. "We are providing jobs to a community that needs jobs, and we're as high-tech as you can get." ❖

Temperature-Resistant Materials Enable Space-Like Cold on Earth

NASA Technology

In spacecraft construction, even components like tape can require cutting-edge technology.

During the mid-1990s, engineers at the Jet Propulsion Laboratory (JPL) were tailoring an outfit for the Cassini space probe—which has now been exploring Saturn and its moons for more than 11 years—that would shield it from the extreme temperature fluctuations and other harsh conditions of interplanetary travel.

There was a lot at stake. A joint project of NASA, the European Space Agency, and the Italian Space Agency, the $1.4 billion probe remains the most complex, sophisticated unmanned spacecraft ever built, carrying 12 scientific instruments and six more aboard its Huygens lander.

"We had a need for a robust tape we could bind our blankets with, and there wasn't a tape available with the various optical properties we needed," recalls Mark Duran, thermal blanket engineer at JPL. Until then, the center had been using a glass cloth tape that outgassed traces of silicone, which could contaminate optical surfaces. The silicone could be baked out, but then it contaminated the vacuum bake-out chamber.

Duran's team turned to Bristol, Pennsylvania-based Dunmore Corporation, a major supplier of specialized films for space applications since the 1980s. Based on NASA's needs, the company came up with a line of specialized tapes, including the one used on Cassini, a laminate of carbon-filled Kapton polyimide backed by a tight-woven scrim. With this reinforcement, the engineers could attach the insulating blankets with lacing cord, allowing them to be taken on and off over the course of multiple tests. "We can use a single set of blankets for the entire lifecycle of the program," Duran says.

In the 1990s, Dunmore Corporation custom-made a carbon-filled Kapton polyimide tape for the Jet Propulsion Laboratory to reinforce the edges of insulating blankets on the Cassini space probe, allowing them to be attached with lacing cord. The company also pioneered the process of vacuum-metalizing polyimide films for space insulation, resulting in lightweight, multilayer insulations that have found various applications on Earth.

The blankets JPL uses to keep spacecraft around room temperature in space—where they would otherwise fluctuate between about -150 °F and 480 °F—also incorporate Dunmore technology, as the company specializes in multilayered insulation. While early NASA missions used reflective foils for insulation, Dunmore helped to pioneer the process of vacuum-metalizing polyimide films for space insulation, combining thin films of substances like Mylar and Kapton with metals from aluminum to germanium and indium tin oxide, giving them specific thermal, optical, and other properties.

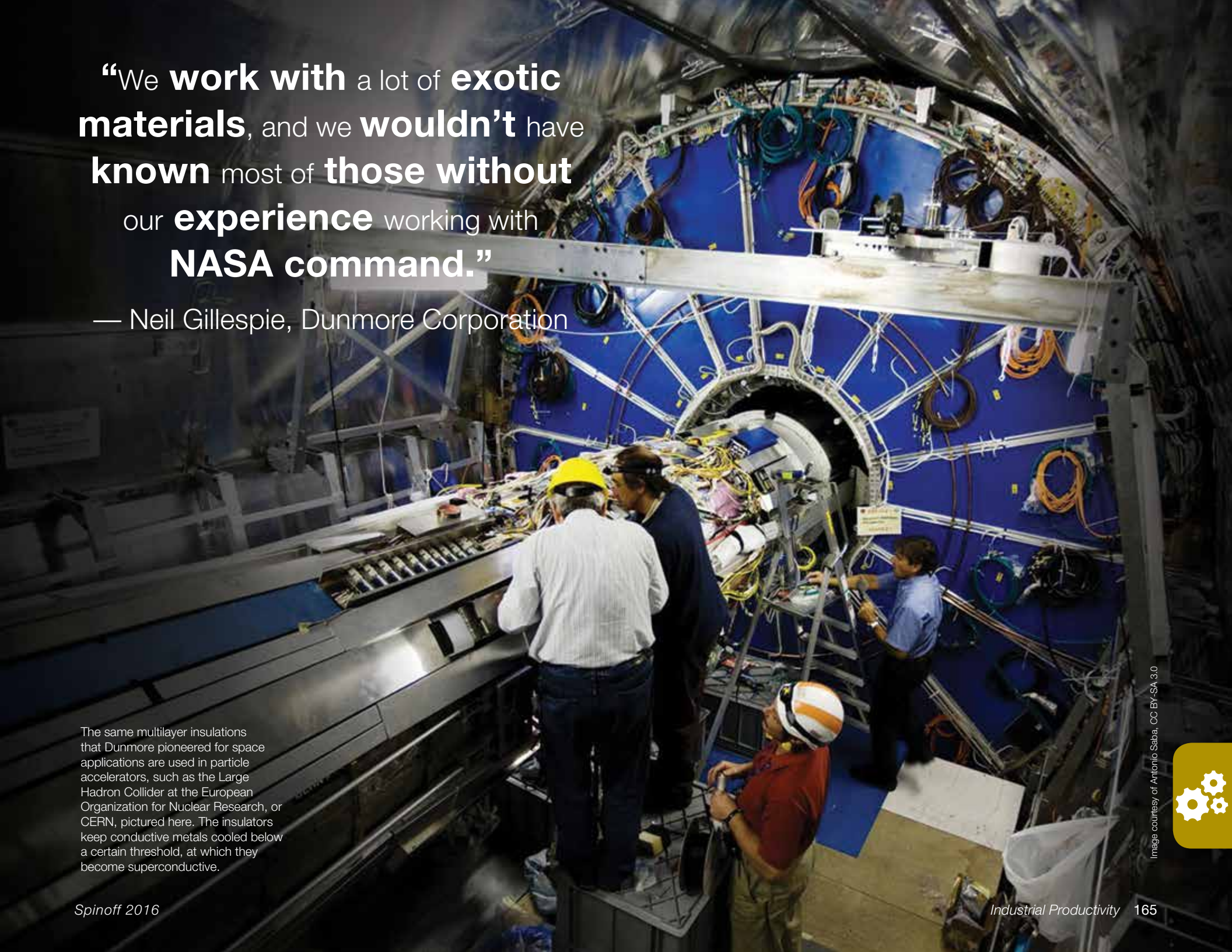
The results were ultra-light, reflective insulation films that could be applied in many more layers than metal foils without adding too much weight to the spacecraft.

"They have many different metals they're able to apply to film, depending on what our specifications are," Duran says, noting that different spacecraft encounter different conditions. A probe visiting Jupiter, for example, would require a conductive surface to ward off electrical jolts from the Jovian charged-particle belts.

While the company is far from the only provider of such materials for NASA missions, Duran says JPL ends up procuring about 75 percent of its thermal films, for example, from Dunmore. "Just about everything we've built over the last 20 years has had, in some form, a Dunmore product on it."

Many of these were standard company products at the time, but others, like the tapes, began as collaborations. "They're in tune with their customers' needs and will produce products, working with us, that aren't in their catalog," Duran says.

Later, when JPL faced the tricky task of coating a Teflon blanket that would allow its CloudSat Earth-observing satellite to dump heat from high-powered electronics while warding off warmth from the sun,



"We work with a lot of exotic materials, and we wouldn't have known most of those without our experience working with NASA command."

— Neil Gillespie, Dunmore Corporation

The same multilayer insulations that Dunmore pioneered for space applications are used in particle accelerators, such as the Large Hadron Collider at the European Organization for Nuclear Research, or CERN, pictured here. The insulators keep conductive metals cooled below a certain threshold, at which they become superconductive.

Duran and his team again turned to Dunmore. It was a challenge, as the material is most famous for allowing nothing to stick to it, but the company succeeded.

Technology Transfer

It was this sort of collaboration to meet NASA's needs that led to many of the products the company sells for terrestrial applications, says Neil Gillespie, vice president of new business ventures for Dunmore. While the company was pioneering its line of multi-layered insulations, for example, NASA engineers asked for specific weights and optical properties, and the company figured out how to meet those specifications.

"We experimented with a lot of different material configurations and coatings to ensure we were developing products with optimal characteristics without adding too much weight," Gillespie says. "It involved a great deal of trial and error and ultimately produced a highly efficient family of products."

In the vacuum of space, the primary mode of heat transfer is radiation, so the thermal protection system must be highly reflective to manage dramatic temperature changes, allowing optimal performance of the spacecraft and its instruments, he explains. The company created light, feathery insulation consisting of many layers that reflect both the sun's heat back into space and the interior warmth back into the spacecraft, maintaining a constant interior temperature.

Benefits

In addition to radiation, terrestrial insulation systems also have to contend with convection and conduction. In a multi-layer system, reflective materials deflect heat just as they do in space, while the multiple layers of material trap air, which is a poor heat conductor and thus slows convective and conductive heat transfer. Weight being less of a concern, foils may be used in reflective insulation for a building, for example, but these materials can feed a fire if it becomes hot enough, presenting a hazard. Metalized polyester, on the other hand, melts away from a flame, Gillespie says. "That was a direct spinoff, from a technical standpoint, of the knowledge we brought from our NASA work."

Another popular use for Dunmore's insulations is in transportation of cryogenic materials—substances like hydrogen, oxygen, or natural gas, that are super-cooled into liquid form. Like a Thermos, the tanks that carry these substances employ a vacuum envelope that nearly prevents convective heat transfer, but, just as in space, radiant heat can still penetrate.

Enter 20–40 layers of lightweight, metalized, reflective polyester. Just as insulation in space needs to let in just enough of the sun's heat to keep the spacecraft warm, the tanks must keep their contents cold enough to stay liquefied but warm enough that they can still be stirred. Liquid natural gas, for example, has to be stored around -260° F. Helium, with the lowest boiling point, is transported at about -450° F—close to absolute zero. The difference is in the number of layers of insulation.

The same technology applies to other cryogenic applications, such as particle accelerators and magnetic resonance imaging (MRI) machines, and the insulations Dunmore created for space applications can be found in these as well. In the case of a particle accelerator, Gillespie explains, when a conductive metal is cooled below a certain threshold, its electrons pair off, forming a lattice that allows electrons to

Dunmore has a long line of temperature-resistant tapes, including varieties for wire and cable wrap, for sealing the edges of the company's multilayer insulation, and for creating nonstick surfaces. Several of these were originally created for NASA applications.

Dunmore combines various thin films with different metals to create multilayer insulations with specific thermal, optical, and other properties.

pass through it without scattering, and therefore without resistance. It's become superconductive.

In particle accelerators belonging to the European Organization for Nuclear Research (CERN), Oak Ridge National Laboratory in Tennessee, and others, conductive metals are cooled by liquid helium or nitrogen, surrounded by vacuum envelopes containing Dunmore's insulations.

"It's exactly what they use in space," Gillespie says, adding that the same products are used in MRIs, which also use superconductive materials to generate a strong enough pulse to penetrate the body.

Dunmore has learned other lessons from its work with NASA that have now found commercial applications, such as how to make labels for circuit boards that can withstand the heat of soldering. Circuit boards also require the protection of thin, lightly metalized film to dissipate static electrical charges that might otherwise fry components. The company started making these electrostatic shields for Earth applications but expanded its offerings through work it did for satellites, which are especially susceptible to static electrical charges in the dry environment of space.

Electrostatic dissipation is an application that's continued to grow in importance on Earth. "As things have gotten smaller, static electricity has gotten to be a bigger problem," Gillespie says, explaining that a nanocircuit's wires and parts are so tiny and fragile that any electrical jolt will fry them.

And the tapes Dunmore developed for use on spacecraft? Their high heat tolerance has made them suitable for consumer electronics, and they are also used as wire and cable insulation aboard aircraft due to their strength and effectiveness as an insulator.

Having developed so many aerospace products, the company naturally established a presence in the emerging field of commercial space, working with companies like SpaceX, Orbital Sciences, Virgin Galactic, Blue Origin, and Bigelow Aerospace. "We're still very active in that market and delighted to be so," Gillespie says. "It's very exciting these days."

Duran says Dunmore's willingness to collaborate with clients like NASA to develop new products has made it the biggest player in its field. "They have a catalog that is humongous, and they offer just about every film known to man."

Gillespie agrees. "We work with a lot of exotic materials, and we wouldn't have known most of those without our experience working with NASA command." ❖

Dunmore's use of thin, metalized films to create lightweight, multilayer insulation has found uses not just in protection against the temperature extremes of space but also for insulating liquefied gas tanks and superconductive elements of magnetic resonance imaging machines, among other Earth applications.

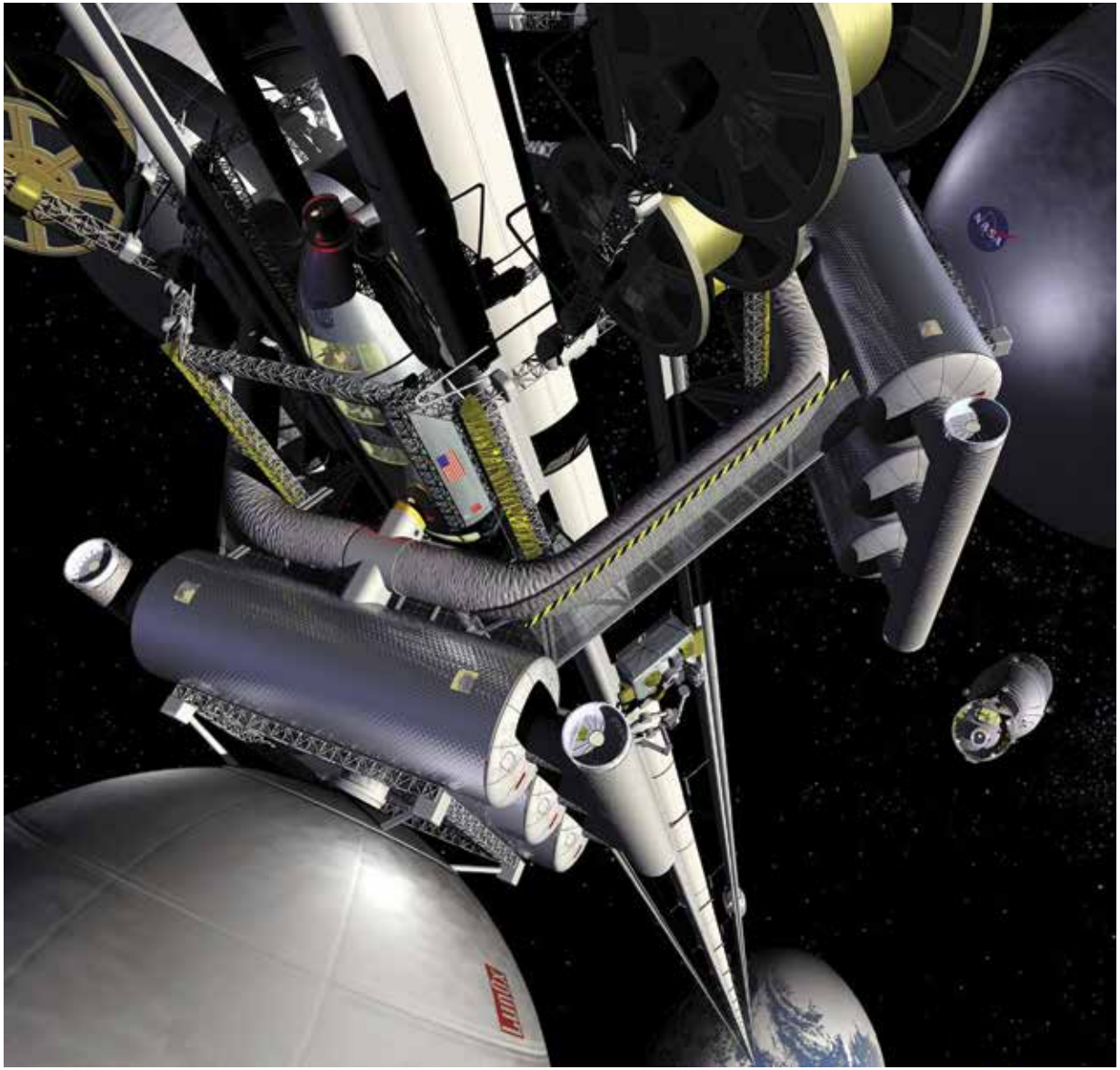
Lasers Enable Alternative Power Transmission

NASA Technology

Science fiction writer Arthur C. Clarke, in his hugely successful 1979 work *The Fountains of Paradise,* crafted a story around the development of a technology that had been proposed since at least the late-1890s: a space elevator. Simple but provocative, its design calls for a cable to rise 24,000 miles from Earth's equator to a satellite in geosynchronous orbit. Spacecraft and payloads would climb up the cable and launch into space, upending the costly, resource-intensive rocket launch method currently used.

Through the years, that concept has taken a leap from the pages of fiction to the realm of scientific inquiry, as governments and private industry have been working on cracking various logistical barriers to its realization. For its part, NASA's Space Technology Mission Directorate is also helping to advance innovation in that and other visionary technologies through its Centennial Challenges Program. Started in 2005, the program offers cash prizes for inventors, including small businesses and student groups, to come up with innovative solutions to technical problems of interest to both the Agency and the Nation. Based on feedback from the public and from private industry, in its inaugural year the program initiated the Space Elevator Challenge.

One of the contests was to help overcome a key conundrum in the space elevator scheme—how to power the robot "climbers" that would be used to carry spacecraft and other payloads up the elevator and into orbit. Because of the distances involved, the robot would need to operate without being connected to electrical wires; batteries, while portable, lack adequate reserves of power. The only feasible alternative at the moment is to beam light onto photovoltaic arrays installed on the climbers, which would convert incoming photons into electricity. The "cordless extension cord," as it's called, would be useful for powering not only space elevators but also exploration vehicles such as rovers and other devices.



An artist's depiction of a technology that has long been a mainstay of the science fiction genre: a space elevator. Transporting and launching satellites and other spacecraft using an elevator shaft that extends thousands of miles into space would obviate the need for costly rocket launches from Earth's surface.

“It might not be **powering** a **space elevator** yet, but **we think** the **technology’s ripe** for **revolutionizing** what these **aerial vehicles** can do and **how long** they **can do it.”**

— Tom Nugent, LaserMotive

The requirements for the 2009 Power Beaming Challenge were the most demanding, as competitors had to power their robots up a dangling cable for one kilometer at a minimum speed of two meters per second to qualify for a cash prize. LaserMotive’s robotic climber was the only machine out of the three entered into the competition that reached the coveted one-kilometer bumper (left), doing so on four separates occasions and at a maximum speed of 3.97 meters per second, earning the team $900,000 from NASA. Inset: Steve Burrows (left) and Dave Bashford of LaserMotive prepare their robot for one of its successful ascents during the competition.

To advance the technology, the Spaceward Foundation arranged with NASA to run a sub-competition as a part of the Space Elevator Challenge, which was called the Power Beaming Challenge. The objective for each team was to utilize the photovoltaic-based approach to design a robot that could climb a cable suspended in mid-air for a certain distance and at a certain speed.

Technology Transfer

The Power Beaming Challenge was held in 2005, 2006, 2007, and 2009, and the requirements became more stringent as the years progressed. In 2005 and 2006, rules held that, to claim a cash prize, participating robots had to climb 50 meters of cable at a speed of 1 meter per second; in 2007 the required distance was increased to 100 meters; in 2009, competing robots had to climb 3,280 feet, or one kilometer, into the air at a minimum pace of at least two meters per second. (For the kilometer-long contest, organizers forsook the crane they had been using for a helicopter, which hoisted the ultra-long cable into mid-air for 45-minute intervals, the length of time each team had to accomplish the feat.)

Not a single team managed to win prize money in any year, that is, except for Seattle-based LaserMotive. Physicist and laser expert Jordin Kare and fellow scientist Tom Nugent decided to form the group, comprising themselves and other industry experts, in preparation for the 2007 competition after watching the previous year's contest in Las Cruces, New Mexico. "Most of the teams were using spotlights to direct light onto their climbers," Nugent says. "We thought we could do better."

By doing better, Nugent meant employing diode lasers, which provide more light intensity than spotlights. By the mid-2000s these semiconductor lasers had become efficient enough to make the leap from industrial to commercial applications, such as laser hair removal, materials processing, and telecommunications. Their expanded use helped reduce the costs of production, making it possible for a startup like LaserMotive to incorporate the technology in its scheme.

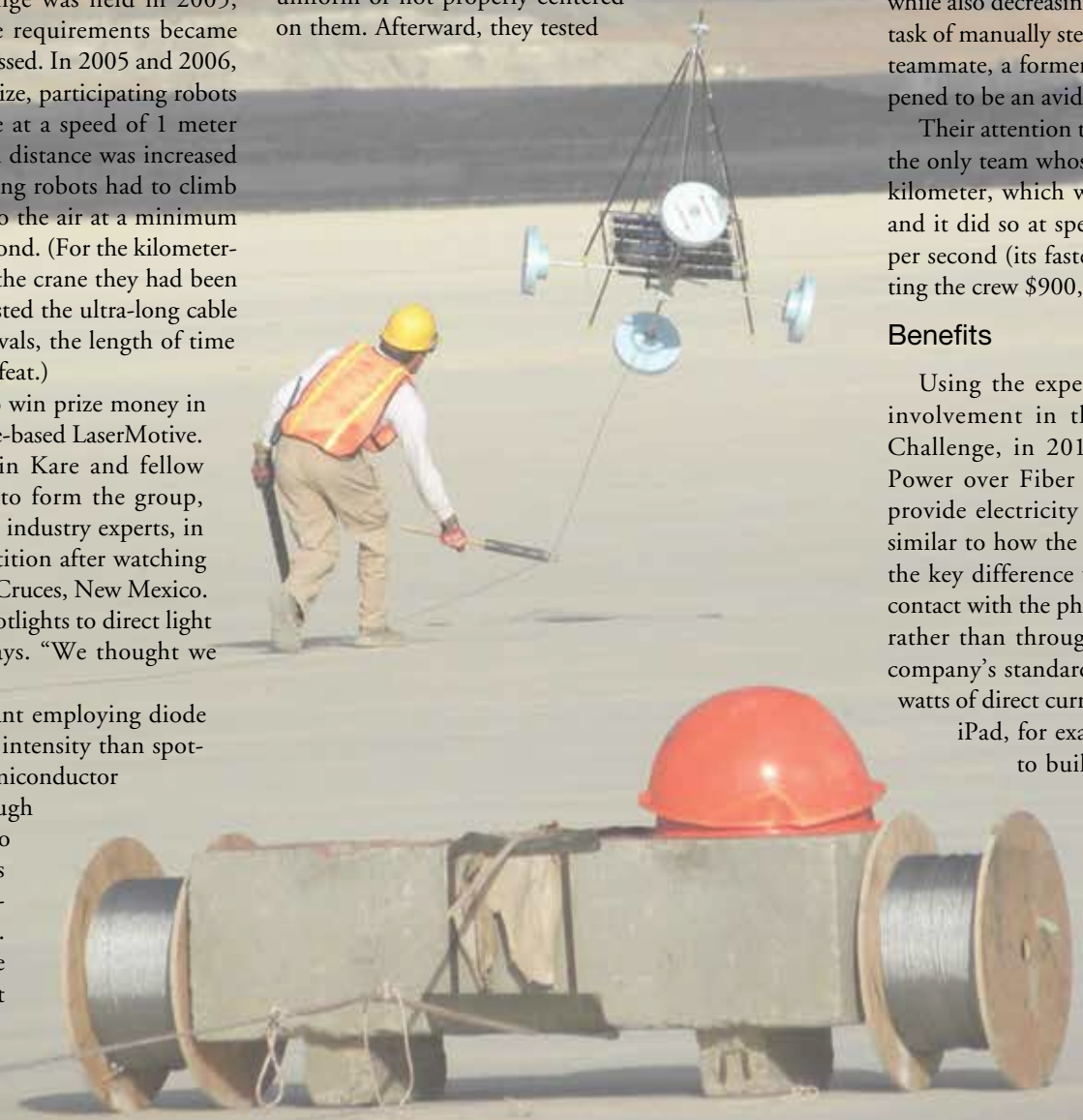
In addition to ordering a customized laser diode that combined multiple diodes into a compact but high-intensity light source, the team worked diligently in designing and building the robot, which was a huge undertaking by itself, says Nugent. Among their major innovations was optimizing its photovoltaic arrays so that they maintained efficiency even when the beam was not uniform or not properly centered on them. Afterward, they tested the entire setup by powering the climber repeatedly on a treadmill, which helped them "to do a lot of iterations, which prepared us better for the actual event," he adds.

In the 2007 competition, LaserMotive took a gamble and tweaked some of the system mechanics in order to increase the climber's efficiency, but it had the effect of rendering it inoperable. In 2009 the team didn't repeat its mistake. The crew simulated the climb multiple times in advance and, in the process, improved their plan of attack while also decreasing the likelihood of failure. The critical task of manually steering the laser was left to the youngest teammate, a former Marine who, as Nugent notes, happened to be an avid video gamer.

Their attention to detail paid off. LaserMotive became the only team whose climber ascended the cable the full kilometer, which was done on four separate occasions, and it did so at speeds above the minimum two meters per second (its fastest was 3.97 meters per second), netting the crew $900,000 as a result.

Benefits

Using the expertise and money gained from their involvement in the NASA-funded Power Beaming Challenge, in 2012 LaserMotive commercialized its Power over Fiber (PoF) technology. The system can provide electricity to a variety of devices in a method similar to how the company powered its robot climber, the key difference with PoF being that the laser makes contact with the photovoltaic panels via fiber optic cables rather than through manually steering the beam. The company's standard, off-the-shelf model is rated for 10 watts of direct current (DC) power, enough to charge an iPad, for example, and there are designs in place to build one that can provide 400 watts—



Spaceward Foundation volunteer Michael Keating served as the "tetherman" for the 2009 competition, responsible for making sure the cable did not snag and that each robotic climber was brought back to Earth gently. Here, Keating prepares to catch LaserMotive's climber after an attempt.

the amount of juice needed to power either a small multicopter or a drone.

Other companies offer similar technology, but what separates LaserMotive from the rest of the pack, Nugent says, is the availability of higher wattages (most other companies' models provide less than a watt of power) and also the added safety features. If the fiber optic cable were to be cut, for example, the laser would shut off automatically, preventing eye injuries.

The main reason customers are using the technology is for electrical isolation. One Federal research lab runs a high-voltage experiment requiring controlled explosions, Nugent says, and they don't want a power system to suddenly have kilovolts coming back to them through electrical wires. "By using the Power over Fiber system, they are able to run this experiment and have it be completely electrically isolated, not having to worry about damaging any of the electronics in their control system."

Meanwhile, another group is looking to use the technology for a suite of sensors that require isolation from radio frequency noise. "An electronic power supply has the potential for generating radio frequency signals that can interfere with data collection, Nugent explains, "so they're evaluating Power over Fiber because they would be able to get a clean DC power output."

Another potential application is for powering underwater robots. Lasers do not propagate very far through water, and conventional copper wires are heavy and thickly insulated, causing drag. PoF removes all of those inefficiencies.

In addition to PoF, LaserMotive is also working on another technology, UAV Power Links, with UAV standing for unmanned aerial vehicle. The technology works much like the one that powered the company's prize-winning robotic climber in that a ground-based laser diode will power the device. "What we're developing will be able to keep these UAVs powered indefinitely within the laser's line of site," Nugent says, adding that they're designing it so that the photovoltaic panels and the laser will automatically point toward each other, negating the need for manual operation.

Among UAVs, multicopters stand to benefit the most from the technology; because copter blades require a lot of energy to create lift, when carrying a payload their batteries usually have to be replaced about every 20 minutes, with the landing, battery-swapping, and re-launching to get back into position taking some 15 minutes. Nugent cites Hollywood for why this is a problem. "If you're shooting a film or a commercial, that's a lot of down time, which is money down the drain because crews have to be out there longer and sets have to be readied again. Costs can add up quickly."

For a UAV that's conducting military reconnaissance, it's not so much an issue of time savings, but the fact that they "cannot afford to have it not be in the air," Nugent says. "Your eye in the sky is not going to be looking if you're not up there."

As of this writing, only the military and certain industries such as movie and television crews, with permits, are allowed to operate UAVs, but Nugent is hopeful the Federal Aviation Administration will allow more widespread commercial use of them by 2016, which is when he expects UAV Power Links to have been tried, tested, and ready for purchase. "It might not be powering a space elevator yet, but we think the technology's ripe for revolutionizing what these aerial vehicles can do and how long they can do it." ❖

LaserMotive's success in the Power Beaming Challenge allowed the company to commercialize its Power over Fiber (PoF) technology, which provides electricity to devices through fiber optic cables. PoF is most commonly used to provide electricity to devices that require electrical or radio frequency isolation.

Helium Recapture System Reclaims Hydrogen for Industry Use

NASA Technology

Rising helium prices might not put much of a dent in the average birthday party balloon budget, but they add up quickly for an organization like NASA, which uses up to 100 million cubic feet of helium each year. A new technology developed with NASA funding, however, will not only allow the Agency to reuse its helium but also let various industries recapture the hydrogen used in processes like treating metal and making glass or silicon.

NASA uses helium to purge hydrogen lines around launch pads and rocket test stands, explains Jonathan Dickey, engineer with the Mechanical Design Group at Stennis Space Center, the largest rocket test facility in the United States. "Our main propellant is liquid hydrogen, and we do a pretty brisk business in the stuff."

The hydrogen is brought by barge or tanker truck and piped to test stands in liquid form through flexible lines. Any hydrogen left in the lines quickly turns to gas, which, being highly flammable, has to be blown out before the lines are disconnected. Due to the cryogenic temperatures, though, blowing air—or most other gases—through the lines is impossible.

"Air would solidify into blocks of solid oxygen and nitrogen," Dickey explains. "Helium is the only element that liquefies at a lower temperature than hydrogen, so we can use it and it will still be a gas."

Until now, the two mixed gases have been blown out of flare stacks, where the hydrogen is burned off. But in 2009, with a 1996 law that would take the Federal Government out of the helium business scheduled to finally begin taking effect, NASA put out a call for proposals for a technology that would make the Agency less susceptible to rising helium prices.

Among those who responded was Trent Molter. Having previously founded Proton Energy Systems, now Proton OnSite, a company that manufactures hydrogen, nitrogen, and zero-air generators, and working on his doctorate in fuel cell technology, Molter had recently founded Sustainable Innovations, LLC, which is based in East Hartford, Connecticut, and focuses on clean-energy technology. His company had been developing a reverse form of fuel cell technology that would use an electrical charge to separate and purify hydrogen, whereas an actual fuel cell combines hydrogen with oxygen to create a charge.

"It was really all about thinking of new ways to apply existing fuel cell technology to create new products," Molter says.

Technology Transfer

Stennis was interested and entered into a Small Business Technology Transfer (STTR) contract with Sustainable Innovations, with Dickey acting as the technology monitor. The following year, Stennis awarded the company a Phase II STTR contract to build a prototype for the system.

While Sustainable Innovations had tinkered with the technology previously, Molter says, "The Stennis application was the first time we wrapped a full system around it, so that was a huge stepping stone for us."

At the heart of the system is the same proton exchange membrane technology used in hydrogen fuel cells, but in this application, a charge applied to electrodes on either side of the cell drives hydrogen protons through the membrane, while electrons loop across through an external circuit, and the gas is recombined on the other side, leaving any other elements behind. In the case of NASA's hydrogen lines, the only other element present is helium, which is then stored for reuse.

"The Stennis people care about the helium more than the hydrogen," Molter says.

Others, however, care plenty about the hydrogen.

Benefits

Hydrogen is used in several industrial processes, especially for the removal of oxides from steel, glass, and

Stennis Space Center is in the business of testing rocket engines, which requires cryogenic liquid hydrogen and oxygen to be piped to rocket test stands. Helium, being the only element with a lower freezing point than hydrogen, is then used to blow any residual hydrogen out of the lines. Sustainable Innovations' hydrogen capture technology will allow that helium, which is set to increase in price as the Federal Government gets out of the helium business, to be isolated, stored, and reused, saving the center hundreds of thousands of dollars a year.

semiconductors such as silicon wafers. The gas combines with any oxygen in the substance and carries it off in the form of water.

"People use a lot of hydrogen for these applications," Molter says, estimating the near-term market at around $100 million annually. "And they vent the hydrogen they don't use. We can essentially scoop up the vented hydrogen and clean it up." The gas can then be reused at low cost.

As hydrogen fuel cell technology continues creeping toward the critical mass that would roll it into the mainstream, Molter sees a major additional use for all the hydrogen that's currently going to waste. The energy market for hydrogen could be up to $50 billion per year, he says. "There are a lot of uses for hydrogen in energy, beyond cars. Some are largely undefined, and some are being defined now."

A major advantage of Sustainable Innovations' first commercial product, called H2RENEW, is that it not only separates and cleans hydrogen but also simultaneously pressurizes it for storage, giving the technology a two-for-the-price-of-one quality. "Conventional hydrogen compressors are separate devices from the hydrogen recycling unit, and they rely on rotating machinery," Molter says. "So ordinarily you would have two large, expensive pieces of equipment to provide both functions." In H2RENEW, though, as long as the voltage is applied, the electrochemical separation process continues, and hydrogen is pushed into the storage tank to the required pressure.

"Each device on its own is interesting, but when you combine the functions, that makes it really exciting," he says. He also envisions a compressor using the technology: "This product, in some rendition, would be able to separate hydrogen made through other means and compress the hydrogen that would be fed into a vehicle."

The existing machine is also modular, so units can be stacked to meet capacity requirements.

Sustainable Innovations is also in the process of patenting two methods that allow the technology to work with highly contaminated gases that would hinder performance in any conventional fuel cell technology. "It allows us to operate with some pretty nasty feed gases," Molter says.

Sustainable Innovations took a technology it created to allow Stennis Space Center to reuse helium and applied it to the recapture, cleaning, and pressurizing of hydrogen used in industrial processes, saving companies money. In addition to H2RENEW, the company is planning two more devices based on the same electrochemical platform, a sort of reverse hydrogen fuel cell technology.

Further STTR contracts and Small Business Innovation Research contracts with various other NASA field centers have continued to advance the technology.

The company, which now has about 16 employees, also has two more products in the pipeline, based on the same electrochemical platform. The HALO-GEN, based on reversible hydrogen/bromine chemistry, is planned to be a low-cost, high-efficiency battery that would allow a "smart grid" powered by wind or solar energy to provide a constant power supply, even in the absence of wind or sun. The system's energy storage component is projected to cost less than half that of the best competition under development. And CO2RENEW would harness carbon dioxide waste emissions, electrochemically converting the greenhouse gas into useable chemicals and hydrocarbon fuels.

"The platform for the other two products is very similar, so we're really leveraging the work we did on the NASA product," Molter says. "If we achieve a higher efficiency with one product, oftentimes we can achieve the same benefit across the board."

At Stennis, the helium recapture system was tested and validated by spring of 2015 and was expected to be permanently installed and in use by the end of the year.

"On an average year, if we can recapture and reuse all the helium, it would save hundreds of thousands of dollars," says Dickey.

Molter says the NASA-funded work not only got the technology off the ground but also helped to make it credible as a commercial product. "We brought the very first unit we built under the STTRs to some commercial customers and did a show-and-tell and collected data, and that's helped with our fundraising and commercial partnering," he says. "I think this is an example of one of those projects that work out really well for both sides." ❖

Laser Vision Helps Hubble, Package Shippers See Clearly

NASA Technology

For more than 25 years, the Hubble Space Telescope has provided stunning photos of the universe unequalled in their depth, detail, and distinction. Hubble imagery has been used for calendars, T-shirts, coffee mugs, computer decals, and countless other products, but, more importantly, also for groundbreaking scientific research both in our galaxy and across the observable universe. NASA hopes to continue using the tool for as long as possible, even as it prepares to launch the high-powered James Webb Space Telescope (JWST) in 2018.

However, in its early days, Hubble wasn't capable of sending back such breathtaking photos. Within weeks of launch, it became apparent that something was wrong, as the images beamed back to Earth were fuzzy and out of focus. It was determined by analysts that Hubble's primary mirror had been ground to the wrong shape and was too flat by 2.2 micrometers—or one-fiftieth the thickness of a human hair—causing reflected light from the edge of the mirror to be focused on a different point than light coming from near the center. A commission led by the Jet Propulsion Laboratory determined that the device used to create the precisely shaped but nonspherical mirror had been incorrectly assembled and that the mirror's manufacturer had failed to notice the problem before Hubble was launched.

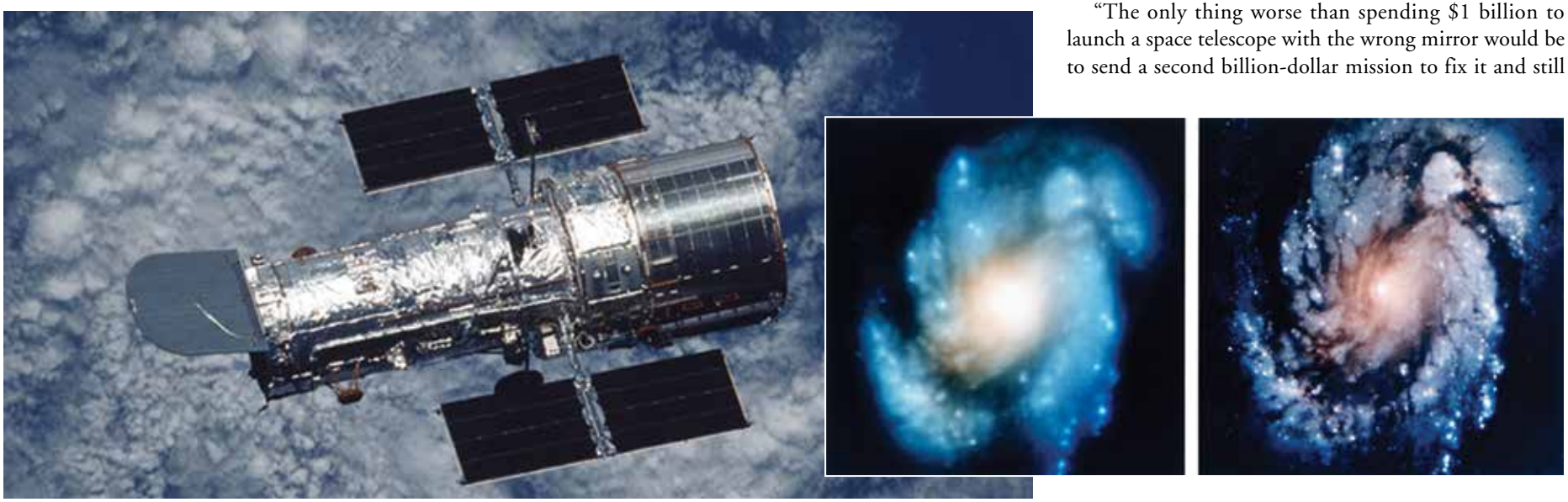
NASA decided on a two-step approach to address the problem. During the first repair mission to Hubble, astronauts would replace the Wide Field Planetary Camera (WFPC) with an improved version featuring advanced detectors and more accurate contamination control along with built-in corrective optics, known as WFPC 2. Secondly, the astronauts would replace one of Hubble's original components, the High-Speed Photometer, with the Corrective Optics Space Telescope Axial Replacement (COSTAR), which would work like a pair of eyeglasses to better focus the telescope's view of the universe.

But first, the Agency wanted to make sure the repairs going up into space would indeed improve Hubble's ability to capture images and not suffer from any undiscovered flaws.

Technology Transfer

NASA put out a call for optics companies to prove they could verify the shape of a mirror hidden from view and detect any defects, however slight. Along with other companies, AOA Xinetics, now a Cambridge, Massachusetts-based subsidiary of Northrup Grumman, made the trek to Goddard Space Flight Center with its aberrated beam analyzer (ABA), which it built to meet NASA's specific requirements.

"The only thing worse than spending $1 billion to launch a space telescope with the wrong mirror would be to send a second billion-dollar mission to fix it and still



A misshapen mirror aboard the Hubble Space Telescope caused the first images beamed back to Earth to be fuzzy and out of focus. After the installation of new optics, tested by an abberated beam analyzer invented by AOA Xinetics to ensure the new lenses would work perfectly, Hubble began sending back crystal-clear, vivid images from across the observable universe.

have the wrong mirror," says Cameron Dryden, director of AOA's systems and service business. The challenge, nicknamed the "Sense-Off," consisted of a series of five mirrors for the companies to measure, each a slightly different shape and one purposely shaped to match the defective mirror on Hubble. AOA needed to use its analyzer to determine both the mirror's flaw and how to compensate for the fuzzy image using a static corrector.

"Before this challenge, we didn't have a piece of optical test equipment capable of solving this problem," Dryden recalls. Prior to creating the ABA, he says, AOA had experience in measuring the way the atmosphere bends and distorts light, a process that requires split-second measurements but not high levels of accuracy relative to the measurements NASA needed. For the "Sense-Off," accuracy was paramount, but the company could take all the time it needed.

The team decided to illuminate the mirror using flat wave-fronts of light from a laser, knowing that the waves bouncing back could allow the ABA to detect the unseen mirror's shape, right down to microscopic divots and bumps.

Within 30 days, a team from AOA designed and created the new tool and drove down to Goddard with the ABA in the back of a station wagon. The instrument not only detected the mirror's shape accurately but did so to within three-thousandths of a wavelength of light, something that had never been done before. AOA's analyzer was selected by NASA as the tool used to verify both COSTAR and WFPC 2 were perfect before being sent into space. Thanks in part to AOA's work, Hubble has been sending captivating images back ever since.

Benefits

After developing the ABA, "There was a complete shift of mentality" at AOA, Dryden says, leading the company to consider three-dimensional imaging when presented with a new problem. "From then, it just opened up a whole suite of applications with an overarching goal of making images better and more useful," he says.

Shortly after the work on Hubble, AOA used the ABA to create the Mass Scanning and Dimensioning System, originally used by FedEx to quickly and accurate create 3D images of the packages that would need to be sorted and shipped in a given day.

Utilizing the improved optics capabilities it developed for NASA, AOA Xinetics has worked with Kroger grocery stores on a scanning system that better and more rapidly identifies products, allowing customers with large orders to take advantage of self-checkout aisles.

The scanning system "creates a contour map of parcels as they travel down a conveyor belt past a laser ranging imager," Dryden says. "Height contours are subsequently analyzed to determine the location of each parcel and its dimensions," which helps to identify packages that might require additional charges due to size or weight. Previously, someone would have to manually pull items off conveyor belts and use a tape measure to single out packages.

This imaging system, which has since been adopted by all major shipping services, including the U.S. Postal Service, has been utilized by "hundreds of machines running millions, if not billions, of hours for 20 years," he adds.

Building on the FedEx work, AOA partnered with Kroger grocery stores to develop the Scan Tunnel to ease checkout at its stores. Customers put their products on a conveyor belt, which then travels through an upright tunnel with laser scanners on three sides, capturing product information from brand name to bar code for identification and pricing. This allows customers with larger orders to take advantage of self-checkout aisles. Scan Tunnel uses 14 scanning cameras and 2 types of dimensioners, an improvement over the 7 cameras and 1 dimensioner used in FedEx's system, Dryden says. The Scan Tunnel was named Retail Innovation of the Year in 2010 by *Planet Retail* magazine, after the first machines debuted, and AOA is working with Kroger to install additional machines throughout the country.

Both products have roots in the initial work to save Hubble from obsolescence. "Some companies we work with introduce us as the people who fixed the Hubble telescope, and that might be a little overstating it, but it certainly has helped us make inroads with a number of commercial companies," Dryden says.

Now, after 25 years, Hubble continues to provide breathtaking images of the galaxy, long exceeding the optimistic predictions that it would send back views of the heavens for only 15 years. While JWST will eventually replace and outshine Hubble, there's every reason to think Hubble will continue to dazzle for at least another 5–10 years. ❖

Space-Ready Durometers Measure Hardness on Earth

NASA Technology

There are no mechanic shops in space.

Following the Space Shuttle Columbia accident in February 2003, NASA implemented additional safety inspections to be conducted in space to ensure returning Shuttles weren't in danger of fracturing or losing integrity upon reentry into Earth's atmosphere.

Every time a Shuttle landed at either Edwards Air Force Base or Kennedy Space Center, engineers and mechanics painstakingly examined every square inch for damage, says Mark Dub, an extravehicular tool engineer at Johnson Space Center. "You'd see these little dings, dents, chips, cracks, divots on the underside of the Shuttle," he says, adding that prior to the Columbia accident, it was unclear whether the damage was inflicted in space or during reentry.

Once spaceflight resumed two years later, NASA began using the orbiter boom sensor system, an extension of a robotic arm carried by the Shuttle, to "carry a package of cameras and lasers that you would use underneath the Shuttle to inspect it and check for damage," Dub says.

Shuttles would also perform a 360-degree pitch maneuver, in which the Shuttle would flip nose-over-engines onto its back while approaching the International Space Station (ISS). Astronauts on the ISS would examine the tiles on the Shuttle's underbelly as it approached, taking photos to be sent back to Mission Control for analysis.

If missing or damaged tiles were found, one of several in-space repair options called for astronauts on a spacewalk to don special backpacks filled with a two-part "goo" called a cure-in-place ablator (CIPA) that both filled cracks and could be used to replace entire tiles if needed, Dub says. The two parts of the CIPA, which he compares to caulk, would mix as dispensed, allowing a catalyst to enable the goo to harden within about 24 hours.

Carrying replacement tiles was out of the question, as most of the Shuttle's estimated 22,000 tiles were precisely shaped according to placement on the Shuttle, Dub says. Tiles closer to the nose and wing edge were thicker to better withstand the greater heat of reentry in those regions, for example.

But in order to ensure the repair work was strong enough to withstand the flight back through Earth's atmosphere, NASA needed a little help.

A view of the Space Shuttle Endeavour as the STS-118 crew puts the spacecraft though a rendezvous pitch maneuver, allowing the crewmembers on the nearby ISS to document the vehicle's thermal protection system condition.

Technology Transfer

Durometers are gauges used to determine the hardness of a nonmetallic substance—anything from sporting equipment and tires to shoe soles and lobster shells, explains JC Blum, vice president of operations at Buffalo Grove, Illinois-based Rex Gauge Inc. One of three durometer manufacturers in the country, Blum says his company was initially approached by Lockheed Martin on NASA's behalf before working directly with the Agency.

Rex Gauge has been making gauges and specializing in durometers since 1942 and, in general, the design hasn't changed much in that time, Blum says. The bottom of the gauge is a spring-loaded indenter, which is pushed into whichever substance needs to be tested for hardness and measures the amount of penetration into the material under a given spring force. The gauge has a dial to display the hardness of the substance on a scale of zero to 100 durometers, he says.

Rex Gauge had an advantage over the other durometer manufacturers in that its parent company, Schultes Precision Manufacturing, is a machine shop and could quickly turn around any custom work needed by clients, Blum says.

Most of the standard durometer's functionality aligned with NASA's needs in space, but the Agency needed something that could be easily seen through the visors astronauts wear to protect from the unfiltered light of the sun.

"If you look at our standard product line, the dials are much smaller on top," Blum says. To meet NASA's requirements, Rex Gauge adopted a larger dial, roughly the size of a pocket watch face at about 2 ½ inches in diameter, and instead of relying solely on numbers, added a red and green background. That way, astronauts would be able to tell at a glance whether the goo was hard enough or needed more curing time.

The durometer's barrel was given a matte finish for easier gripping by pressurized gloves, and the top was modified to have more of a mushroom shape to make it easier to grab. Additionally, the barrel was given a tether point and bayonet probe, common attributes on tools used for extravehicular activities, to allow for ease of access and securing into an astronaut's tool belt or toolbox.

"Putting the bayonet probe on the durometer made it a lot easier to carry it out there, to store it when you're not using it and to use it when you are," Dub explains. "The tether point on top of the handle was a spot where you could attach a hook to it, and that hook would keep the durometer from floating away."

Benefits

The durometer modified by Rex Gauge for NASA was crucial when making CIPA applications and tile repairs, Dub says. Readings in the red area indicated the CIPA had not yet cured sufficiently to protect the Shuttle from the searing heat of reentry. A green reading meant the tile was ready to withstand the return trip.

Blum says NASA was pleased with the durometer, noting that it "was and remains an integral part of the thermal protection tile repair system."

Back on Earth, Blum says, the company made a special Web site to highlight its work with NASA.

"We enjoyed having the opportunity to work with NASA, for sure," he says. "It was very cool to have a gauge go up into space."

The durometer has certainly became something of a conversation piece, he adds.

"All our gauges have model numbers. This one is the SG-5000, and everyone's like, 'What's SG?' That's for space gauge," he says with a chuckle.

The company has since incorporated the larger dials into its new line of digital durometers for easier readability. The first year the new, larger display was the standard option for the Model DD-4 durometer, sales increased 35 percent, Blum notes.

Following the work on NASA's durometer, the company established a partnership with the Space Foundation, earning a Space Certification which allows Rex Gauge to use a "Space-Certified" logo on marketing materials as well as the company's Web site. The gauge made for NASA is also featured as a highlight on another section of the company's Web site promoting custom-made gauges. ❖

An astronaut in training holds the modified durometer, made by Rex Gauge, that was used to ensure any repaired or replaced tiles on the underside of a space Shuttle were hard enough to withstand the heat of reentry from orbit.

Rex Gauge modified a durometer to meet NASA's needs for repairing and replacing the thermal protection tiles on the underside of the Space Shuttle, including enlarging the device's dial. When the resized dial was applied to the company's digital model, sales increased 35 percent.

High-Temperature Superconductors Deliver Power without Heat

NASA Technology

It came to be known as the "Woodstock of Physics." Thousands of scientists tried to squeeze into the Sutton Ballroom of the New York Hilton, overflowing into the aisles and halls, as the American Physical Society's March 1987 meeting was about to get underway. The presentations would last until after three o'clock in the morning, with hundreds of attendees lingering until dawn, buzzing with excitement at the impending, revolutionary technological breakthroughs on the horizon.

Newspapers that year foretold electric cars, magnetically levitating high-speed trains, nuclear fusion plants, and extraordinary savings in energy. The miracle behind all the excitement? High-temperature superconductive (HTS) ceramics.

"At the time, there was great optimism that this would have huge commercial benefits," says Ed Canavan, cryogenic engineer at NASA's Goddard Space Flight Center. "It's only now, almost three decades later, that we're starting to get some of the HTS material into practical applications."

Superconductive materials at very low temperatures allow electricity to pass with no resistance, zero losses, and maximum efficiency. Until the 1980s, the problem was that the amount of energy it took to attain the low temperatures that cause this phase change was often too large to realize the benefit of lower electrical losses. Superconducting metals require temperatures below about 20 K, or -424 °F. The high-temperature superconducting ceramics discovered in 1986 and '87, on the other hand, undergo phase change at temperatures as high as 92 K (-294 °F).

"It's not high-temperature in the normal sense of the term," Canavan clarifies. But it's a warm enough temperature to be maintained by liquid nitrogen, which boils at 77 K and can be bought for less than the price of bottled water or even produced onsite.

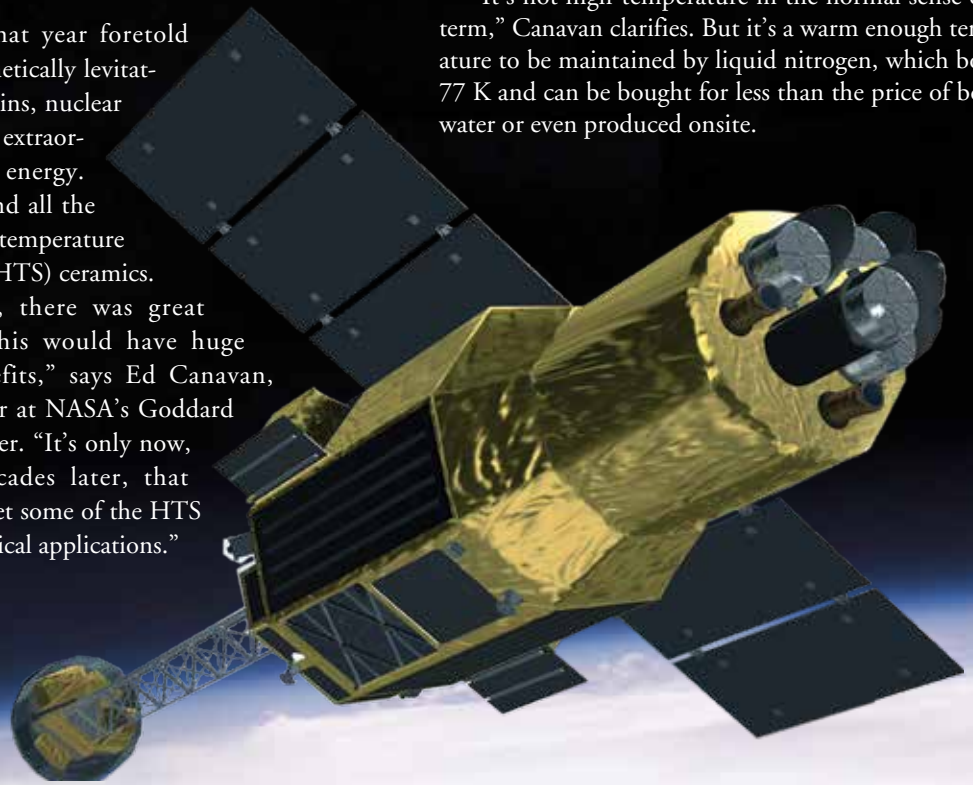
But these superconducting ceramics posed a host of technical challenges. They are chemically complex, and many are brittle and difficult to manufacture in useful lengths. Most challenging, the boundaries between their grains, if not perfectly aligned, cause steep reductions in the maximum current they can carry before losing superconductivity.

By the mid-2000s, the superconductor industry was able to move high currents over long distances using these ceramics arranged in a tape-like geometry, although the technology still was generally not cost-competitive.

In 2008, as work was getting underway on Japan's ASTRO-H orbiting observatory, Canavan and other researchers at Goddard needed high-temperature superconducting leads to carry a current from a room-temperature power source to a cooling system operating near absolute zero. NASA is contributing the X-ray satellite's high-resolution soft X-ray spectrometer, whose detectors are made ultrasensitive by temperatures about one-twentieth of a degree above absolute zero.

For its contributions to two previous, similar Japanese missions, Goddard had used delicate rods of the ceramic yttrium barium copper oxide (YBCO).

"If we had used normal, metallic wire, the heat carried by the wire from the middle-level temperature stage in the instrument to the lower-temperature region would just swamp the cooling power," Canavan says. Metallic wire would introduce heat both by conducting it along its length and by generating heat as the electric current



NASA contributed the soft X-ray spectrometer for Japan's ASTRO-H X-ray astronomy satellite. To carry electricity, but not heat, from a room-temperature power source to a cryogenic superconducting electromagnet aboard the satellite, Energy to Power Solutions developed a set of hybrid, superconductive leads. The electromagnet is used to cool the instrument's detectors to near absolute zero, making them ultrasensitive.

> In general, superconductors are very useful devices for any time large amounts of power need to be conveyed in a small space."
>
> — Chris Rey, Energy to Power Solutions

passed through it. A superconducting ceramic, on the other hand, is a poor conductor of heat and a perfect conductor of electricity, so it transmits little heat and produces none.

By the time work on ASTRO-H started, though, the company that had supplied the fragile YBCO rods no longer manufactured them. "In the meantime, Tai-Yang had developed a means for slitting superconducting tapes developed for electric power distribution down to a size reasonable for our application," Canavan says, referring to the Knoxville, Tennessee-based company now known as Energy to Power Solutions, or E2P.

Technology Transfer

The company, which specializes in superconductivity and cryogenics, also made its superconducting tapes with YBCO, but they were much more flexible and durable than the cylinders NASA had used on previous missions.

"The challenge was that the allowable heat load was so small it was very difficult to come up with a design," says Chris Rey, president of Energy to Power Solutions, noting that only 100 to 200 microwatts of heat could be transferred by the leads, which also had to be as compact as possible.

While mechanically more robust than solid ceramics, the micron-thick YBCO layer in these tapes is still sensitive to many factors, Canavan says. "It took a thorough knowledge of the material properties to be able to produce tapes small enough to meet the thermal requirements yet still capable of surviving all the processing and testing a flight component receives."

The leads E2P delivered have a hybrid design, with normal metal wires carrying the current from the power source into the instrument and down to an intermediate-temperature connector. From this point, the superconducting leads carry the current down to a liquid helium tank, which operates at 1.2 K.

There it powers a superconducting electromagnet, Canavan explains. Inside the bore of the magnet is a cylinder of paramagnetic salt that heats up and cools down as the magnetic field is increased and decreased. By flipping heat switches that connect it to the liquid helium tank and the X-ray detector as the magnetic field ramps up and down, heat is drawn out of the detector at 0.05 K, lifted up to 1.2 K, and dumped into the helium tank.

NASA delivered the leads to Japan in July of 2014, where the spectrometer underwent months of testing. The satellite was scheduled to launch in late 2015.

Benefits

"In the world of astrophysics, there are a number of reasons that cooling your telescope and/or your detector is necessary to get the extreme sensitivity needed to see very faint, distant objects," Canavan says. "Having these HTS leads that allow you to carry amps of current while not leaking heat down to your low-temperature region is a big advantage."

While his company's technology will help the ASTRO-H mission trace the growth of the universe's largest structures, determine the spin of black holes and the properties of neutron stars, and examine the behavior of material in extreme gravitational fields, among other groundbreaking work, Rey is trying to put it to work here on Earth.

"We have had some commercial sales, but we would very much like to expand our commercial footprint," he says, adding that, while other companies have similar technology, they have not developed the sort of ultra-low-heat lead his company created for NASA. One obvious market, he says, is in magnetic resonance imaging machines, which also use cryogenic superconductors to power their imaging technology.

"In general, superconductors are very useful devices for any time large amounts of power need to be conveyed in a small space," he says.

Rey says the early expectations raised for high-temperature superconductive ceramics may have been unrealistic in terms of the time it would take to widely apply the technology (a 40-year timeline might have been more accurate), but not necessarily in the scope of the discovery's impact. He says great progress has been made since the initial discovery. The materials' complex chemistry posed a major challenge at first, followed by the difficulty of growing kilometer-length ceramic crystals with near-perfect grain alignment, another hurdle that has been cleared. Now, he says, the main obstacle is cost.

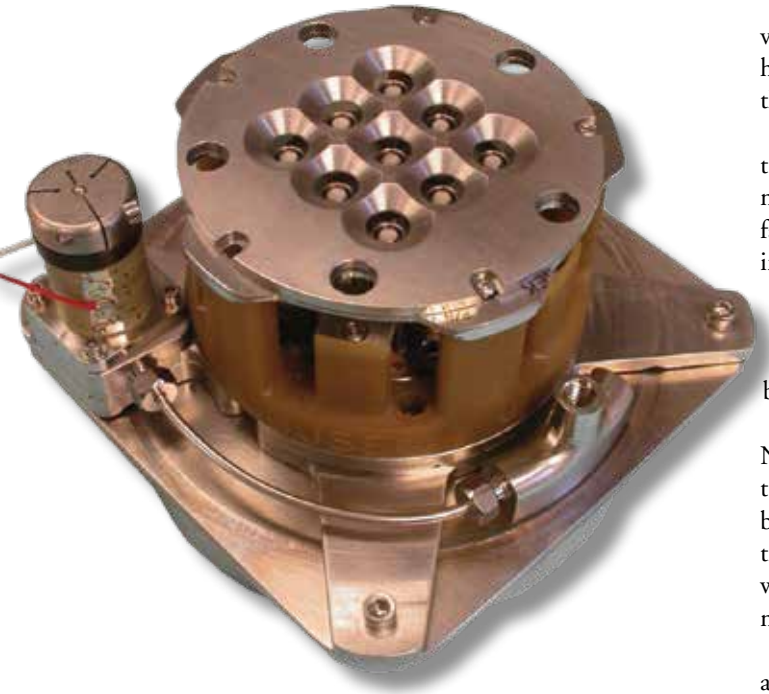
"To move to larger, more high-volume applications, you need to get through the cost-reduction stage that the niche applications provide," Rey says—niche applications like the ones he's working on, for use in space and on Earth. "What we have attempted to do is engineer novel, lower-cost solutions rather than the brute-force approach that others are attempting." ❖

One clear Earth application for the sort of ultra-low-heat superconductive leads that Energy to Power Solutions developed for the ASTRO-H satellite is in magnetic resonance imaging machines, which are also powered with cryogenic superconductors.

Electrospray Thrusters Boost Efficiency, Precision

NASA Technology

When NASA thrusters are mentioned, most people imagine something like the breathtaking launch of the Saturn V rocket that sent astronauts to the Moon. Its five enormous F-1 engines generated more power than 85 Hoover Dams, and liftoff shook tiles off the ceiling of the observation room three miles away. But the agency that is currently topping that feat with its coming Space Launch System, planned to be the most powerful rocket ever built, is also now demonstrating the most delicate thrusters ever flown, so gentle they max out at a thrust equal to the weight of a fine grain of sand.



Following its development of extremely precise, delicate, and efficient electrospray thrusters for the disturbance reduction system NASA provided for the European Space Union Laser Interferometer Space Antenna, or LISA, Pathfinder spacecraft, Busek designed a similar thruster for use in nanosatellites, which have tight space constraints.

When engineer John Ziemer joined NASA's Jet Propulsion Laboratory in 2000, one of his first projects was to survey possible thruster technology for a disturbance reduction system (DRS) that was to be NASA's contribution to the European Space Agency's (ESA) Laser Interferometer Space Antenna, or LISA, Pathfinder mission. The mission is to demonstrate technology that could one day enable measurements of gravitational waves in space.

"This could be a whole new way to look at the universe," Ziemer says. "You could see supermassive black holes coalescing at the center of galaxies or look back to the early universe."

The existence of gravity waves is predicted by the theory of relativity, but they've never been measured, mainly because they're barely perceptible—so slight, in fact, that the job of the DRS is to counteract outside influences as negligible as the force of photons from the sun striking the craft's shell. Given LISA's surface area, this would be about equivalent to the push of a mosquito landing, Ziemer explains. "A gravity wave would be swamped by that disturbance."

The DRS would also have to be unusually long-lived. Normally, thrusters are used only occasionally and briefly to put a spacecraft in place or change trajectory. But because the DRS must allow the craft to perfectly follow the test mass floating at its center, it has to be running whenever testing is being performed. Accordingly, the mission requires thrusters with a life of up to 3,000 hours.

NASA's contribution to LISA Pathfinder was funded as Space Technology 7 (ST7) under the Agency's New Millennium Program, which works to put the latest technology to the test in space.

During the buildup to the project, Busek, a company specializing in spacecraft propulsion and located in Natick, Massachusetts, was working on developing thrusters for use on nanosatellites under a Small Business Innovation Research (SBIR) contract it had won from Glenn Research Center two years earlier. As ST7 got underway and Ziemer became the project's cognizant engineer for thrusters, Busek was one of two companies selected to compete for the contract to supply the subtlest thrusters ever flown: a technology called electrospray.

> "There really isn't anything that can compete with electrospray, in terms of thrust efficiency."
>
> — Nate Demmons, Busek

"There really isn't anything that can compete with electrospray, in terms of thrust efficiency," says Nate Demmons, director of Busek's Electrospray Group. It works by applying an electrostatic field to the surface of an ionized, conductive liquid such as a molten salt, he explains. The charge distorts the surface into what's known as a Taylor cone. At a certain voltage threshold, the electrostatic field overcomes the liquid's surface tension, and a fine spray is ejected from the tip of the cone. These tiny droplets are then electrostatically accelerated to increase the thruster's power.

Having a negligible vapor pressure, Demmons explains, ionic liquids don't evaporate in the vacuum of space, as most fluids would. It was the discovery of these liquids in the 1990s, which have the right surface tension, viscosity, and conductivity, that led to a "Renaissance in electrospray," he says.

The force of the spray, however, still is not easy to control, Ziemer says, noting the ESA worked for about a decade to master electrospray for the LISA project before ultimately switching to a precision cold-gas thruster system to meet budget and schedule constraints.

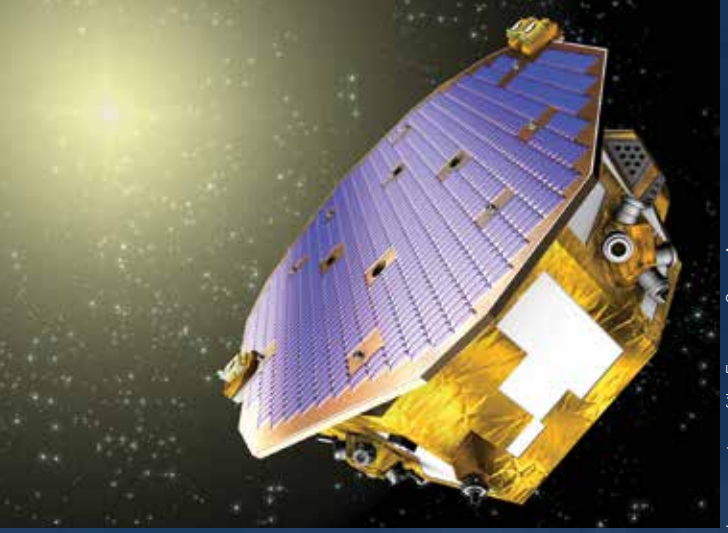


Image courtesy of the European Space Agency

As part of NASA's Space Technology 7 project, Busek developed electrospray thrusters that max out at the weight of a fine grain of sand for the disturbance reduction system on the European Space Agency's LISA Pathfinder spacecraft. The craft is trying out technology that could be used in the future to detect gravity waves, which are predicted by the theory of relativity but have never been directly observed.

Busek refined its control of the thrusters' delicate touch by developing a piezoelectric valve that manages the propellant flow rate. The behavior of such a thruster is difficult to observe or characterize, as the droplets it produces may be smaller than a wavelength of visible light, making them literally invisible. "Regardless, if you can control the voltage and current very closely, you can control the thrust," says Ziemer, adding that the energy output can then be predicted down to the number of atoms that will be accelerated.

"Busek showed that, with the extra valve, they could not only meet the long-life requirement but also meet the thrust requirements," he continues.

Busek was selected to supply two clusters of four thrusters each for the ST7-DRS project, which the company delivered in 2008. The craft was finally launched in 2015, marking the first time electrospray thrusters were flown in space.

Technology Transfer

"In 2008, we did not stop our research," Demmons says. "LISA was mission-specific work, but electrosprays have other benefits we wanted to take advantage of."

The thrusters the company had developed under the contract were capable of thrusts of up to just 30 micronewtons—about equivalent to the weight of the aforementioned mosquito. Busek has since scaled up the technology and returned to the original intent of its work with Glenn—providing propulsion for nanosatellites, such as the increasingly popular CubeSats. These inexpensive little satellites are now used by Government agencies, companies, universities, and hobbyists for purposes like Earth imaging or carrying out experiments in space. There are, however, virtually no options for onboard propulsion that meet the tight volume constraints of these tiny spacecraft, leaving them unable to change orbit or control how quickly their orbits decay.

Busek has successfully produced 100-micronewton and 1-millinewton electrospray thrusters for use on CubeSats, as it works its way up to a 20-millinewton booster that would be required to alter a small satellite's orbit. This is about the force generated by other electronic propulsion systems at their lowest power.

Benefits

More traditional ion thrusters operate at about 50 to 60 percent efficiency, meaning only a little more than half the power used to run them is converted to thrust, due to the energy spent generating, containing, and managing the ionized plasma that propels them. Meanwhile, the electrospray system Busek built for the LISA Pathfinder operates at about 70 percent efficiency.

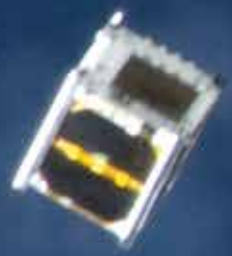
There are also other applications for aspects of the technology. For example, Busek has sold the carbon nanotube electrostatic field emitters it designed for the electrospray thrusters to universities for uses such as electron microscopy. The firm is actively exploring applications within the semi-conductor manufacturing field as well.

The company is most interested in opportunities to get its CubeSat electrospray thrusters into space. Although no units have yet flown, a government or commercial client willing to take on some risk could partner with Busek to make it happen.

There are several other options for satellite manufacturers, however. Busek has developed and now offers several thrusters, including Hall effect thrusters, micropulsed plasma thrusters, radio-frequency ion thrusters, and green monopropellant thrusters—most of which were developed with at least some NASA funding.

"Busek is an expert satellite propulsion house with a stable of technology options," says Vlad Hruby, president of Busek. "After a lot of development work, a number of our thrusters are on the cusp of commercialization, whereas others have already been proven in space."

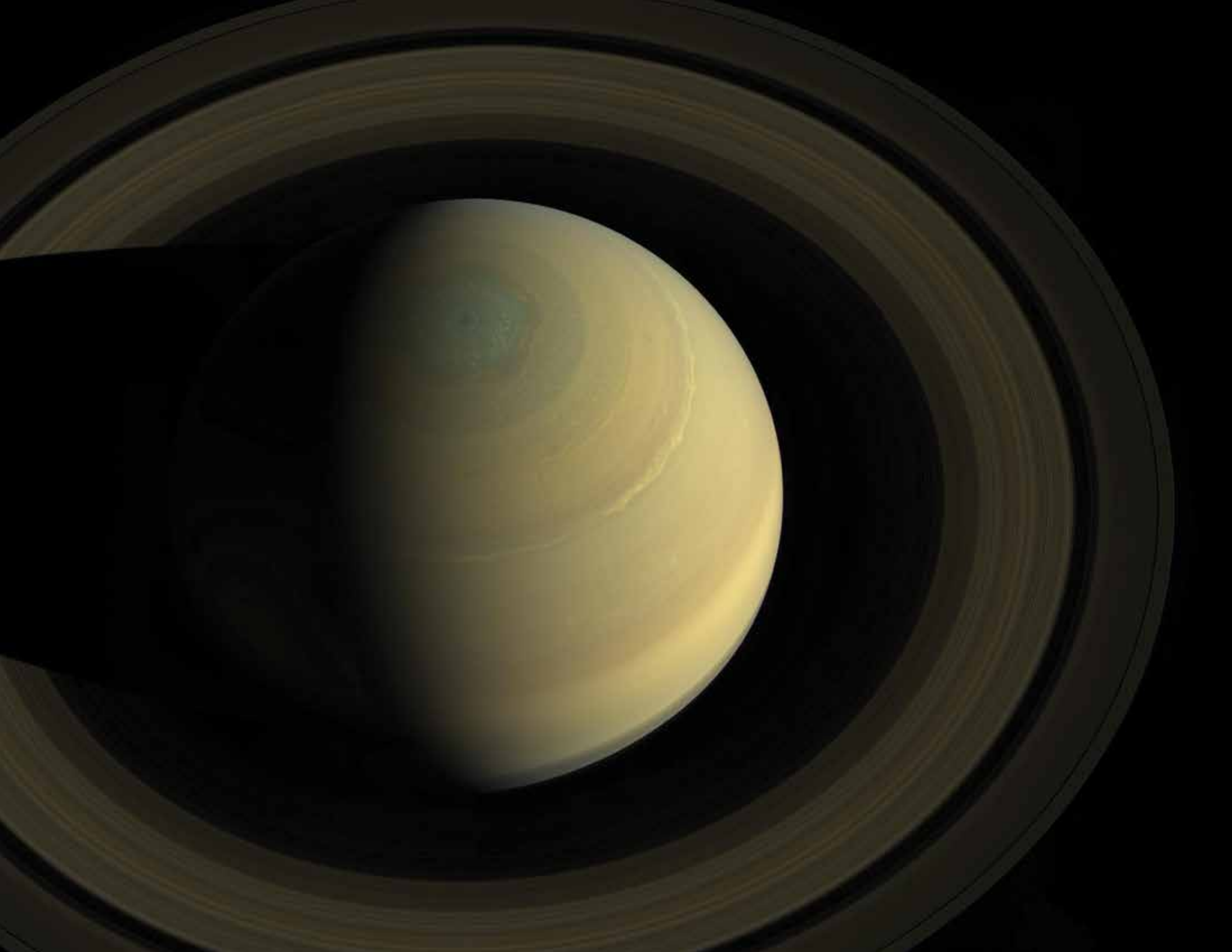
None, however, enable the extreme micro-precision Busek developed during the LISA Pathfinder mission—a mission expected to open up a new way to observe the universe, from unveiling mysteries in the planet's crust and ocean currents to spotting events billions of light-years away. ❖



Since delivering its electrospray thrusters to the Jet Propulsion Laboratory in 2008, Busek has added a similar propulsion technology to its line of thrusters available for use on nanosatellites such as CubeSats, which, at 10 centimeters across, have tight space constraints.

Partnership News

Every year, NASA partners with private companies, universities, nonprofit organizations, and other government entities to pioneer new technologies, conduct studies, and engage the public. Partnerships in 2015 included efforts to improve technology for self-driving cars, assess traumatic brain injuries in warfighters, monitor glacier melting, explore volcanoes, and help citizens identify asteroids and spot auroras, among others. One project even explored ways to keep bug guts off plane wings.



Partnership News

A Glacial Melt with Global Implications

Researchers at the University of Texas at Austin, NASA, and other organizations have discovered two seafloor troughs that could allow warm ocean water to reach the base of Totten Glacier, East Antarctica's largest and most rapidly thinning glacier. The discovery likely explains the glacier's extreme thinning and raises concern about its impact on sea-level rise.

The result, published in the journal *Nature Geoscience* in 2015, has global implications, because the ice flowing through Totten Glacier alone is equivalent to the entire volume of the more widely studied West Antarctic Ice Sheet. If Totten Glacier were to collapse completely, global sea levels would rise by at least 11 feet (3.3 meters). As in the West Antarctic Ice Sheet, complete collapse of Totten Glacier may take centuries, although the timing of retreat in both places is the subject of intensive research.

The data for this study were gathered as part of the International Collaboration for Exploration of the Cryosphere through Airborne Profiling (ICECAP) project, which, together with the East Antarctic component of NASA's Operation IceBridge mission, made the first comprehensive survey of the Totten Glacier Ice Shelf and nearby regions between 2008 and 2012. Other coauthors of the study come from research organizations and universities in Australia, France, and England.

The Totten Glacier Catchment (outlined in dark blue) is a collection basin for ice and snow that flows into the ocean. The catchment is estimated to contain enough frozen water to raise global sea levels by at least 11 feet.

Feeling the Heat

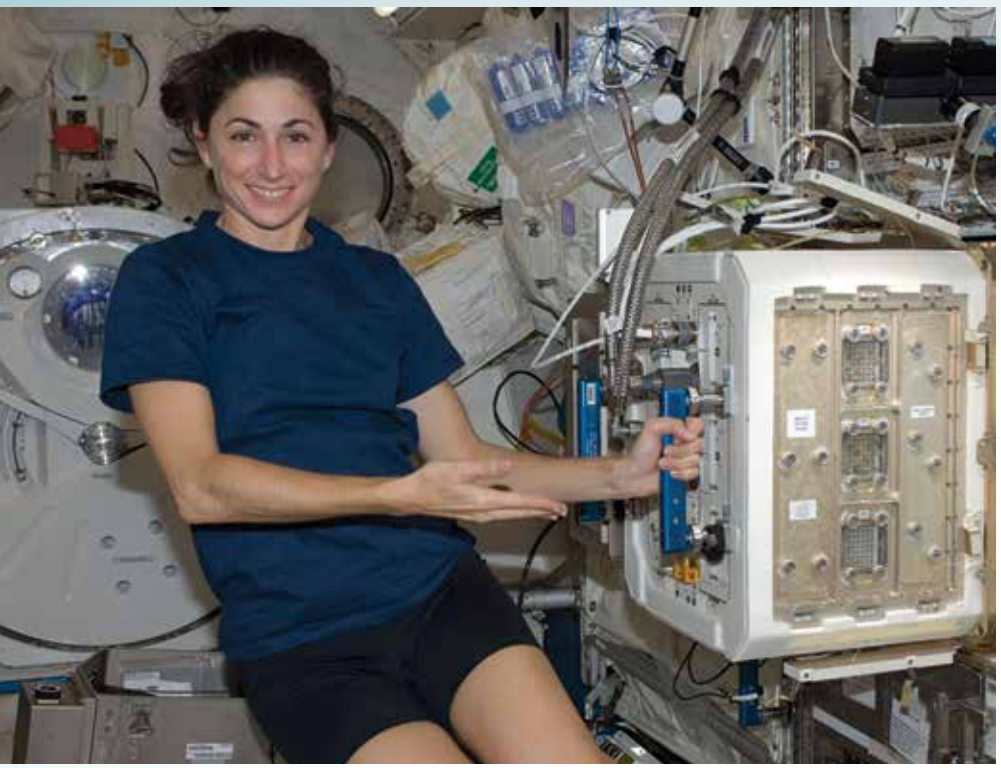
Volcanoes have always fascinated Carolyn Parcheta. She remembers a pivotal moment in sixth grade, watching a researcher take a lava sample on a science TV program.

"I said to myself, I'm going to do that someday," said Parcheta, now a postdoctoral fellow based at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California.

Exploring volcanoes is risky business. That's why Parcheta and her co-advisor, JPL robotics researcher Aaron Parness, are developing robots that can get into crevices where humans wouldn't be able to go, gaining new insights about these wondrous geological features. Her research endeavors were recently honored in National Geographic's Expedition Granted campaign, which awards $50,000 to the next "great explorer."

In addition to improving models for use on Earth, the research has implications for extraterrestrial volcanoes.

In a recent experiment, the team had its first robot, VolcanoBot 1, roll down a fissure—a crack that erupts magma—that is now inactive on the active Kilauea volcano in Hawaii. It was able to descend to depths of 82 feet (25 meters) in two locations on the fissure, although it could have gone deeper with a longer tether, as the bottom was not reached on either descent. The researchers plan on returning to the site soon with a lighter, smaller unit, dubbed VolcanoBot 2, in order to descend even deeper for further investigation.



NASA Astronaut Nicole Stott is pictured near the Mice Drawer System (MDS) in the Kibo laboratory of the ISS. Modules such as MDS are helping researchers understand bone formation and health.

Dem Bones, Dem Bones

Growing bone on demand sounds like a space-age concept—a potentially life-changing one—but related research is hardly science fiction, as a study into a key bone-growing protein was recently funded to take place in orbit aboard the International Space Station.

"This research has translational application for astronauts in spaceflight and for patients on Earth who have osteoporosis or other bone-loss problems from disease, illness, or trauma," said Dr. Chia Soo, University of California, Los Angeles professor of plastic and reconstructive surgery and orthopedic surgery.

Ground tests for an investigation known as Systemic Therapy of NELL-1 for Spaceflight-Induced Osteoporosis began in 2015. By studying the NELL-1 protein aboard the space station, researchers hope the microgravity tests will reveal additional insights into how it works. This may help refine and optimize future use of the protein for therapy in humans on Earth.

Burn Notice

New maps of two recent California megafires that combine unique datasets from the U.S. Forest Service (USFS) and NASA's Jet Propulsion Laboratory (JPL) are answering some of the urgent questions that follow a huge wildfire: In all the acres of blackened landscape, where are the live trees to provide seed and regrow the forest? Which dead trees could endanger workers rebuilding roads and trails? What habitats have been affected?

The maps, so detailed that they show individual trees, cover the areas of two California megafires—the 2013 Rim fire, which burned more than 250,000 acres (390 square miles) near and in Yosemite National Park, and 2014's King fire near Lake Tahoe—before, during, and after the active burns. As the Forest Service directs ongoing recovery and restoration projects in the two areas, it is using the maps to target its efforts toward important goals such as reducing soil erosion and protecting wildlife.

The maps include observations from three instruments: JPL's Airborne Visible/Infrared Imaging Spectrometer (AVIRIS); JPL's MODIS/ASTER Airborne Simulator (MASTER), which observes in thermal infrared; and lidar data showing terrain and canopy in high resolution. AVIRIS and MASTER are airborne prototypes of two instruments that will one day launch as a part of the Hyperspectral Infrared Imager (HyspIRI) satellite mission, which will study Earth's ecosystems and provide critical information on natural disasters.

"In some areas of the King fire, you don't see any green for miles and miles," said Carlos Ramirez, program manager of the USFS's Remote Sensing Laboratory in McClellan, California. "It's likely there are not going to be any viable seed sources where the fire was that intense. With the AVIRIS dataset, we get an inventory of living vegetation and the condition of it. That gives people in charge of putting together restoration plans an idea of where to focus their attention."

Wildfires increase erosion by burning off plants that stabilize soil and diffuse rain. Intense burns often create a water-resistant layer atop the soil so that rain runs off instead of soaking in, cutting deep channels and increasing flood and landslide danger downstream. The maps identify where trees and plants are still alive and erosion control is not needed.

The Forest Service is also working with the University of California, Davis and nongovernmental organizations to manage the goals of simultaneously clearing hazardous burned timber and preserving habitats for as many species as possible.

Above, soil scientists begin an evaluation of the area burned during the 2013 Rim fire in order to assess the need for emergency soil-protection measures. Below, new vegetation is shown growing just three weeks after the fire ended. Highly detailed maps created by NASA and the U.S. Forest Service can pinpoint pockets of green down to individual trees, which can indicate potential seed sources and wildlife habitats.

NASA, Nissan Drive Self-Driving Cars

NASA's Ames Research Center and Nissan North America partnered in 2015 to research and test self-driving capabilities for automobiles. Ames will assist in reimbursed design, development, testing, and assessment of Nissan's autonomous vehicles, including the use of Ames' campus for testing.

As Ames participates in this reimbursed partnership, NASA will benefit from Nissan's shared expertise in innovative component technologies for autonomous vehicles, shared research to inform development of vehicular transport applications, access to appropriate prototype systems, and provision of test beds for robotic software.

Lessons learned from integration, testing, and demonstrations will enable Nissan North America to better plan for development and commercialization of autonomous vehicles and applications.

Aurorasaurus Sightings Multiply

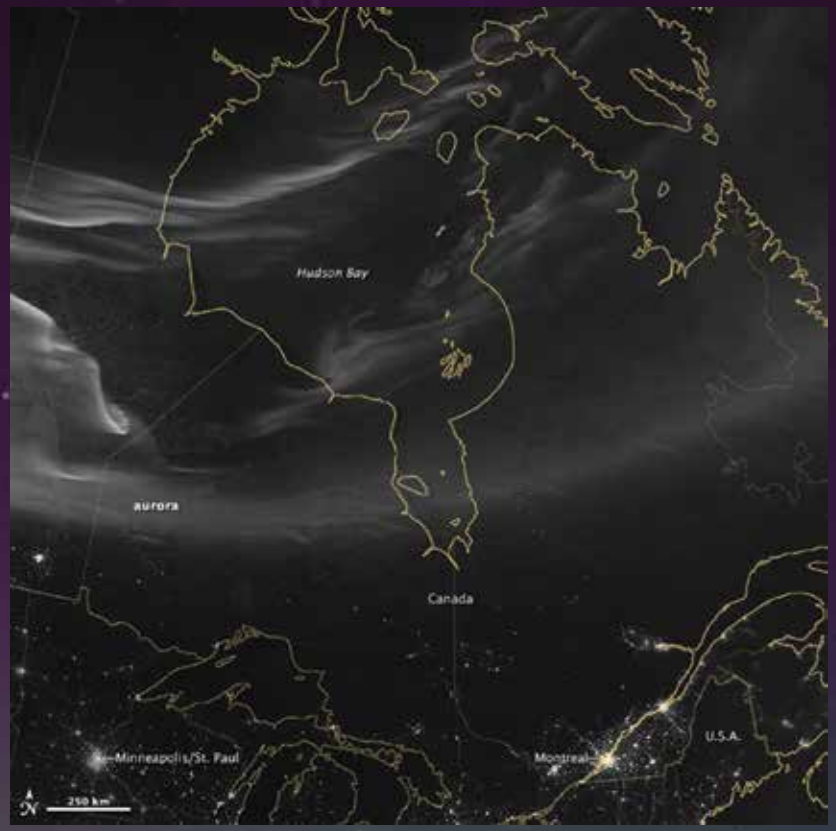
Even Earth's skies were celebrating St. Patrick's Day in 2015, when a severe geomagnetic storm—the strongest of the past decade—painted the sky with green, red, and blue auroras from New Zealand in the south to Alaska, Canada, and large parts of Europe in the north. Conditions provided a fantastic opportunity for aurora viewing from above and below.

A coronal mass ejection was first observed by NASA and National Oceanic and Atmospheric Administration instruments on March 15. When the particles reached Earth two days later, the Suomi NPP satellite acquired imagery of the Aurora Borealis from above, while skywatchers on the ground captured some spectacular views and began reporting aurora sightings on Twitter.

The images were submitted through Aurorasaurus, a citizen-science project designed to improve a person's chance of seeing the aurora by collecting and sharing observations reported via Twitter, the project's Web site, and iOS and Android apps. The project assembles tweets and reports in real time and places them on a map, along with information about cloud cover and the extent of the auroral oval—the region centered around each pole where the aurora is estimated to be visible.

For the St. Patrick's Day storm, Aurorasaurus gathered 35,000 aurora-related tweets and reports, and users verified more than 250 of them as positive sightings. The project sent more than 360 real-time notifications alerting users that an aurora might be visible near them.

The project intends to use the citizen-science observations as "ground truth" for improving auroral oval models. Aurorasaurus is a research project supported by the National Science Foundation and designed by researchers from the New Mexico Consortium, NASA, Pennsylvania State University, and Science Education Solutions.



The Suomi NPP satellite acquired this view of the Aurora Borealis around 1:30 a.m. EDT on March 18, 2015. Auroras appear as white streaks over Hudson Bay and southern Canada. At the same time, the Aurorasaurus project scraped social media feeds for photos of the phenomenon taken by individuals on the ground (background).

Keepin' It Fresh

NASA has joined forces with the U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration, and U.S. Geological Survey to transform satellite data designed to probe ocean biology into information that will help protect Americans from harmful freshwater algal blooms.

Algal blooms are a worldwide environmental problem causing human and animal health risks, fish kills, and off-taste and odor in drinking water. In the United States, the cost of freshwater degraded by harmful algal blooms is estimated at $64 million annually.

The new $3.6 million, multi-agency effort will use ocean color satellite data to develop an early warning indicator for toxic and nuisance algal blooms in freshwater systems and an information distribution system to help expedite public health advisories.

"The vantage point of space not only contributes to a better understanding of our home planet, it helps improve lives around the world," said NASA Administrator Charles Bolden. "We're excited to be putting NASA's expertise in space and scientific exploration to work protecting public health and safety."

The new network builds on previous NASA ocean satellite sensor technologies created to study the global ocean's microscopic algal communities, which play a major role in ocean ecology, the movement of carbon dioxide between the atmosphere and ocean, and climate change. These sensors detect the color of the sunlit upper layer of the ocean and are used to create indicators that can help identify harmful algal blooms.

An algal bloom in Lake Erie, as seen from space.

Big Game Hunters, Take Note

A software application based on an algorithm created by a NASA challenge has the potential to increase the number of new asteroid discoveries by amateur astronomers.

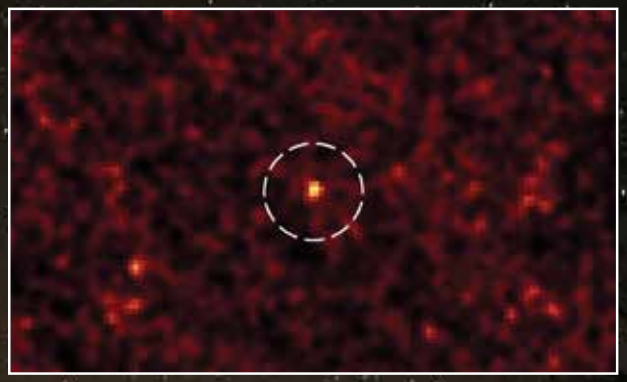
Analysis of images taken of our solar system's main asteroid belt between Mars and Jupiter using the algorithm resulted in a 15 percent increase in positive identification of new asteroids.

During a panel at the 2015 South by Southwest Festival in Austin, Texas, NASA representatives announced the release of a free desktop software application developed by NASA in partnership with Planetary Resources Inc., of Redmond, Washington. The application, which can be used by anyone, is based on an Asteroid Data Hunter-derived algorithm that analyzes images for potential asteroids.

The Asteroid Data Hunter challenge was part of NASA's Asteroid Grand Challenge and offered a total of $55,000 in awards for participants to develop significantly improved algorithms to identify asteroids in images captured by ground-based telescopes.

"The Asteroid Grand Challenge is seeking non-traditional partnerships to bring the citizen-science and space-enthusiast community into NASA's work," said Jason Kessler, program executive for the Asteroid Grand Challenge. "The Asteroid Data Hunter challenge has been successful beyond our hopes, creating something that makes a tangible difference to asteroid-hunting astronomers and highlights the possibility for more people to play a role in protecting our planet."

Those interested in the software can download it by visiting http://topcoder.com/asteroids.



Asteroids such as this one (circled) will be easier to identify using an algorithm created as a result of a NASA partnership.

Aerodynamic Nuisance Control

Two NASA experiments designed to help reduce fuel consumption and pollution emissions recently flew on a specially outfitted Boeing 757 airplane called the ecoDemonstrator.

The first technology to be tested is called the Active Flow Control Enhanced Vertical Tail Flight Experiment. NASA worked with Boeing to install 31 tiny jets called sweeping jet actuators that can manipulate, on demand, the air that flows over the ecoDemonstrator 757's vertical tail and rudder surfaces. An aircraft's vertical tail is primarily used to add stability and directional control during takeoff and landing, especially in the event of an engine failure. But when the aircraft is cruising at altitude, the large, heavy tail is not necessary.

Ground studies by a team of NASA, Boeing, University of Arizona, and California Institute of Technology researchers on a full-scale 757 vertical tail in a wind tunnel at NASA's Ames Research Center showed the active flow control jets could increase side force by 20 to 30 percent. Researchers expect the flight tests to confirm those results. A 20 percent increase in side force could allow designers to scale down the tail by about 17 percent and reduce fuel usage by as much as one-half percent.

In another set of flight tests, NASA began assessing how well five different coatings repel insect residue for an experiment called Insect Accretion and Mitigation. Bug remains may be only a nuisance on cars, but on some airplane designs they also cause drag, which increases fuel consumption. Engineers at NASA's Langley Research Center in Hampton, Virginia, developed and tested a number of nonstick coatings that were tested on the right wing of the ecoDemonstrator.

"Solutions to reduce fuel use by 1 or 2 percent may not sound like much," said Collier. "But shaving aircraft fuel consumption by even a few percentage points can save millions of dollars and help protect the environment from harmful emissions."

Researchers at NASA's Langley Research Center check results following preliminary NASA flight tests of nonstick coatings, which were selected in the hopes they could keep bug splatter off wings.

Collision Avoidance for Drones and Jets

A new Government-developed Automatic Ground-Collision Avoidance System (Auto-GCAS) that could significantly reduce the incidence of aircraft accidents is currently being integrated into the flight-control systems of the U.S. Air Force's fleet of F-16 fighter aircraft. The software aims to prevent accidents in which an aircraft is unintentionally piloted into the ground, a mountain, a body of water, or any other obstacle, known as controlled flight into terrain (CFIT).

Pioneered by a partnership between the Office of the Undersecretary for Personnel and Readiness, the Air Force Research Laboratory, NASA's Armstrong Flight Research Center, the Air Force Test Center, and Lockheed Martin, the system is expected to be applicable to a wide variety of civil and military aircraft.

Extensive flight-testing at Armstrong demonstrated that advanced computing technology could significantly reduce the number of accidents attributed to CFIT, a leading cause of fatalities in both civilian and military aviation that results in roughly 100 deaths each year in the United States alone. Although cockpit warning systems have virtually eliminated CFIT for large commercial air carriers, the problem still remains for fighter aircraft, helicopters, and general aviation.

NASA has been jointly developing automatic collision avoidance technologies with the Air Force for nearly three decades. In 2012 the system was installed in a Dryden Remotely Operated Integrated Drone (DROID) and flown from a far-flung, dry lakebed surrounded by rugged desert terrain. Throughout the test series, the smartphone-assisted autopilot repeatedly executed pull-ups or sharp turns to avoid imminent impact with terrain in the DROID's flight path.

Future NASA research with smartphone-augmented unmanned aircraft may have significant applications in developing sense-and-avoid technology for civil aviation and remotely piloted or autonomous aircraft sharing the national airspace system.

Three, Two, One . . .

More than 30 high school, college, and university teams launched student-built rockets during the 15th annual NASA Student Launch event in 2015 near NASA's Marshall Space Flight Center in Huntsville, Alabama.

Middle- and high-school teams attempted to reach an altitude of one mile, where they deployed onboard science experiments, before landing safely using a system of recovery parachutes. University and college teams participated in one of two other events with more challenging requirements, competing for a share of $50,000 in prize money. Student teams shared their research results with NASA, which may use them to design and develop future Agency projects.

The event was run by Marshall's Academic Affairs Office and supported by NASA's Office of Education, Human Explorations Operations Mission Directorate, and Centennial Challenges Program at Agency headquarters, as well as Orbital ATK Propulsion Systems of Promontory, Utah.

From the Belly of a Dragon

Newly 3D-printed wrenches, data to improve cooling systems, protein crystals, and seedling samples returned aboard a SpaceX Dragon capsule following a resupply mission to the International Space Station (ISS). Researchers will use samples and data returned to improve scientific studies on Earth and build on research that will enable space exploration.

Printed parts and hardware returned from the first phase of operations for the 3D Printing In Zero-G technology demonstration aboard the station. A study team from NASA and the company Made In Space, of Moffett Field, California, demonstrated the first-ever 3D printing in space using relatively low-temperature plastic feedstock on the ISS. The test phase culminated in the printing of a ratchet wrench using a design file transmitted from the ground to the printer.

Made In Space's printer has become a commercially available resource for printing in microgravity (*Spinoff* 2015).

Many physical science investigations take place aboard the ISS. Hardware and data from a recent study of critical liquids and crystallization returned aboard Dragon: on the orbital laboratory, researchers examined liquids on the verge of boiling to understand how the flow of heat in liquids behaves in microgravity. This is important to the development of cooling systems for space exploration, with additional applications to waste disposal and recycling processes on Earth.

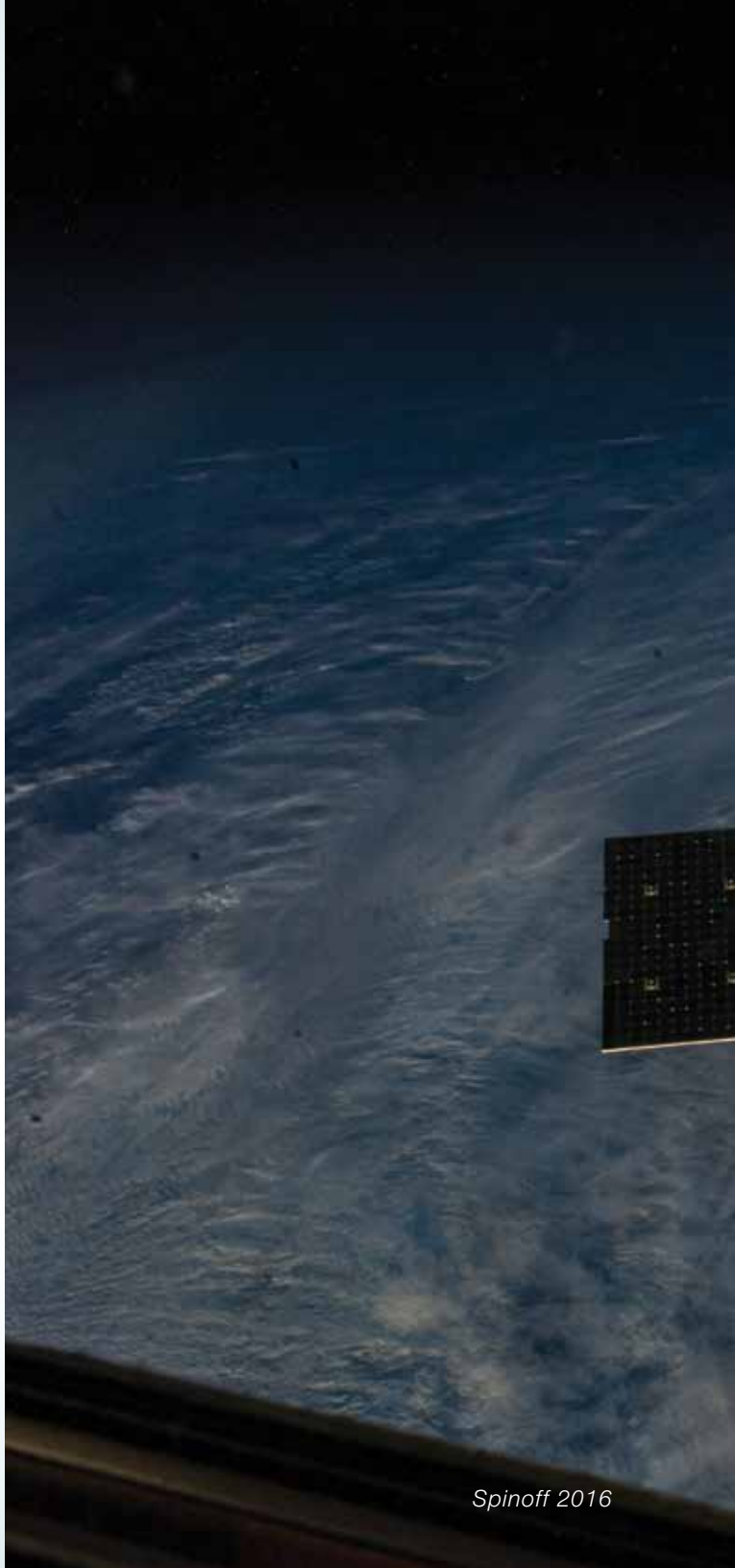
The Advancing Membrane Protein Crystallization by Using Microgravity investigation aimed to produce high-quality crystals of the cystic fibrosis protein and other closely related proteins. Since many medically relevant proteins are difficult to crystalize on Earth, researchers attempt to grow them in space to help determine their shape and structure for drug development. Scientists hope to improve drug therapies for cystic fibrosis, a genetic disorder that causes severe damage to the lungs and digestive system.

Seedlings of the plant *Arabidopsis thaliana*, or thale cress, featured heavily in three other studies that returned samples with the SpaceX Dragon. Growing organisms like these to study plant biology in space may enable future space exploration by providing a source of food and helping to create breathable air for astronauts.

Samples from the Advanced Plant Experiments 03-1 were returned to help scientists better understand the effects of microgravity on the development of roots and cells in plant seedlings. Researchers will conduct a detailed analysis on the returned plant samples to learn about the molecular and genetic mechanisms that control plant development. With this knowledge, scientists may be able to improve agricultural and energy research on Earth, leading to crops that use resources more efficiently.

And finally, samples from Seedling Growth-2 will help scientists determine the effects of microgravity and light on plant growth, development, and cell production. The plants are grown in different wavelengths of light (red and blue), and both the plant growth and the expression of selected genes are compared to control plants on Earth.

"In the long term, these studies will aid in growing plants on space missions, as well as developing better crop species on Earth," said John Kiss, principal investigator for Seedling Growth-2.



“These studies will aid in **... developing** better crop species **on Earth.”**

— John Kiss, University of Mississippi

ISS Expedition 42 Commander Barry "Butch" Wilmore shows off a ratchet wrench made with a 3D printer on the station. The wrench and other parts returned to Earth in SpaceX's Dragon capsule, along with a number of important science experiments.

A Giant LEAP for Green Flight

The arrival of an experimental demonstrator at NASA Armstrong Flight Research Center in 2015 may herald a future in which many aircraft are powered by electric motors. The Leading Edge Asynchronous Propeller Technology (LEAPTech) project tested the premise that tighter propulsion-airframe integration, made possible with electric power, can deliver improved efficiency and safety, as well as environmental and economic benefits. Over several months, NASA researchers ground-tested a 31-foot, carbon-composite wing section with 18 electric motors.

The project was carried out in partnership with Empirical Systems Aerospace of Pismo Beach, which handled system integration and instrumentation, and Santa Cruz's Joby Aviation, which designed and manufactured the motors, propellers, and wing section.

The experimental wing, called the Hybrid-Electric Integrated Systems Testbed (HEIST), was mounted on a specially modified truck. Instead of being installed in a wind tunnel, the HEIST wing section was attached to a supporting truss while the vehicle was driven at speeds up to 70 mph.

The experiment is a precursor to a development of an X-plane demonstrator proposed under NASA's Transformative Aeronautics Concepts program. Researchers hope to fly a piloted X-plane within the next couple years after removing the wings and engines from an Italian-built Tecnam P2006T and replacing them with an improved version of the HEIST wing and LEAPTech motors. Using an existing airframe will allow engineers to easily compare the performance of the X-plane with the original P2006T.

Key potential benefits of LEAPTech include decreased reliance on fossil fuels, improved aircraft performance and ride quality, and aircraft noise reduction.

LEAPTech is a key element of NASA's plan to help a significant portion of the aircraft industry transition to electrical propulsion within the next decade. According to Mark Moore, an aerodynamicist at Langley, "LEAPTech has the potential to achieve transformational capabilities in the near term for general aviation aircraft, as well as for transport aircraft in the longer term."

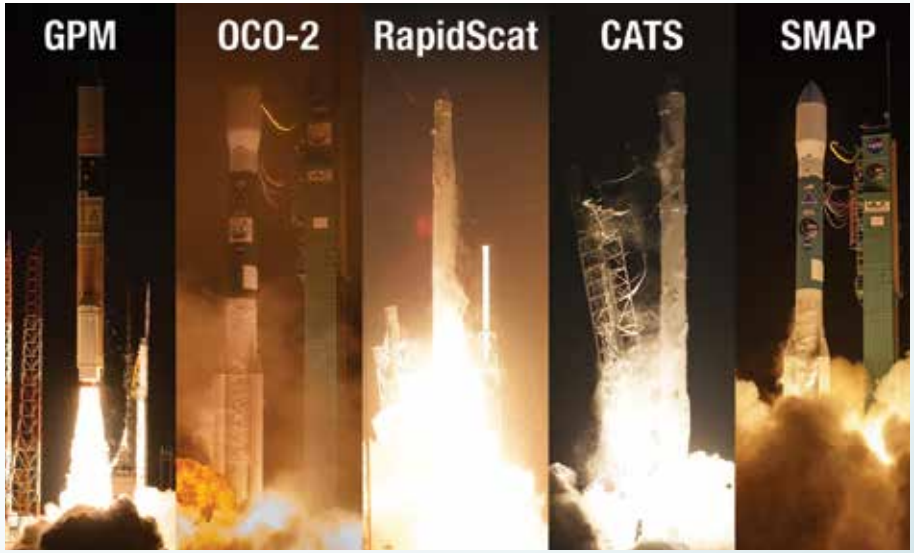
Eyes on Earth

Five new NASA Earth-observing missions are now operational after the busiest year of NASA Earth-science launches in more than a decade. They include: the Global Precipitation Measurement Core Observatory, a collaboration between NASA and the Japan Aerospace Exploration Agency; the Orbiting Carbon Observatory-2 satellite; two instruments now mounted on the exterior of the International Space Station; and NASA's newest Earth-observing satellite, the Soil Moisture Active Passive.

With these newcomers, NASA now has 19 Earth-observing space missions in operation, giving scientists an unprecedented look at numerous patterns on a global scale.

"The highly accurate measurements from these new missions will help scientists around the world tackle some of the biggest questions about how our planet is changing," said Peg Luce, deputy director of the Earth Science Division at NASA Headquarters. "These new capabilities will also be put to work to help improve lives here on Earth and support informed decision-making by citizens and communities."

Like all NASA data, observations will be freely available to the international scientific community and decision makers in the United States and abroad.



In the Eye of the Beholder

Scientists at NASA Ames Research Center and San Jose State University have developed and validated a brief eye-movement-based test to assess brain health. The early work on this new "oculometric" analysis was funded by NASA to evaluate the use of eye-movement responses as a quantitative probe of human visual and vestibular function after exposure to microgravity or other spaceflight-related performance effects. In a recent project funded by the Office of Naval Research, NASA is working to adapt and refine this technology to assess mild-to-moderate traumatic brain injury (TBI) in order to provide the Navy with a noninvasive, effective tool for determining when individual sailors exposed to an impact or explosive blast have been adversely affected and when their brain function has fully returned to its normal baseline.

Initial results from an ongoing TBI study are promising, showing that the NASA technology can detect and characterize mild impairment of brain function in "recovered" TBI patients without obvious clinical symptoms. "This sub-threshold measure is exactly what is needed to clearly document mild alterations of brain function that would likely be missed using standard neurological and imaging tests," said Lee Stone, a research scientist at Ames.

A second critical feature of this new technology is that the data are easily, inexpensively, and noninvasively collected, so it could be deployed in the field under conditions where access to a neurologist or an MRI would be impractical or impossible. That also means that in the future this device could be deployed in high school locker rooms for real-time use by coaches and trainers during sporting events to protect kids from sports-related brain injuries.

"Our long-term goal is to provide a reliable, yet inexpensive and easy-to-use neural assessment tool that can be used to keep people safe by detecting mild impairments in behavior and preventing permanent injury by keeping the person out of harm's way until their brain fully returns to normal," said Dorion Liston, a researcher at San Jose State University. ❖

Award-Winning Technologies

Not a year goes by without NASA's pioneering technological innovations garnering awards from Government, industry, and research institutions. Some of these, such as lifesaving seismic dampers and tapes for detecting dangerous hydrogen leaks, are spinoff technologies, while others are first-time breakthroughs, like the use of lasers for long-distance communications or groundbreaking research into supernova remnants, neutron stars, and black holes.

Open Innovation

NASA's challenges, prizes, and crowdsourcing efforts result in groundbreaking achievements

The Power of Prizes

Most people recognize Charles Lindbergh as the man who achieved worldwide fame when he made the first nonstop flight from New York City to Paris in 1927. But relatively few people know that Lindbergh did it to win a $25,000 prize (worth approximately $340,000 today) offered by a New York City-based hotel owner—or that Lindbergh was virtually unknown in aviation circles before his historic achievement and that he narrowly outcompeted several teams of experienced airmen to achieve victory.

Lindbergh's story unfolded nearly a century ago, but it continues to serve as an example of the extraordinary things people can accomplish when incentivized by awards, public honors, and cash prizes, as well as the ingenuity unleashed by competition on a level playing field, where underdogs can make their mark. Recognizing the power of this principle, in 2009 President Obama urged Federal agencies to pursue "high-risk, high-reward policy tools such as prizes and challenges to solve tough problems." Answering this call, NASA has increasingly turned to public competitions as a source of fresh ideas to help meet engineering challenges in aeronautics and space exploration.

"Prize competitions have become a key component in NASA's toolkit for developing technology and solving problems," says Gladys Henderson, executive of the Agency's Prizes and Challenges Program. "Because we only pay for success, we have found them to be remarkably efficient in terms of getting the job done—which is a win not just for NASA but ultimately for taxpayers." Henderson notes that the open nature of competitions tends to make them popular among "nontraditional audiences"—that is, those outside the aerospace community—and that the high difficulty of NASA's objectives tends to bring in top talent, tempted by the chance to tackle a unique problem.

A robot scouts the field looking for samples to collect and return during the 2014 Sample Return Robot Challenge. Eighteen teams vied for a $1.5 million NASA prize purse at the competition.

The Agency's flagship effort in prize competitions dates to 2005, when the Centennial Challenges Program was established to engage the public in advancing technologies relevant to NASA missions. After proposing a set challenge for competitors—say, to build a robot capable of finding and collecting geological samples from a large field with varied terrain—along with precise criteria for success, NASA holds an event. Teams use either their own funds or outside investments to develop a technology beforehand and then bring their creations to the competition.

Many of the Centennial Challenges are annual events held over multiple years. The criteria for victory are focused on a significant advancement of the current technology, such that it can take two to five years to award a prize. During the last 10 years, the program has overseen 20 competitions that have disbursed more than $6 million in awards and resulted in innovations in everything from robotics, fuel-efficient flight, and spacesuit gloves to regolith excavators and ascent vehicles for Mars. And the entrants' technological achievements are often staggering: for example, the two winners of the 2011 Green Flight

Challenge demonstrated aircraft that, respectively, flew two people more than 200 miles using the energy equivalent of half a gallon of gasoline—all while maintaining an average airspeed of 100 mph.

Crowdsourcing Success

More recently, NASA has sought to expand public engagement with a chain of programs facilitating challenges, prizes, and crowdsourcing. Each program has its own focus—for example, one creates crowdsourced challenges that are solved by NASA employees, and another is a collaboration between the Agency, Harvard University, and a commercial crowdsourcing company and is targeted at software programmers—but all of them are part of the effort to find low-cost solutions to problems relating to U.S. space and aeronautics missions.

For members of the public, all available opportunities can be accessed through NASA Solve (www.nasa.gov/solve), a Web site designed by the Agency to serve as a portal to the diverse set of available competitions.

Henderson notes that crowdsourcing efforts in particular have had surprising results, because they draw on an open-ended, and ultimately global, community. "A data-mining competition to map dark matter in the universe was solved in under a week," she says, "and the solution outperformed the best algorithms astronomers had been using." The winning algorithm came from a PhD student studying glaciology, who managed to port some of his experience detecting edges in glacial fronts to one of the most difficult areas of astronomical research.

Indeed, NASA has frequently seen winners emerge from unlikely places: another example Henderson likes to point to is a challenge to reliably forecast astronauts' exposure to radiation in the face of a solar proton storm—a long-unsolved puzzle. The winning submission came from a retired radio-frequency engineer living in rural New Hampshire who had never before responded to a Government request for proposals. Yet his prize-winning forecast tool exceeded all of NASA's requirements, not to mention the expectation the Agency had of the challenge's potential to resolve one of the biggest problems in space exploration.

As NASA continued to facilitate and manage crowdsourcing initiatives within the Agency, in 2011 the White House's Office of Science and Technology Policy (OSTP) requested that NASA create the Center of Excellence for Collaborative Innovation (CoECI), which to date has helped manage more than 100 competitions—among them an initiative to develop network protocols to extend the Internet throughout the solar system and the Asteroid Data Hunter Challenge. OSTP asked that NASA use the center to provide guidance to other Federal agencies looking to implement open-innovation initiatives of their own—resulting thus far in nearly 10 cross-agency partnerships to run successful challenges, in addition to countless numbers of consultations.

"We've learned that the contribution crowdsourcing can make to NASA's mission is real," says Jason Crusan, director of NASA's Advanced Exploration Systems Division and also the director of CoECI. "Tapping into a diverse pool of the world's top technical talent has not only resulted in new and innovative ways to advance technologies to further space exploration; it has also led to a whole new way of thinking for NASA and other Government agencies, providing us with an additional set of on-demand tools to tackle complex projects."

The prize purse varies among NASA's competitions and crowdsourcing events; however, prize money is far from the only incentive used to encourage participation. For one, NASA is able to offer in some of its prize programs expenses-paid trips to tour Agency facilities, watch rocket launches, or enjoy other nonmonetary prizes that draw on the unique public appeal and excitement of seeing NASA at work. Also notable for individuals and companies is the prestige associated with participating in, and especially winning, a NASA-run competition. Multiple companies have reported that they were able to leverage their NASA experience to raise private investment funds that far exceed the money awarded in the competition.

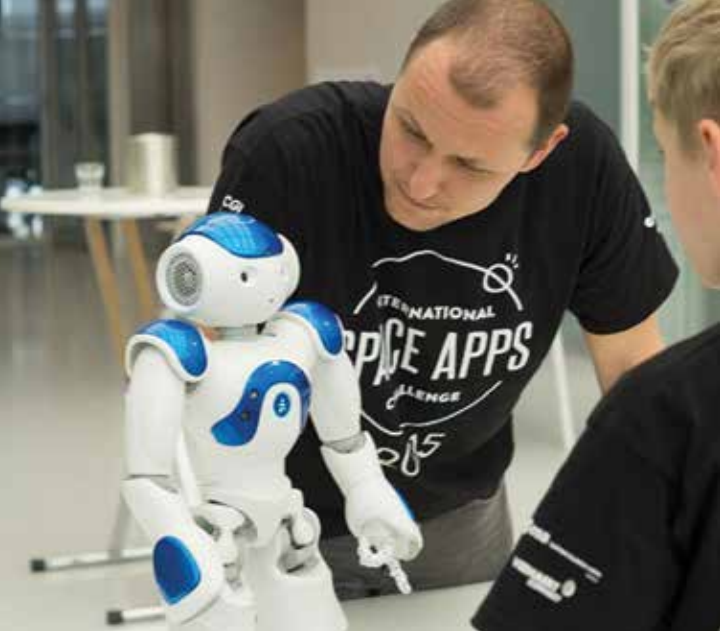
"Our greatest successes come from competitors who not only develop disruptive technology that benefits NASA but also go on to form companies and provide the technology in the commercial marketplace," says Sam Ortega, who managed the Centennial Challenges

Masten Space Systems won a $1 million first-place prize in the 2009 Lunar Lander Challenge, part of NASA's Centennial Challenge Program, with its Xoie lander, pictured here landing during the competition.

Program until mid-2015. He cites the winner of NASA's Power Beaming Challenge, LaserMotive Inc., as an example of the potential spinoff benefits from the contests. (To read about LaserMotive's success in the challenge, as well as its commercial spinoff, see page 168.)

A Universe Awaits: Help Wanted

For some NASA events, the journey is at least as important as the destination. The International Space Apps Challenge, a global, annual hackathon that began in 2012 as a project of the open.NASA team (http://open.nasa.gov), is just as well known for its power to bring people together in communities as it is for the solutions it generates. This year's event saw nearly 13,000 people



Participants in the International Space Apps Challenge tackled NASA-issued challenges with practical applications on other worlds, in space, and on Earth. The Robots Robots Robots challenge asked competitors to build and program their own robots.

gather in 133 locations across 62 countries—in cafes, school libraries, and rented spaces—where they formed small teams to tackle any one of 35 challenges proposed by NASA.

Online tools provided by the Agency allowed participants to work across borders and time zones, forging camaraderie and even friendships as the hackers raced against a 48-hour deadline to create something useful from the 16,000 datasets and 40 APIs made available by NASA.

Also appealing to the general public is the chance to do something unprecedented through one of NASA's citizen-science opportunities. These projects are promoted through the NASA Solve portal, but rather than offer prizes or competitions on a set timescale they invite volunteers from around the world to partner with NASA scientists in working through impossibly large mountains of data. Thanks to Web-based interfaces, members of the public can search through images for dusty disks around stars where planets may have formed, explore and tag surface features on the giant asteroid Vesta, comb through material samples returned to Earth by the Stardust spacecraft in an attempt to find interstellar particles, and characterize both near-Earth and asteroid-belt objects in need of classification.

NASA has found that people love to participate in Agency missions even without money or prestige as incentives. Within a year of operation, for example, citizen scientists using DiskDetective.org (the project to classify debris disks around young stars) logged more than 1 million classifications of potential debris disks—data that will provide future planet hunters with a set of targets to investigate. Mark Kuchner, the astrophysicist at Goddard Space Flight Center who manages the project, called the achievement "mind-boggling" in a NASA press release announcing the milestone.

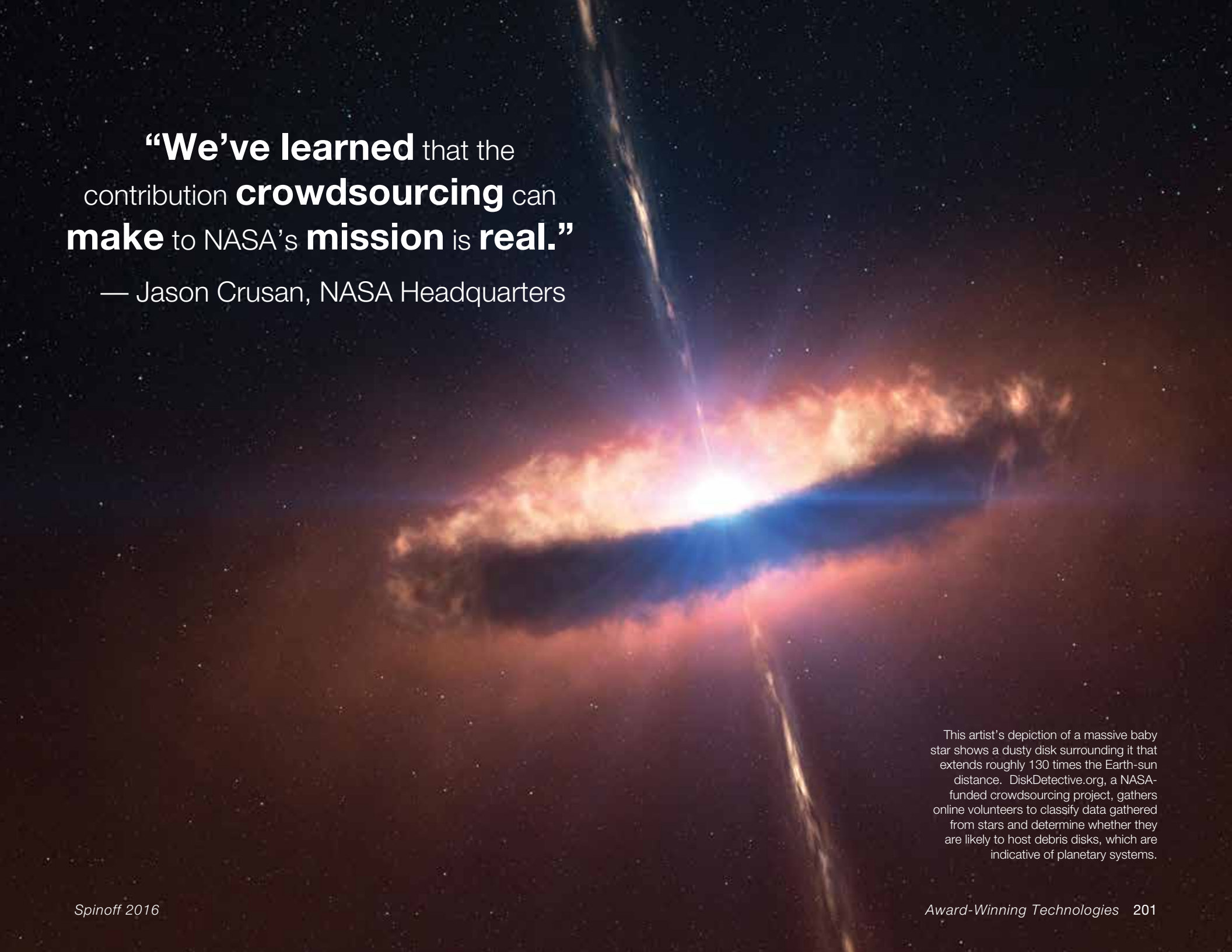
"Involving more people from outside of NASA in our work in substantive ways allows NASA to get more science done more efficiently," says Amy Kaminski, a senior policy advisor in NASA's Office of the Chief Scientist. "With more eyes and hands at work, we can be in more places at once and thus see more, measure more, and analyze more than we ever could by depending only on our science teams."

Back in 1927, Charles Lindbergh needed to make his harrowing flight alone to save on weight and fuel, and at the end of the trip there awaited a large pot of money and lifelong fame. Today's participants in NASA challenges often work in teams that can be up to millions of people, and many aren't necessarily seeking fame or fortune—though some do win considerable prize purses with their victories. Nevertheless, the advances and discoveries they make have already demonstrated world-changing potential and have provided a fruitful test bed of innovation for tackling some of the Agency's most difficult problems. ❖

One of NASA's ongoing missions is to identify and track near-Earth objects, such as asteroids whose path crosses the orbit of our own planet. NASA funds and manages multiple crowdsourcing projects that enable amateur astronomers to help discover these potential threats to Earth.

"We've learned that the contribution **crowdsourcing** can **make** to NASA's **mission** is **real."**

— Jason Crusan, NASA Headquarters



This artist's depiction of a massive baby star shows a dusty disk surrounding it that extends roughly 130 times the Earth-sun distance. DiskDetective.org, a NASA-funded crowdsourcing project, gathers online volunteers to classify data gathered from stars and determine whether they are likely to host debris disks, which are indicative of planetary systems.

Award-Winning Technologies

National Academy of Engineering Adds Two JPL Members

Two researchers at NASA's Jet Propulsion Laboratory (JPL) were elected to the National Academy of Engineering in 2015, the highest professional distinction for engineers.

Graeme L. Stephens, director for the Center for Climate Sciences at JPL, and Dan M. Goebel, a senior research scientist who develops technologies for deep-space missions, join 65 other U.S. members and 12 foreign members as the newest additions to the organization.

The academy, which now has nearly 2,500 members, honors those who have, according to the institution, made outstanding contributions to "engineering research, practice, or education, including, where appropriate, significant contributions to the engineering literature," and to the "pioneering of new and developing fields of technology, making major advancements in traditional fields of engineering, or developing/implementing innovative approaches to engineering education."

Stephens is being honored for his elucidation of Earth's cloud system and radiation balance. His research activities focus on atmospheric radiation, including the application of remote sensing to understand the role of hydrological processes in climate change. An adjunct professor at the University of Reading in England, and a professor at Colorado State University, he has authored more than 240 peer-reviewed publications and a reference textbook on remote sensing of the atmosphere. He also serves as principal investigator of NASA's CloudSat mission and was involved in the early development of NASA's Orbiting Carbon Observatory-2 mission, launched in 2014.

Goebel is being honored for his contributions to low-temperature plasma sources for thin-film manufacturing, plasma materials interactions, and electric propulsion. He received a bachelor's degree in physics, a master's degree in electrical engineering, and a doctorate in applied plasma physics from the University of California, Los Angeles, in 1977, 1978, and 1981, respectively. Goebel is responsible for the development of high-efficiency electric thrusters, advanced long-life propulsion components, and a thruster-life model validation for deep-space missions. He is a fellow of the American Institute of Aeronautics and Astronautics, the Institute of Electrical and Electronics Engineers, and the American Physical Society; an adjunct professor at UCLA; and the author of more than 120 technical papers and a book on electric propulsion.

Newly elected to the National Academy of Engineering are Dan Goebel (left) and Graeme Stephens, both scientists at the Jet Propulsion Laboratory. Background: CloudSat, launched in 2006, is an Earth-observing satellite that uses radar to observe clouds and precipitation from space. Stephens serves as the principal investigator for the mission.

LADEE Wins Popular Mechanics' Breakthrough Award

NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE)—pronounced "laddie"—was a robotic mission that gathered data on the very thin lunar atmosphere, well known for its experiments in long-range, high-speed laser communications and demonstration of a modular approach to spacecraft design. Citing both advancements, *Popular Mechanics* recognized NASA's achievements with its 2014 Breakthrough Award to honor the mission.

"LADEE's design busted up the traditional NASA process in the best way," said *Popular Mechanics* in its press release. "Instead of building LADEE as a one-off spacecraft to fit the mission, they designed a modular system using carbon-fiber units that could be configured like Lego bricks to create craft for a range of missions—at about a tenth of the average cost of missions such as the Mars Science Lab."

LADEE was also the first space mission to demonstrate laser-based communication. Until now, spacecraft have been designed to use radio signals to beam back mission data, a system that has proved reliable but which is now strained by the large files—such as high-resolution imagery—that scientists wish to retrieve. LADEE sent back mission data at transfer speeds exceeding 600 megabits per second, more than six times the previously available rate and comparable to fiber-optic Internet speeds in use on Earth.

NASA's Lunar Atmosphere and Dust Environment Explorer proved to be a groundbreaking mission in multiple ways. In addition to proving that a cost-effective, modular approach to spacecraft design could meet the needs of future space and planetary NASA missions, it also was the first space mission to demonstrate laser-based communication, achieving data-transfer rates comparable to fiber-optic Internet speeds on Earth.

Bright Ideas at NASA

The Ash Center for Democratic Governance and Innovation at the John F. Kennedy School of Government, Harvard University, has recognized two NASA fixtures as part of its inaugural Bright Ideas Program.

According to the center, the Bright Ideas Program began in 2015 as an effort "to further highlight and promote creative government initiatives and partnerships so that government leaders, public servants, and other individuals can learn about noteworthy ideas and can adopt those initiatives that can work in their own communities. Beginning with these Bright Ideas, the Innovations Program seeks to create an open collection of innovations in order to create an online community where innovative ideas can be proposed, shared, and disseminated."

NASA Research Park (NRP) at NASA Ames Research Center received one of the awards. NRP is a world-class, shared-use research and development and education campus for industry, academia, nonprofits, and government. It provides a physical place for innovation and entrepreneurship and serves as a technology accelerator through fostering both informal and formal collaborations. Today the NRP houses more than 70 industry and university partners, with commercially standard leases, and provides onsite collaboration with NASA on a variety of technologies and disciplines. The resulting innovations include projects as diverse as clean energy servers now powering Fortune 500 companies ("Energy Servers Deliver Clean, Affordable Power," *Spinoff* 2010) to a precision coffeemaker designed by an intern from the facility (page 90).

Also winning a Bright Idea Award was NASA's International Space Apps Challenge, a two-day incubator where teams of programmers, students, scientists, space enthusiasts, artists, educators, entrepreneurs, and others gather from around the world to take on one or more of a set number of challenges proposed by NASA and other Government agencies. Most of the challenges revolve around taking Government data and creating apps, Web sites, or hardware to make use of those assets for the benefit of the public. Last year's International Space Apps Challenge saw more than 13,300 participants in 133 locations tackle nearly 1,000 projects.

Hackers in Skopje, the largest city in the Republic of Macedonia, huddle over a project that uses 3D printers to "print" food. The 2015 International Space Apps Challenge gathered more than 13,300 participants from around the world to solve a variety of Government-submitted challenges.

Fiona Harrison, 2015 Rossi Prize winner and the Benjamin M. Rosen Professor of Physics at the California Institute of Technology.

NuSTAR Principal Investigator Receives Astrophysics Prize

The 2015 Rossi Prize has been awarded to Fiona Harrison, a professor at the California Institute of Technology in Pasadena, California, for her "groundbreaking work on supernova remnants, neutron stars, and black holes, enabled by NuSTAR." NuSTAR is NASA's Nuclear Spectroscopic Telescope Array mission. The award, granted by the American Astronomical Society's High Energy Astrophysics Division, is the top prize in high-energy astrophysics.

Harrison is the principal investigator of NuSTAR, launched in June 2012 under NASA's Small Explorer program. It is the most powerful high-energy X-ray telescope ever developed. By focusing high-energy X-rays, NuSTAR is able to study some of the hottest, densest, and most energetic phenomena in the universe, including black holes, collapsed stars, and supernovae remnants. NuSTAR is conducting a census of the black holes in our cosmic neighborhood, examining the origins of high-energy particles in active galaxies, and mapping the remains of supernovae to better understand how stars explode and chemical elements are formed.

The citation for the Rossi Prize notes that Harrison's "assembly and leadership of the extraordinary NuSTAR team has opened a new window on the universe."

"The exciting scientific results from NuSTAR are the culmination of close to two decades of work by a talented and dedicated team," said Harrison. "It is a privilege to work with them, and an honor to be recognized through the Rossi Prize."

Vehicle Design, Surface-Crack Analysis Tool Win NASA Software of the Year Award

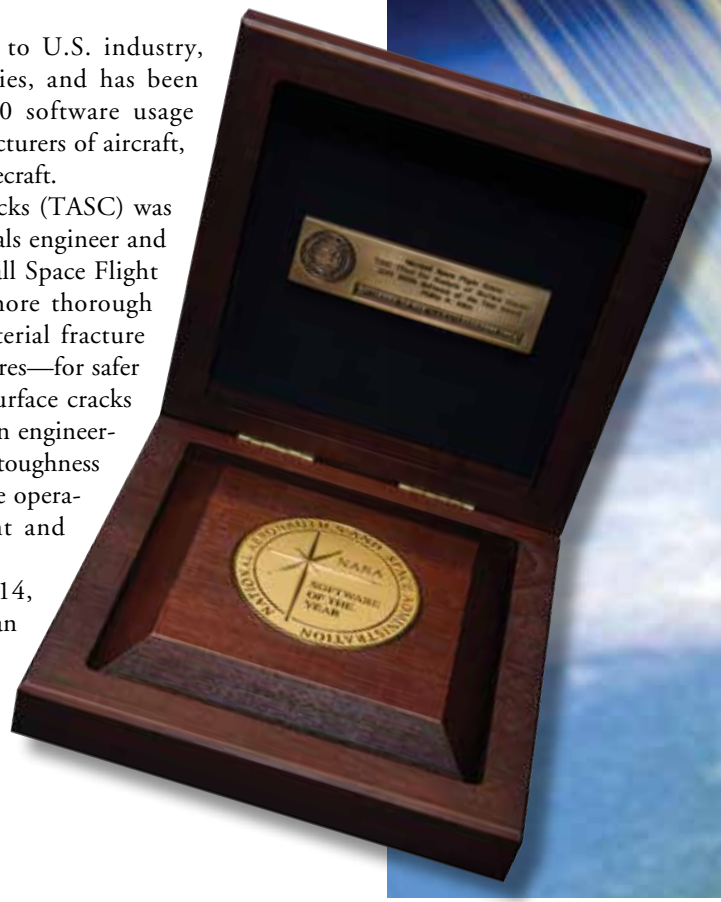
Two NASA software design teams have received the Agency's most recent Software of the Year Award. One program helps determine the structural loads for aircraft and space vehicles; the other performs nonlinear surface-crack analysis to prevent critical structure failures.

The Configuration-Based Aerodynamics (CBAERO) software package was developed by Jeffrey Bowles and David Kinney from NASA's Ames Research Center and Loc Huynh of Eloret Corporation. It's used to predict how the Orion Multipurpose Crew Vehicle, NASA's new spacecraft for human space exploration, and other aerospace designs will react to high temperatures in a variety of simulated flight conditions.

CBAERO has been transferred to U.S. industry, academia, and Government agencies, and has been distributed through more than 50 software usage agreements with major U.S. manufacturers of aircraft, helicopters, launch vehicles, and spacecraft.

Tool for Analysis of Surface-Cracks (TASC) was developed by Phillip Allen, a materials engineer and structural analyst at NASA's Marshall Space Flight Center. The software provides a more thorough understanding of surface crack material fracture toughness—essential to prevent failures—for safer aerospace vehicles and structures. Surface cracks are the most common defect found in engineering structures. Surface-crack fracture toughness tests and fracture analyses ensure safe operation of nearly all of NASA's flight and ground support hardware.

Since its release in January 2014, TASC has been downloaded more than 500 times and is in use by multiple NASA centers, Government contractors, universities, and commercial entities (page 68).



Life-Saving Dampers Secure Buildings, Bridges—and a Hall of Fame Induction

The Space Foundation has inducted into its Space Technology Hall of Fame a NASA spinoff that protects buildings and other structures throughout the world from earthquakes, saving untold lives.

Each year, the foundation's hall of fame ceremony recognizes groundbreaking technologies that have their origins in space missions and research. It honors the scientists, researchers, engineers, entrepreneurs, and innovators responsible for the creation and widespread use of the technologies, while also publicizing their significant societal benefits as a return on the public's investment in space exploration.

Dozens of NASA spinoff technologies have been inducted into the hall of fame since its establishment in 1988. Among them are life-saving devices such as personal locator emergency beacons and advanced medical imaging devices. Others, such as truck aerodynamic enhancements and an active pixel sensor now found in most digital cameras, are ubiquitous in American society and represent hundreds of millions of dollars in revenue or saved costs for businesses.

Taylor Devices Inc., based in North Tonawanda, New York, was recognized during the 2015 ceremony at the Space Foundation's 31st Space Symposium for its work in fluidic dampers used to secure infrastructure both at rocket launches and in bridges and buildings (*Spinoff* 2015). The company's NASA connection stretches all the way back to the Apollo Program, when it worked with Marshall Space Flight Center to develop conventional shock absorbers capable of handling mechanical arms swinging back from the Saturn V rockets at launch. During later NASA work on analog computers, the company developed breakthrough fluidics-based dampers that were modified a few years later for use during the Shuttle launches.

These latter shock absorbers use the same technology now offered by the company to secure any structure that is prone to damage from earthquakes or other vibrations. They were notably employed to secure London's Millennial Bridge, which had shaken unexpectedly on opening to the public, and have been installed in more than 550 buildings and bridges in the most earthquake-prone regions of the world. None have sustained even minor damage during a quake.

"Every Space Foundation Space Technology Hall of Fame inductee is remarkable in its own right, but few display benefits that are as astonishingly apparent as Taylor dampening systems," said Kevin Cook, vice president of marketing and communications at the foundation. In addition to inducting the company, Marshall, Kennedy Space Center, and Goddard Space Flight Center were all recognized for their role in the development of the dampers.

Above: After London's Millennium Bridge had to be closed due to unexpected instability, Taylor Devices was called in to solve the problem. The company retrofitted the bridge with dampers originally designed for a Shuttle launch, which successfully secured the structure. Below, from left to right: Doug Taylor, president of Taylor Devices; Andrew Clarke, co-founder of Chronos Vision GmbH, another 2015 hall of fame inductee; Kevin Cook, vice president of marketing and communications for the Space Foundation; and Richard Hill, vice president of Taylor Devices.

Langley Research Center Recognized for Advancing Helicopter Research

The American Helicopter Society (AHS) International formally named Langley Research Center a Vertical Flight Heritage Site. NASA Administrator Charles Bolden and Jaiwon Shin, Associate Administrator for NASA's Aeronautics Research Mission Directorate in Washington, accepted the designation on behalf of the Agency.

Langley has hosted research on helicopters and other vertical flight aircraft almost since the laboratory was founded in 1917. Most recently, the center has been performing a series of crash tests on a 45-foot-long helicopter fuselage as part of an international effort to improve rotorcraft performance and efficiency. Researchers also want to increase industry knowledge and create more complete computer models that can be used to design better and safer helicopters.

At the ceremony, AHS International presented Langley with a plaque that states: "Since its establishment in 1917 as the Langley Memorial Aeronautical Laboratory, the Langley Research Center has performed groundbreaking research to advance the state of the art in vertical flight."

Langley Research Center technicians pulled this helicopter body, lined with sensors, to a height of 30 feet into the air before dropping it to test safety systems in a crash.

Morpheus Project Wins AES Innovation Award

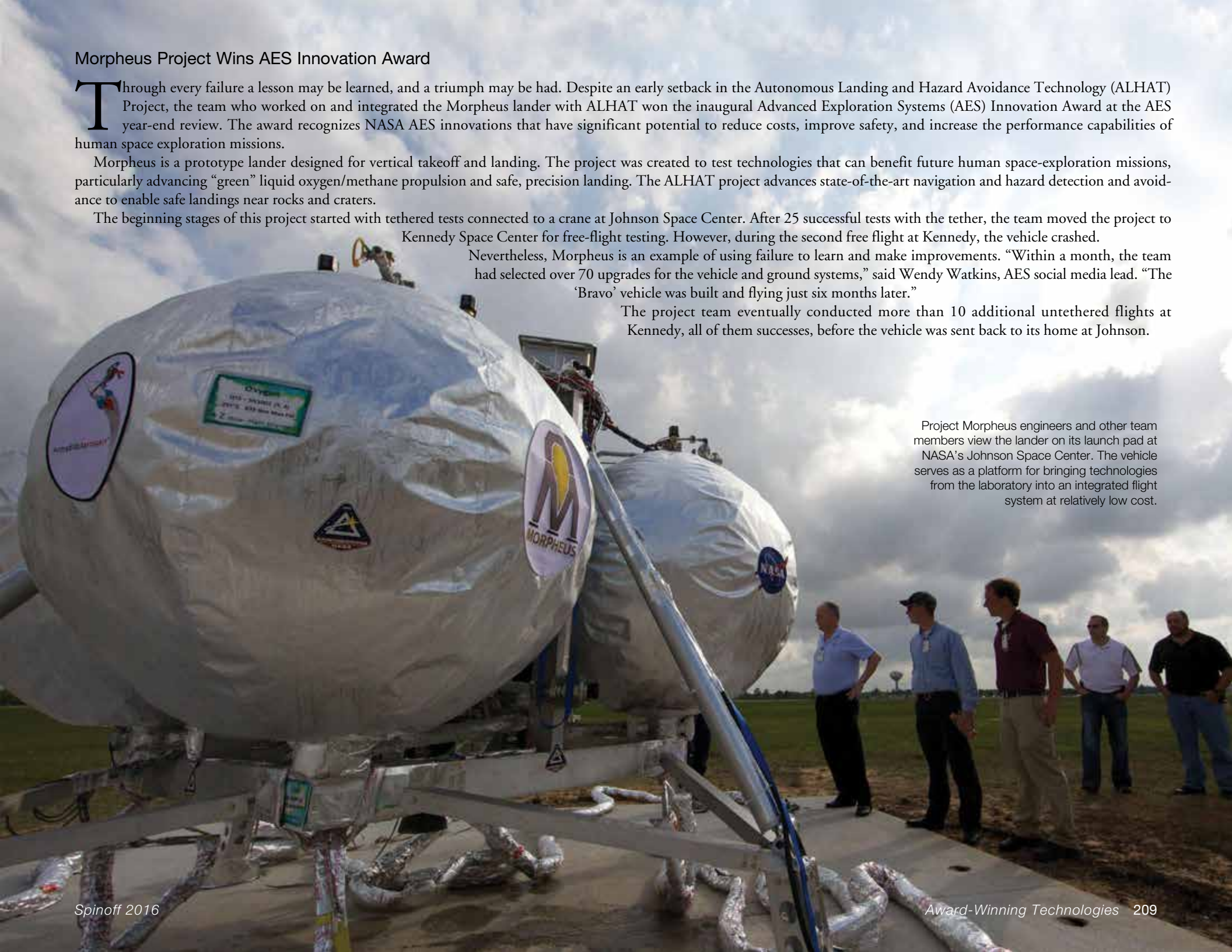
Through every failure a lesson may be learned, and a triumph may be had. Despite an early setback in the Autonomous Landing and Hazard Avoidance Technology (ALHAT) Project, the team who worked on and integrated the Morpheus lander with ALHAT won the inaugural Advanced Exploration Systems (AES) Innovation Award at the AES year-end review. The award recognizes NASA AES innovations that have significant potential to reduce costs, improve safety, and increase the performance capabilities of human space exploration missions.

Morpheus is a prototype lander designed for vertical takeoff and landing. The project was created to test technologies that can benefit future human space-exploration missions, particularly advancing "green" liquid oxygen/methane propulsion and safe, precision landing. The ALHAT project advances state-of-the-art navigation and hazard detection and avoidance to enable safe landings near rocks and craters.

The beginning stages of this project started with tethered tests connected to a crane at Johnson Space Center. After 25 successful tests with the tether, the team moved the project to Kennedy Space Center for free-flight testing. However, during the second free flight at Kennedy, the vehicle crashed.

Nevertheless, Morpheus is an example of using failure to learn and make improvements. "Within a month, the team had selected over 70 upgrades for the vehicle and ground systems," said Wendy Watkins, AES social media lead. "The 'Bravo' vehicle was built and flying just six months later."

The project team eventually conducted more than 10 additional untethered flights at Kennedy, all of them successes, before the vehicle was sent back to its home at Johnson.



Project Morpheus engineers and other team members view the lander on its launch pad at NASA's Johnson Space Center. The vehicle serves as a platform for bringing technologies from the laboratory into an integrated flight system at relatively low cost.

Four More: NASA Wins in 2014 R&D 100 Awards

Each year, NASA Field Centers take home multiple awards given by *R&D 100* magazine, which annually honors the best 100 technological innovations of the year to hit the market. Over the past few decades, many R&D 100 Award winners have gone on to become household names. For 2014, four NASA technologies made the list, demonstrating the numerous ongoing benefits created through the Nation's investment in space and aeronautics research.

Therma-Base

Winning an award was the Thin Titanium-Water Vapor Chamber Therma-Base, a thermal management system for cooling electronics. Along with low weight, high strength, and a high heat-dissipation capability, it also improves thermal performance by up to 15 times compared to a solid copper–based heat spreader. The invention's cutting-edge cooling approach, provides extremely reliable thermal conductivity in a thin and compact package, making it ideal for use with fuel cells and in many space-based, military, and commercial settings—particularly computer electronics and LED-based devices (*Spinoff* 2015).

Thermacore worked with NASA to develop the Thin Titanium-Vapor Chamber, a thermal management device, now commercially available as Therma-Base.

Intellipigment Hydrogen Detection Tape

Among the four technologies recognized was a spinoff from this year's publication (page 72), the Intellipigment Hydrogen Detection Tape commercialized by HySense Technology LLC. The tape changes color when exposed to H_2 gas, allowing technicians to detect and pinpoint leaks of the highly flammable gas in pipes, fittings, joints, and the like. The new product relies on a technology that has long been known for its detection capability but which proved difficult to implement in a solution until research performed by Kennedy Space Center and the University of Central Florida made it possible.

Liquid hydrogen's flammability and propensity to leak mean any pipelines carrying the fuel have to be inspected routinely. To make the process more efficient, Kennedy Space Center collaborated with a university to develop a color-changing hydrogen detection tape.

NiTi Bearings

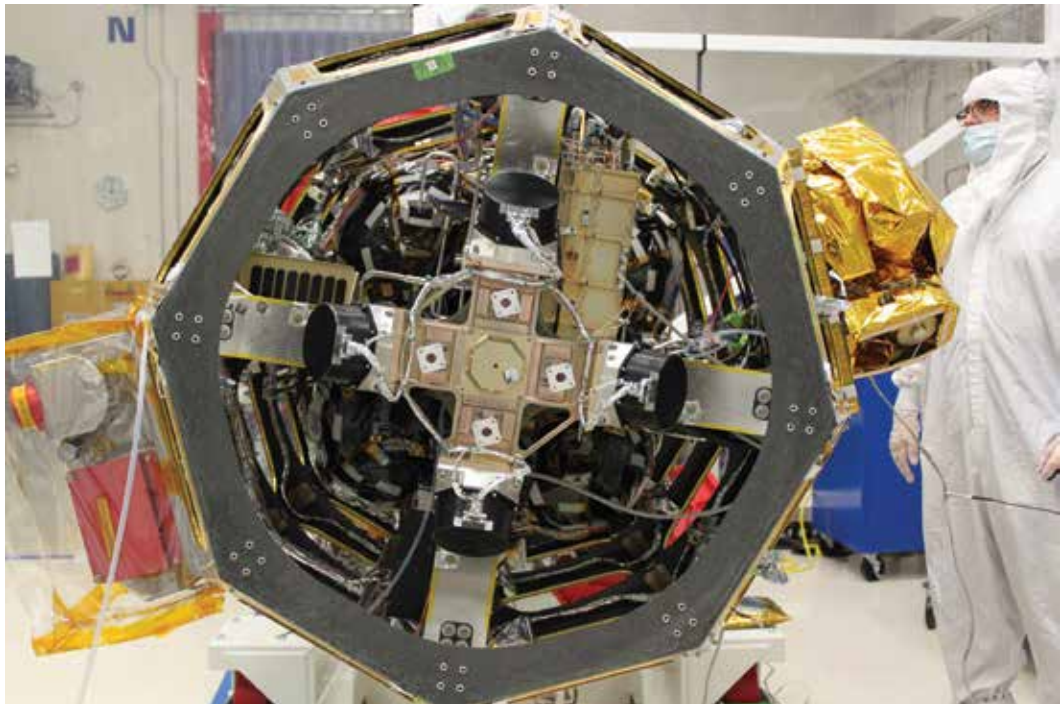
Since 2004, Glenn Research Center has been researching and developing nickel-titanium (NiTi) alloys as replacements for steel in severe bearing applications like those found inside the International Space Station's wastewater processing system. The alloy's history dates to the 1950s, when the Naval Ordnance Lab attempted to use NiTi for bearings, but inadequate manufacturing know-how precluded success. Picking up where the earlier effort left off, NASA worked with Abbott Ball Company to produce high-quality material using a new process that is now protected by two jointly held NASA-Abbott patents and three additional patents solely owned by NASA (*Spinoff* 2015).

Recent bearing manufacturing by Napoleon Engineering and by the Kamatics Corporation provided the proof-of-commercialization needed to secure the award. Though the material is made from relatively expensive ingredients (nickel and titanium), it is expected to find broad applications in spacecraft, aircraft, medical, and food processing systems, and marine equipment where extreme load capability and corrosion resistance is paramount.

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.

Lunar Laser Communication System

Goddard Space Flight Center was recognized along with the Massachusetts Institute of Technology's Lincoln Laboratory for their development of a laser communications system poised to revolutionize the way spacecraft communicate with ground stations. Radio frequency (RF) systems are still the norm for space-based communication, but optical-frequency devices could exceed RF speeds 100 or even 1,000 times over. The Lunar Laser Communication System created by the partners was demonstrated on the Lunar Atmosphere and Dust Environment Explorer spacecraft in 2014, beaming back data to Earth at a rate of over 600 megabits per second. ❖



A new NASA-developed, laser-based space communication system—first tested on the Lunar Atmosphere and Dust Environment Explorer spacecraft, shown here—will enable higher rates of satellite communications similar in capability to high-speed fiber-optic networks on Earth.

Spinoffs of Tomorrow

The goal of NASA's Technology Transfer Program is to inject the Agency's research, technology, and inventions into American industry. This section highlights program achievements in 2015 and showcases just 20 of the thousands of NASA technologies available for licensing.

NASA's Technology Transfer Program

Bringing NASA technology down to Earth

Members of NASA's Technology Transfer Program leadership team, gathered in the Nation's capital in early 2015.

NASA's making it easier than ever for others to use its technology.

The Agency possesses a unique, varied portfolio of technologies, almost all of which are either software or patents that can be licensed or otherwise released into the hands of industry. Following a White House memo in 2011 asking Federal agencies to expand and accelerate technology transfer to the private sector, NASA formulated a five-year plan to redouble its own efforts in that area. One of the first steps taken by the Agency's Technology Transfer Program was a complete reorganization of all NASA patents into a single Agency-level portfolio. (Previously, each of the 10 NASA Field Centers maintained its own respective portfolio.)

Centralizing the Agency's intellectual property opened up more efficient and effective ways of managing the Technology Transfer Program as a whole, says Daniel Lockney, executive of the program. For one, all inventions could now be easily gathered and listed on a single Web site. Not only did this make the portfolio more available to the public; it allowed the program to offer standardized tools to initiate the licensing process Agency-wide.

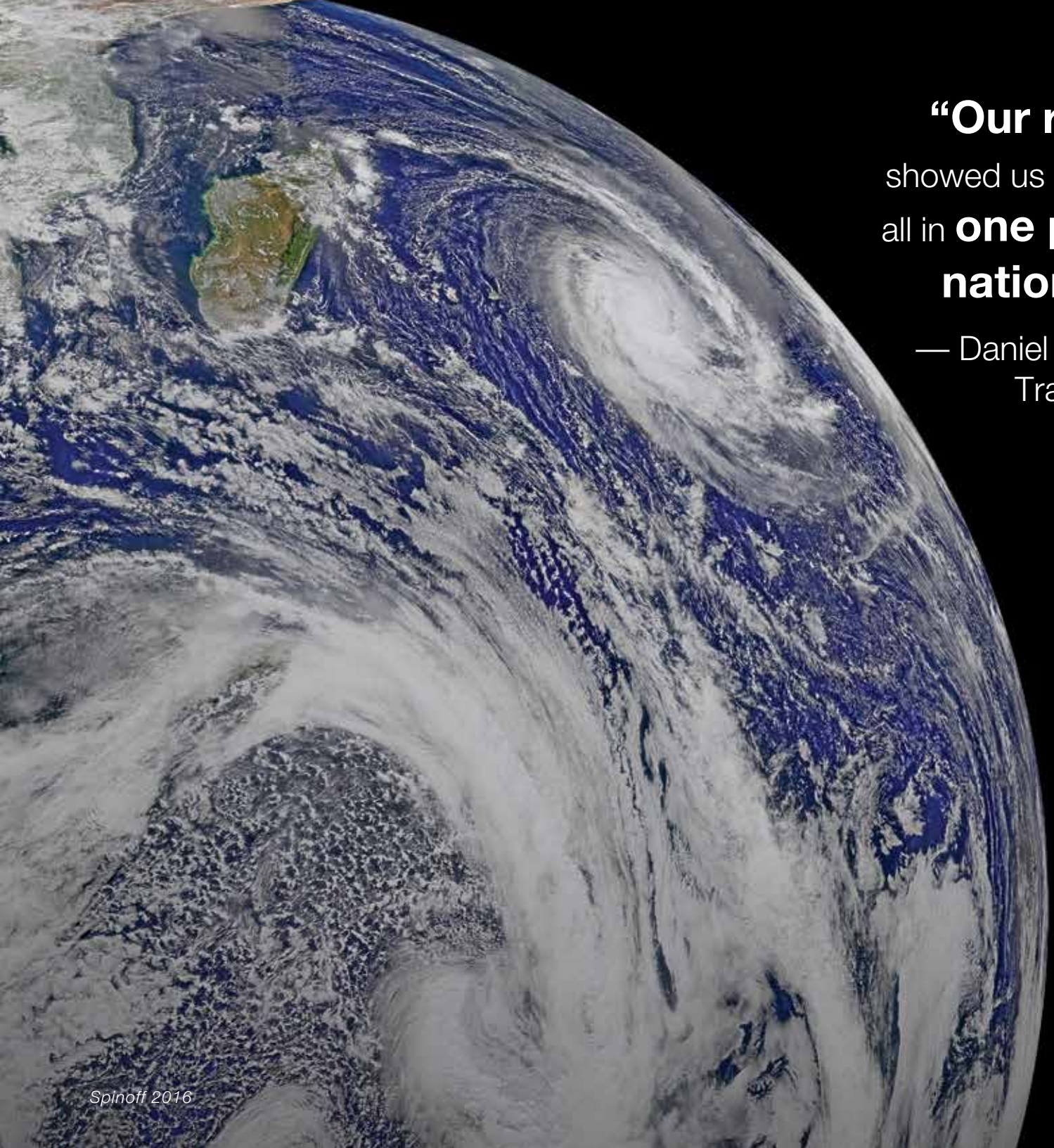
Another benefit was the ability for the program to conduct both a basic inventory and sophisticated analyses of the portfolio. Looking at how technologies are classified by industry and government organizations, program officials determined that NASA's patented inventions each fell into 1 of 15 categories, including sensors, aeronautics, optics, and manufacturing, among others. While placing each technology into one of these bins, program officials also assessed the quality and commercial potential of each patent, the first time in memory such an analysis has been conducted Agency-wide. "Prior to 2014, a lot of NASA groups were going it alone with their Web sites. Our reorganization showed us what we had, put it all in one place, and gave it a national platform," says Lockney.

All of these efforts were combined with a complete redesign of the Technology Transfer Program's Web site, known as the T2 Portal, in late 2014. The portal features the entire invention portfolio, a NASA software catalog, and every story of successful technology transfer featured in *Spinoff* since 1976. Each category can easily be browsed or searched, as can the subcategories for patents and software (all of which, like the patents, was sorted into 15 bins according to potential commercial uses).

Capitalizing on its analysis, early last year the Technology Transfer Program announced the publication of its "Hot 100" list of technologies: a sampling from the program's survey of NASA-patented technologies, including inventions from all 10 field centers, deemed to have the greatest potential for commercial success when placed in the hands of industry. The list was published in *NASA Tech Briefs* magazine—the world's largest-circulation design and engineering publication, with 750,000 monthly readers—as well as on the portal, where it is still accessible.

A current effort by the Agency, scheduled to be completed by the end of 2015, will see every patent with notable commercial potential, more than 1,000 total, receive a plain-language marketing brochure, accessible from the technology's profile on the portal. Other Agency inventions will continue to be passively marketed by inclusion in NASA's QuickLaunch licensing program. QuickLaunch offers nonexclusive licenses and evaluation licenses on hundreds of patents, using standard fees and terms that eliminate negotiation periods and trim the time required to execute a license down to just days.

But perhaps no project better represents the success of the program's efforts to centralize and streamline technology transfer than the software catalog. First released in 2014, the publication, which gathered more than 1,000 pieces of NASA-created code in one place



“Our reorganization showed us **what** we **had**, put it all in **one place**, and **gave** it a **national platform.”**

— Daniel Lockney, Technology Transfer Program

It’s not just NASA hardware and software that find widespread use outside the Agency. Data, such as the detailed information gathered by NASA satellites, is also used by myriad commercial, educational, and research organizations, as well as other government agencies. This image, assembled from data acquired by the Visible Infrared Imaging Radiometer Suite on the Suomi National Polar-Orbiting Partnership spacecraft, shows tropical cyclone Joalane swirling off the coast of Madagascar while winds churn the clouds between South Africa and Antarctica on April 9, 2015. The mountain of data NASA satellites gather each day is used for weather forecasting, climate study, crop prediction, monitoring global trends in surface cover, and countless other applications.

As NASA's Technology Transfer Program consolidated the Agency's intellectual property over the last few years, all the patents and software available to the public were organized into 15 categories to make them easier to find.

for the first time, began primarily as a proof of concept, Lockney says. "I was giving a talk about technology transfer, and afterward someone in the audience asked where she could find our software. I suddenly had the rather alarming realization that I didn't know how to find it," he says.

The program's Software Release Authority Working Group, led by Danny Garcia out of Marshall Space Flight Center, set out to gather as much of it as they could find, organize it, and build a public repository (http://software.nasa.gov) where people could discover and download code. The print catalog came about as a part of that effort, to prove that the Technology Transfer Program could provide users with a single point of entry for everything NASA had to offer. "A paper-and-ink catalog for software might seem like an anachronism, but it proved surprisingly popular," says Terry Taylor, chief of Marshall's Technology Transfer Office. "It was, of course, also accompanied with a fully searchable online database."

Following the first catalog's release, requests to use NASA software soared, and in 2014 the Agency shared more than 1,600 programs with new users—18 percent more than the previous year—with many of them requesting software through the new Web site. Users also constantly requested that they be added to the mailing list for future catalogs, at which point Lockney realized his team would need to update the printed resource annually. "We really have become the victims of our own success," he says, "but for technology transfer this is the kind of problem you want to have."

The 2015/2016 version of the catalog was released in April of last year, and among other things included a two-page infographic showing readers all of the software currently available in the catalog that NASA is using to help design the Space Launch System.

Scheduled for release in early 2016 is an interface for downloading the software directly from the Web site, bringing the acquisition of the code as close to a one-click experience as possible. While all of the software in the catalog is free, some of it is marked for government release only. Still, program leaders believe that even those titles can make an impact: "We think there's real potential here to save on costs, not just for companies but across government agencies as well," says Kathy Dezern, chief of Langley Research Center's Technology Transfer Office, which led all NASA field centers with about 500 software usage agreements this past year.

The past year was a busy one for NASA technology transfer. In addition to the ongoing reorganization of the portfolio and portal, program staff facilitated more than 60 new licenses, helped apply for and maintain hundreds of patents, gave more than 130 conference presentations and webinars on available-to-license technologies, and handled about 2,000 requests for NASA software.

These activities are undertaken to fulfill Congress' mandate that NASA disseminate the results of its aeronautics and space activities as widely as possible, but they're also done in the knowledge that successful technology transfer—spinoffs—ultimately benefit the American public. "We haven't been able to track quantifiable information exhaustively," says Lockney, "but from the research we have done, we know that spinoffs have at least created tens of thousands of jobs, saved hundreds of thousands of lives, reduced billions of dollars in costs, and generated billions of dollars in revenue."❖

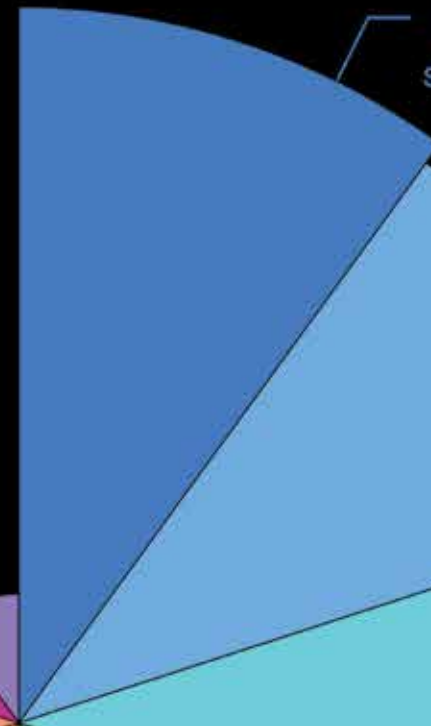
The following are just 20 of the thousands of NASA technologies currently on offer—two from each Field Center. For a full listing of available Agency technologies, or to download the full software catalog, visit http://technology.nasa.gov.

The latest version of NASA's software catalog features more than 1,000 pieces of code created by NASA and was published in April 2015.

NASA Technology Transfer 2015

By the Numbers

NASA's Technology Transfer (T2) Program manages the Agency's invention portfolio, ensuring that these technologies are spread to the private sector as much as possible. Below is a peek at some of T2's accomplishments this past year, including the disclosure of new technologies, marketing and licensing efforts, and reporting on benefits.



1,984
Software Usage Agreements

1,499
Active Patents in the T2 Portfolio

804
Patents Newly Advertised for Licensing

744
Software Catalog Titles Published

442
New Technologies Published in *NASA Tech Briefs* Magazine

130
Conference and Webinar Presentations on New Technologies

113
U.S. Patents Issued

111
U.S. Patent Applications Filed

64
New Commercial and Evaluation Licenses

52
Commercialized Technologies Published in *Spinoff*

Ames

Dynamic Weather Routes Tool

A method and system for dynamic, automated corrections to weather avoidance routes for aircraft

Convective weather, such as severe thunderstorm activity, is the largest cause of delay in the U.S. national airspace system. When such weather is forecast, traffic managers select weather avoidance routes before takeoff. Until now, however, there haven't been any automated tools to help operators determine when those alternate routes could be modified or eliminated during flight to reduce delay.

The Dynamic Weather Routes (DWR) tool created by Ames Research Center does just that, continuously and automatically analyzing aircraft traveling on preselected weather avoidance routes in order to find corrections to their flight plans. Every 12 seconds, it computes and analyzes trajectories, and if a reroute is found that can save five minutes or more relative to the current flight plan, the flight is posted to a list displayed to the airline and traffic manager. A graphical user interface enables visualization of proposed routes on a traffic display. If needed, users can adjust the reroute parameters, and various reroute metrics will all be updated dynamically as the user modifies a proposed route.

Benefits

- Real-time automation finds high-value reroute options
- Rapid-feedback, interactive user interface
- Wind-corrected flying time analysis
- Minimum-delay weather avoidance and conflict resolution

Applications

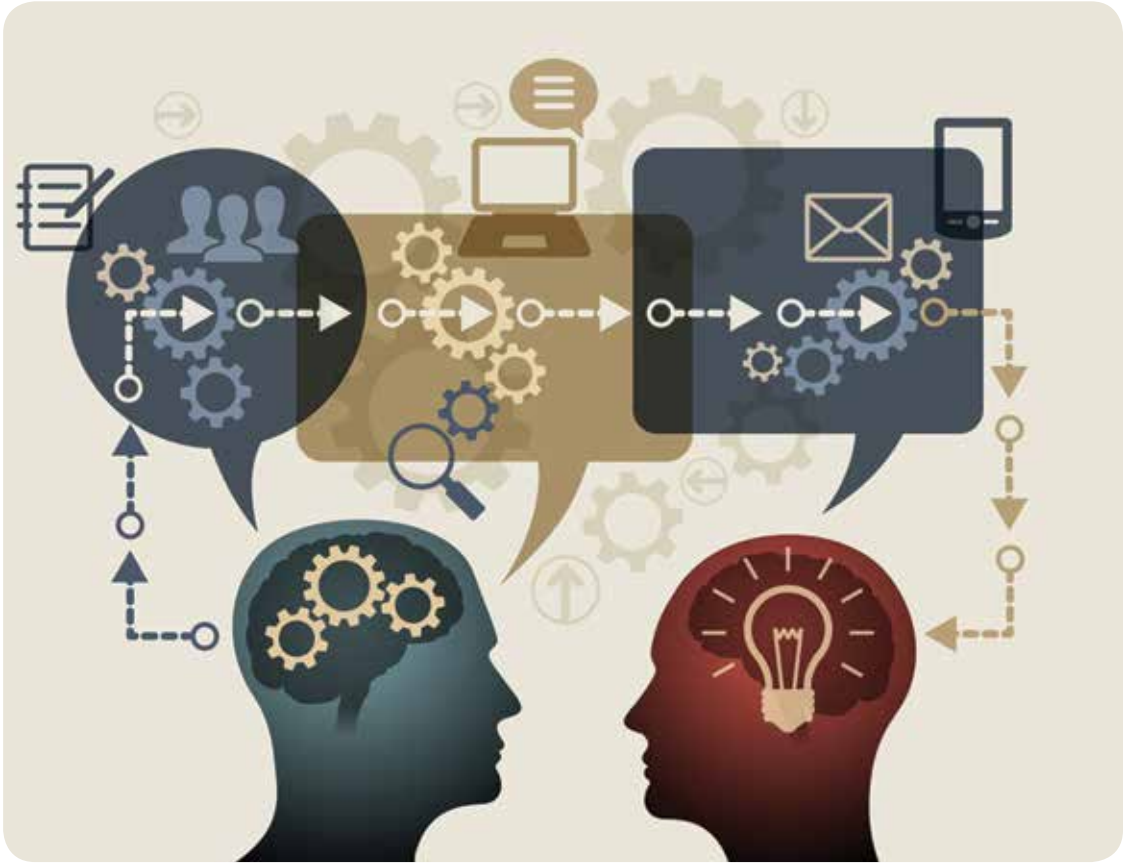
- Air traffic management
- Airline flight dispatch operations

Silent Speech

Sub-audible speech recognition based on electromyographic signals

While human-to-human and human-to-machine communication occurs in many ways, traditionally, that communication is mainly visual and verbal. As a result, technology to enhance human communication has focused on audible tasks such as those addressed by commercial speech-recognition software.

An alternative way of communicating, developed at Ames Research Center, is based on the direct interpretation of nervous system control signals sent to speech muscles by the brain. The technology noninvasively interprets aggregate surface measurements of electromyographic signals (EMGs) to categorize muscle activations prior to sound generation. Such signals arise when reading or speaking to oneself with or without actual lip or facial movements. Hence, obtaining the speech information does not require visual observation, such as machine lip-reading, to enhance recognition in high noise. The effectiveness of reading EMG signals has been demonstrated in several new ways to perform common interface functions, including joystick control, typing, and simple speech command interfacing.



Benefits

- Reasonable accuracy
- Resistance to presence of noise
- Soundless communication in difficult environments
- Noninvasive sensing

Applications

- Human-to-machine commands
- Military operations
- Physically and speech-disabled persons
- Underwater operations
- Medical and emergency service workers
- Robotic command/control

Armstrong

Integrated ADS-B System for Tracking Unmanned Aircraft

Improving safety and efficiency in military, reconnaissance, and research applications

Innovators at Armstrong Flight Research Center have developed an integrated communications and control system for unmanned aircraft systems (UAS) that utilizes automatic dependent surveillance broadcast (ADS-B) technology. The primary objective of this system is to address the safety concerns relating to UAS sharing airspace with traditional aircraft. This state-of-the-art technology is capable of real-time traffic and weather updates in three-dimensional trajectories and can be reengineered for specific missions and applications, giving the user a customized experience.

The Federal Aviation Administration (FAA) has determined that ADS-B is a critical component in meeting next-generation air traffic control requirements and will replace radar as the FAA's primary surveillance method. Armstrong innovators have leveraged this regulatory change to create a communications and control system that is superior to currently available offerings. This technology is designed to ultimately meet the functional requirements for operation in the national airspace system, such as separation assurance from other air traffic and communications with air traffic control. By integrating ADS-B surveillance technology with improved communications and sophisticated display options, Armstrong has created a combined hardware and software package that improves safety for both UAS and other aircraft, enhances command and control, and addresses regulatory requirements.

Benefits

- Enhances sense-and-avoid capabilities for UAS, increasing safety for other aircraft as well as people and property on the ground
- Utilizes existing global positioning system (GPS) hardware and software
- Easy to implement
- Satisfies Federal requirements for ADS–B "Out" to be installed on all aircraft

Applications

- Civilian general aviation
- Military missions and training
- Law enforcement
- Scientific research, including crop and meteorological data collection
- Public safety surveillance and reconnaissance
- Aerial photography and mapping
- Traffic monitoring
- Freight transportation
- Communication and broadcasting

Fiber-Optic Sensing Portfolio

A unique suite of sensing technologies for a range of applications

Engineers are continually seeking new ways of looking at information and determining what is important. Armstrong Flight Research Center's fiber-optic sensing system focuses on critical data the researcher needs. Whether it is used to determine shape, stress, temperature, pressure, strength, operational load, or liquid level, Armstrong's technology offers ultrafast, reliable measurements.

Originally developed to measure strain on unmanned aerial vehicles and other aircraft—Armstrong's primary research areas—the technology has the potential to be used in a wide variety of fields in addition to aeronautics. Applications include endoscopic surgery, to ensure precise placement of the tiniest catheters and to track their movement. In clean-energy markets, the system can improve the efficiency and increase the longevity of turbines by monitoring blade shape and force. For oil drilling operations, the sensors can provide data on drill direction as well as temperature and pressure. Armstrong-derived sensors could also provide liquid level sensing in industrial, pharmaceutical, and cryogenic applications.

Benefits

- Thousands of sensors on a single strand
- High-resolution visualization
- Powerful processing algorithms that allow refresh rates of 100 scans per second
- 3D-shape determination and visualization

Applications

- Energy-market infrastructure and equipment
- Biomedical devices
- Industrial, pharmaceutical, and cryogenic monitoring
- Aeronautical and aerospace vehicles

All NASA licenses are individually negotiated with the prospective licensee, and each license contains terms concerning commercialization, license duration, royalties, and periodic reporting. NASA licenses may be exclusive, partially exclusive, or nonexclusive. If your company is interested in these or other Armstrong technologies, scan this code or visit http://www.nasa.gov/offices/ipp/centers/dfrc.

Glenn

Cellular Reflectarray Antenna

A simple-to-install design for satellite and communications solves problems of traditional parabolic reflectors

Glenn Research Center presents a new concept design for terrestrial satellite dishes and communications systems, ideal for satellite subscription services and as backup communication for large events. Glenn's Cellular Reflectarray Antenna (CRA) has been developed and tested for use with next-generation Ka-band satellites, although it can be used with all bands of satellite communication. The CRA is a unique design that promises to usurp conventional parabolic reflectors. Specifically, the CRA is designed to receive satellite signals within a specified geographic area, or cell, of approximately 1,500 square miles.

Glenn's CRA is a vast improvement over current dishes in terms of its ease of installation: it has an out-of-the-box setup using just a simple compass to align with magnetic north. Whereas parabolic reflector antenna systems are bulky, unsightly, and difficult to install, the CRA's design features a flat shape that is inconspicuous and aesthetically pleasing, especially for residential applications. In addition, the planar shape of the CRA provides important robustness and reliability compared to parabolic systems by avoiding the wind-loading performance issues that often plague bulkier antennas during even light wind conditions.

Benefits

- Simple installation that can be performed by untrained users
- Flat, compact design that is aesthetically pleasing and avoids problems from wind
- Board material and dimensions and dual-frequency operation improves signal reception
- CRA operates only within a given geographic cell, significantly deterring piracy

Applications

- Broadband satellite communications
- Residential and business entertainment
- Emergency communications for disaster response and recovery situations
- Back-up communication for large events, such as concerts, conventions, the Olympics, etc.

Compact Full-Field Ion Detector System

A next-generation radiation detector

Glenn Research Center has developed and patented the Compact Full-Field Ion Detector System (CFIDS), a radiation particle detection system that provides information on the kinetic energies, directions, and electric charges of subatomic particles. The integrated package consists of a spherical Cherenkov detector, a compact detector stack, and low-noise, large-area detectors based on silicon carbide. The detectors and configuration can be modified to suit specific applications. The technology is an improvement over more conventional gas ionization detectors because the higher density of the solid media provides higher sensitivity to radiation.

Originally developed to measure the properties of cosmic rays in outer space, the technology can be adapted for use on Earth for radiation dosimetry aboard high-altitude aircraft and in proton radiation therapy for cancer treatment. CubeSats are also an ideal low-cost, low-risk platform for utilizing this system to conduct science observations, either solo or in multiple locations as a swarm.

Benefits

- Offers improved performance over gas ionization detectors
- Monitors radiation exposure of humans and sensitive instruments aboard manned and unmanned spacecraft and high-altitude aircraft
- Incorporates technologies that provide information on the kinetic energies, directions, and electric charges of subatomic particles into a single, compact detection system

Applications

- Space science missions
- Radiation dosimetry on high-altitude aircraft
- Monitoring proton radiation therapy for cancer treatment
- Measuring general radiation exposure

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Goddard

Lotus Coating

Mitigating dust accumulation and repelling liquids

A unique, lotus leaf-like, nano-textured dust mitigation coating with hydrophobic properties, developed at Goddard Space Flight Center, is now available for licensing. Originally developed to address dust accumulation and contamination in space environments, the coating can also be used in numerous aeronautic and earthbound applications.

Goddard's Lotus Coating is a lightweight, passive coating that has super-hydrophobic properties and can prevent a variety of particles, liquids, or ice from sticking to a coated surface. The coating's unique nano-textured surface and overcoat reduces surface energy and contact surface area, giving the coating anti-contamination and self-cleaning properties similar to a leaf on the lotus plant. This durable, transparent coating can be applied to a variety of rigid and flexible surfaces by spin coating, brush application, or spray application, making it useful in a variety of situations.

Benefits

- Mitigates the accumulation of dust, liquid, and ice
- Can coat virtually any surface
- Easy to apply

Applications

- Ideal for surfaces that cannot easily be cleaned
- Spacecraft surfaces and components, such as radiators, mirrors, and solar arrays
- Wide-ranging industrial applications, including textiles, automotive parts, healthcare and pharmaceutical equipment, and construction materials and equipment

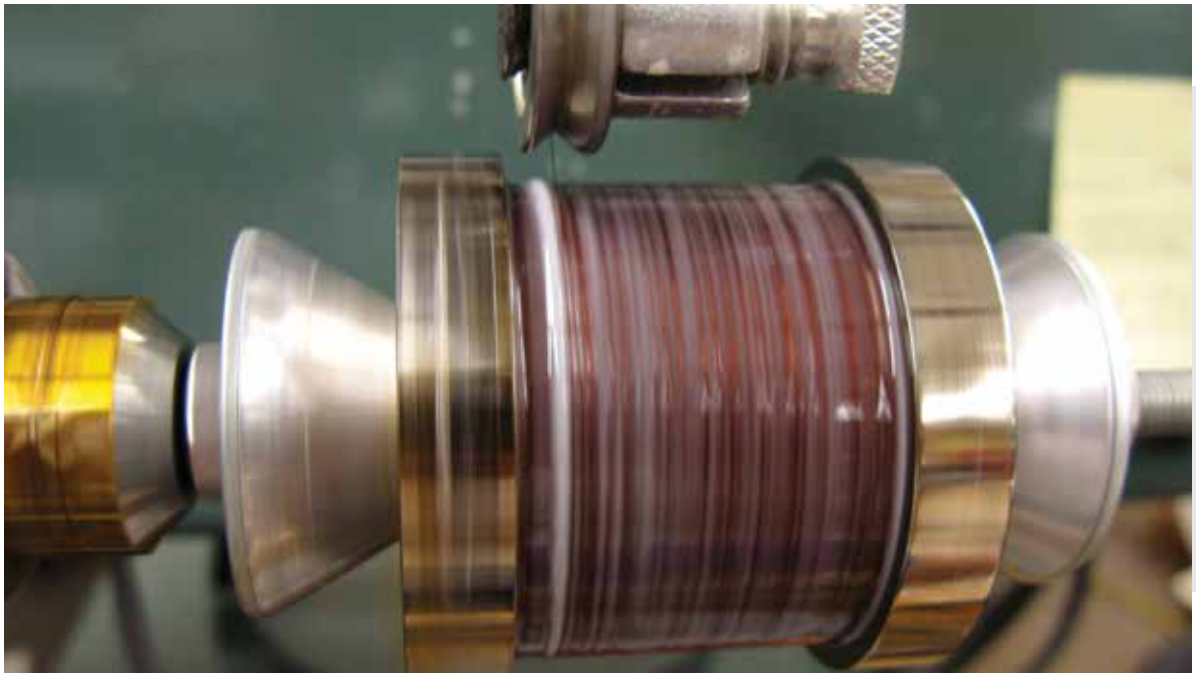
High-Field Superconducting Magnets

Novel, versatile, compact superconducting magnets with low-temperature capability

Goddard Space Flight Center's new superconducting magnet comprises a superconducting wire wound in adjacent turns around a mandrel, a thermally conductive potting material configured to fill spaces between the adjacent turns, and a voltage-limiting device applied across each end of the superconducting wire. The thermally conductive potting material and the superconducting wire provide a path for heat dissipation.

The magnet has a very high field-to-current ratio of at least 1.1 tesla/ampere; is small, lightweight, and capable of achieving high magnetic field strengths at low currents; can be cooled down rapidly without risk of damaging the wiring; can be ramped up and down in field at very high rates; generates a minimum amount of hysteresis heat; and adds a minimized heat load onto cryogenic systems from the leads, because less current is required to generate a given magnetic field.

Goddard's magnet represents a significant improvement over existing, commercial, state-of-the-art magnets. It has been successfully tested in advanced adiabatic demagnetization refrigerator systems and has been found to have no commercial equivalent. The magnet is versatile and can be used in a number of applications requiring magnetic fields at low temperatures.



Benefits

- Lightweight, compact design compared to available commercial options
- Extraordinary field-to-current ratios
- High cooling power and low-temperature capability
- Versatile and efficient—the magnets can be ramped up and down in field at very high rates

Applications

- MRI machines
- Mass spectrometers
- Particle accelerators

JPL

Analyzing Software for Global Positioning System and General Satellite Tracking

A flexible, capable, general-purpose GPS data analysis system

NASA's Jet Propulsion Laboratory (JPL) has developed its GIPSY-OASIS II software to substantially improve positioning accuracy for both ground and space applications. While civilian GPS typically has an accuracy within 3.5 meters, GIPSY-OASIS II can perform analysis that improves accuracy to a sub-centimeter level for all GPS users.

In addition, JPL's software architecture offers automated, fast operations, is highly modular, and can be adapted to a variety of GPS and non-GPS applications. GIPSY-OASIS II incorporates the most precise, up-to-date models available to generate and maintain real-time positioning data, which can readily be applied to virtually any GPS estimation problem and can easily be optimized and automated for that purpose.

Benefits

- Provides positioning accuracy to the sub-centimeter level
- Highly flexible and adaptable to a variety of GPS and non-GPS applications
- Incorporates the most precise and up-to-date models for improved accuracy
- Processes range, pseudorange, Doppler, and many other data types

Applications

- Satellite position and timing determination
- Climate studies
- Regional and global geodesy, solid earth dynamics
- Airplane positioning
- Ground-based GPS devices

Analog Artificial Neural Network

On-chip learning using an analog approach to capacitor and refresh training

Artificial neural networks—that is, computational models inspired by the brain—offer a special computing paradigm that is ideal for machine learning. This is particularly useful for learning tasks such as pattern recognition and regression, which are widely used in a variety of industries. Software implementations of neural networks are often inconveniently slow and can require vast computing resources, and existing hybrid implementations are impractical for large-scale neural networks. Innovators at NASA's Jet Propulsion Laboratory have developed an analog artificial neural network to address these shortcomings.

An analog neural network can be implemented such that a training network and a validation network are distinct but share the same synaptic weights, which can be stored as charges on one or more capacitors. The training network computes the changes in synaptic weights, updates these weights in real time, and learns new and incomplete training patterns. At the same time, the validation network confirms the cross-validation or test dataset and checks for the overlearning state without interrupting the training network. Cascade back propagation, a gradient descent technique for supervised learning, is well-suited for this particular hardware learning implementation because hidden neurons can be added when the learning rate falls below a threshold level.

Benefits

- Simultaneous training and validation activities
- Flexible architecture allows for network expansion

Applications

- Robotics and machine learning
- Data processing
- Pattern recognition

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.

Johnson

Battery Management System

Simple, reliable, safe battery management for high-voltage systems

With batteries playing a larger role in vehicles, homes, and businesses, Johnson Space Center invites interested parties to license its battery management system (BMS). The technology is a simple, reliable circuit that detects a single bad cell within a battery pack of hundreds of cells, and it can also monitor and balance the charge of individual cells in series. It's cost-effective and can enhance safety and extend the life of critical battery systems, including high-voltage lithium-ion batteries used in electric vehicles and other next-generation renewable energy applications.

The circuit in NASA's BMS uses fewer connecting pins than competing technologies, which reduces complexity and improves reliability. At the same time, voltage sensing helps avoid damage from over-voltage that can occur during charging and from under-voltage that can occur through excessive discharging.

The BMS uses saturating transformers in a matrix arrangement to monitor cell voltage and balance the charge of individual battery cells that are in series within a battery string. The system includes a monitoring array and a voltage sensing and balancing system that integrates simply and efficiently with the battery cell array.

Benefits

- Decreases the occurrence of thermal runaway and catastrophic failures
- A low pin count reduces complexity and increases reliability
- Detects the individual bad cells within series and parallel cells
- Extends battery life by managing cells within a string
- Prevents damage from too much or too little voltage
- Less expensive than existing commercially available solutions

Applications

- Electric, plug-in hybrid, and hybrid-electric vehicles
- Telecommunications backup systems
- Space mission-critical battery backup systems
- Uninterruptible power systems
- Electric utility storage for renewable energy
- High-voltage critical battery systems

Robo-Glove

Wearable technology that reduces the force needed to operate tools

Originally developed by NASA's Jet Propulsion Laboratory and General Motors, the Robo-Glove technology is a spinoff of Robonaut 2, the first humanoid robot in space. A wearable human-grasp-assist device, the glove allows the user to tightly grip tools and other items for longer periods of time without experiencing muscle discomfort or strain. For example, an astronaut working in a pressurized suit outside the space station or an assembly operator in a factory might need to use 15–20 pounds of force to hold a tool during an operation. Use of the Robo-Glove, however, potentially reduces the needed force to just five pounds.

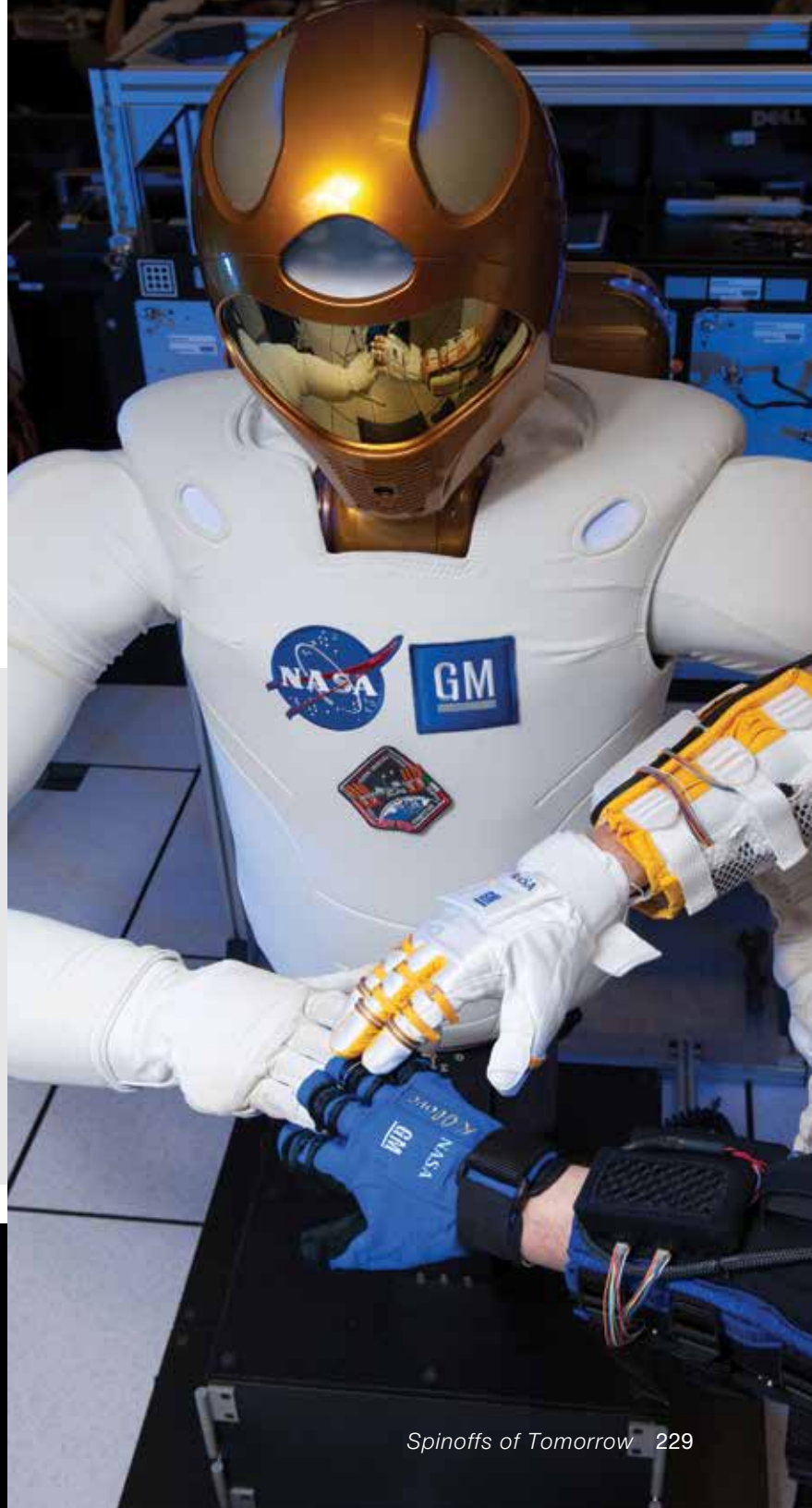
Robo-Glove has the potential to help workers, such as construction workers, hazardous material workers, or assembly line operators, whose jobs require continuous grasping and ungrasping motions. It also has potential applications in prosthetic devices, rehabilitation aids, and assisting people with impaired or limited arm and hand strength. It is a self-contained unit—essentially a robot on your hand—with actuators embedded in the glove that provide grasping support to human fingers. When the user grasps an object, the synthetic tendons automatically retract, pulling the fingers into a gripping position and holding them there until the sensor is released by releasing the object.

Benefits

- Reduces muscle strain from repetitive motion tasks
- Lightweight, with a small, compact design
- Pressure sensors give a sense of touch or haptic feedback
- Actuators, pressure sensors, and synthetic tendons are all embedded within the device

Applications

- Construction
- Hazardous material handling
- Automotive repair
- Manufacturing
- Repetitive motion work
- Oil and gas exploration



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Kennedy

Coherence Multiplexing of Wireless Surface Acoustic Wave Sensors

Wireless, passive, durable gas sensors in a multi-sensor network

The Coherence Multiplexing of Wireless Surface Acoustic Wave Sensors is an integrated multi-sensor network that is used to quickly identify gaseous leaks in extreme environments. The sensor network was developed at Kennedy Space Center, in collaboration with the University of Central Florida, for use in ground systems, spaceflight, and space exploration. The NASA innovation involves the sensors' multiplexing capability, which has improved the quality of data transmission by reducing data degradation while increasing the number of sensors that can exist within the same network.

The technology detects gaseous leaks using a chemical sensing film that is located on a piezoelectric substrate, which wirelessly transmits the data collected through pairs of antennas. The multiplexed system is unique because it allows multiple sensors to communicate simultaneously without incurring degradation through returning signal echoes.

Benefits

- Capable of operating in extreme environments on Earth and in space
- Rapid response times
- Precise leak location reporting
- Secure transceiver-sensor communication
- Efficient for long distances
- Communicates with multiple sensors simultaneously without performance degradation

Applications

- Military aircraft and vehicles
- Gaseous storage and transport areas in power plants, manufacturing facilities, and cryogenic containers
- Devices to monitor strain within bridges

Layered Composite Insulation

A new cost-saving piping insulation with product loss-prevention benefits

Kennedy Space Center seeks to license its Layered Composite Insulation (LCI) technology for commercial applications. Designed in Kennedy's Cryogenics Test Laboratory, this easy-to-use system can benefit many industries that depend on regulation of low temperatures in equipment and products. The synergistic effect of improvements in materials, design, and manufacture of this new insulation technology exceeds the performance of current multilayered insulation or foam insulation products. This new piping insulation can save money and prevent product loss for companies that transfer fluids such as liquefied natural gas, refrigerants, chilled water, crude oil, or low-pressure steam, as well as for companies that move refrigerated containers and need to protect food, medicine, and other perishable commodities.

The technology combines a unique layered cryogenic insulation system with specific manufacturing, packaging, wrapping, and rolling methods. It can be continuously rolled or can be manufactured in blanket, sheet, or sleeve form. The LCI can also be utilized on aerospace cryogenic equipment and terrestrial cryogenic tanks, pipes, and valves with many commercial applications.

Image courtesy of Ildar Sagdejev, CC BY-SA 4.0

Benefits

- Performs up to six times better than current multilayered insulations
- Performs better at soft and high vacuum levels than the world's best bulk insulator (ultra-low-density silica aerogel)
- Protects against loss of product or over-pressurization of tanks in case of vacuum-jacket failure
- Reduces heat leakage with innovative edge/joint feature
- Provides good radiation shielding and maximum suppression of gas conduction with compact spacing between layers
- Reduces installation, maintenance, and life-cycle costs

Applications

- Equipment to transport, store, and handle cryogenic fluids
- Research and medical cryo-equipment
- Transportation for refrigerated vehicles

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Langley

Novel Aromatic and Aliphatic Diamines

For advanced polymer applications

NASA's Langley Research Center chemists have synthesized a class of novel diamines for epoxy resins that possess both aromatic and aliphatic characteristics. These molecules have been shown useful in two unrelated areas.

First, the diamines have been demonstrated to aid in the dispersion of carbon nanotubes into polymer matrices. Single-walled carbon nanotubes (SWNT) have countless applications, but their utilization has been somewhat impeded by their inability to interface with polymers and by the bundling of the tubes. The diamine molecules enable SWNTs to be dispersed in a polymer and inhibit nanotube bundling.

Second, composite materials containing the diamines possess the ability to provide both structural and radiation-shielding functions. Because the diamines are both aliphatic and aromatic, they are endowed with the dual properties of high hydrogen content and high strength and are particularly well-suited to radiation-shielding applications.

The unique properties of these molecules also make them likely candidates for other unanticipated applications.

Benefits

- Aid in the dispersion of carbon nanotubes in polymer matrices
- Possess both aromatic and aliphatic characteristics
- Provide structural and radiation-shielding functions in a composite material
- Have the unusual combination of high hydrogen content and aromatic groups
- Produce composite materials that are nonleaching
- Technology encompasses a diverse set of molecules

Applications

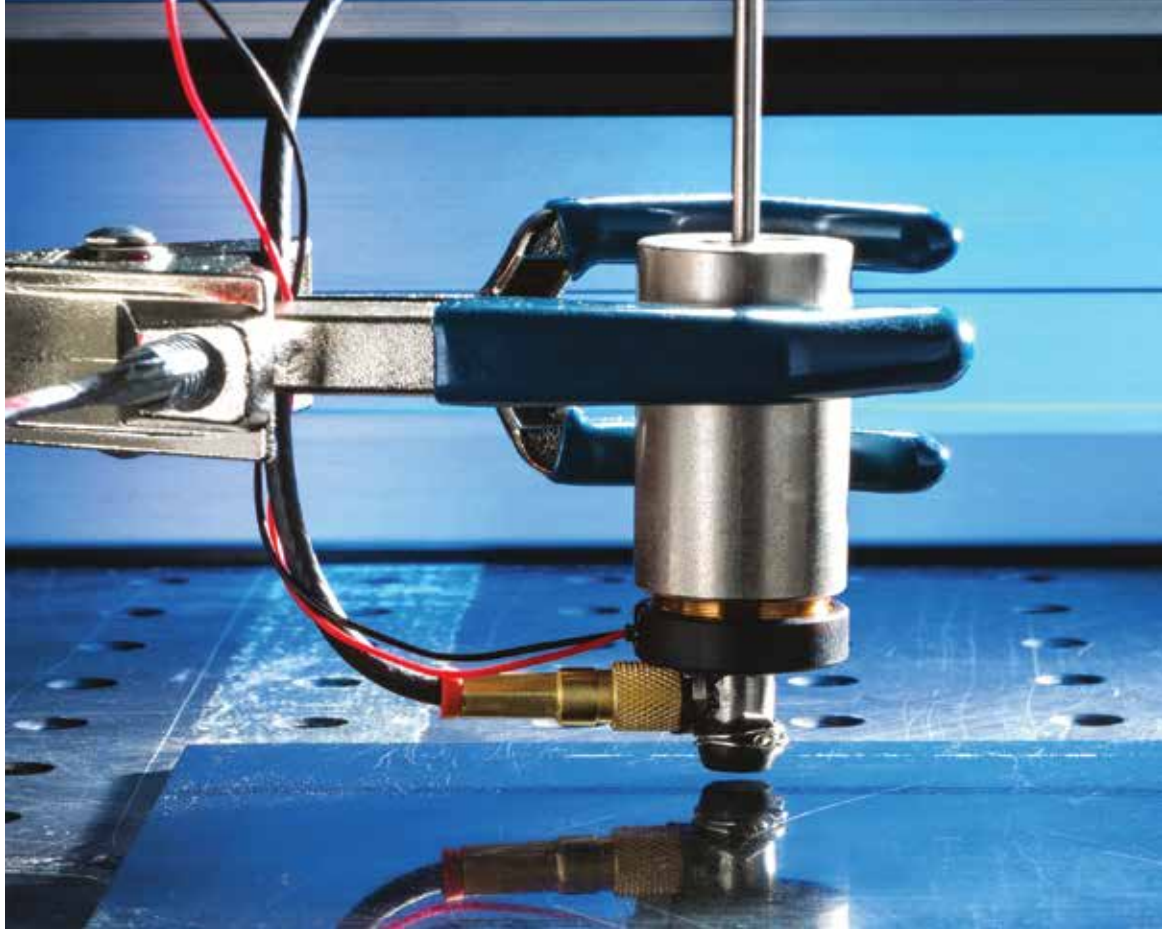
- Single-walled carbon nanotube composite materials
- General chemistry
- Radiation shielding

Floating Ultrasonic System

Nondestructive inspection of surfaces without an external liquid couplant

Most ultrasonic scanners require an external liquid coupling agent such as water, gel, or oil to make a good contact between the probe and the surface being scanned. However, some surfaces are sensitive to moisture and/or contamination created by these agents. Researchers at Langley Research Center have created the Floating Ultrasonic System to address this issue. NASA's technology is based on a momentary-touching scheme, where a vibrating probe comes into contact with the structure for fractions of a second while performing measurements, giving the probe the appearance of floating across a surface. Initial test results have also shown NASA's system to have comparable performance to liquid-couplant-based ultrasonic scanners.

NASA's Floating Ultrasonic System includes a transducer assembly with a flexible membrane tip. The vibrating, or "floating," transducer design provides two critical functions. First, it applies a small force that enables coupling of the ultrasonic energy from the transducer to the surface being inspected. Second, it facilitates easy movement of the probe over the surface being inspected.



Benefits

- No external liquid couplant needed
- Full freedom of movement
- Easier and faster movement of the probe across the test surface due to reduced friction
- Can be used to scan a variety of materials, including composites and metals
- Anticipated cost is comparable to other ultrasound techniques

Applications

- Aerospace inspections, whether in manufacturing or in-service
- Aviation vehicle health
- Metallic and composite automotive parts
- Medical devices used to image soft tissue
- Oil and gas pipelines and other distribution and storage infrastructure

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Marshall

Thermal Management Coating

Using microspheres to absorb excess heat

A new NASA-created thermal management coating technology has flown on the International Space Station for more than four years, with constant exposure to atomic oxygen and ultraviolet rays, while suffering less than 1 percent degradation. Now available for licensing from Marshall Space Flight Center, the technology works as a protection system against excessive heat situations that could otherwise destroy or damage valuable assets.

The composition of this coating includes a resinous binder containing microspheres—microscopic particles in the form of a solid phase-change material encapsulated in an inert shell. These microspheres will absorb large amounts of heat that can be stored and released at a lower temperature. By loading the binder with varying amounts of microspheres, the coating can be adapted to virtually any heat situation. This technology has been successfully tested in the 100 °F to 900 °F range.

Benefits

- Easily applied, lightweight, nonablative, and residue-free
- Absorbs exponential amounts of heat at lower ranges (below 100 °F)
- Long-term durability, unaffected by ultraviolet rays
- Temperature-adjustable to a specific application
- Can be pigmented to any desired color
- Environmentally friendly
- Will not affect telemetry or communications performance

Applications

- Fire protection systems
- Residential and commercial paints
- Camping equipment
- Air conditioning, temperature management systems
- Military and aerospace
- Automotive

Non-Collinear Valve Actuation System

Reduces the mass and footprint of traditional valve actuation systems

Marshall Space Flight Center scientists have invented a novel valve actuator wherein the primary actuating system and return spring system are arranged non-collinearly. In the past, valve actuators employed pressure-actuated piston and return spring systems with a linear arrangement, requiring bulky return springs. In response to the need to reduce the mass of valve actuators for flight systems, NASA developed the non-collinear valve actuator.

The actuator may be used in a variety of applications that will benefit from lighter actuating systems or a smaller system footprint. A prototype of the NASA actuator has been built to regulate the flow of a quarter-turn ball valve.

Benefits

- Lower mass than other conventional collinear designs
- A compact, smaller footprint for actuation systems
- The return spring system's shorter stroke length may lead to longer actuator life
- Low cost

Applications

- Chemical plants
- Electrical power-generating plants, particularly nuclear facilities
- Liquid-fuel rocket propulsion
- Oil and gas producers and refiners
- Water supply and treatment
- Iron and steel plants

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Stennis

Accurate Measurement of OPA Concentration for Disinfection Applications

A cost-effective option that does not produce hazardous waste

An analytical process has been developed at Stennis Space Center that can verify a known concentration of the disinfectant O-phthalaldehyde (OPA). OPA effectively inhibits the growth and recovery of microorganisms. NASA uses OPA in the International Space Station's (ISS) water coolant loops, which collect excess heat loads from equipment and crewmember. By preventing microbial growth in the system, OPA inhibits corrosion.

When the previously used method for developing, analyzing, and validating OPA concentrations—a proprietary process—was no longer available to NASA, Stennis researchers looked into alternative methods. A subsequent literature search, however, revealed that all known alternatives were labor-intensive and involved hazardous materials, meaning they could not be used aboard the ISS. In response, NASA developed a simple, inexpensive process to analyze and validate OPA concentration, which is now available for licensing and partnership opportunities.

Benefits

- Cost-efficient design
- Easy, inexpensive process that is not labor-intensive or hazardous
- Does not produce hazardous waste

Applications

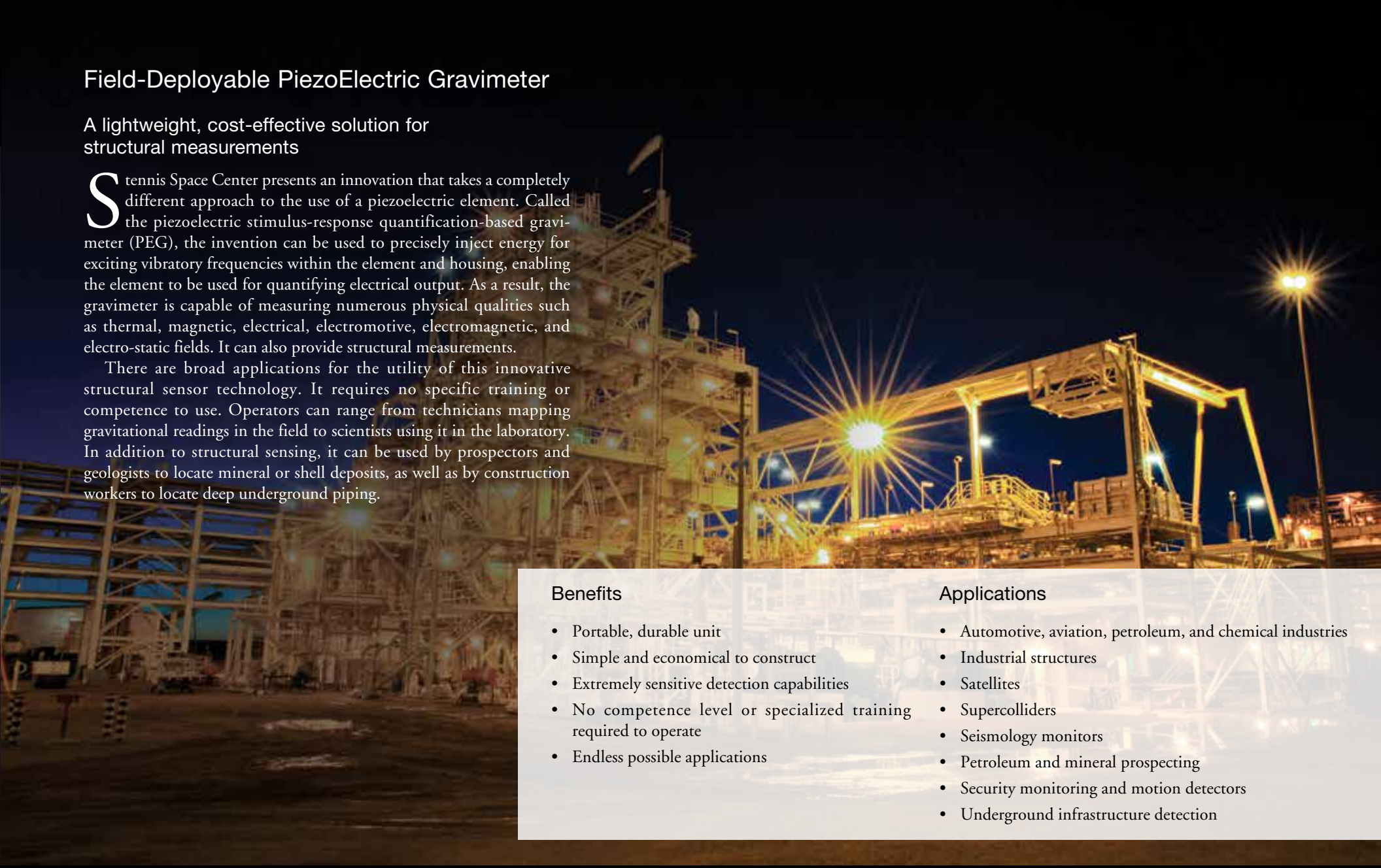
- Urological instrumentation, endoscopes, and other heat-sensitive, semi-critical medical devices
- Cleaning, disinfection, and storage of patient-care devices

Field-Deployable PiezoElectric Gravimeter

A lightweight, cost-effective solution for structural measurements

Stennis Space Center presents an innovation that takes a completely different approach to the use of a piezoelectric element. Called the piezoelectric stimulus-response quantification-based gravimeter (PEG), the invention can be used to precisely inject energy for exciting vibratory frequencies within the element and housing, enabling the element to be used for quantifying electrical output. As a result, the gravimeter is capable of measuring numerous physical qualities such as thermal, magnetic, electrical, electromotive, electromagnetic, and electro-static fields. It can also provide structural measurements.

There are broad applications for the utility of this innovative structural sensor technology. It requires no specific training or competence to use. Operators can range from technicians mapping gravitational readings in the field to scientists using it in the laboratory. In addition to structural sensing, it can be used by prospectors and geologists to locate mineral or shell deposits, as well as by construction workers to locate deep underground piping.



Benefits

- Portable, durable unit
- Simple and economical to construct
- Extremely sensitive detection capabilities
- No competence level or specialized training required to operate
- Endless possible applications

Applications

- Automotive, aviation, petroleum, and chemical industries
- Industrial structures
- Satellites
- Supercolliders
- Seismology monitors
- Petroleum and mineral prospecting
- Security monitoring and motion detectors
- Underground infrastructure detection

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FLC — Federal Laboratory Consortium
GRC — Glenn Research Center
GSFC — Goddard Space Flight Center
JPL — Jet Propulsion Laboratory
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KSC — Kennedy Space Center
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(212) 490-3999
www.techbriefs.com
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New York, NY 10036

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NP-2015-10-2096-HQ