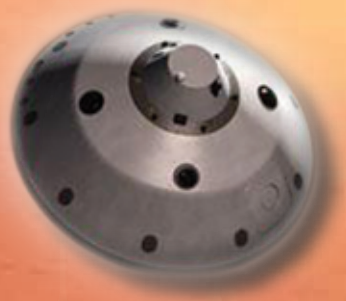
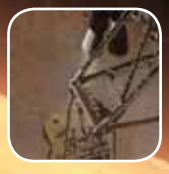
National Aeronautics and Space Administration

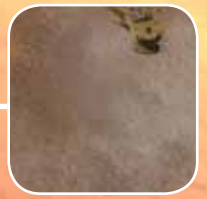
SPINOFF

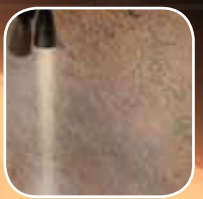













2013

SPINOFF

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;
   - are developed as a result of know-how gained under a funding agreement or collaboration with NASA;
   - incorporate NASA technology in the 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 as a result of the Small Business Innovation Research or Small Business Technology Transfer programs; or
   - are developed using data or software made available by NASA.
2. NASA's premier annual publication, featuring successfully commercialized NASA technologies.

2013

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On the Cover:

An artist's depiction shows the Mars Curiosity rover during its descent onto the Red Planet (background). NASA technologies like Curiosity (right) lead to partnerships and advances in products and services as diverse as (clockwise from top inset) software to measure fatigue, refuges for miners, medical training devices, personal aircraft, and insulation for homes and buildings.

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SPINOFFS

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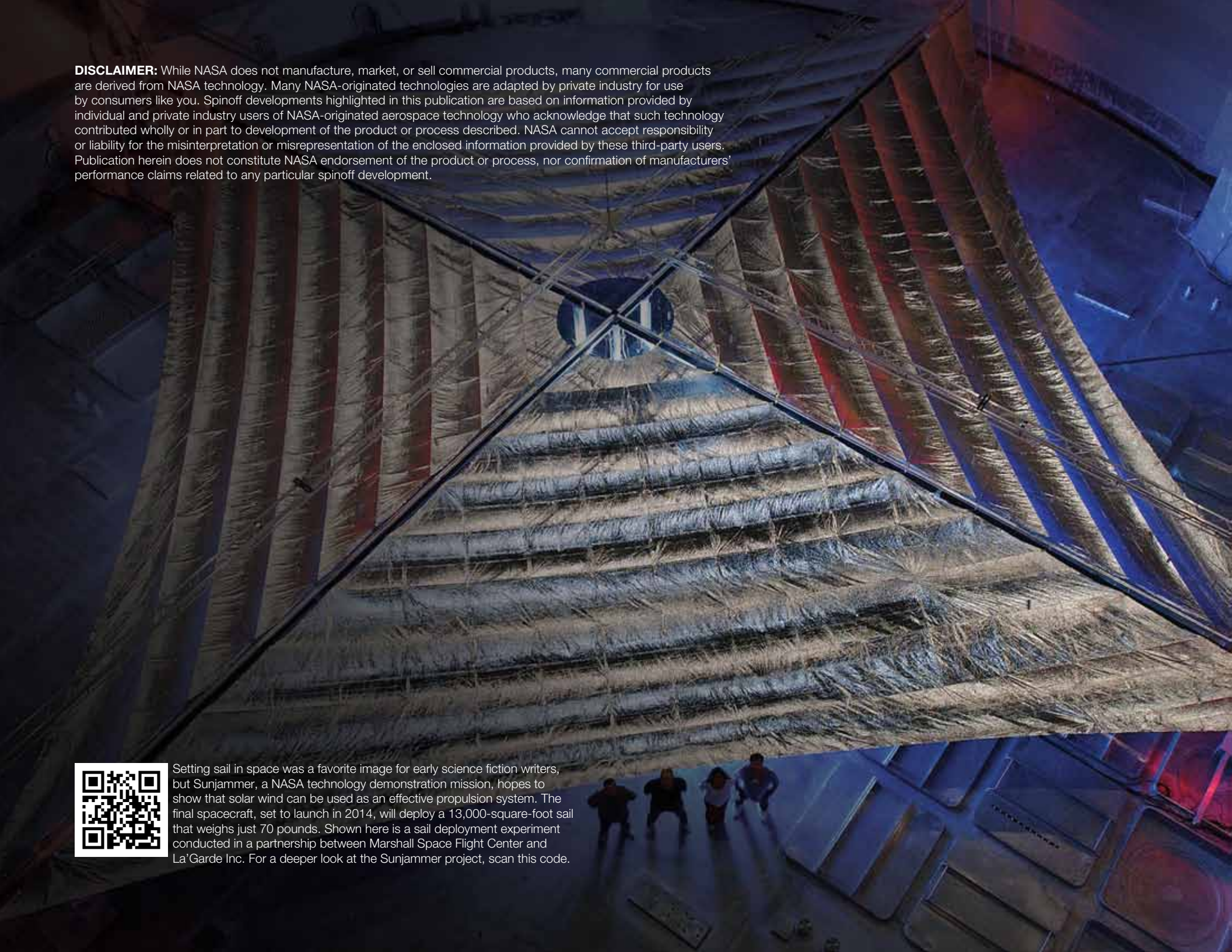
DISCLAIMER: While NASA does not manufacture, market, or sell commercial products, many commercial products are derived from NASA technology. Many NASA-originated technologies are adapted by private industry for use by consumers like you. Spinoff developments highlighted in this publication are based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



Setting sail in space was a favorite image for early science fiction writers, but Sunjammer, a NASA technology demonstration mission, hopes to show that solar wind can be used as an effective propulsion system. The final spacecraft, set to launch in 2014, will deploy a 13,000-square-foot sail that weighs just 70 pounds. Shown here is a sail deployment experiment conducted in a partnership between Marshall Space Flight Center and La'Garde Inc. For a deeper look at the Sunjammer project, scan this code.

Foreword

At NASA, we love to take on ambitious goals, especially those that inspire us to create innovative technologies where existing tools fall short. We are currently in a new and rapidly evolving era of space exploration, one that includes a complete transformation of how we get to low Earth orbit and beyond. It's an era that is witness to the birth of commercial space, with the Agency playing a key role in helping the private sector develop safe and affordable transportation systems. And it's an era where we are developing the technologies to send humans to new destinations such as an asteroid and Mars.

NASA is creating a future in space exploration and aeronautics that will benefit the US economy and all of humankind. Exciting advances such as solar electric propulsion for robotic missions, the Mars Science Laboratory, new Earth-observing satellites, and the James Webb Space Telescope underscore the importance of today's investment in space technology for tomorrow's discoveries and accomplishments.

To make these incredible technologies come to life, NASA researchers, engineers, and contractors often work alongside our many partners in industry and academia. These partnerships not only further our missions; they also create a large number of spinoff technologies with tangible benefits that are making an impact on our lives today. Each year, NASA's *Spinoff* publication presents the best recent examples of these benefits.

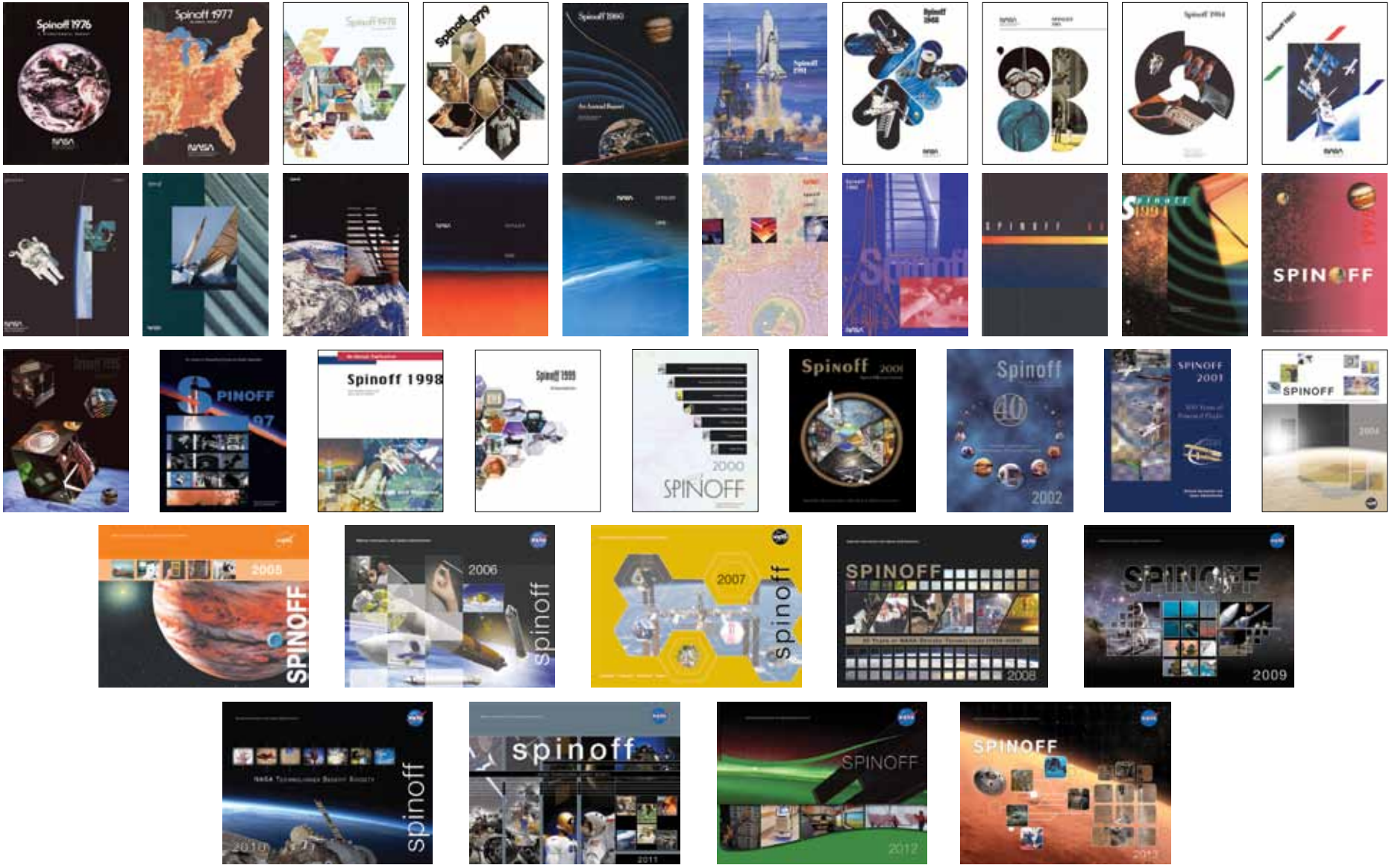
Some of my personal favorites in this year's edition include:

- The PICA-X heat shield, a low-density, high-temperature resistant material that is utilized by the SpaceX Dragon capsule for safe entry into Earth's atmosphere. NASA developed the core technology for its Stardust spacecraft, which in 2006 returned to Earth a capsule filled with comet particles that were used for research. Through its application on Dragon, the first commercial spacecraft to send cargo to the International Space Station (ISS), the heat shield is playing a critical role in opening up space to the private sector. (page 62)
- NASA-developed data mining tools have created algorithms that commercial airline companies use to sift through flight data and find anomalies they were previously unaware of. As a result, one company modified its operating procedures and has worked with air traffic control towers to improve the quality of its approaches and landings. (page 58)
- A car manufacturer is taking advantage of decades of NASA research on the relaxed human posture naturally assumed in microgravity. Company scientists tested the application of NASA standards in car seats, determining that its design could reduce physical exhaustion in drivers by 50 percent. The auto maker debuted its new NASA-derived seats in 2013 and will be including them in many upcoming standard and luxury car models. (page 60)
- Partnering with NASA through a Space Act Agreement, one company created an air revitalization system fit for sending up to seven crewmembers on trips to low-Earth orbit destinations such as the ISS. The same system now powers refuges placed deep underground, where miners can retreat in an emergency, breathing clean air while awaiting rescue. The company has hired more than 30 employees and its refuge can save mining companies $30,000 in maintenance costs over alternative shelters. (page 68)
- Seeking to create a national early warning system for detecting threats to US forests, NASA partnered with four other government agencies to develop monitoring capabilities using satellite data. The efforts led to the creation of ForWarn, a national forest monitoring system that uses NASA data to help public authorities, scientists, and conservationists locate, track, and neutralize potential problems. (page 104)

Charles F. Bolden, Jr.
Administrator
National Aeronautics and Space Administration

In addition to the 41 spinoffs you will find featured in this book, this year's publication also includes a new section profiling 18 NASA technologies that are currently available for licensing and/or development opportunities ("Spinoffs of Tomorrow," page 176). Our 10 field centers are brimming with ideas that have great commercial potential, and the inventors and contributors to those technologies are eager to see their work transferred to the private sector for the benefit of the public.

From life-saving shelters to innovations that protect the environment to components that are making commercial space transport possible, technology transfer represents a core part of NASA's mission and identity. It ensures that what we do each and every day for space and aeronautics has as wide an effect as possible—for the benefit of all.



For over 50 years, NASA has created new technologies with direct benefit to the public sector, supporting global competition and the economy. The resulting commercialization has contributed to products and services in the fields of health and medicine, transportation, public safety, consumer goods, energy and environment, information technology, and industrial productivity. Since 1976, NASA has featured over 1,800 technologies in its *Spinoff* publication.

Introduction

The successes of past and current NASA missions have taught us a great deal about what we need in order to journey safely beyond our planet and enable the future of aviation. And as we look to a future filled with ambitious science and exploration goals, it's clear that there is much more technology NASA must create—technology that will not only enable our future missions but also secure the nation's economic future by promoting the development of a national technological and industrial base from which to sustain the US leadership role in air and space.

For well over a decade, astronauts have been living on the International Space Station (ISS), giving us unprecedented insight into how human beings can survive, work, and even thrive during an extended visit to space—knowledge that will prove crucial for future deep space missions. The microgravity environment of the ISS also serves as a unique laboratory that has facilitated a number of important scientific discoveries, made possible by NASA's commitment to maintaining a human presence in low Earth orbit. All the while, our many missions in robotic space exploration, Earth science, and aeronautics have continued to improve our understanding of our world and place in the cosmos.

Many of these advances and enabling technologies, originally developed to meet mission needs, have spun off into commercial products that make life on Earth better today. Every year, *Spinoff* presents some of the best recent examples of these secondary benefits—each a reminder that today's investment in space pays significant dividends in the long run. Among the spinoffs highlighted in this year's book you will find:

- An award-winning filtration system, developed for use in space, that is now available to consumers as a bottle with a built-in filter, removing impurities and dangerous contaminants on the go. Adventurers and weekend warriors doing everything from sports to camping are using this NASA-developed technology to instantly create safe drinking water out of a variety of convenient water sources such as lakes and streams. (page 82)
- One of the world's hottest solar energy plants took its inspiration from the Space Shuttle Main Engine. Techniques used to build the rocket are being applied to a solar power tower that incorporates molten salt to absorb and hold heat in order to generate electricity on demand for 75,000 homes. The company is creating more than 4,300 jobs for the project, and its NASA-enhanced technology presents a 20 percent cost advantage over other solar thermal technologies while promising zero harmful emissions. (page 100)
- While supercomputers do a lot of the heavy lifting in scientific modeling, not all scientists have access to them. One company caught NASA's attention by adapting programming libraries to utilize the graphics cards found in ordinary desktop computers. Through the Small Business Innovation Research (SBIR) program, the company created software that now gives researchers at NASA and elsewhere unprecedented power from computers they already work with. (page 116)
- A team of NASA researchers spent decades purposefully inducing 8,000 aircraft spin-stalls—the cause of many fatal accidents in general aviation—and learned how to design aircraft that could resist spins. Thanks to NASA's research, the Federal Aviation Administration created a spin-resistance standard, which one company used as the guiding criteria for creating a consumer-friendly light sport aircraft with spin-resistance built in for increased safety. (page 52)
- Planning for an extended stay on Mars, NASA worked with a private company to develop wind-powered turbines capable of enduring the harsh, cold conditions on the Red Planet. The same features that made these turbines suitable for Mars have made them a natural fit in many environments on Earth. They now provide power in several countries and are particularly valuable in isolated grids, where they cost less to use than diesel fuel. (page 106)

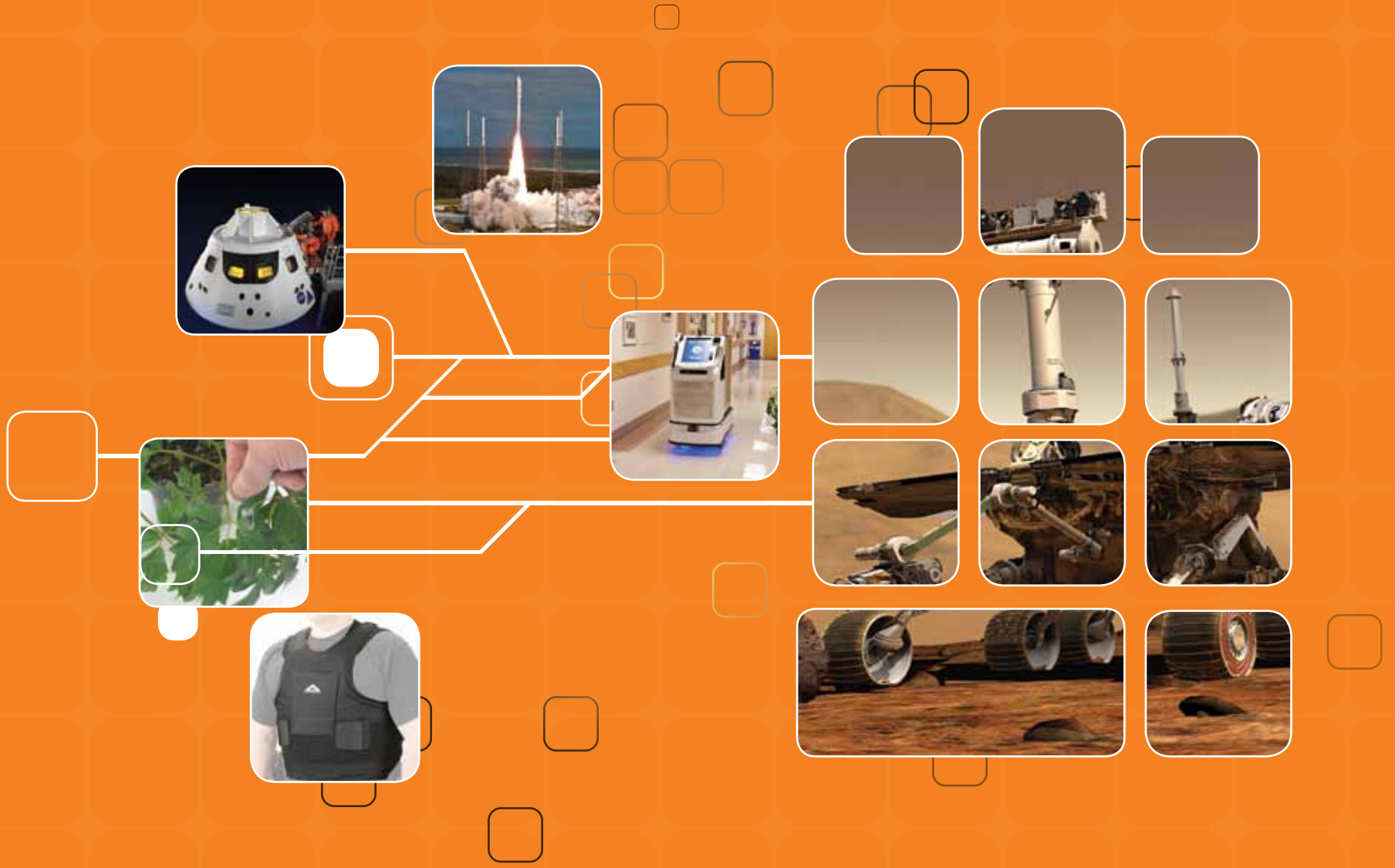
Mason Peck
Chief Technologist
National Aeronautics and Space Administration

The daring missions NASA has planned will require technology more advanced than anything we've seen before. We are hard at work creating those cutting-edge technologies, laying a foundation that will enable astronauts to visit an asteroid by 2025 and Mars in the 2030s.

And just as our current presence in space on the ISS was made possible with the help of other governments and collaboration through private partnerships, so also will NASA's future endeavors involve others' help. I'm particularly excited at the prospect of citizen science, incentive prizes, and challenge-driven open innovation to enable individuals to get involved in their space program by building their own space technology innovations, conducting their own science, and sharing those advances with the world. The Asteroid Grand Challenge, announced in June 2013, is the newest and most extensive example of how NASA is creating new channels for individuals and organizations alike to contribute meaningfully to the hard work of space exploration, scientific discovery, and the creation of new products and services that come out of that discovery. You too can be a rocket scientist! With collaboration between NASA, other governments, our commercial partners, and all of you, I'm certain that our future is bright. These efforts will not only help our Nation reach its most ambitious goals in space exploration; they will continue to spin off into new technologies that benefit society.

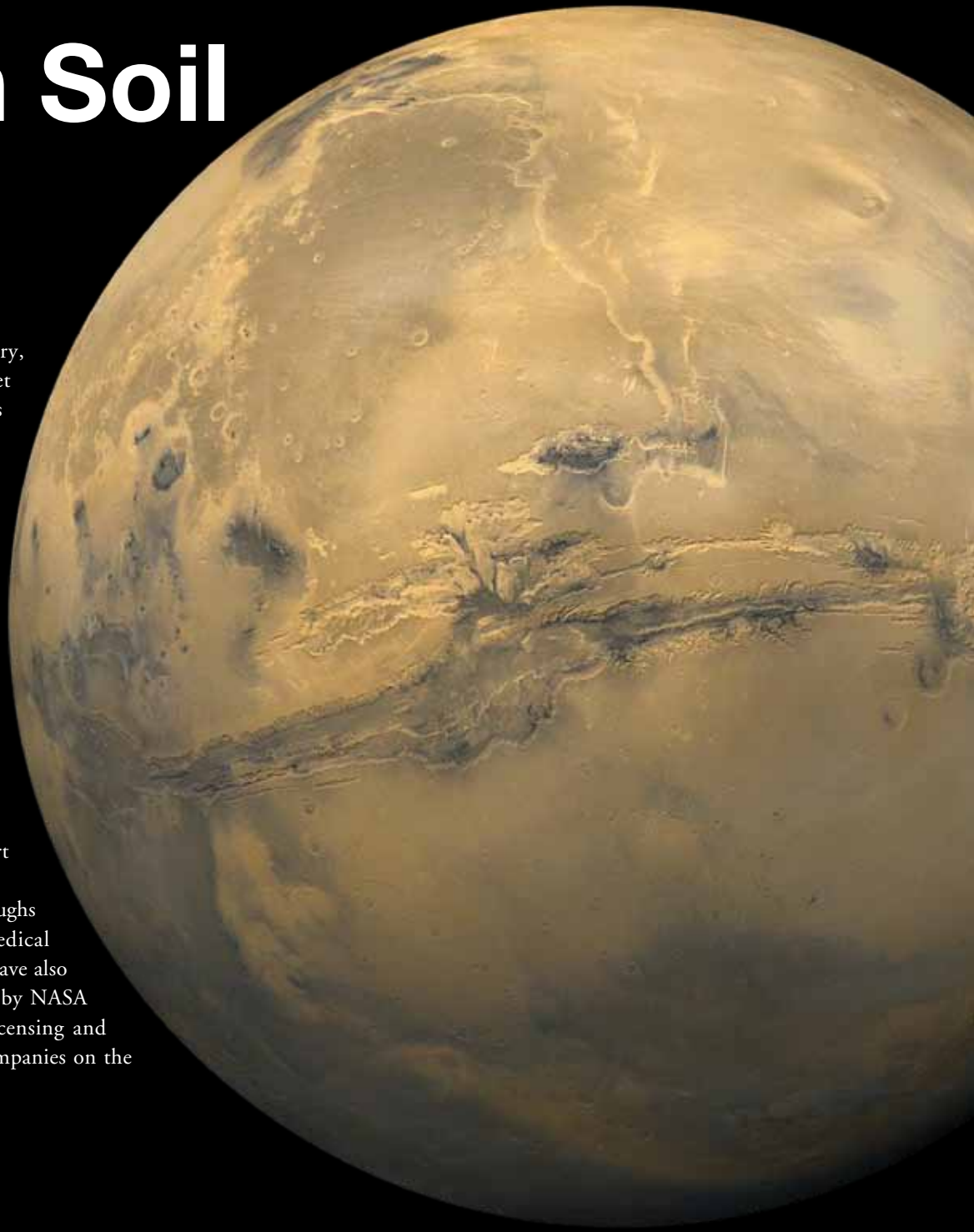
Mars Spinoffs

Spinoff has documented dozens of NASA technologies that were initially designed for missions to Mars but which are now protecting the lives of policemen and soldiers, enhancing sporting events for fans, safely detecting dangerous chemicals, and much more. For decades, Mars-derived NASA spinoff products and services have created jobs, generated revenue, and saved costs—real returns on our Nation's investment in some of the Agency's most daring missions.



From Martian Soil

NASA's most ambitious missions yield practical benefits for society



More than any other place, the Red Planet embodies the mystery, allure, and challenge of deep space exploration. Mars is a planet both fraternal and foreign to our own, alike in so many respects but also a striking reminder of how fragile the conditions conducive to life are. Its intriguing qualities have made it the centerpiece of planetary exploration: more robotic missions have aimed to orbit or land on Mars than any other planet or moon in the solar system (apart from our own), and NASA Administrator Charles Bolden recently called it "the ultimate destination in our solar system for humanity."

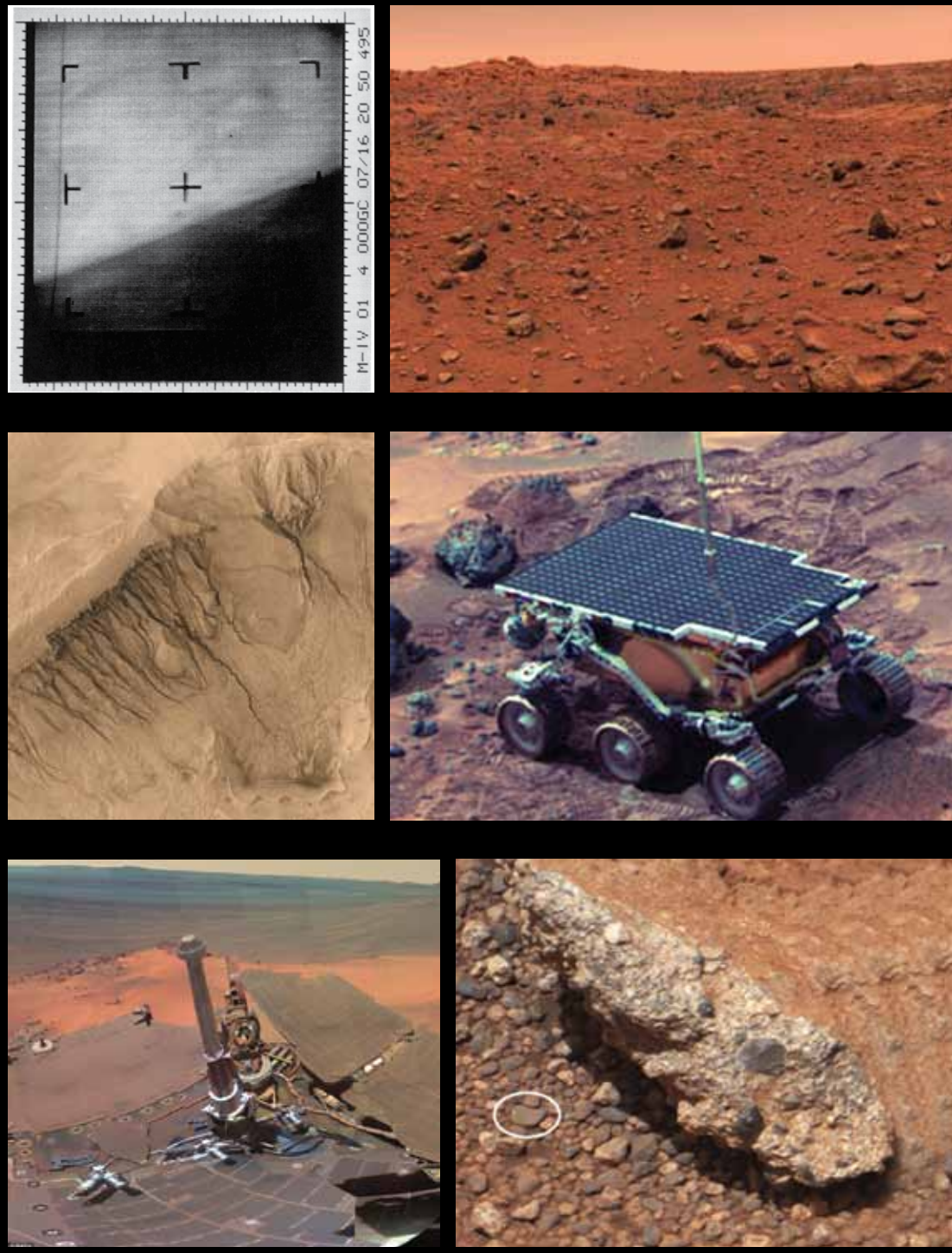
The unique challenges posed by past, present, and planned future missions to Mars have required NASA to push the boundaries of what is possible time and again—whether it's solving the technical obstacles of delivering a car-sized rover safely to its surface, developing techniques for growing fresh food in an extraterrestrial greenhouse, or figuring out how to shield astronauts from harmful radiation during their voyage. Much of NASA's human spaceflight program, including a decade of people living and working on the International Space Station, has focused on understanding how the human body will react to long-term habitation in space, to prepare in part for long-term missions like traveling to and living on the surface of Mars.

Along the way, the Agency has produced new materials, inspired breakthroughs in communications, authored innovative software, made important medical advances, and much more—including technologies designed for Mars that have also found commercial application here on Earth. Advances in science fostered by NASA for missions to Mars, for example, have since been made available for licensing and development, sometimes providing off-the-shelf solutions that help put companies on the

cutting edge of their industries. Other times, NASA's commercial partners are involved through the entire process: from solving the tough challenges posed by the space agency's goals to subsequently finding markets for the resulting products. Space Act Agreements and the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs allow companies to provide essential services to NASA while ensuring that the results of these partnerships will live on through added jobs, services, products, and revenue for the economy.

Recent discoveries, like the radiation measurements made by Curiosity during its trip to the Red Planet, have made it clear that a manned mission to Mars will require a host of technologies not yet invented or refined enough to enable a safe and successful trip. This is familiar territory for NASA, which has always had to invent the future it imagines. And if history is any indication, many more spinoffs will come as a result of NASA's ongoing investment in the game-changing, cutting-edge technologies that we will need to finally set foot on the red, dusty soil of our celestial neighbor.

In addition to spinoffs appearing in this year's book (pages 106, 130), the following are a few of the dozens of NASA-created or -derived technologies that not only have enabled past and future Mars missions but have also spun off into tangible benefits for the Nation.



Some of the historic moments in Mars exploration include: On top, the first close-up image ever taken of another planet (left) and the first color image ever taken on another planet's surface (right); in the middle, gullies possibly formed by flowing water as captured by Mars Global Surveyor (left) and the Sojourner rover as captured by Pathfinder in 1997 (right), the first successful Mars landing in over 20 years; and on bottom, the Martian landscape as captured by Opportunity (left) and rounded pebbles imaged by Curiosity (right) that were formed in an ancient streambed not unlike those found on Earth.

Delivering Clean, Affordable Power

A fuel cell developed for Ames Research Center uses solar power to split water into oxygen for breathing and hydrogen for fuel. While ideal for use on Mars, the technology can also be used to create clean energy on Earth. Its inventor founded Bloom Energy of Sunnyvale, California, and today provides cost-effective, environmentally friendly energy to a host of companies, including eBay, Google, Walmart, AT&T, and The Coca-Cola Company. When powered with fossil fuels, its Energy Servers are 67 percent cleaner than a coal-fired power plant, and they are 100 percent cleaner when powered by renewable fuels.

Protecting Public Safety Officers

In order to create the Mars Pathfinder's mission-critical airbags in the 1990s, JPL collaborated with New Ipswich, New Hampshire's Warwick Mills Inc. to weave multilayer textiles for the airbags for both Pathfinder and the Mars Exploration Rovers. Warwick Mills applied techniques from the collaboration to its puncture- and impact-resistant TurtleSkin product line. The company's metal flex armor vests offer stab protection comparable with rigid steel plates, and its SoftPlate body armor offers protection from handgun bullets. International public safety and military customers are now benefiting from the TurtleSkin products.

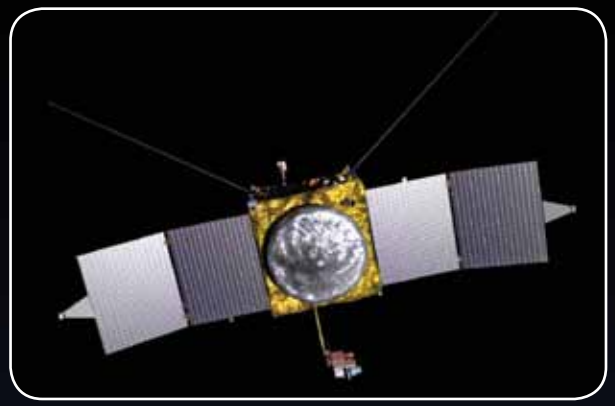
Paving the Way for Hospital Robots

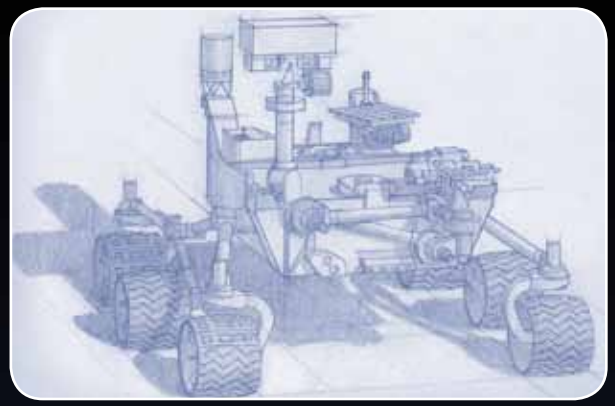
NASA's Jet Propulsion Laboratory (JPL) provided funding for the Massachusetts Institute of Technology to develop capabilities for robots like Rocky 7, a NASA test rover that demonstrated navigation and sampling technologies useful on Mars. After developing the operating system, Daniel Theobald started working at Cambridge, Massachusetts-based Vecna Technologies. Today, Vecna's QC Bot incorporates systems based on the NASA work and is being used to ease logistics at hospitals. The technology has contributed to 20 new jobs at the company.

"A human mission to **Mars** is today the **ultimate destination** in our **solar system** for **humanity**. . . . **Our** entire **exploration program** is aligned to **support this goal."**

— Charles Bolden, NASA Administrator

The Mars Science Laboratory, also known as Curiosity, was launched from Cape Canaveral Air Force Station Space Launch Complex 41 on November 26, 2011. For a deeper look at NASA's Mars exploration program, scan this code.



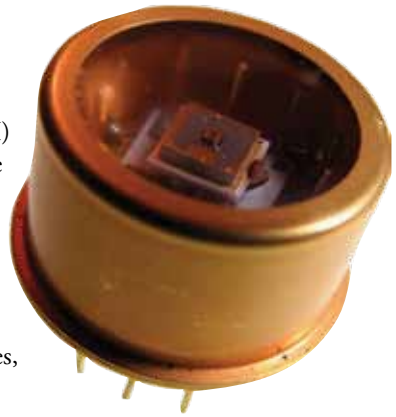


Future Mars missions include the Mars Atmosphere and Volatile EvolutioN (MAVEN) orbiter (left inset), which launched in late 2013, and a follow-up rover based on Curiosity's design (sketch shown in the center inset) proposed for launch in 2020. MAVEN will look for clues as to why Mars lost much of its atmosphere and most of its water to space, making the planet increasingly hostile to life. The 2020 science rover will likely search for signs of past life and could even collect samples for a possible future return to Earth. For a human exploration mission, the Orion crew module (right inset and background) will serve as both transport and a home to astronauts during their journey.

Bringing Main Street to Life

Berkeley, California-based earthmine inc. licensed 3D data-generation software and algorithms from JPL that were originally used to create a 3D representation of Mars' terrain, which allowed autonomous routing of the Mars Exploration Rovers. earthmine combined the software and algorithms with its unique capture hardware and Internet delivery technology, resulting in a system that integrates topographic information to deliver accurate street-level geospatial data through a web-based interface. Entire municipalities are collected through high-quality, 3D panoramic images—including every road, alley, and freeway—to create a complete, consistent, and publicly accessible geospatial view of cities for official and commercial applications.

Boosting Optical Communication



Brooklyn, New York-based Amplification Technologies Inc. (ATI) employed SBIR funding from JPL to improve its solid-state photomultiplier technology for interplanetary communication networks. ATI developed a small, energy-efficient, extremely high-gain sensor capable of detecting light down to single photons in the near-infrared wavelength range. The company has commercialized this technology in the form of its NIRDAPD photomultiplier, ideal for use in free space optical communications, lidar and ladar, night-vision goggles, and other light-sensing applications.

Providing an Early Warning of Biological Threats

Early Warning Inc., of Troy, New York, licensed powerful biosensor technology from Ames that was originally developed to look for life on Mars. Incorporating carbon nanotubes tipped with single strands of nucleic acid from waterborne pathogens, the sensor can detect targeted, disease-causing bacteria, viruses, and parasites. Early Warning features the NASA biosensor in its water analyzer, which can alert organizations to potential biological hazards in water used for agriculture, food and beverages, showers, and at beaches and lakes—within hours, instead of the days required by conventional laboratory methods.

Enabling Plants to Text Message Farmers

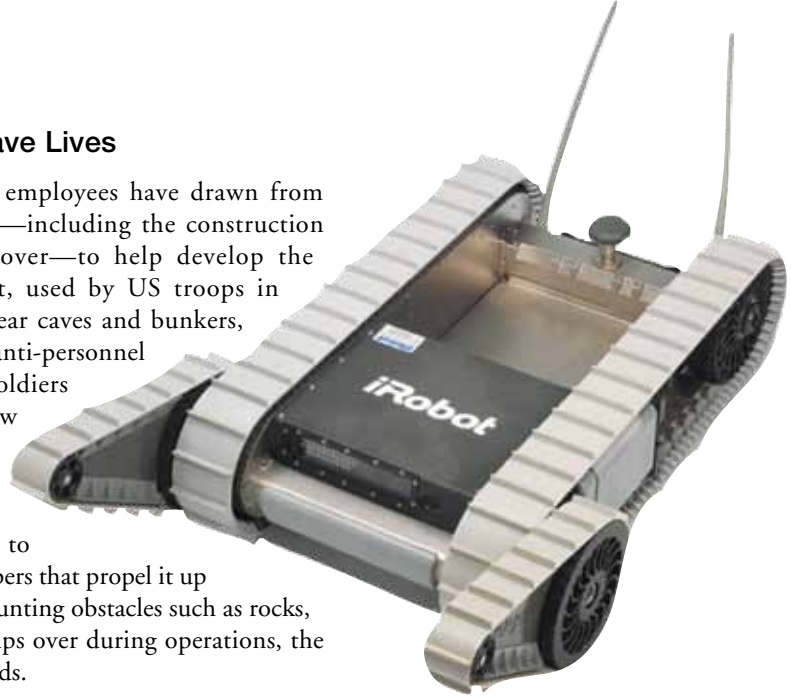
BioServe Space Technologies—a nonprofit, NASA-sponsored research partnership center—developed a leaf sensor that can monitor plants using electrical pulses, allowing anyone from astronauts to farmers to measure plant water levels directly. While particularly beneficial for growing food on long-duration space missions, Berthoud, Colorado-based AgriHouse Brands Ltd. has commercialized the technology, which now allows "thirsty" plants to send text messages to farmers asking for more water.

Analyzing Rocks and Minerals

• nXitu Inc., of Mountain View, California, entered into a Phase II SBIR contract with Ames to develop technologies for the next generation of scientific instruments for materials analysis on future Mars missions. The work resulted in a sample handling system that could find a wide range of applications in research and industrial laboratories as a means to load powdered samples for analysis or process control. The technology can characterize materials that cannot be ground to a fine size, such as explosives and research pharmaceuticals, and applications include the chemical, cement, inks, pharmaceutical, ceramics, and forensics industries.

Braving Battlefronts to Save Lives

A number of iRobot Inc. employees have drawn from their NASA experiences—including the construction of a prototype Mars rover—to help develop the PackBot Tactile Mobile Robot, used by US troops in Iraq and Afghanistan to help clear caves and bunkers, search buildings, and cross live anti-personnel minefields. PackBot provides soldiers with a safe first look so they know what to expect and how to respond. The robot can climb grades up to 60 percent and survive submersion in water up to 6.6 feet deep, and it possesses flippers that propel it up stairs, over curbs, and through daunting obstacles such as rocks, rubble, and debris. If PackBot flips over during operations, the robot can right itself within seconds.



Making Panoramic Photography a Snap

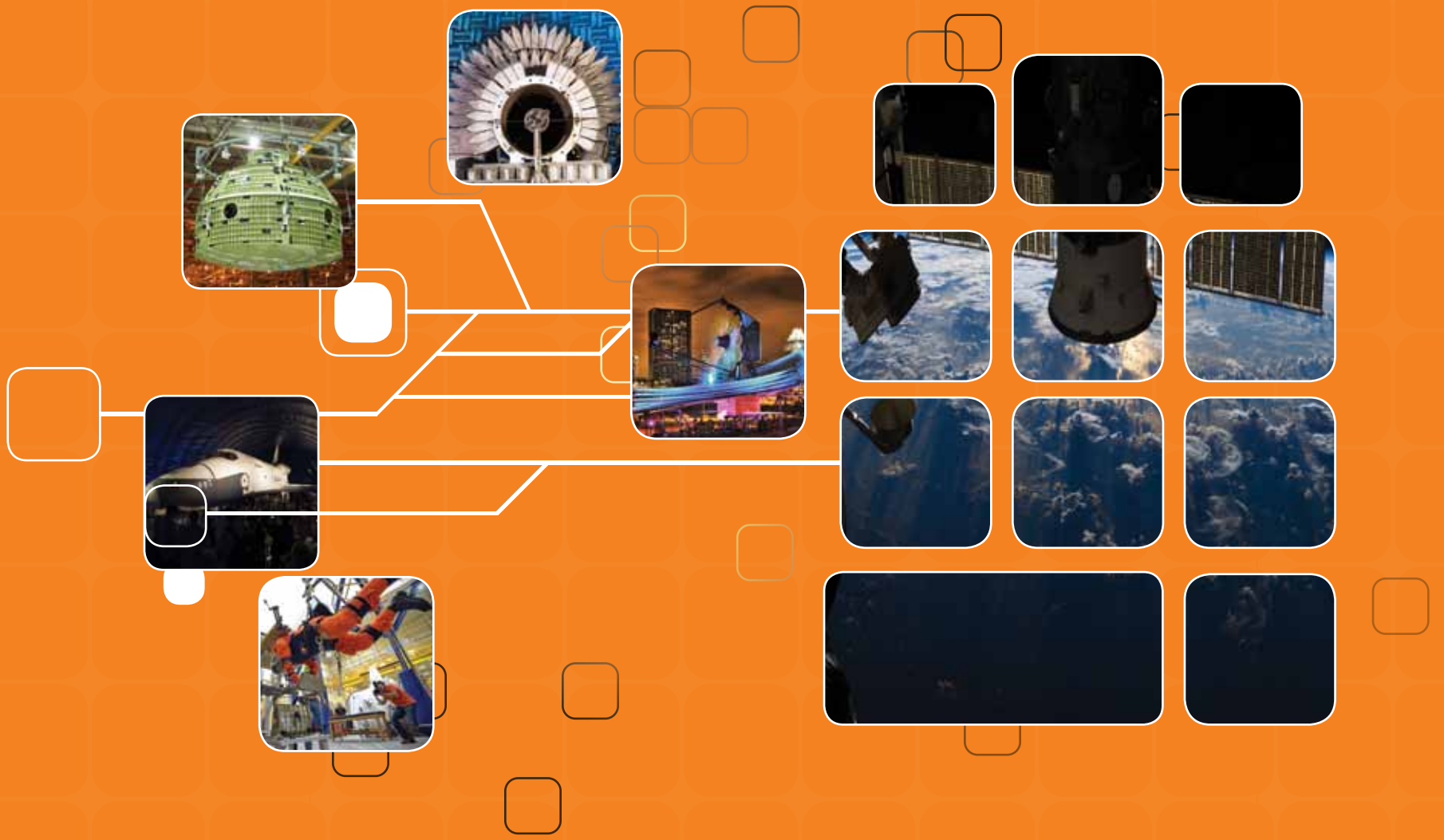
The Mars rover Panoramic Mast Assemblies inspired scientists at Ames and Carnegie Mellon University to find photographic and virtual exploration applications for consumers. Along with Austin, Texas-based Charmed Labs LLC, scientists created a prototype for the Gigapan robotic platform for consumer cameras, which automates the creation of highly detailed digital panoramas. The scientists also created a website and photographic stitching software to accompany the Gigapan platform. Among other places, the technology is now being used in baseball stadiums across the country: New York City-based Major League Baseball Advanced Media LP customized the Gigapan platform to accommodate in-game shots that capture nearly the whole stadium. Fans navigate the photos online and tag themselves and their friends using social media tools.

Supporting Drug Discovery

Biolog received SBIR contract work with NASA to develop technology for avoiding catastrophic crop failure during long-term space travel, like on a trip to Mars. Biolog brought its NASA-improved microbe-monitoring technology to market as the Phenotype MicroArray and the OmniLog System. The Phenotype MicroArray allows researchers to obtain a comprehensive picture of a given drug's effect on a specific cell, and the OmniLog system can monitor thousands of phenotypes simultaneously. ❖

Executive Summary

Spinoff has featured more than 1,800 of the most compelling, beneficial technologies to emerge from NASA's innovative technology transfer initiatives. Following its congressional mandate to share the benefits of its research with the public, NASA has long facilitated the transfer and commercialization of its technology alongside of partners in industry, academia, and government. These spinoffs have touched nearly every area of life, including the fields of health and medicine, transportation, public safety, consumer goods, energy and environment, information technology, and industrial productivity.



Executive Summary

Health and Medicine

36
Innovative Software Tools Measure Behavioral Alertness

To monitor astronaut behavioral alertness in space, Johnson Space Center awarded Philadelphia-based Pulsar Informatics Inc. SBIR funding to develop software to be used onboard the International Space Station. Now used by the government and private companies, the technology has increased revenues for the firm by an average of 75 percent every year.

40
Miniaturized, Portable Sensors Monitor Metabolic Health

In order to measure astronauts' metabolic rates in space, Glenn Research Center partnered with Case Western University and the Cleveland Clinic to develop the Portable Unit for Metabolic Analysis (PUMA). Cleveland-based Orbital Research licensed and then modified PUMA to help the US Navy assess pilot oxygen problems and is now designing a device that can be used in hospitals.

42
Patient Simulators Train Emergency Caregivers

Johnson Space Center teamed up with Sarasota, Florida-based METI (now CAE Healthcare) through the STTR program to ruggedize the company's patient simulators for training astronauts in microgravity environments. The design modifications were implemented in future patient simulators that are now used to train first responders in the US military as well as fire departments and other agencies that work in disaster zones.

44
Solar Refrigerators Store Life-Saving Vaccines

Former Johnson Space Center engineer David Bergeron used his experience on the Advanced Refrigeration Technology Team to found SunDanzer Refrigeration Inc., a company specializing in solar-powered refrigerators. The company has created a battery-free unit that provides safe storage for vaccines in rural and remote areas around the world.

46
Monitors Enable Medication Management in Patients' Homes

Glenn Research Center awarded SBIR funding to ZIN Technologies to develop a platform that could incorporate sensors quantifying an astronaut's health status and then communicate with the ground. ZIN created a device, developed the system further, and then formed Cleveland-based FlexLife Health to commercialize the technology. Today it is part of an anti-coagulation management system for people with cardiovascular disease.

48
Handheld Diagnostic Device Delivers Quick Medical Readings

To monitor astronauts' health remotely, Glenn Research Center awarded SBIR funding to Cambridge, Massachusetts-based DNA Medical Institute, which developed a device capable of analyzing blood cell counts and a variety of medical biomarkers. The technology will prove especially useful in rural areas without easy access to labs.

Transportation

52
Experiments Result in Safer, Spin-Resistant Aircraft

The General Aviation Spin Program at Langley Research Center devised the first-of-their-kind guidelines for designing more spin-resistant aircraft. Thanks to NASA's contributions, the Federal Aviation Administration introduced the Part 23 spin-resistance standard in 1991. Los Angeles-based

ICON Aircraft has now manufactured a new plane for consumer recreational flying that meets the complete set of criteria specified for Part 23 testing.

56
Interfaces Visualize Data for Airline Safety, Efficiency

As the A-Train Constellation orbits Earth to gather data, NASA scientists and partners visualize, analyze, and communicate the information. To this end, Langley Research Center awarded SBIR funding to Fairfax, Virginia-based WxAnalyst Ltd. to refine the company's existing user interface for Google Earth to visualize data. Hawaiian Airlines is now using the technology to help manage its flights.

58
Data Mining Tools Make Flights Safer, More Efficient

A small data mining team at Ames Research Center developed a set of algorithms ideal for combing through flight data to find anomalies. Dallas-based Southwest Airlines Co. signed a Space Act Agreement with Ames in 2011 to access the tools, helping the company refine its safety practices, improve its safety reviews, and increase flight efficiencies.

60
NASA Standards Inform Comfortable Car Seats

NASA developed standards, which included the neutral body posture (NBP), to specify ways to design flight systems that support human health and safety. Nissan Motor Company, with US offices in Franklin, Tennessee, turned to NASA's NBP research for the development of a new driver's seat. The 2013 Altima now features the new seat, and the company plans to incorporate the seats in upcoming vehicles.

62
Heat Shield Paves the Way for Commercial Space

The Phenolic-Impregnated Carbon Ablator (PICA) heat shield, a light-weight material designed to withstand high temperatures, was used for the Stardust's reentry into Earth's atmosphere. Hawthorne, California-based SpaceX later worked with the inventors at Ames Research Center to outfit PICA on its Dragon capsule, which is now delivering cargo to and from the International Space Station through NASA's Commercial Resupply Services contracts program.

68
Air Systems Provide Life Support to Miners

Through a Space Act Agreement with Johnson Space Center, Paragon Space Development Corporation, of Tucson, Arizona, developed the Commercial Crew Transport-Air Revitalization System, designed to provide clean air for crewmembers on short-duration space flights. The technology is now being used to help save miners' lives in the event of an underground disaster.

72
Coatings Preserve Metal, Stone, Tile, and Concrete

John B. Schutt, a chemist at Goddard Space Flight Center, created a coating for spacecraft that could resist corrosion and withstand high heat. After retiring from NASA, Schutt used his expertise to create new formulations for Daytona Beach, Florida-based Adsil Corporation, which now manufactures a family of coatings to preserve various surfaces. Adsil has created 150 jobs due to the products.

74
Robots Spur Software That Lends a Hand

While building a robot to assist astronauts in space, Johnson Space Center worked with partners to develop robot reasoning and interaction technology. The partners created Robonaut 1, which led to Robonaut 2, and the work also led to patents now held by Universal Robotics in Nashville, Tennessee. The NASA-derived technology is available for use in warehousing, mining, and more.

76
Cloud-Based Data Sharing Connects Emergency Managers

Under an SBIR contract with Stennis Space Center, Baltimore-based StormCenter Communications Inc. developed an improved interoperable platform for sharing geospatial data over the Internet in real time—information that is critical for decision makers in emergency situations.

78
Catalytic Converters Maintain Air Quality in Mines

At Langley Research Center, engineers developed a tin-oxide based washcoat to prevent oxygen buildup in carbon dioxide lasers used to detect wind shears. Airflow Catalyst Systems Inc. of Rochester, New York, licensed the technology and then adapted the washcoat for use as a catalytic converter to treat the exhaust from diesel mining equipment.

82
NASA-Enhanced Water Bottles Filter Water on the Go

Complex systems on the ISS collect and recycle moisture from every possible source—including sweat and urine—to be filtered for recycled use. Greenbrae, California-based ÖKO now sells a water bottle that employs NASA filtration media to purify water as the user squeezes it through the device.

84
Brainwave Monitoring Software Improves Distracted Minds

Neurofeedback technology developed at Langley Research Center to monitor pilot awareness inspired Peter Freer to develop software for improving student performance. His company, Fletcher, North Carolina-based Unique Logic and Technology Inc., has gone on to develop technology for improving workplace and sports performance, monitoring drowsiness, and encouraging relaxation.

86
Thermal Materials Protect Priceless, Personal Keepsakes

NASA astronaut Scott Parazynski led the development of materials and techniques for the inspection and repair of the shuttle's thermal protection system. Parazynski later met Chris Shiver of Houston-based DreamSaver Enterprises LLC and used concepts from his work at Johnson Space Center to develop an enclosure that can withstand 98 percent of residential fires.

88
Home Air Purifiers Eradicate Harmful Pathogens

Marshall Space Flight Center funded the University of Madison-Wisconsin to develop ethylene scrubbers to keep produce fresh in space. Akida Holdings of Jacksonville, Florida, licensed the technology and developed Airocide, an air purifier that can kill airborne pathogens. Previously designed for industrial spaces, there is now a specially designed unit for home use.

90
Thermal Materials Drive Professional Apparel Line

Johnson Space Center investigated phase change materials (PCMs) to use in spacesuit gloves to help maintain comfortable temperatures. Years later, Boston-based Ministry of Supply developed a dress shirt that incorporated the NASA-derived PCMs, could wick away moisture, and also control odors and bacterial growth. Deemed Apollo, the shirt performs like active wear and is available in white and oxford blue.

92
Radiant Barriers Save Energy in Buildings

Langley Research Center needed to coat the Echo 1 satellite with a

fine mist of vaporized metal, and collaborated with industry to create "radiant barrier technology." In 2010, Ryan Garrett learned about a new version of the technology resistant to oxidation and founded RadiaSource in Ogden, Utah, to provide the NASA-derived technology for applications in homes, warehouses, gymnasiums, and agricultural settings.

Energy and Environment

96
Open Source Initiative Powers Real-Time Data Streams

Under an SBIR contract with Dryden Flight Research Center, Creare Inc. developed a data collection tool called the Ring Buffered Network Bus. The technology has now been released under an open source license and is hosted by the Open Source DataTurbine Initiative. DataTurbine allows anyone to stream live data from sensors, labs, cameras, ocean buoys, cell phones, and more.

100
Shuttle Engine Designs Revolutionize Solar Power

The Space Shuttle Main Engine was built under contract to Marshall Space Flight Center by Rocketdyne, now part of Pratt & Whitney Rocketdyne (PWR). PWR applied its NASA experience to solar power technology and licensed the technology to Santa Monica, California-based SolarReserve. The company now develops concentrating solar power projects, including a plant in Nevada that has created 4,300 jobs during construction.

102
Procedure-Authoring Tool Improves Safety on Oil Rigs

Dark, cold, and dangerous environments are plentiful in space and on Earth. To ensure safe operations in difficult surroundings, NASA relies heavily on procedures written well ahead of time. Houston-based TRACLabs Inc. worked with Ames Research Center through the SBIR program to create an electronic procedure authoring tool, now used by NASA and companies in the oil and gas industry.

104
Satellite Data Aid Monitoring of Nation's Forests

The USDA Forest Service's Asheville, North Carolina-based Eastern Forest Environmental Threat Assessment Center and Prineville, Oregon-based Western Wildlands Environmental Threat Assessment Center partnered with Stennis Space Center and other agencies to create an early warning system to identify, characterize, and track disturbances from potential forest threats. The result was ForWarn, which is now being used by federal and state forest and natural resource managers.

106
Mars Technologies Spawn Durable Wind Turbines

To develop and test wind power technology for use on Mars, Ames Research Center turned to Northern Power Systems (NPS), based in Barre, Vermont. Ames awarded NPS an SBIR contract so the company could enhance their turbine's function. Today, over 200 NASA-derived Northern Power 100s are in operation on Earth and have reduced carbon emissions by 50,000 tons annually.

110
Programs Visualize Earth and Space for Interactive Education

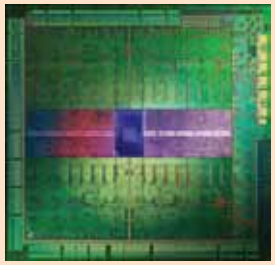
Kevin Hussey and others at the Jet Propulsion Laboratory produced web applications to visualize all of the

spacecraft in orbit around Earth and in the Solar System. Hussey worked with Milwaukee, Wisconsin-based The Elumenati to rewrite the programs, and after licensing them, the company started offering a version that can be viewed on spheres and dome theaters for schools, museums, science centers, and other institutions.

Information Technology

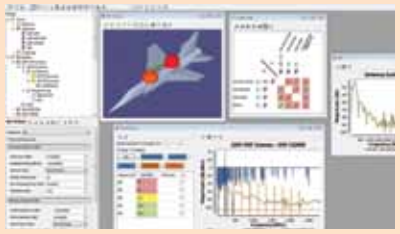
114
Processor Units Reduce Satellite Construction Costs

As part of the effort to build the Fast Affordable Science and Technology Satellite (FASTSAT), Marshall Space Flight Center developed a low-cost telemetry unit which is used to facilitate communication between a satellite and its receiving station. Huntsville, Alabama-based Orbital Telemetry Inc. has licensed the NASA technology and is offering to install the cost-cutting units on commercial satellites.



116
Software Accelerates Computing Time for Complex Math

Ames Research Center awarded Newark, Delaware-based EM Photonics Inc. SBIR funding to utilize graphic processing unit (GPU) technology—traditionally used for computer video games—to develop high-computing software called CULA. The software gives users the ability to run complex algorithms on personal computers with greater speed. As a result of the NASA collaboration, the number of employees at the company has increased 10 percent.



118
Simulation Tools Prevent Signal Interference on Spacecraft

NASA engineers use simulation software to detect and prevent interference between different radio frequency (RF) systems on a rocket and satellite before launch. To speed up the process, Kennedy Space Center awarded SBIR funding to Champaign, Illinois-based Delcross Technologies LLC, which added a drag-and-drop feature to its commercial simulation software, resulting in less time spent preparing for the analysis.

120
Software Simplifies the Sharing of Numerical Models

To ease the sharing of climate models with university students, Goddard Space Flight Center awarded SBIR funding to Reston, Virginia-based Parabon Computation Inc., a company that specializes in cloud computing. The firm developed a software program capable of running climate models over the Internet, and also created an online environment for people to collaborate on developing such models.

122
Virtual Machine Language Controls Remote Devices

Kennedy Space Center worked with Blue Sun Enterprises, based in Boulder, Colorado, to enhance the company's virtual machine language (VML) to control the instruments on the Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction mission. Now the NASA-improved VML is available for crewed and uncrewed spacecraft, and has potential applications on remote systems such as weather balloons, unmanned aerial vehicles, and submarines.

124
Micro-Accelerometers Monitor Equipment Health

Glenn Research Center awarded SBIR funding to Ann Arbor, Michigan-

based Evigia Systems to develop a miniaturized accelerometer to account for gravitational effects in space experiments. The company has gone on to implement the technology in its suite of prognostic sensors, which are used to monitor the integrity of industrial machinery. As a result, five employees have been hired.

Industrial Productivity

128
Reactors Save Energy, Costs for Hydrogen Production

While examining fuel-reforming technology for fuel cells onboard aircraft, Glenn Research Center partnered with Garrettsville, Ohio-based Catacel Corporation through the Glenn Alliance Technology Exchange program and a Space Act Agreement. Catacel developed a stackable structural reactor that is now employed for commercial hydrogen production and results in energy savings of about 20 percent.

130
Cameras Monitor Spacecraft Integrity to Prevent Failures

The Jet Propulsion Laboratory contracted Malin Space Science Systems Inc. to outfit Curiosity with four of its cameras using the latest commercial imaging technology. The company parlayed the knowledge gained under working with NASA to develop an off-the-shelf line of cameras, along with a digital video recorder, designed to help troubleshoot problems that may arise on satellites in space.

132
Testing Devices Garner Data on Insulation Performance

To develop a test instrument that could garner measurements of the thermal performance of insulation under extreme conditions, researchers at Kennedy Space Center devised the Cryostat 1 and then Cryostat 2. McLean, Virginia-based QinetiQ North America licensed the technology and plans to market it to organizations developing materials for things like piping and storage tank insulation, refrigeration, appliances, and consumer goods.

134
Smart Sensors Gather Information for Machine Diagnostics

Stennis Space Center was interested in using smart sensors to monitor components on test stands and avert equipment failures. Partnering with St. Paul, Minnesota-based Lion Precision through a Cooperative Agreement, the team developed a smart sensor and the associated communication protocols. The same sensor is now commercially available for manufacturing.

136
Oxygen Sensors Monitor Bioreactors and Ensure Health and Safety

In order to cultivate healthy bacteria in bioreactors, Kennedy Space Center awarded SBIR funding to Needham Heights, Massachusetts-based Polestar Technologies Inc. to develop sensors that could monitor oxygen levels. The result is a sensor now widely used by pharmaceutical companies and medical research universities. Other sensors have also been developed, and in 2013 alone the company increased its workforce by 50 percent.

138
Vision Algorithms Catch Defects in Screen Displays

Andrew Watson, a senior scientist at Ames Research Center, developed a tool called the Spatial Standard Observer (SSO), which models human vision for use in robotic applications. Redmond, Washington-based Radiant Zemax LLC licensed the technology from NASA and combined it with its imaging colorimeter system, creating a powerful tool that high-volume manufacturers of flat-panel displays use to catch defects in screens.

140
Deformable Mirrors Capture Exoplanet Data, Reflect Lasers

To image and characterize exoplanets, Goddard Space Flight Center turned to deformable mirrors (DMs). Berkeley, California-based Iris AO, Inc. worked with Goddard through the SBIR program to improve the company's microelectromechanical DMs, which are now being evaluated and used for biological research, industrial applications, and could even be used by drug manufacturers.

In just the last 10 years, NASA's efforts in space exploration have supported a better quality of life on Earth. Here's a snapshot of how the Nation's investment in space has paid dividends by creating jobs, saving lives, reducing costs, and generating revenue (right). *Spinoff* has profiled dozens of NASA technologies now at work in diverse commercial sectors (left), improving everything from health and medicine to industrial productivity. There's more space in your life than you think.

BY THE NUMBERS: Ten Years of Spinoff Benefits

Total technologies featured in *Spinoff* by category, 2004-2013

- Health and Medicine **58**
- Transportation **50**
- Public Safety **56**
- Consumer Goods **70**
- Energy and Environment **68**
- Information Technology **69**
- Industrial Productivity **84**

Jobs CREATED **18,000***

Lives SAVED **444,000**

Costs REDUCED **$4.9 Billion**

Revenue GENERATED **$5.1 Billion**

* Quantifiable benefit totals for jobs created, lives saved, revenue generated, and costs reduced are approximate and based on responses to a survey sent to companies featured in *Spinoff* since 2000. For more information, visit http://spinoff.nasa.gov/resources.html.

NASA Technologies Enhance Our Lives on Earth

Innovative technologies from NASA's space and aeronautics missions transfer as benefits to many sectors of society. Each benefit featured in *Spinoff* 2013 is listed with an icon that corresponds to the mission from which the technology originated. These NASA-derived technologies, when transferred to the public sector:

Health and Medicine

Transportation

Public Safety

Consumer Goods

International Space Station

Space Telescopes and Deep Space Exploration

Satellites and Imaging Technology

Space Transportation

Astronaut Life Support

Aeronautics Research

Energy and Environment

Information Technology

Industrial Productivity

NASA Spinoff Technology Across the Nation

Health and Medicine

1. Innovative Software Tools Measure Behavioral Alertness (PA)
2. Miniaturized, Portable Sensors Monitor Metabolic Health (OH)
3. Patient Simulators Train Emergency Caregivers (FL)
4. Solar Refrigerators Store Life-Saving Vaccines (TX)
5. Monitors Enable Medication Management in Patients' Homes (OH)
6. Handheld Diagnostic Device Delivers Quick Medical Readings (MA)

Transportation

7. Experiments Result in Safer, Spin- Resistant Aircraft (CA)
8. Interfaces Visualize Data for Airline Safety, Efficiency (VA)
9. Data Mining Tools Make Flights Safer, More Efficient (TX)
10. NASA Standards Inform Comfortable Car Seats (TN)
11. Heat Shield Paves the Way for Commercial Space (CA)

Public Safety

12. Air Systems Provide Life Support to Miners (AZ)
13. Coatings Preserve Metal, Stone, Tile, and Concrete (FL)
14. Robots Spur Software That Lends a Hand (TN)
15. Cloud-Based Data Sharing Connects Emergency Managers (MD)
16. Catalytic Converters Maintain Air Quality in Mines (NY)

Consumer Goods

17. NASA-Enhanced Water Bottles Filter Water on the Go (CA)
18. Brainwave Monitoring Software Improves Distracted Minds (NC)
19. Thermal Materials Protect Priceless, Personal Keepsakes (TX)
20. Home Air Purifiers Eradicate Harmful Pathogens (FL)
21. Thermal Materials Drive Professional Apparel Line (MA)
22. Radiant Barriers Save Energy in Buildings (UT)

Energy and Environment

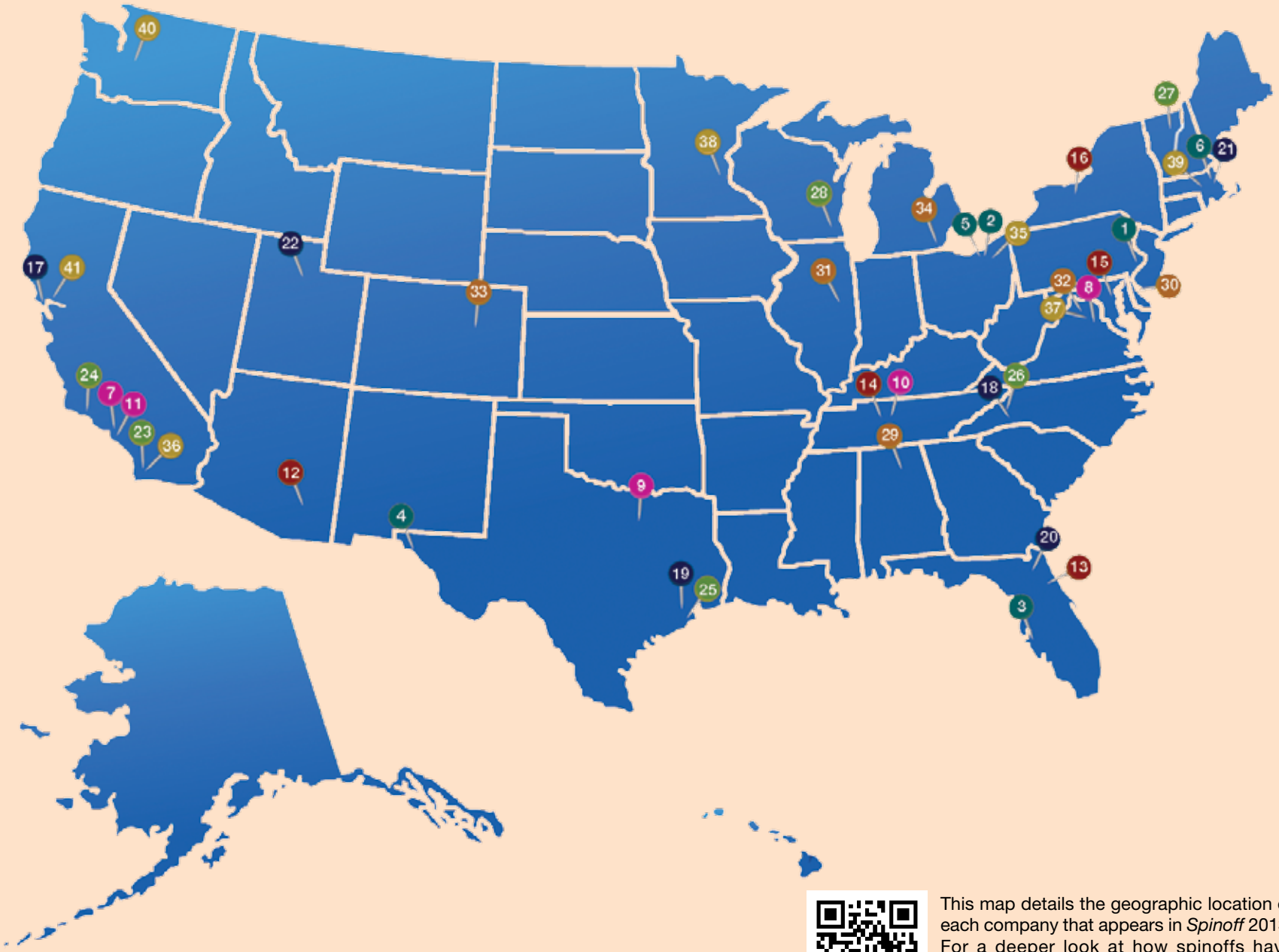
23. Open Source Initiative Powers Real-Time Data Streams (CA)
24. Shuttle Engine Designs Revolutionize Solar Power (CA)
25. Procedure-Authoring Tool Improves Safety on Oil Rigs (TX)
26. Satellite Data Aid Monitoring of Nation's Forests (NC)
27. Mars Technologies Spawn Durable Wind Turbines (VT)
28. Programs Visualize Earth and Space for Interactive Education (WI)

Information Technology

29. Processor Units Reduce Satellite Construction Costs (AL)
30. Software Accelerates Computing Time for Complex Math (DE)
31. Simulation Tools Prevent Signal Interference on Spacecraft (IL)
32. Software Simplifies the Sharing of Numerical Models (VA)
33. Virtual Machine Language Controls Remote Devices (CO)
34. Micro-Accelerometers Monitor Equipment Health (MI)

Industrial Productivity

35. Reactors Save Energy, Costs for Hydrogen Production (OH)
36. Cameras Monitor Spacecraft Integrity to Prevent Failures (CA)
37. Testing Devices Garner Data on Insulation Performance (VA)
38. Smart Sensors Gather Information for Machine Diagnostics (MN)
39. Oxygen Sensors Monitor Bioreactors and Ensure Health and Safety (MA)
40. Vision Algorithms Catch Defects in Screen Displays (WA)
41. Deformable Mirrors Capture Exoplanet Data, Reflect Lasers (CA)



This map details the geographic location of each company that appears in *Spinoff* 2013. For a deeper look at how spinoffs have benefited your state and local economy, scan this code.

NASA Technologies Benefiting Society

NASA research and development has tangible, secondary benefits that go beyond supporting mission needs. Spinoffs create jobs, generate revenue and save costs for businesses both large and small, and even save lives. Through home air purifiers, medical sensors, unique solar power plants, and more, NASA technology works for the benefit of the Nation and world.

Health and Medicine

Through technology transfer partnerships, NASA innovations become a vital part of our Nation's healthcare industry. From solar-powered refrigerators that keep vaccines cool to handheld diagnostic devices, advances from NASA research boost fitness, improve medical instruments, enhance disease treatments, and save lives. Spinoffs featured in this section:

- Measure Behavioral Alertness
- Monitor Metabolic Health
- Train Emergency Caregivers
- Store Life-Saving Vaccines
- Enable Medication Management in Patients' Homes
- Deliver Quick Medical Readings

Innovative Software Tools Measure Behavioral Alertness

NASA Technology

For astronauts working aboard the International Space Station (ISS) in low-Earth orbit, getting adequate sleep is a challenge. For one, there's that demanding and often unpredictable schedule. Maybe there's an experiment needing attention one minute, a vehicle docking the next, followed by unexpected station repairs that need immediate attention. Next among sleep inhibitors is the catalogue of microgravity-related ailments, such as aching joints and backs, motion sickness, and uncomfortable sleeping positions.

And then there is the body's thrown-off perception of time.

Because on the ISS the Sun rises and sets every 45 minutes, the body's circadian rhythm—the internal clock that, among its functions, regulates the sleep cycle based on Earth's 24-hour rotation—falls out of sync.

"They go to the cupola and look at these incredible sunrises just before they're supposed to go to bed," says NASA flight surgeon Smith Johnston, who is chief of the Fatigue Management Team, "and it gives the astronaut a giant dose of light that suppresses your melatonin and keeps you from being able to sleep."

In order to steady the brain's production of melatonin, enabling some sleep stability, astronauts shield their windows from all sunlight and wear face masks. For its part, the medical team back on Earth also constantly monitors their health and can, among a number of measures, prescribe medications to balance circadian rhythms or help to resolve other sleep-related problems.

Why so much attention is paid to making sure astronauts get enough slumber time is simple: The demands placed on an astronaut—who must both subsist in an artificial environment and carry out mission objectives—require that he or she operate at peak alertness.

Long-distance verbal check-ins with medical personnel is one way crewmembers communicate their levels of alertness, but the Agency is currently evaluating the utility of technology that provides a quantitative measure of a person's vigilance at any given time. The innovation has the potential to improve the health and performance of not only astronauts but also the many people who engage in similar high-risk activities.

Technology Transfer

In the early-1980s, David Dinges, a professor of psychology in psychiatry at the University of Pennsylvania Perelman School of Medicine and among the world's preeminent sleep experts, developed what has become one of the most widely used tests for determining behavioral alertness. The Psychomotor Vigilance Task (PVT) is a test that requires a person to watch a screen for a light stimulus and press a response button as quickly as possible when the light is detected. The light comes on repeatedly at random intervals of a few seconds until enough responses are acquired to establish—to the millisecond—the speed of the subject's visual reaction times. The test yields results for the stability of focused attention by measuring the number of errors of omission (performance lapses) and errors of commission (impulsive responses). By detecting these performance changes, the PVT records the degree of deficits in alertness and vigilant attention, as well as response speed.

> "When people get high fatigue scores on the PVT they always say, 'I had no idea I was this impaired. I had no idea I needed to get some sleep.' The test has the potential to save lives."
>
> —Daniel Mollicone, Pulsar Informatics Inc.

NASA astronaut Ron Garan views a point on Earth through one of the windows in the cupola of the International Space Station (ISS). The 15 sunrises and sunsets that occur on the ISS in a 24-hour period disrupt crewmembers' sleep patterns.

Although the traditional 10-minute PVT was practical for laboratory studies and clinical trials that, for example, gauge the effects of experimental sleep loss or the effects of psychoactive medications on human alertness, its duration made it less than ideal as a test for astronauts working in space, given their limited discretionary time.

"Every minute is just precious to us," says NASA's Johnston, "and there's

NASA astronaut Dottie Metcalf-Lindenburger practices simulated space maneuvers on the ocean floor near Key Largo during NASA Extreme Environment Mission Operations (NEEMO) 16 in June 2012. Astronauts there took the 3-minute PVT test to help refine the algorithm for use in actual orbit. Inset: NASA Flight Surgeon Josef F. Schmid works with the PVT in NEEMO's Aquarius underwater habitat. For a deeper look at NEEMO, scan this code.

Image courtesy of Hervé Stevenin

While sleeping, astronauts in space must tether themselves to the floor. They also often use facemasks to block out the light, helping to induce sleep.

so much to get done, and it's also a matter of having the astronauts be focused on their tasks and not getting sidetracked for too long a time."

So in the mid-2000s, Dinges and his colleague Mathias Basner from the same institution, with funding from NASA and the National Space Biomedical Research Institute, began working on a 3-minute version of the PVT for astronauts. The challenge lay in developing and validating an algorithm that could produce results that were nearly as sensitive as the results produced using the 10-minute version. Development began by measuring astronaut PVT performance during four NASA Extreme Environment Mission (NEEMO) operations, where astronauts perform duties in an underwater research facility where the environment closely resembles that of space. The results from those tests gave Dinges and Basner the data needed to optimize an algorithm, in part by determining how well an astronaut could react to the test when he or she is operating at peak alertness. Those reaction times would form the basis of a performance score used by astronauts on the PVT-B (the "B" is for brief) on the International Space Station. As they made substantial progress toward achieving these goals, it was clear that other aspects of the test would also need to be improved for use in space.

For one, the traditional PVT portable test device was cumbersome—not conducive for the limited confines of a spacecraft or the ISS. What was needed was a PVT that added little or no mass. Also essential was that it become a self-test; the program needed to be simple enough for an astronaut to use without any assistance.

That is where Philadelphia-based software engineering firm Pulsar Informatics came into play. Pulsar's president and CEO Daniel Mollicone trained with Dinges at the university en route to earning his doctorate in biomedical engineering. In 2006 Dinges asked Mollicone, who had worked on NASA projects in the past, if the company could develop the software for ISS.

It was not a simple request. Applying technology that was once carried out by a dedicated machine onto programs that run on personal computers, which is what astronauts use in space, is complicated by the fact that personal computers are not specifically designed to collect reaction times with the high precision essential for rapid objective evaluation of alertness. The PVT requires that reaction times be precisely measured in the milliseconds—that is, in thousandths of a second. But the company's engineers were up to the challenge: They had previously developed a proprietary robotic calibration system that could overcome such problems. Pulsar and NASA quickly entered into a contract to support a collaborative team of scientists and engineers lead by Dinges to develop a version of the PVT suitable for use by astronauts during space missions.

"We were young, ambitious engineers, and we were developing tools of similar nature and had the basic capability, so we agreed to take it on," Mollicone says.

One of 15 sunsets astronauts experience each day while onboard the ISS.

Benefits

Being able to constantly react quickly when required to do so is essential for astronauts because space missions can pose dangerous situations that require fast and accurate reactions. The PVT-B Self Test was renamed by NASA for ISS as the Reaction Self-Test. It informs astronauts when their performance drops below optimal ranges.

Since 2009, astronauts have been using the software on the ISS in order to gather data on the impact of certain space flight conditions (e.g., elevated workloads and reduced sleep time) to validate the PVT Reaction Self-Test as a useful operational support tool for astronauts.

When an ISS astronaut performs the Reaction Self-Test and receives feedback from the test indicating a diminished behavioral alertness performance score, the tool is essentially providing a warning sign indicating caution. "That's when the astronaut may consult with their flight surgeon to implement some fatigue countermeasures that get the astronaut back up to peak alertness", says Mollicone. Fatigue countermeasures might take the form of various sleep medications, mandated days off, power naps, and pushed back mission timelines, among others.

NASA flight surgeon Smith Johnston says the potential for the shortened PVT test is promising. "Daniel (Mollicone) and his team is currently working on developing a mission support software dashboard for flight surgeons that will use results based on each astronaut's PVT performance to create models so we know how well the astronaut is coping with or reacting to his or her environment," says Johnston. "It's a critical feedback tool, and once it's integrated into an operational tool, it's going to be amazing."

And it's not just NASA that's benefitting from the 3-minute self-test. Pulsar Informatics has contracts with other government agencies, namely the Department of Transportation and the Navy.

"The Navy has to be ready 24 hours a day, 7 days a week," says Mollicone. "And as we're heading toward a Navy with more automation aboard ships, each crew member is given more responsibilities. We're working to make sure that personnel are getting adequate rest so they can do their jobs reliably."

Trucking companies and commercial airlines use the self-test to better understand operational fatigue in order to prevent their drivers and pilots, respectively, from getting into fatigue-induced accidents. Mollicone says the test would be perfect for all drivers, noting that up to 40 percent of road accidents are caused by fatigue.

"When people get high fatigue scores on the PVT they always say, 'I had no idea I was this impaired. I had no idea I needed to get some sleep,'" he says. "The test has the potential to save lives."

The uptick in Pulsar's business over the last several years seems to suggest that more and more people and organizations are recognizing the importance of managing fatigue. Since partnering with NASA 5 years ago, the number of full-time engineers and computer developers has grown from 3 to 24. Revenues have grown, on average, 75 percent every year.

"Because of the collaboration with NASA, we've had this incredible success," Mollicone says. "And we're excited to continue pushing the limits of this technology for use here on Earth, where it's every bit as relevant." ❖

Miniaturized, Portable Sensors Monitor Metabolic Health

NASA Technology

On Earth, gravity might weigh you down, but it also builds you up. For astronauts working in space for long durations, the weightless environment can cause a host of detrimental health effects, such as a loss of bone and muscle mass. Another side effect is cardiovascular deconditioning.

NASA's Portable Unit for Metabolic Analysis (PUMA) uses miniaturized sensors to measure a person's metabolic rate.

One way of gauging cardiovascular conditioning is by analyzing a person's metabolic rate, or the amount of energy he or she expends in a given period, and one of the key ways this is done is by analyzing the amount of oxygen a person consumes and carbon dioxide they produce during respiration.

The body's ability to utilize oxygen—a critical component in energy production—is, in addition to genetics, dependent on a person's level of physical fitness. A strong heart can pump oxygenated blood faster, and healthier muscle tissue can absorb the element more efficiently.

Analyzing metabolic rates traditionally requires industry-standard metabolic carts. The machines are bulky and heavy, consisting of a computer system, monitor, and breathing tubes all assembled on a push cart. Wanting a more portable and lightweight device to use on the International Space Station (ISS), in 2002 NASA Glenn Research Center partnered with Case Western University and the Cleveland Clinic to develop what in 2006 became the Portable Unit for Metabolic Analysis (PUMA).

PUMA offers most of the functionality of a metabolic cart but condensed into a portable, wearable system. Each unit consists of headgear that supports a mask connected to sensors that measure oxygen and carbon dioxide partial pressure, volume flow rate, heart rate, and gas pressure and temperature. The oxygen and carbon dioxide sensors are located on the left side of the mask, the flow sensors on the right, and all are connected optically and electrically to an electronics box—powered by a camcorder battery—that fits into a small, wearable pack. This computer performs the basic calculations before sending the data wirelessly and in real time to a remote computer that stores and displays the metabolic data.

"We're happy with what we developed," says Glenn engineer Dan Dietrich. "And what makes PUMA stand out from other similar units that have been developed is the quality of the sensors. Aside from gauging a person's metabolic rate, they're sensitive enough to be used to monitor specific health conditions."

Technology Transfer

Cleveland-based Orbital Research Inc. had previously worked with NASA to develop an electrocardiogram harness with dry electrodes, and during that stint the company heard about PUMA. Convinced of its potential applications in athletic training and patient monitoring in hospitals, the firm began talks with the Agency on commercializing the technology. But Orbital Research expanded its plan to include military applications when the company realized that the Naval Air Systems Command (NAVAIR) was requesting proposals to assess the health of pilots during flight. Hence, Orbital Research proposed monitoring the exhaled oxygen and carbon dioxide levels of NAVAIR's pilots with an improved metabolic sensor system.

The reason? Military pilots, who rely on oxygen masks when flying at high altitudes, are at risk of experiencing hypoxia—a condition where the body is deprived of an adequate oxygen supply. Pilots can experience a range of symptoms, including headaches, fatigue, shortness of breath, and nausea. In the worst-case scenario, they can pass out. By monitoring oxygen and carbon dioxide levels, Orbital would attempt to determine the onset of the potentially deadly condition. With both Earth and air-based concepts to pursue, Orbital Research entered into a Space Act Agreement with NASA in 2009.

For fighter pilots to be able to wear a metabolic sensor system, all of the components needed to be made smaller and lighter. For one, this meant developing a more portable electronics box. It also meant developing even lighter sensors that could be retrofitted onto a pilot's oxygen mask. The PUMA sensors and the casing weighed a pound, which was too heavy. "If you're a pilot and you're pulling 9 Gs and you have a sensor package weighing half a pound in your facemask, that's equivalent to four and a

half pounds of weight that's going to be yanking on your neck," says Fred Lisy, president of Orbital Research.

Working with Glenn, the company further improved the design of the PUMA equipment. For example, a smaller electronic package was used to power the LEDs on the carbon dioxide sensors, which also saved on space and power consumption without sacrificing performance. At the completion of the NAVAIR program, Orbital Research had developed an improved metabolic sensor system called the Pilot Physiologic Assessment System (PPAS). The retrofitted sensors now weigh less than an ounce, and the electronics box is small enough to fit into a pocket of a survival vest.

The timing for the metabolic monitoring technology's advancement was propitious. In May 2011, the Air Force grounded its fleet of F-22 fighter pilots because of potential malfunctions in the oxygen generation system onboard the aircrafts. After entering into another contract, Orbital Research utilized the platform technology and produced a suite of sensors, including carbon dioxide sensors, for the pilots' masks. After being worn by pilots flying the F-22, the data gathered has been invaluable in correlating the physical state of the pilot with the performance of the life support system throughout the F-22 flight mission.

F-22 pilot Lt. Col. Devin "Sparky" Traynor wears an oxygen mask fitted with sensors designed to detect the onset of hypoxia. Orbital Research derived the technology through NASA's work with PUMA.

Benefits

The company has come a long way in advancing the PUMA technology for other applications. One of its current projects is developing software for the Navy that will take the data gleaned from the sensors to predict when the conditions are eminent that a pilot will be susceptible to hypoxia. Such a program would be a boon because hypoxia is highly individualistic and, therefore, has been difficult to predict. "We want to be able to alert the pilot so he can perform actions to mitigate the problem," says Lisy. "It could be as simple as a kinked air hose or his mask coming loose, and so we want him to troubleshoot the problem and then leave him enough time, if he still can't correct the problem, to be able to pull the backup oxygen system."

A similar technology is being investigated for the Navy's scuba divers that use rebreathers—systems that prevent bubbles from rising to the surface by rebreathing the recirculated air. In this application, the sensing hardware will be utilized to ensure that the rebreather is effectively cleaning the air so that the diver has the proper oxygen mixture throughout the dive.

Hospital care is another environment where the technology will prove useful and where Orbital Research is also setting its sights. Because the sensors are more precise than other current technologies, they are able to detect smaller quantities of oxygen changes even in an oxygen rich environment. This is particularly important for patients on supplemental oxygen support where too much or too little oxygen could be damaging, or at least counterproductive, to recovery. Using the monitoring system, the medical staff would be able to prescribe the right amount of oxygen that the patient needs, thereby eliminating the guesswork.

Summing up the company's work with NASA so far, Lisy says the Agency has been an exemplary partner. "NASA's support, especially in calibrating the system and optimizing the performance, has been invaluable. I hope we can continue to work together to launch this product into other markets." ❖

Patient Simulators Train Emergency Caregivers

NASA Technology

Medical training is one of the most important aspects of preparing astronauts for space. Every crewmember must become proficient in basic emergency skills, such as CPR, ventilation, and intubation. In the early 2000s, astronauts were being trained in Houston at Wyle Laboratories, the medical operations contractor for Johnson Space Center. At the time, the recent launch of the International Space Station (ISS) had ushered in an age of prolonged missions in low-Earth orbit. NASA wanted to be able to train crewmembers in a real microgravity environment because most actions to administer medical aid in weightless conditions required an adjustment from what is done on Earth.

Performing CPR is a prime example. The weight of one's body drives the compressions, but that force is nullified in microgravity. To compensate, astronauts in space must plant their feet onto the roof of the spacecraft to gain leverage and carry out the compressions while suspended upside down. Mastering such an atypical maneuver is best done through simulated practice.

Technology Transfer

Getting astronauts trained for these emergency scenarios meant having them practice on mannequins onboard a Boeing KC-135 Stratotanker, an aerial refueling military aircraft that, at the time, also moonlighted as a reduced gravity aircraft. Many who have ridden on one affectionately call it the "Vomit Comet." The plane simulates a microgravity environment by flying in a parabolic flight path, producing a series of 25-second stretches of weightlessness at a time.

For the mannequins, NASA Johnson Space Center turned to Sarasota, Florida-based METI (now CAE Healthcare), one of the nation's foremost developers of patient simulators. The company had gained recognition from the healthcare sector for developing the Human Patient Simulator (HPS)—a robust, high-fidelity mannequin used for medical training in intensive care and anesthesia. But this time NASA turned to the company's Emergency Care Simulator (ECS). Simplified and far more portable (its only external part is an "umbilical cord" that connects to a power and pneumatics box), the ECS was used in nursing schools and in emergency medicine training.

"As opposed to the HPS, with the ECS you're not dealing with a lot of medical monitors, ventilators or anesthesia machines," says CAE Healthcare director of engineering and innovation Hugo Azevedo, who worked with NASA on the project. "It's a simplified product designed to meet the training needs of first responders."

With the appropriate simulator chosen, the space agency wanted to make sure it could withstand the rigors of training and react appropriately in a space-like environment. In the fall of 2002, NASA entered into a Small Business Technology Transfer (STTR) agreement with METI to develop a microgravity-adapted ECS.

The ECS was modified in two important ways. The first were the adjustments made to account for the body's changes when exposed to microgravity. For example, aboard a spacecraft, astronauts tend to inhale more CO_2, so engineers tweaked the system's algorithms to account for how increased CO_2 inhalation and other factors would affect a person's physiology.

Then there was the issue of the simulator's sturdiness. When crewmembers practiced CPR on the ECS while flying in the KC-135, its arms would pop out of their sockets, the ribcage would be damaged, and the neck would flip around until it became detached, ruining the internal wiring. "They were putting quite a bit of force on the mannequins," Azevedo says. "You don't even realize how much force you're applying when you're in a non-gravity environment." To compensate for the increased exertion, stronger mounting structures were implanted to add rigidity and sounder structural integrity.

At the end of 2004, the modified ECS model was delivered to NASA, where it was used for training and for helping flight surgeons to keep their core competencies. The Agency also used the mannequin to help reconfigure an advanced life support procedure manual. "Using the ECS, crewmembers first walked through the procedure the way it was written, and then they followed the revised instructions," says NASA physiologist Victor Hurst IV. "Their feedback allowed us to revise the manual, and those same procedures are used onboard the ISS."

CAE Healthcare's Emergency Care Simulator (ECS) is designed primarily for training first responders in CPR, ventilation, and intubation.

Benefits

The benefits of the NASA partnership didn't end with the space agency. The ruggedized features of NASA's ECS were made a permanent feature of the company's commercial line. In response, the military, namely the Army Medics and the Air Force's Critical Care Air Transport Team, has bought the ECS to train troops in real-life emergency scenarios without fear of breaking the equipment. Fire departments and other agencies that employ first responders have also used the product in simulated training environments.

In the years following, CAE Healthcare released newer products, including the iStan, a completely wireless patient simulator, and Caesar, which is specially designed for training in disaster response and combat casualty scenarios. Both were designed with ruggedized hardware as a result of the knowledge gleaned from improving the ECS.

Recalling the collaboration with NASA, Acevedo is clear about how important it was for furthering the development of both the technology and the firm. "It's paramount," he says. "I remember 10 years ago we were a fairly small company with fairly big aspirations, and these types of projects were very helpful. It gave us a financial balloon that allowed us to do a lot of development that we otherwise couldn't do." ❖

ECS® is a registered trademark of CAE Healthcare.

NASA scientists onboard a reduced-gravity aircraft use the ECS to experiment with streamlining an airway management technique.

Solar Refrigerators Store Life-Saving Vaccines

NASA Technology

Over the years, NASA has advanced photovoltaic (PV) technology in order to advance many of its missions. This renewable source of energy is produced when certain "photoemissive" materials, such as silicon, eject electrons upon absorbing photons from sunlight. These free electrons can be captured, and the resulting current can be used as electricity. The space agency first used solar power in 1958 when Vanguard 1 was successfully launched into space.

Since then, NASA has harnessed the Sun's energy to power many other satellites, probes, rovers, and even the International Space Station (ISS). The ISS's iconic 115-foot solar array wings, each of which contains 32,800 solar cells that produce 32 kilowatts of electricity, were developed under the management of Glenn Research Center.

While photovoltaic technology has certainly benefitted space exploration, NASA has also helped transfer many of those technologies into a variety of commercial uses in telecommunications, water pumping systems, medical equipment, and lighting, just to name a few.

Technology Transfer

For his part, David Bergeron, who formerly headed the Advanced Refrigerator Technology Team at Johnson Space Center, sought to apply the innovations he helped develop—PV solar heat pumps for cooling lunar bases—here on Earth. After licensing the NASA technology, in 1999 he founded Solus Refrigeration Inc.—now called SunDanzer Refrigeration Inc.—and developed what became the company's signature solar-powered refrigeration units, which have gone on to benefit many industries (*Spinoff* 2003).

One of the El Paso, Texas-based company's models—a battery-free unit called the PV Direct-Drive model refrigerator—is now making another important contribution by ensuring that life-saving vaccines are available in rural communities all over the world.

SunDanzer's PV Direct-Drive refrigerator was designed in the early 2000s for off-the-grid users who are located where the sun shines at least 5 hours per day. The unit connects directly to the solar panel, thereby eliminating the need for a charge controller or batteries, which can be tedious to replace and add extra cost over the lifetime of the unit. A key technology is the solar-powered vapor compression heat pump that circulates refrigerant throughout the interior and removes heat. In response to that process, a nontoxic, water-based phase change material freezes, creating an "ice pack" that enables temperature maintenance inside the enclosure.

With its low-maintenance dependability, in 2009 the refrigerator caught the attention of the Program for Appropriate Technology in Health, or PATH, a global health nonprofit organization that focuses on innovative technologies. PATH had established the Battery-Free Solar Refrigerator challenge, a contest where companies could apply for funding to qualify their refrigerators as suitable for vaccine storage with the World Health Organization (WHO). With encouragement from the organization, SunDanzer applied and won the funding.

In 2010, the company renewed its license with NASA for the battery-free technology, then started modifying the unit's specifications to meet the WHO's standards.

The task of making its refrigerator vaccine-friendly wasn't easy, according to Jim Airola, SunDanzer's director of business

SunDanzer Refrigeration's Solar Direct-Drive Vaccine Refrigerator doesn't require batteries, which can be tedious to replace and add extra cost over the lifetime of the unit.

Development. The main challenge lies in maintaining a consistent degree of cold. "Vaccines thrive in a very specific temperature range, between around 35-46 °F," he says, "and configuring our refrigerator to meet that level of precision turned out to be a complicated process." But the company achieved that precision by, among other things, utilizing a fan to circulate the air more evenly and closing off areas near the top and bottom of the unit where the temperatures often fell out of the acceptable range.

All that work paid off when in 2011, following trial tests, the WHO prequalified the Solar Direct-Drive Vaccine Refrigerator, powered by NASA technology, as safe to use in hot zones around the world.

Benefits

According to Airola, SunDanzer's vaccine refrigerator is an attractive option for clinics that operate in sunny, rural areas with little or inconsistent access to electricity.

First is the simplicity of design. "You don't need any expertise to hook it up," he says. "It's just plug and play." Its battery-free construction also means that fewer things can malfunction that would require an expert to fix. "With the conventional battery-powered units, there's a lot of wiring and things that could go wrong if you don't know what you're doing. Our refrigerators require minimal maintenance and are intended to run for at least 15 years."

And while these iceboxes work most efficiently with plenty of direct sunlight, the company's proprietary phase change materials, which are adept at storing thermal energy, can sustain the unit's internal temperature during bouts of heavy cloud cover. For instance, the refrigerator can withstand 3½ days during combination cloudy weather and outside temperatures of 109.4 °F. In addition, the corrosion-resistant steel exterior and the lockable top-opening door provide increased durability and security.

In the short period that SunDanzer's vaccine refrigerators have been on the market, they have found homes in rural areas, such as in West African Senegal, where the company has installed 15 units. The United Nations Children's Fund, which buys 40 percent of the global purchases of these refrigerators every year, is the company's number one customer.

Through its work with PATH and the WHO, Airola says the company has learned a lot about how vaccines—and vaccine refrigerators—play an important role in staving off disease and maintaining public health, especially in developing countries. "We're proud that our refrigerators play a role in helping people stay healthy," he says. "It was well worth our efforts." ❖

SunDanzer™ is a trademark of SunDanzer Refrigeration Inc.

"Our refrigerators require minimal maintenance and are intended to run for at least 15 years."

—Jim Airola, SunDanzer Refrigeration Inc.

A vaccine refrigerator's solar panel is mounted to the roof of a rural African clinic. The United Nations Children's Fund, which provides assistance to children in developing countries, is the company's number one customer. Inset: A unit is situated inside a Kenyan clinic.

Monitors Enable Medication Management in Patients' Homes

NASA Technology

Astronauts experience some strange things when they live and work on the International Space Station (ISS). For one, they get taller. Thanks to microgravity, the disks between the vertebrae of the spine are no longer compressed. For another, their bones and muscles begin to weaken because they do not have to work against gravity to move and conduct daily tasks; astronauts simply float along doing their chores and work.

DeVon Griffin, a project manager in NASA's Human Research Program at Glenn Research Center, remembers in the early 2000s when astronauts ran on a treadmill on the ISS with weight to counter these physical changes taking place in their bones. "The assumption was that the exercise should be comparable to the same kind of exercise that you get from just your daily activities on Earth, but despite going through the motions, the astronauts were still losing their body's bone mass in the weight-bearing portions of the skeleton," he says.

In an attempt to understand what was happening, and to determine what could be done to lessen the effects in microgravity, the National Space Biomedical Research Institute funded Dr. Peter R. Cavanagh, formerly of the Department of Biomedical Engineering at the Cleveland Clinic's Lerner Research Institute, to quantify the force transmitted to the foot during ISS treadmill exercise. The goal of this effort was to try and match the daily force loading on the treadmill with what would be experienced during an average Earth day. To do this, Cavanagh installed pressure sensors in the shoes of astronauts. But the data collection capability for such a device on the ISS was lacking, says Griffin. "There was a need for something that could capture, store, and transmit data, but also be as small and lightweight as possible."

Adequate exercise is extremely important to help astronauts maintain a healthy amount of bone and muscle mass while in space. Here, astronaut Sunni Williams runs on the first treadmill installed on the International Space Station (ISS).

Technology Transfer

To build a small and mobile monitoring and processing system for use onboard the station to capture, store, and transmit sensor data about astronauts back to Earth, Glenn awarded Small Business Innovation Research (SBIR) funding to Cleveland-based ZIN Technologies. Using those funds, ZIN developed a platform that could incorporate various sensors quantifying an astronaut's health status and then communicate the information to the ground.

"The group developed a prototype that worked," says Griffin. "The device could go anywhere, and the technology was very adaptable."

For NASA, the technology could be used for virtually all sensors, thus allowing data collection from any device designed to monitor astronaut performance and health. On Earth, the partners envisioned it being advantageous for doctors to remotely monitor their patients, which is why ZIN partnered with the Cleveland Clinic shortly after demonstrating their first generation hardware.

After obtaining additional funding from Cleveland State University, the Global Cardiovascular Innovation Center, and the Ohio Third Frontier Fund, ZIN developed the technology further and strengthened their relationship with the Cleveland Clinic by forming a new Cleveland-based company called FlexLife Health to commercialize the spinoff technology.

> “Patients love it because they don’t have to come into the clinic as often. . . . With a system like this, patients don’t have to leave the house as much.”
>
> —Frederick J. Mindermann, FlexLife Health

Benefits

In late 2012, FlexLife Health launched the first version of the technology called vMetrics. As part of an anti-coagulation management system for people with chronic cardiovascular disease, sensors paired with vMetrics were specifically designed to monitor the levels of anti-clotting agents like warfarin in a patient’s blood. These levels must be closely monitored because if the dosage is too high, there is a risk of bleeding. If the dosage is too low, the medication becomes less effective at preventing a possible blood clot.

According to Frederick J. Mindermann, CEO and president of FlexLife Health, “Monitoring oral anti-coagulation medication can be difficult and time consuming. It requires frequent visits to your physician’s office to have blood drawn, and then wait for the clinician to advise you on the appropriate dosing. Now, there’s a better way to manage your treatment.”

vMetrics enables the monitoring of medication in real time at the patient’s home. After placing a blood sample in a separate testing instrument, data about the sample is automatically sent to the vMetrics device. The device then sends the information to FlexLife’s secure server, where the data is stored and can be accessed by health professionals or transferred to the patient’s electronic medical record.

ZIN Technologies developed a device to store and transmit information about astronauts’ health on the ISS. The company then developed the system further and formed FlexLife Health to commercialize the technology as part of an anti-coagulation management system for people with cardiovascular disease.

Using vMetric’s touchscreen, patients and health care professionals can interact—ask and answer questions—and physicians, nurses, or pharmacists can adjust the patient’s dosage if necessary.

“Patients love it because they don’t have to come into the clinic as often,” says Mindermann. “With a system like this, patients don’t have to leave the house as much.” In an increasingly cost-constrained medical system, saving money by avoiding clinic visits is an important benefit as well.

Based on the results of a clinical trial incorporating vMetrics, nearly 83 percent of trial participants reported that the technology made management of their medication easier and/or saved time. For these reasons, Mindermann is optimistic about future applications of the technology to monitor patients across a range of chronic conditions including congestive heart failure, hypertension, diabetes, chronic obstructive pulmonary disease, stroke, myocardial infarction, atrial fibrillation, sleep apnea, and more.

“For someone with congestive heart failure, it is important to monitor weight and heart rate, and to ask questions about daily health,” he says. “vMetrics has an extensive platform that we plan to expand following this initial warfarin work.”

Griffin says he is happy that the space technology is being used on Earth, but he hasn’t ruled out the possibility of using it in space. Even though the current exercise program is more stringent than ever, astronauts continue to experience a certain amount of bone loss in space, and that remains a concern for long-term flights. ❖

Handheld Diagnostic Device Delivers Quick Medical Readings

An artist's rendition of an astronaut gathering samples on the surface of Mars. Long-term space missions would require that astronauts have access to remote health monitoring devices, like the Reusable Handheld Electrolyte and Lab Technology for Humans (rHEALTH) sensor.

NASA Technology

In a 1962 speech, President John F. Kennedy said, "We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills." And what a feat of engineering it was in 1969 when, after 4 days and 239,000 miles of rocket-powered thrust, NASA's lunar module landed on the Moon's surface, turning an important page in humankind's progress.

Fast-forward to 2013, and the space agency has its sights set on another lofty goal: a manned landing on the Red Planet. "'A human mission to Mars is today the ultimate destination in our solar system for humanity, and it is a priority for NASA," said NASA Administrator Charles Bolden in a recent speech.

And what a page-turner that will be. Based on current technology, the best estimate is that it will take crewmembers 7-10 months before they land on Martian soil. For comparison, the Mars Curiosity rover took more than 8 months to complete its 352 million-mile flight path. And while the Curiosity mission is a marvel of engineering, a mission that sends humans to Mars will be an even larger challenge, because many innovations will have to be developed to ensure that astronauts have the necessary tools to survive what could be years spent in space.

One aspect critical to an astronaut's long-term survival away from Earth is effective and efficient health-monitoring technologies. In space, there are no laboratories that can analyze blood samples in order to check for possible diseases or deficiencies.

In 2003, NASA scientists were already looking for a device that in one reading could register red and white blood cell counts as well as other substances, such as electrolytes, hormones, and other molecules. It also needed to be conducive to use in space. "We needed something that was miserly in terms of the resources it required, had a long shelf life, and was very light, adaptable, and portable," says Emily Nelson, a senior research engineer at Glenn Research Center.

Unable to find anything "off the shelf" that fit the bill, Nelson says, "We came to realize we needed something specially designed to meet our requirements, so we identified our essential requirements and broadcast a call for solicitations."

Technology Transfer

Answering the call was Cambridge, Massachusetts-based DNA Medicine Institute Inc. (DMI). Founded in 2008, the company specializes in developing innovative medical devices, and NASA's solicitation fell within its expertise. That year, Glenn awarded Small Business Innovation Research (SBIR) funding to the firm, which went on to design the Reusable Handheld Electrolyte and Lab Technology for Humans (rHEALTH) sensor. It's a compact, portable device that utilizes a battery of technologies to measure all of the substances NASA needed to monitor, in addition to other biomarkers. (A *biomarker* is any measurable substance in the body that can indicate various conditions; for example, a high antibody count might indicate an infection.)

The first critical components of the device are the microfluidic handling units, which are tiny channels that prepare the drawn blood for analysis by moving it through the device, which performs a series of tasks such

as separating, diluting, and mixing various constituents. But unlike conventional blood tests, which use cartridges that must be discarded after every test, the rHEALTH sensor's units, in addition to being more efficient, are also reusable, which cuts down on both costs and the volume of material that needs to be brought into space. Next is the device's novel use of optical fluorescence technology, which can singlehandedly measure biomarkers, electrolytes, and analytes (biochemical substances) and also performs cell counts. The substance in question will glow if it's in the sample, and its fluorescent intensity indicates how much of it is present.

The third major component of the technology is an example of big things coming in small packages. It was developed through separate SBIR contracts, the first of which was awarded the following year. In that round of solicitations, NASA Glenn sought proposals for a technology that had the potential to perform a massive number of tests simultaneously on a single blood sample, which no product on the market could do at the time.

DMI answered the call with its nanostrip reagents. "They're kind of similar to urine analysis or pH test strips where you have a series of different pads for sensing analytes," says Eugene Chan, the company's founder and president. "The big difference is we've shrunk that technology over a billion-fold in volume so that we can implement that at the blood cell level." Each individual nanostrip can perform a panel of blood tests, and it is also encoded with a fluorescent tag, similar to a bar code, that identifies which set of analytes are being measured. A set of multisensor nanostrips could then measure hundreds of biomarkers or more from one blood sample.

Nelson says the innovation is a game changer. "Once it's fully developed, the DMI technology could permit more blood tests per sample than anything on the market," she says. "It would also allow greater flexibility to define the types of tests that would be done, whether they are routine blood panels or novel biomarkers that are used for cutting-edge research. Chan's pioneering innovations could bring revolutionary new capabilities to medical diagnosis and treatment, whether that's in a clinical setting or in the emergency room or in space."

Benefits

With its low mass, efficiency, and versatility, the rHEALTH sensor is vying with other recently developed portable diagnostic devices for the right to be used for space medical research onboard the International Space Station (ISS). Scientists would like to collect data on dozens of biomarkers on the ISS to help better understand some of the biggest medical concerns for long-duration spaceflight, including immune dysregulation, bone loss, muscle atrophy, kidney stone formation, and visual dysfunction. The sensor has already been proven to work in microgravity simulations following tests done on parabolic flights, which mimic the weightlessness of space.

The rHEALTH sensor is also currently available for purchase by universities and research centers, and within the next year the company is expecting to get the product approved by the Federal Drug Administration for use in hospitals, clinics, and even homes. "We want to provide information for the masses," Chan says. "With the device, people can measure their insulin levels, thyroid hormone and cholesterol levels, practically anything. And beyond just the variety of measurements is the time factor; from pin prick to results spans all of two minutes."

"A lot of times you don't want to wait for the central lab to get the information back to you," Chan says, "or you might be in space where there's no central lab or in the field somewhere in the middle of Africa. Having this high-powered test in the palm of your hand is what this is really all about."

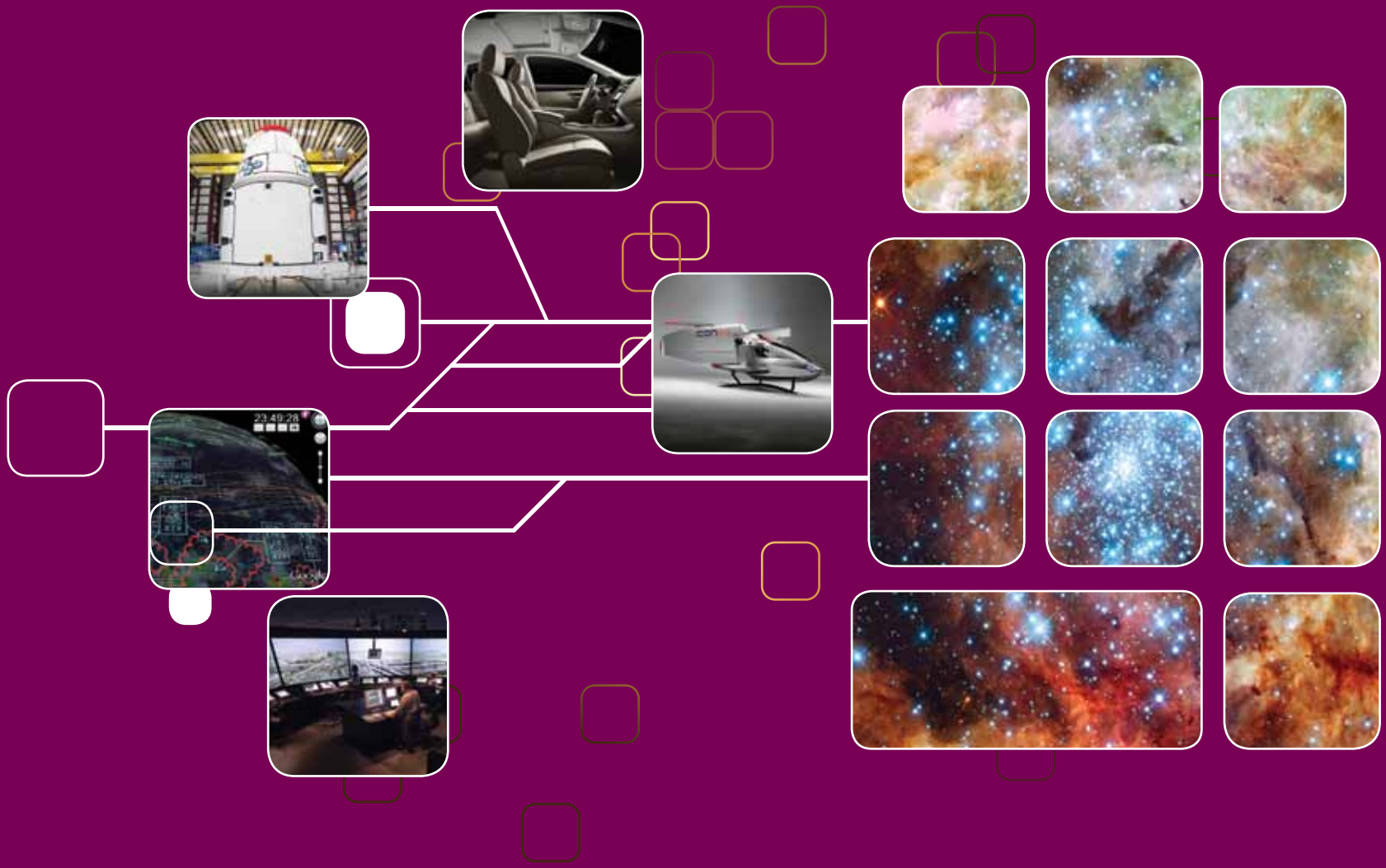
The rHEALTH sensor utilizes nanostrip technology to analyze dozens of biomarkers simultaneously. The device was also designed with efficiency and reusability in mind.

This technology is made possible, Chan says, with support from a forward-thinking agency such as NASA. "It takes that space-age kind of thinking to develop something that's a breakthrough," he says. "Ever since they've [NASA] demonstrated an interest in this, the general field has picked up. The Agency has really galvanized the whole sector." ❖

Transportation

Innovations created by NASA are ubiquitous on the highway and in the air. NASA technology is hard at work in our Nation's transportation systems, doing everything from improving the comfort of car seats to making flights more cost effective—they are even playing a key role in America's growing commercial space industry. Spinoffs featured in this section:

- Result in Safer, Spin-Resistant Aircraft
- Visualize Data for Airline Safety, Efficiency
- Make Flights Safer, More Efficient
- Inform Comfortable Car Seats
- Pave the Way for Commercial Space



Experiments Result in Safer, Spin-Resistant Aircraft

NASA Technology

James M. Patton Jr. completed a whopping 8,000 spin turns throughout his career at NASA. As a research pilot at Langley Research Center, Patton and his team—which consisted of engineers Paul Stough and Dan DiCarlo along with test pilot Phil Brown—were bent on understanding and preventing a dangerous condition called "spin."

Spin, which is caused by stall, or a reduction in lift during flight, sends an airplane spiraling toward the ground. While pilots are taught how to recover from a spin, even very experienced pilots can struggle with the task when they find themselves in a spin. According to the Aircraft Owners and Pilots Association, 28 percent of all fatal accidents in general aviation involve the stall-spin scenario.

To conduct research on spins, the Langley team utilized four different airplanes with four different wing shapes: a Grumman American AA1 Yankee, a Cessna 172, a Beechcraft C-23 Sundowner, and a Piper VA-2. When flying the aircraft, the pilots deliberately caused spins to occur. In case of an emergency, each plane had a spin recovery parachute attached to its rear to deploy and arrest the plane's descent.

At the time of their research—in the 1970s and '80s—the percentage of fatalities due to stall-spin was higher than it is today. Very little was known or understood about designing general aviation aircraft to resist spins, but the Langley crew became experts on the subject.

"Phil and I had to use the recovery parachute a total of 29 times," says Patton. "We also wore personal parachutes, but we never had to use them."

In 1973, the group started NASA's General Aviation Spin Program to devise the first-of-their-kind guidelines for designing more spin-resistant aircraft. Over the years, the program produced more than 100 technical reports and generated the knowledge and techniques that now enable safer aircraft designs. Thanks to NASA's contributions, the Federal Aviation Administration (FAA) introduced the Part 23 spin-resistance standard in 1991 to assist engineers in evaluating an aircraft's stall and spin characteristics.

Patton has received numerous awards for his NASA work, and in 2009 he and Phil Brown were inducted into the Virginia Aviation Hall of Fame for their extensive contributions to improving aviation safety and advancing aeronautics research. Even though Patton retired from NASA in 1987, his team's daredevil work continues to inspire aircraft designers and pilots seeking new heights today.

Research by NASA's General Aviation Spin Program contributed to the Federal Aviation Administration's (FAA) Part 23 spin-resistance standard. Here, James Patton Jr. (center) stands with James Bowman Jr. (left) and Sanger Burk (right) in front of a spin research aircraft.

Technology Transfer

While at Stanford Business School, Kirk Hawkins, a former US Air Force F-16 pilot, became keenly interested in a new category of aircraft designated by the FAA as Light Sport Aircraft (LSA). In 2005 the FAA established LSA to include simple-to-operate and easy-to-fly aircraft that could be flown using a Sport Pilot license—also a new category. The LSA category limits Sport Pilots to fly in lower altitudes, in uncongested airspace, during daylight hours, and in good weather. Certification for the license focuses on the fundamentals of flying and reduces the time and cost of a traditional private pilot license by about 50 percent.

Together with Steen Strand, an entrepreneur focused on consumer product design, Hawkins formed Los Angeles-based ICON Aircraft to manufacture a new LSA specifically for consumer recreational flying.

At first, Hawkins and his carefully chosen team of designers and engineers aimed to design a vehicle that was spin-recoverable, or more easily recovered from a spin. In the middle of the process, however, they reconsidered. "We wanted to design a plane that was spin-resistant," says Hawkins, founder and CEO of ICON. "We knew it would set us back about a year and a few million bucks, but we knew it was the right thing to do."

Turning to the FAA Part 23 standard, Hawkins and his team contacted people from the Langley team to learn more. Informed by NASA research, the ICON team found that in order to prevent a spin, they needed to prevent a stall. They executed this by incorporating a wing cuff on the aircraft to separate the wing into two distinct parts: one that allowed a stall to begin and one that prevented it from continuing. This, in turn, prevented a spin.

To test its design, ICON engineers treated the Part 23 standard like a rigorous exam and subjected its new sport plane—deemed the A5—to several hundred test

"If it wasn't **for** the **NASA work**, there would be no **FAA standard**, and we **wouldn't** have **done this."**

—Kirk Hawkins, ICON Aircraft

As a Light Sport Aircraft, the A5 was made for consumer recreational flying. For safety, it incorporates spin-resistance—an advantage, according to its makers, that is similar to antilock brake systems in cars. For adventure, the A5 can take off from and land on both water and ground.

Alongside the **safety** elements, the **A5** boasts a **number** of additional **features based** on the idea, **“If you** can drive, you **can fly.”**

The wings of ICON Aircraft's A5 fold back so it can fit on a custom towing trailer or in a residential garage. It runs on aviation or automotive gasoline and can fly up to 120 miles per hour.

cases required by the standard. Eventually, the A5 met the complete set of criteria specified for Part 23 testing.

"If it wasn't for the NASA work, there would be no FAA standard, and we wouldn't have done this," says Hawkins. "When we saw the results, it was pretty phenomenal. I think the safety advantage is a disruptive one, analogous to antilock brake systems in cars."

Benefits

Hawkins compares the spin-resistance of the A5 to antilock brakes in cars because they are designed to respond to maximum braking by the driver without losing control. This way, drivers can do what they are inclined to do—keep their foot on the brake—and the vehicle responds predictably. The spin-resistance characteristics of the A5 are similar.

"If you mis-fly and get into a spin, you panic," explains Hawkins. "The first thing you do is pull the stick back. It's like stomping the brake and saying, 'Whoa! I don't want to do this.' The right answer is to relax back pressure on the stick, fly toward the ground, recover the wings, level them out, and then slowly reapply the pressure so you miss the ground. We wanted to make an airplane where, if you do pull the stick back, as is the pilot's natural reaction, it doesn't get worse. It gets better."

Hawkins says the spin-resistance of the A5 will save lives. Before a spin even begins to occur, the A5 provides a warning that tells the pilot he or she is doing something wrong. This is especially beneficial in sport flying because flying typically occurs at low altitude, where a spin is most dangerous.

In addition to spin-resistance, the A5 also offers a complete airplane parachute, another NASA spinoff ("Rocket-Powered Parachutes Rescue Entire Planes," *Spinoff* 2010), which can bring the plane gently to the ground should an emergency occur. "It provides confidence to the customer that safety is built in, though you likely will never have to use it," says Hawkins. "Just like when you buy a car, you have an airbag—but you rarely have to use it."

Alongside the safety elements, the A5 boasts a number of additional features based on the idea, "If you can drive, you can fly." For example, ICON is collaborating with Lotus Engineering to incorporate premium lightweight automotive-quality components for the two-person cockpit. The interior instrument layout resembles a sports car. Plus, the key instruments are grouped in one cluster, and the safety controls are grouped in another easy-to-reach console. The A5 also has a wraparound window canopy with removable side windows for a clear view.

For convenience, the A5's wings can fold back so the aircraft can fit on a custom towing trailer or in a residential garage. As an "amphibious aircraft," the A5 can take off from and land on both water and ground, requiring only 750 feet of runway or water. It also has retractable landing gear.

Powered by a fuel-injected Rotax 912 iS engine, which reportedly delivers up to 70 percent better fuel efficiency than comparable engines, the A5 runs on both aviation fuel and automotive gasoline. The maximum speed is 120 miles per hour.

So far, the company has received more than 1,000 orders for the A5. The first one will be completed in the summer of 2014. In addition to individuals purchasing the spin-resistant aircraft for personal use, ICON has demand from businesses for multiple A5 aircraft, including flight schools, flying clubs, resorts, and adventure companies. In 2012 the A5 also showed up in an unlikely place: in a new Microsoft Flight PC game using the A5 as the default aircraft in its starter pack.

While NASA may have put a new spin on flight design several decades ago, ICON Aircraft is putting the spinoff technology into pilots' hands for safer aircraft today. ❖

Interfaces Visualize Data for Airline Safety, Efficiency

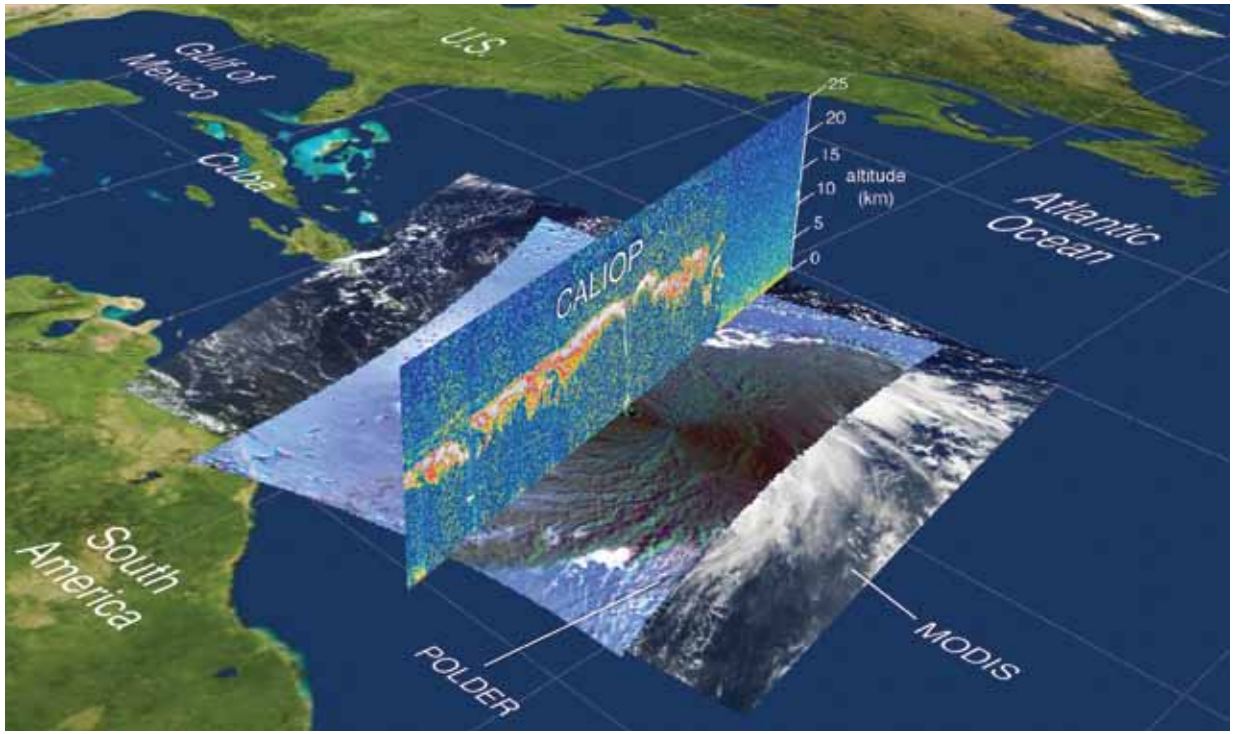
NASA Technology

It was Henry Ford who said, "Anyone who stops learning is old, whether at 20 or 80. Anyone who keeps learning stays young." Following such an adage, it's safe to say that NASA will never grow old. From distant galaxies to Martian landscapes to Earthly atmospheres, the Agency never stops uncovering new information or learning about our universe.

Take the group of six Earth-observing satellites known as the A-Train Constellation, launched by NASA and its international partners over the last couple of decades. Each satellite orbits the Earth one after another (like a set of cars on a train) to simultaneously measure clouds, aerosols, atmospheric chemistry, and other components. The data combine to paint a more complete picture of how the various atmospheric constituents interact with one another, and how the composition of the atmosphere affects Earth's climate.

Near the middle of this group flies the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite, a spacecraft that provides measurements of the altitude of aerosols and clouds in the atmosphere. Armed with new information from CALIPSO, scientists hope learn more about how clouds and aerosols regulate Earth's weather, climate, and air quality.

As A-Train orbits and gathers data on what's happening in the atmosphere, NASA scientists and Agency partners work on the ground to learn how to visualize, analyze, and communicate the information obtained from space.



Data from various A-Train instruments provide a more complete picture of Hurricane Bill in 2009.

Technology Transfer

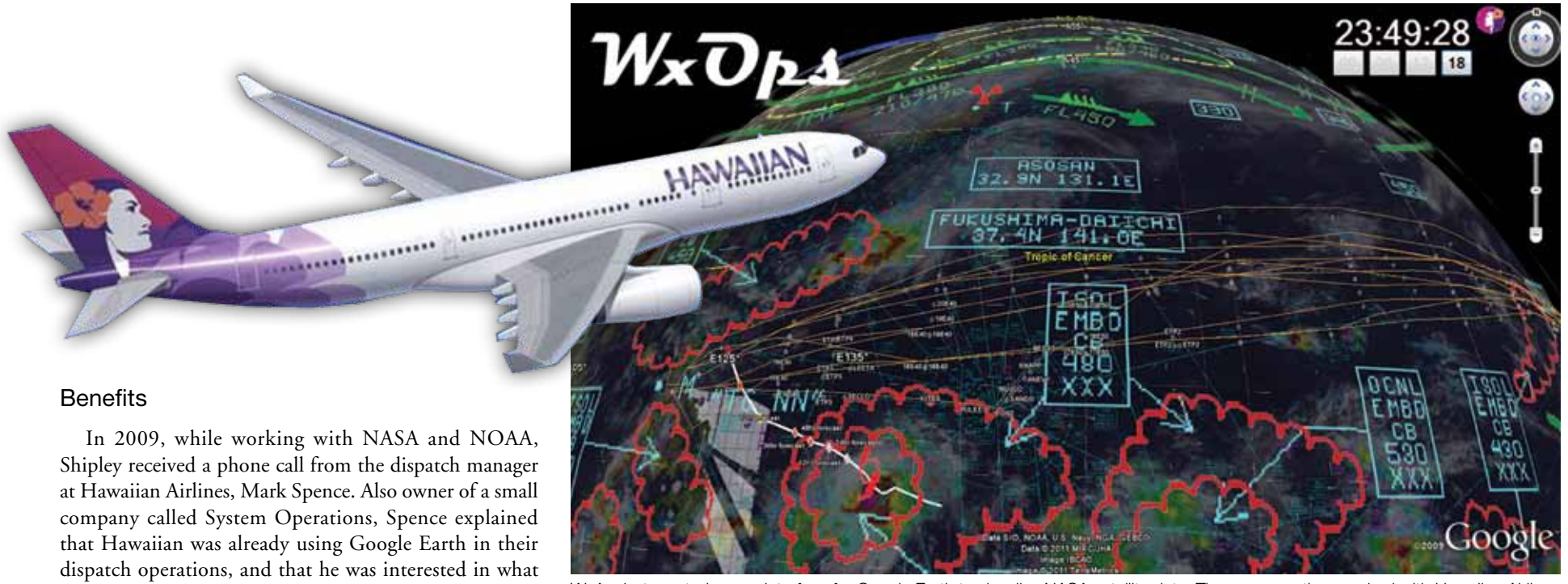
In 2008, NASA's Langley Research Center awarded Small Business Innovation Research (SBIR) funding to Fairfax, Virginia-based WxAnalyst Ltd. to construct a transparent user interface for Google Earth, a virtual globe system, to visualize data like that from CALIPSO. The partners wanted to devise a new capability for an interactive display of geographical data on top of the virtual globe.

WxAnalyst had already developed a prototype tool called WxAzygy. As Scott Shipley, the director of WxAnalyst, describes, "We wanted to be able to see exactly what is in the atmosphere—in real time, height, latitude, and longitude. We also wanted to make it so if you click on something in the air, Google Earth doesn't think you are clicking on Texas. Instead, it knows you are clicking on the hurricane above it."

Kurt Severance, a senior computer engineer at Langley, says NASA saw potential for visualizing data sets, like CALIPSO's, in this way. "The technology could add scientific value to Google Earth," he says. "NASA saw promise in adding this functionality—and that there would be a capability that a number of projects might be able to leverage to see data more clearly."

Through the partnership, the WxAzygy user interface was further refined so users could see and work with the data where it was over Earth. When a user clicks or touches selected features above the surface, WxAzygy interprets the request.

After its Langley work, WxAnalyst proceeded to obtain additional funding from Goddard Space Flight Center's SBIR program to use WxAzygy with COLLADA, a technology for 3D imaging, and Google Earth. After that, the company further improved its technology with the National Oceanic and Atmospheric Administration (NOAA).



WxAnalyst created a user interface for Google Earth to visualize NASA satellite data. The company then worked with Hawaiian Airlines to show data about the skies (above) to schedule commercial planes more precisely.

Benefits

In 2009, while working with NASA and NOAA, Shipley received a phone call from the dispatch manager at Hawaiian Airlines, Mark Spence. Also owner of a small company called System Operations, Spence explained that Hawaiian was already using Google Earth in their dispatch operations, and that he was interested in what Shipley was doing.

"He said I was doing things that Hawaiian wanted to do in Google Earth," says Shipley. "They were looking at four-dimensional things like volcanic ash plumes and cyclones, and they wanted to know where they were."

Together, Spence and Shipley formed a joint venture company called WxOps. After providing a demonstration of WxAzygy on Google Earth to Hawaiian Airlines, the airline started using the software to help see four-dimensional data in the skies and route its planes accordingly. Now the technology helps the airline manage flights carrying over 6 million passengers a year from Hawaii to the western United States, the South Pacific, Australia, and Asia.

"Their dispatchers are in touch with their pilots all the time, and this system allows them to roll with the punches as conditions change," says Shipley.

Spence says he and his team are able to make better business decisions based on business intelligence, due to real-time data, which also results in increased safety and fuel efficiency. In particular, the technology assists the airline in predicting turbulence, as well seeing where lightning is striking. According to Spence, current weather models correctly predict convection, frontal boundaries, tropical movement, icing, and turbulence approximately 70 percent of the time. Now, he says, "We can combine various data sets to get a better picture."

Hawaiian Airlines is also benefiting by scheduling aircraft more precisely. In the winter of 2012, a storm was predicted to affect a flight from Honolulu to New York. After using WxAzygy, Spence released the flight. "We landed safely five hours after the last snowflake fell, while the other carriers cancelled flights," he says. "It allowed us to operate when we might have been more reluctant, because I would have lacked the necessary business intelligence to make that decision."

In the future, Spence and Shipley predict pilots will be able to use the technology onboard during flight to make decisions about where to go to avoid dangerous situations. Aside from airlines, Shipley is also working with a potential customer who wants to use the technology for radar data on NASA World Wind, a virtual globe system similar to Google Earth. Shipley is also exploring how to use the technology to visualize underground data. "It could be beneficial for geology educators and students, as well as valuable to industries such as mining and fracking," he says.

The biggest challenge Shipley is currently facing is having too much good information. "We have over 50 data layers and it becomes unintelligible. We are trying different things to see what works. If you have 50 layers and point at something, what are you pointing at? Which layer?"

Whether for pilots, students, or scientists, one thing is certain: the technology will continue to inform people in beneficial new ways. In line with Ford's idea, this NASA spinoff will help to keep people young. "NASA sees a lot of value in the dissemination of products using technology like this," says Severance. "It helps people see that computer graphics can be used to gain a better understanding of natural phenomena." ❖

WxAzygy® is a registered trademark of WxAnalyst Ltd.

Data Mining Tools Make Flights Safer, More Efficient

NASA Technology

When an aircraft experiences catastrophic failure, it's not difficult to tell that something has gone wrong. But even if an airplane reaches its destination without an incident, it may still have bent or broken the boundaries of safe operating procedures. Figuring out what those boundaries should be—what "normal" operation should look like—and devising ways of effectively tracking them can be a tough task. Typically, this is accomplished using modeling and real-world tests, followed by equipping vehicles with a variety of sensors so that flight data can be recorded and analyzed.

But an average commercial airplane generates a massive amount of data each flight: everything from instrument positions to sensors to voice recordings are collected and stored for later analysis. With so much data, there is no good way for problems to stand out unless a commercial company already knows what those problems look like. Says Captain Jeff Hamlett, the director of flight safety at Southwest Airlines Co., "We have mounds of data; the big request is always, 'Tell me something I don't know.' We have to start with something specific, like an issue we discovered in a pilot report, and then we can search through the system and discover the breadth and depth of the issue."

Discovering these concerns and addressing them before they cause an accident is also one of NASA's missions. The Aviation Safety Program under the Aeronautics Research Mission Directorate has many initiatives to enable safer air transportation systems. Among them, in the Intelligent Systems Division at Ames Research Center, is a small team of researchers who have been tasked with applying data mining algorithms to aviation safety problems.

Tower controllers test out NASA software tools in a simulation at the Agency's Future Flight Central air traffic control tower simulator at Ames Research Center.

Technology Transfer

NASA has lots of expertise in data mining—that is, creating tools to discover interesting patterns in large data sets. But in order to ensure its techniques can make a real impact on flight safety and efficiency, Ames has sought the help of commercial partners, among them Dallas-based Southwest.

Says Nikunj Oza, a researcher at Ames and leader of the data mining team, "We've made partnerships with Southwest and others, who then make their data accessible to us to facilitate our development. In return, they get certain insights into their data, and they can give us feedback on how well our algorithms are working, as well as what adjustments might make them more accurate or user friendly."

For Hamlett, the value of a NASA-Southwest partnership had become apparent in 2003, when Southwest identified a higher rate of steep approaches in the flight data than was being reported by its pilots. "We turned to our pilot self-reporting program, expecting to find lots of reporting about unstable approaches, but we couldn't match the number that we were seeing in our data," he says.

Hamlett instead tried searching by phrases within pilot reports, using a NASA-developed tool called Perilog. "It turns out that when you read some of the elements of the report," he says, "they are describing an unstable approach—saying things like 'we were struggling to get the airplane configured' or 'we were too fast'—and using all the words that describe an unstable approach, even if they hadn't reported it as such." Southwest used reported information to identify and communicate certain issues

to air traffic controllers, making them aware, for example, of how certain instructions impacted an airplane's operations. By collaborating with them, Southwest has since seen a steady improvement in the quality of approaches.

"That's just one example of how NASA provided us a tool that helped us look at our data in a way we never thought about before," says Hamlett.

Another collaborative effort between Southwest and the Human Factors Division at Ames resulted in an improved, rewritten set of operating procedures for the airline in 2004. Says Hamlett, "They played a big part in making sure that we get a good process for reviewing all of our normal operations." And from that work, Hamlett made the acquaintance of Ashok Srivastava, then head of the data mining team in the Aviation Safety Program at NASA.

Following year-long discussions between Hamlett and Srivastava, in 2011 NASA and Southwest signed a Space Act Agreement to share algorithms and flight data. The arrangement would help the Ames team ensure that their research was suitable for real-world applications, and it would help Southwest to make the most out of its large and growing body of data.

Benefits

As Oza puts it, NASA's algorithms—the two used by Southwest are the Multivariate Time Series (MTS) search and Virtual Sensors—specialize in "letting the data speak for itself by finding unusual flights and candidate anomalies, without having any preconceived notion of what is normal or abnormal. The drawback is that sometimes you find statistical anomalies that are not safety concerns, but the benefit is that sometimes you'll find anomalies that you weren't seeing before that turn out to be safety concerns or have other operational significance, such as excessive fuel use."

One such revelation came when Southwest began tracking planes in an effort to boost fuel efficiency. Says Hamlett, "What we were trying to do was look at the performance of aircraft between certain cities to see if there was a particular plane or city pair that was off normal and causing us to burn too much fuel." What Southwest discovered instead was an unusual signature with one particular plane, which when investigated turned out to be caused by inaccurate sensors. "It wasn't what we set out to do, but it turned into a success for us," says Hamlett.

Like many airlines, Southwest has traditionally looked for performance issues in its data using exceedances checked against a model. During arrival, for instance, the plane might record an exceedance if it is travelling faster than 250 knots while its altitude is less than 10,000 feet. Each morning, the company looks at a report of all the exceedances that took place the previous day and decides what action to take in the case of undesirable trends.

Using NASA's tools, Hamlett says Southwest can now query the data itself to figure out what normal operations really look like. "Just because we expect an airplane to be on speed at 1,000 feet, on glide path, on course, doesn't mean that's what normally happens. I think what we got out of this technology is the ability to ask, 'What is normal?' Because that turns out to be really powerful, and we can say 'OK, we need to make this correction in our training,' or 'Maybe we need to adjust our concept of what the ideal is.'"

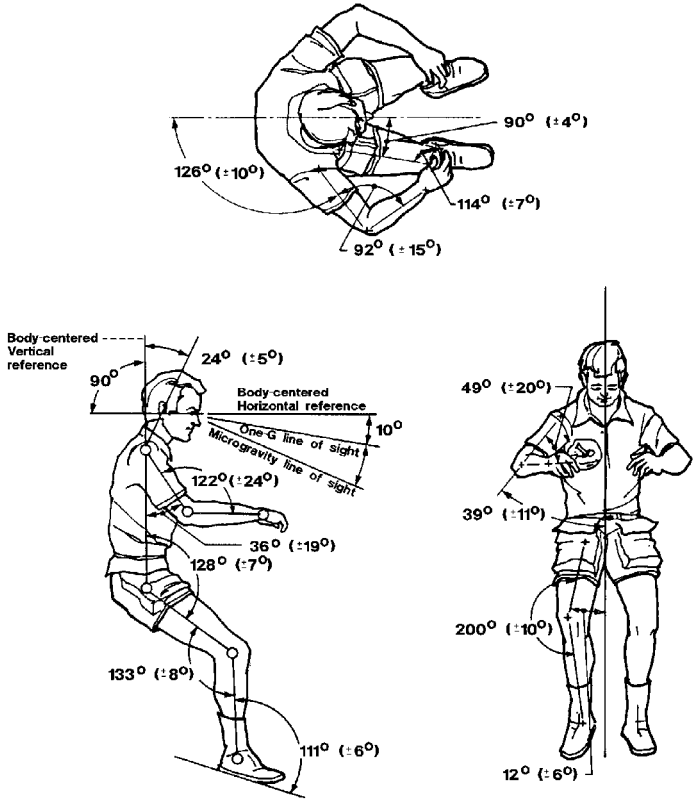
Oza is glad to see that NASA's work is making an impact on commercial flight safety. "If you go into a dark room with a flashlight, your beam only hits a small area, and you don't know what's in the space that's dark. We're essentially going in with a broader beam, if not a floodlight. What you find may or may not turn out to be problematic—but at least you now know what's there." ❖

Using algorithms created by NASA, Southwest Airlines was able to identify areas of concern in certain flight data. By working with its pilots and air traffic control, the company has since seen an increase in the number of stable approaches by its aircraft.

NASA Standards Inform Comfortable Car Seats

NASA Technology

In the beginning, safety trumped comfort in spacecraft designs for human space travel. Mihriban Whitmore, a manager in the Human Research Program at NASA's Johnson Space Center, describes, "Early space capsules like Gemini and Apollo were small in size and had a seat-driven design where most of the flight activities were performed while the crew were strapped to their seats."



The neutral body posture (NBP) shown here was created from measurements of 12 people in the microgravity environment onboard Skylab. In the 1980s, NASA developed special standards, which included NBP, to specify ways to design flight systems that support human health and safety.

The emphasis was on function, not form. In due time, however, the Agency devoted more attention and resources to understanding how a spacecraft could provide comfort as well as safety and function to astronauts. One of the first things NASA examined was the neutral body posture (NBP), or the posture the human body naturally assumes in microgravity.

Whitmore says NBP is important to consider when designing safe, comfortable, and efficient systems and hardware for space. "There was a need for measurable, easily interpretable standards and guidance to help design and develop next-generation human-rated spacecraft," she says.

NASA's first view of NBP came from Skylab, NASA's first space station, where photos of crew members were taken while they physically relaxed in the microgravity conditions of space. These photos demonstrated that the body automatically entered into a particular posture with certain angles made by the joints and certain positions assumed by the limbs.

By the 1980s, NASA had identified and documented the characteristics of NBP in the Man-Systems Integration Standards (MSIS) NASA-STD-3000. The MSIS specified ways to design space flight systems that support human health, safety, and productivity, and it was intended to inform the design of all NASA vehicles and systems with a human crew. Specifically, the Agency used the NBP standard for the design of space workstations and tools.

Since Skylab, NASA has significantly built on its human posture research. For one, a Space Shuttle study demonstrated that there is a range of NBPs for individuals. In another posture study, researchers found the spines of astronauts lengthened in zero gravity on the International Space Station (ISS)—information that has since influenced the size and design of the recently-developed Orion Multi Purpose Crew Vehicle. Lastly, NASA has future plans to perform a new study on the changes that occur to body shape, size, and NBP onboard the ISS.

Even though the original MSIS NASA-STD-3000 has been replaced by the NASA Space Flight Human Systems Standard NASA-STD-3001, all of NASA's work on NBP has governed the development of everything from work areas in the ISS—such as the Cupola—to comfortable new car seats in vehicles here on Earth.

Technology Transfer

In 2005, scientists and engineers at Nissan Motor Company, which has US offices in Franklin, Tennessee, turned to NASA's NBP research as a starting point for the development of a new driver's seat for Nissan vehicles.

Like an astronaut, the driver of a car needs to be safe and comfortable to operate the vehicle efficiently for extended periods of time. Because Nissan had observed that a person's posture appeared to play a direct role in how physically tired he or she became while driving, the company decided to use NASA's NBP as a benchmark for a comfortable, balanced posture, with the intention of lessening fatigue on a person's body.

Akinari Hirao, the manager of the vehicle component engineering development division at Nissan, explains, "Typical customer demand for seats is comfort, especially fatigue-free. This was the motivation for the development."

To decrease driver exhaustion, Nissan aimed to ensure the driver's spine was supported to relax in its natural position, as outlined in NASA's NBP studies. The company thought such a design would successfully minimize the muscular loading on a driver's back, pelvis, and torso. "We hypothesized that a neutral body posture, as measured by NASA in microgravity, seems to be a comfortable posture and we validated it by our experiments," says Hirao.

Benefits

In 2006, Nissan published the results of its first study on its new experimental seat with a two-piece backrest to maintain NBP. The results confirmed that the seat

supported the spine and areas from the pelvis to the chest and improved blood flow. The driver's posture remained near NBP while seated in the experimental seat, and fatigue was substantially reduced during long-term sitting.

The second phase of the company's research, published in 2007, evaluated the prototype seat in dynamic long-term driving conditions on a freeway. The results showed a 50 percent reduction in physical exhaustion during driving, thanks to the new posture, compared to the amount of fatigue experienced in conventional car seats. The authors maintained that the new driving posture supported by the seat was close to the NBP documented by NASA in microgravity conditions.

The new seat design is articulated, which means that it has two sections connected by a flexible joint. "Our seat has no additional mechanical structures compared with a conventional seat. We made it through optimizations of the seat surface shape and deformation properties of the backrest," explains Hirao. "It provides proper continuous supports from the pelvis to the thorax. And, it keeps the spine shape naturally in the sitting posture."

Having had such positive results, the car manufacturer debuted the seat derived from NASA research in the 2013 Altima, and the company now has plans to include it in many upcoming Nissan and Infiniti vehicles. In addition, the technology will be applied not only to the driver's and front passenger's seats but in the rear seats of the vehicles as well.

Nissan believes the seats will make long car rides more pleasant for both drivers and passengers because a person's muscles will work less when sitting in either the six-way adjustable driver seat, the four-way adjustable front passenger seat, or the rear seats.

Hirao says he is thankful for all of NASA's work on NBP. "In my personal opinion, it is very important that the valuable research results from government projects are open to the public. The new seat brings comfort and less fatigue to the occupants in vehicles." ❖

Nissan Motor Company utilized NASA's research on NBP to design new car seats for the 2013 Altima. According to the company's research, the new seats support a posture near NBP, which results in improved blood flow and reduced fatigue for the driver. The company plans to incorporate the seats in many upcoming Nissan and Infiniti vehicles.

Heat Shield Paves the Way for Commercial Space

NASA Technology

Comets are beautiful, and apparently it's a youthful kind of beauty, because they look about the same from the time they were born. Often referred to as dirty snowballs, they're composed of materials—rocks, dust, and frozen gases that emit their famous glow when vaporized by the heat of the sun—that were left over from the solar nebula after the planets were formed. Yet unlike the planets, comets haven't changed much over these billions of years, and for this reason scientists believe they hold clues to the beginnings of the solar system. That was the inspiration behind NASA's decision in the 1990s to send a spacecraft, aptly named Stardust, into the cosmos to retrieve samples of cometary matter for study back on Earth.

But before Stardust could begin its 3.5 billion-mile journey to the comet Wild 2, NASA needed new, innovative technologies to enable the mission. For example, Stardust would be returning to Earth faster than any manmade object before it, plunging into the atmosphere at speeds of 28,600 mph. Heat shields used in previous NASA missions were simply incapable of withstanding the blast of heat Stardust would create upon its return. Agency engineers looked at materials the Department of Defense had developed, but while durable enough they were too heavy.

Then one of the principal investigators for the mission, Ben Clark of Martin Marietta (now Lockheed Martin), found out about the Phenolic-Impregnated Carbon Ablator (PICA). Developed at Ames Research Center in Northern California, the PICA heat shield weighs one-fifth as much as its conventional counterparts and can withstand temperatures up to 5,000 °F. A key to the technology was using a ceramic carbon substrate for structural strength rather than relying on a polymer material to "glue" the material together. This traditional approach of gluing the material together with a polymer was used for the Apollo heat shield as well as those for all of the Mars lander missions up until Curiosity. The benefit of the ceramic substrate as opposed to the polymer is its hardiness—its ability to handle extreme temperatures without charring or melting. It seemed the perfect heat shield to use on Stardust.

Delivered on a shoestring budget in 1998, PICA was then quickly outfitted onto Stardust's Sample Return Capsule, which, if all was successful, would return the cometary matter back to Earth for study. On February 7, 1999, the spacecraft launched into space and began its nearly 5-year odyssey to reach Wild 2. All the Agency could do was anxiously wait. "Because this was a discovery-class mission, we didn't have the luxury of going through a very methodical, full-matrix engineering where you perform all these tests and make sure there's no chance of failure," says NASA engineer Dan Rasky, one of the originators of PICA. "We had to get something done with very modest resources, and on a very tight schedule."

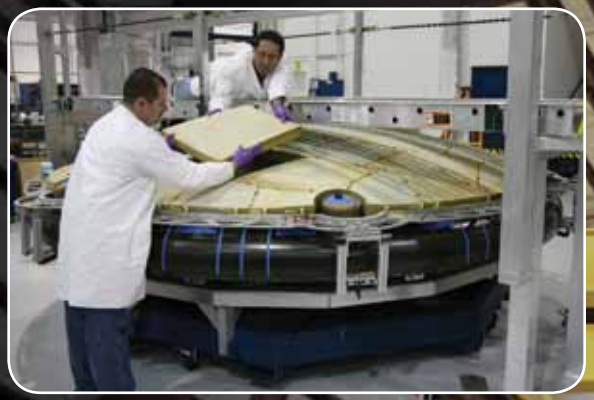
In the early morning of January 15, 2006, 7 years of apprehension would climax in the passage of what Rasky calls a few "white-knuckle" moments that began when the capsule plunged into the Earth's atmosphere. On monitors it appeared as a large shimmering orb, and as it got closer to Earth, a tail, not unlike a comet's, etched a radiant line across the sky. Soon after, its parachute opened, which braced the capsule for a soft, assured landing in Utah's West Desert. "It was a high-wire act all the way," Rasky says, "and everything worked out beautifully."

Technology Transfer

The technology that allowed for the Stardust capsule's safe landing would soon find another home, this time on the privately owned and operated Dragon spacecraft—which would go on to set a number of firsts for the emerging commercial space industry, an industry whose growth the space agency has set out to foster.

In 2002, Elon Musk founded Hawthorne, California-based Space Exploration Technologies Corporation, more popularly known as SpaceX, with the express

Ames Research Center's Arc Jet Complex reproduces heating and pressure conditions similar to the flight environment spacecraft experience during atmospheric reentry. Here the heat shield material that would be used for the Stardust spacecraft is being tested for reliability in those conditions.



The Space Exploration Technologies', or SpaceX, Dragon spacecraft stands inside a processing hangar at Cape Canaveral Air Force Station in Florida. Engineers install PICA-X tiles on the first Dragon flight's heat shield carrier structure (top inset). On December 8, 2010, the company's Falcon 9 rocket propels Dragon into low Earth orbit for its first test flight (center inset), and, after nearly 3 and a half hours in orbit, the capsule is retrieved after a successful splash down into the Pacific ocean 500 miles off the coast of Mexico (bottom inset).

purpose of revolutionizing space transportation, to the point where people could one day live on other planets. A more immediate opportunity presented itself in January 2006 when NASA, in preparation for the retirement of the Space Shuttle Program, put a call out for proposals under its Commercial Orbital Transportation Services (COTS) program, which would contract with companies to develop spacecraft that could deliver cargo to and from the International Space Station (ISS). SpaceX, which had begun developing the Dragon spacecraft a few years before, applied for and won a COTS contract later that year.

Having seen the Stardust capsule's successful reentry, the company was very interested in the choice of PICA as a material for their heat shield. Fortunately, under the provisions of the contract, in addition to financial funding SpaceX also had access to NASA's brain trust of engineers for technical consultation, which the firm made full use of. "The group of people we worked with had basically designed every American heat shield since the Apollo days," says Andrew Chambers, the company's project lead in this arena. "We were able to tap 40–50 years of knowledge and experience, which was absolutely invaluable."

Over the next few years Ames and SpaceX worked closely with one another, and throughout much of 2008 Rasky worked half-time for SpaceX through an Interagency Personnel Assignment agreement. With this particular heat shield, Dragon's designers would have to contend with a challenge that Stardust didn't pose—size. Stardust's Sample Return Capsule only required a PICA shield that was a little over 1 meter in diameter; to protect the much bulkier Dragon a 4-meter version was needed. With the 1-meter shield, Rasky and his team worked with Fiber Materials Incorporated to fabricate a single piece of PICA, but that wouldn't be possible with the larger Dragon cargo transporter. To solve that problem they devised an efficient and cost-effective method for manufacturing smaller PICA tiles, which were then fabricated into a single heat shield.

Another area of synergy was the development of the Mars Curiosity rover, which was of similar diameter and also utilized a large tiled heat shield. Both design teams had to deal with many of the same challenges. While the Mars rover had a head start on production, the Dragon capsule flew first, although too late for any feedback into the Mars capsule that was already en-route. Fortunately, the heat shield worked flawlessly, providing much relief for those on both teams.

In December 2008 the company was ready to qualify their version of the heat shield material. Christened PICA-X, it was successfully tested at Ames' Arc Jet Complex, where it was subjected to temperatures of nearly 3,500 °F, comparable to conditions it would experience upon reentry. Close cooperation with NASA was vital during this test series, as the Agency possesses one of the few facilities in the world that is able to create the sort of heating environment experienced by a spacecraft reentering, but even then it was only possible to test a 4-inch sample. The true challenge came at the end of Dragon's 3-hour test flight on December 8, 2010. From Cape Canaveral, the company's Falcon 9 rocket thrust the spacecraft into low Earth orbit, where it performed several maneuvers. Then it began its descent back to Earth. If things went according to plan, Dragon would securely parachute down into the ocean off the coast of Baja, California. This was another white-knuckle occasion.

"All this theory, all of this analysis, all of the speculation about how PICA would perform on a scale like this, it all came down to this one landing," says Chambers. "You could feel the anticipation."

The final act was over in a matter of minutes, once Dragon pierced the Earth's atmosphere. The spacecraft withstood the extreme temperatures of reentry (which caused the capsule to glow white-hot), then deployed its parachutes and splashed down into the deep-blue waters. After its recovery 20 minutes later, SpaceX became the first private company in history to return a spacecraft successfully from orbit. "It was definitely one of the most exciting moments," Chambers says.

Benefits

Since its landmark reentry back to Earth, the company has hit other milestones. In May 2012 Dragon became the first commercial spacecraft to exchange cargo payloads onboard the ISS. On October 7 of that same year, Dragon performed its first official resupply mission to the ISS, delivering 882 pounds of vehicle hardware, crew supplies, and science-related paraphernalia. It's one of at least 12 such missions the company is carrying out through the Agency's Commercial Resupply Services contracts program.

On August 3, 2012, NASA also announced that, through its Commercial Crew Integrated Capability initiative, SpaceX was one of three companies awarded a contract to develop the next generation of spacecraft capable of sending humans into orbit. The firm had earmarked the Dragon for manned flights from the start, and the additional funding will allow for the development of life support and crew escape systems and onboard controls, all of which are necessary for human transport.

The company's advancements haven't escaped the notice of companies that have satellites operating in low-Earth orbit. The SpaceX Falcon 9 rocket—used to power Dragon—is available for commercial satellite launches. There are 50 launches planned through 2017.

The public-private partnership, says Chambers, has been a successful one. "If we look at the bigger picture than just the heat shield," he says, "we have all these other collaborations with NASA, and it's moving everybody forward. They have a wealth of resources and institutional knowledge, and because we're a small dynamic company we have the ability to execute efficiently."

Rasky from Ames agrees. "I honestly think it serves as a model for the way NASA can work with private industry going forward," he says. "If we work to support deserving commercial space companies, we can both succeed and do more together than we can separately." ❖

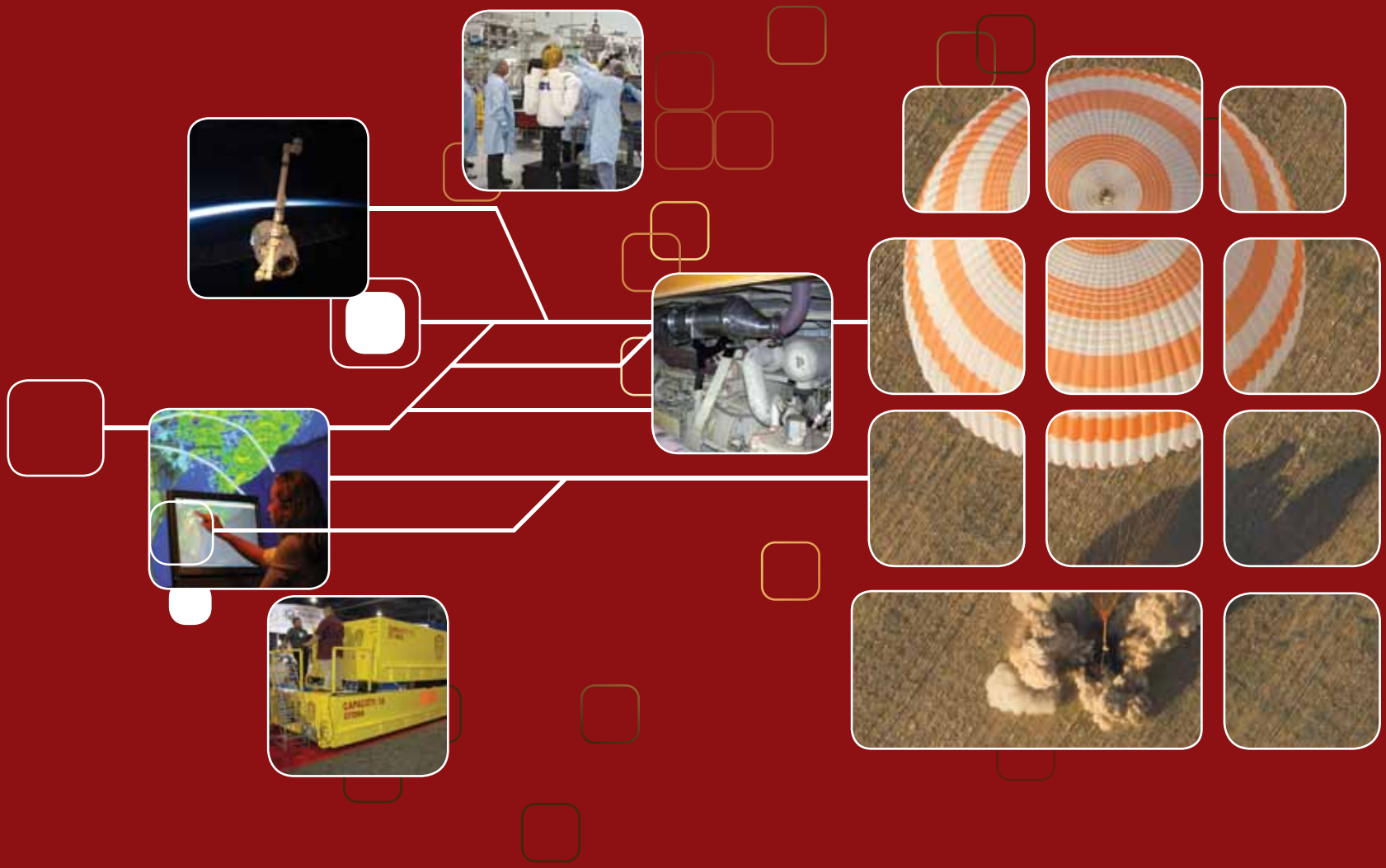
SpaceX became the first **private company** in **history** to **return** a **spacecraft** successfully from **orbit**.

On March 3, 2013 crewmembers aboard the International Space Station snapped a photo of SpaceX's Dragon spacecraft before it docked, delivering 2,300 pounds of cargo to astronauts. The capsule returned to Earth on March 26 with a larger 3,000-pound payload, which included returned science experiments and old equipment.

Public Safety

For NASA missions, safety is of the umost importance for everyone from astronauts in orbit and pilots in the sky to their support staff and engineers on the ground. Many of the Agency's insights into keeping its personnel safe find wider applications in industry, keeping everyone from miners and warehouse workers to airplane passengers protected against potential dangers. Spinoffs featured in this section:

- Provide Life Support to Miners
- Preserve Metal, Stone, Tile, and Concrete
- Spur Software that Lends a Hand
- Connect Emergency Managers
- Maintain Air Quality in Mines



Air Systems Provide Life Support to Miners

NASA Technology

On July 21, 2011, the Space Shuttle Atlantis, having successfully completed a 13-day mission to ferry supplies and spare parts to the International Space Station (ISS), touched down on the Kennedy Space Center's runway for the last time, marking the completion of NASA's 30-year Space Shuttle Program. The Agency has set its sights on new horizons, such as sending humans to Mars and designing other spacecraft to explore the deeper reaches of the solar system. But one agency's shift of focus can be the private sector's gain.

Paragon's seven-person Commercial Crew Transport-Air Revitalization System (CCT-ARS) successfully completed testing for use in space environments.

Before their retirement, the space shuttles, as one of their main functions, transported American astronauts to and from the ISS. In their absence, crewmembers now hitch rides onboard the Russian Soyuz spacecraft. But over the last few years, NASA, in accordance with its goal of promoting commercial space flight, has partnered with several US companies under its Commercial Crew Development (CCDev) program to develop privately operated space vehicles and supporting technologies capable of fulfilling that transport role.

In 2009 NASA began accepting funding proposals for the first phase of its program. One of those companies, Paragon Space Development Corporation, offered to develop a critical piece of life support equipment: a compact air purification system.

For an astronaut, a spaceship's interior is a protective cocoon that provides a breathable atmosphere, but it's a bubble of air that must be constantly purged of impurities. Each NASA shuttle had been equipped with its own air revitalization system whose numerous components were dispersed throughout the vehicle. The company's vision was to combine all of those discrete parts into a single, dependable module that could be installed onto any commercial spacecraft.

Paragon is no stranger to developing life support systems for extreme environments. The Tucson-based firm developed protective, deep-sea diving suits for the US Navy and is working on fabricating next-generation space suits for use in future NASA missions. Coincidentally, at the time company engineers were already developing an air purification system in anticipation of a future boom in commercial space transport.

"The timing was right for us to apply," says Barry Finger, Paragon's director of advanced concepts and business development.

NASA agreed, and in 2010 the two entities entered into a Space Act agreement.

"The NASA partnership with Paragon represented the optimal model of how you would want to stimulate the maturation of commercial space flight technology," says NASA engineer Don Totton, who oversaw the project. "They had a very defined concept that they were trying to develop, which is a short duration environmental control and life support system that could be commercially utilized on different spacecraft in low earth orbital missions as an integrated package."

It didn't take long for results to arrive. Working in consultation with Agency engineers, in 10 months Paragon announced completion of the Commercial Crew Transport-Air Revitalization System (CCT-ARS)—an all-purpose unit containing no fewer than seven life-sustaining components: carbon dioxide removal, trace contaminant removal, air filtration, post-fire atmospheric recovery, cabin air circulation, a dehumidifier, and air temperature control.

Aside from the dehumidifying mechanism, which the company developed into a proprietary technology, Paragon's chief contribution lies in making it possible for a single fan to circulate the air through all those subsystems.

"I would call it a trick," Finger says, "but that's not giving enough credit to the team. A lot of hard engineering was applied to make one fan do all of that."

Yet for all that the CCT-ARS accomplishes, on a typical 60-hour trip to and from the ISS, the only

"The **NASA** partnership with **Paragon** represented the **optimal model** of how you would **want** to **stimulate** the **maturation** of commercial **space** flight **technology**."

—Don Totton, Johnson Space Center

The SpaceX Dragon commercial cargo craft is grappled by the Canadarm2 robotic arm at the International Space Station. For a deeper look into NASA's Commercial Crew Program, scan this code.

> “After an explosion or an accident . . . all he has to do is get in there.”
>
> —Connie Hendren, Mineshield

maintenance required is a simple changing out of the carbon dioxide filters two, maybe three times.

Says Finger, “Other than that, you don’t have to touch the machine at all.”

Technology Transfer

Crewmembers endure a dark and dangerous environment. Clean air, an urgently important resource, must be artificially supplied within a protective chamber. Several days may pass before they return to the safety of the Earth’s surface.

This tableau could very well describe space travel, but there is another extreme circumstance that fits the bill—survival in the wake of a mining disaster.

From toxic fume leaks and gas explosions to flooding and earthquake collapses, mines are susceptible to any number of potentially life-threatening catastrophes. That’s why these deeply burrowed holes in the Earth are required by law to contain what are called refuge alternatives. The steel-clad shelter units are stocked with food, water, first aid kits, communication systems, and a steady supply of clean, temperature-controlled air. Enough provisions are housed in each chamber to sustain a crew for up to 4 days until help arrives.

Not long after Paragon announced completion of the CCT-ARS, made possible by partnering with NASA through a Space Act Agreement, the Mine Safety and Health Administration (MSHA), the federal agency responsible for enforcing health and safety regulations in the mining industry, saw the potential in having such a machine be operational in a refuge alternative. After being

Mineshield’s refuge alternative chambers can be fitted with the CCT-ARS, which simplifies what miners need to do to ensure their safety in an emergency.

contacted by numerous companies that supply refuge alternatives, Paragon—following numerous meetings with MSHA officials, conducting independent research, and touring the Bailey Mine in Pennsylvania—agreed that its air revitalization system had much to offer, not just skyward in Earth’s orbit, but within its hollowed depths as well.

As a result, in March 2012 Paragon partnered with Lancaster, Kentucky-based refuge alternative builder Mineshield LLC, which purchased the licensing rights for 10 years to manufacture the air revitalization unit for its chambers.

Benefits

Recall what Paragon’s Barry Finger said, that, aside from changing out the carbon dioxide filters every so many hours, the machine doesn’t require any tampering or adjusting. That, in a nutshell, is the CCT-ARS’s major contribution to Mineshield’s refuge alternative chamber. And it’s a contribution that cannot be overestimated.

“After an explosion or an accident, it’s a very confusing time for the miners,” says Mineshield CEO Connie Hendren. “With this new module, we have taken any type of decision making away from the man, and all he has to do is get in there.”

This battery-operated unit, capable of operating nonstop for over 4 days, takes care of nearly everything else.

Although still a top-of-the-line product in the refuge alternative market, the company’s older generation system requires more upkeep during an emergency when compared to the CCT-ARS. While its carbon dioxide scrubbers need to be replaced every 12 hours or sooner, the newer system’s more efficient ones only require a changing out once every 24 hours. The older unit’s temperature control system—a traditional fan system that requires manual adjusting—is now automated by means of a liquid cooling unit that maintains the desired temperature. Another automated improvement over the older model is the oxygen distribution subsystem, which is programmed to sustain the optimal ratio of oxygen in the chamber.

The air revitalization system’s trace contaminant removal component is a welcomed addition to the refuge shelter, serving an accessory role to the new major contaminant purge system that miners pass through before entering the living area of the chamber. Although separate from the air revitalization unit, Paragon also

developed that technology. The system works by having miners crawl, or rather squeeze through, inflated air duct barriers produced by the company, DuctSox. The fabric is an air diffuser, which, in this scenario, dispels contaminants from a miner's body. Paragon engineers, by applying computational fluid dynamics, have ensured that enough of a positive pressure is created so that the contaminants are forced out through the front entrance and not entrained into the refuge alternative.

In addition to making the CCT-ARS module function more efficiently, the purge will save companies money in the long run. The older system requires using far more compressed air, which is costly to refill, and also limits the number of miners that can enter the shelter at any given time. Indeed, when all of the technology's efficiencies are taken into account, Mineshield CEO Hendren says that by using its new alternative refuge, mining companies stand to save $30,000 per chamber in maintenance costs.

With the benefits of the new alternative refuge model so clearly defined, the mining community's response shouldn't be surprising.

"I tell you, everybody I've showed it to wants one," says Hendren.

Many companies that bought the old model now want theirs retrofitted with the new technology. Other sectors such as the Department of Homeland Security and the Department of Defense are looking into using the chambers as safe rooms.

The uptick in business has allowed Mineshield to hire at least 30 new employees, and the firm plans to expand operations further in the near future.

And as for Paragon, the company's star continues to rise. In November 2012, the Space Foundation declared the CCT-ARS a Certified Space Technology.

"It's really an exciting time for the company," says Paragon's Finger. "We're seeing a lot of applications for our products, both in space and in other markets." ❖

Coatings Preserve Metal, Stone, Tile, and Concrete

NASA Technology

As numerous achievements have taken place in space over the last 50-plus years, a number of innovations have simultaneously taken place on the ground. For example, Jack Triolo, a senior engineer at NASA's Goddard Space Flight Center, worked with John B. Schutt, a chemist extraordinaire and coatings specialist at Goddard from the 1960s through the 1990s. Schutt spent considerable time experimenting with formulas to create super-durable coatings for spacecraft.

"My job was to fly different coatings in space," says Triolo, "and while some of John's coatings didn't work out so well, some of them were really great."

In particular, one of Schutt's more impressive mixtures was a specific inorganic formula made from potassium silicate and zinc. Not only could the concoction keep corrosion from forming on the steel or metal surfaces it was applied to, but it dried quickly to a hard, durable finish. With just one coat, the technology delivered corrosion resistance and could withstand extremely high temperatures.

"Many chemists were doing something similar at the time, but they approached the combination in different ways," says Triolo.

The magic in Schutt's formula came from having just the right amount of potassium silicate and zinc so that it would chemically combine with metal. "It became electrically conductive," says Triolo. "The zinc was electrically connected through the potassium silicate to the steel or the metal it was protecting."

Though the coating was never used in space, it proved useful here on Earth at Kennedy Space Center, where it protected the launch facilities from degradation due to corrosion from the salty, tropical environment and heat from the fiery rocket launches. But that is not the only place the coating found a home.

Technology Transfer

NASA patented Schutt's formula and then granted a license to a private company, which supplied the technology for use on bridges, pipelines, power stations, and more (*Spinoff* 1984, 1985, and 1990). One of the most memorable applications was on the interior of the Statue of Liberty.

Because the potassium silicate zinc formula provides long-lasting protection with a single application, it has enabled significant material and labor cost savings wherever it is used. In 1995, the innovation was inducted into the Space Technology Hall of Fame.

Meanwhile, Schutt retired from NASA in the 1990s and later began employing his NASA expertise to create new hybrids of the inorganic formulation for Daytona Beach, Florida-based Adsil Corporation.

Jim Gibson, the director of business development at Adsil, says, "We wanted to protect metal from corrosion, and Schutt developed formulas that worked in the real world. They were optimized so they were easy to use and affordable."

Years later, Adsil now holds several patents related to inorganic, siloxane coatings that are being used to protect metal and other types of materials in a variety of environments. Sadly, Schutt passed away in 2011; his formulations, however, continue to bring benefits to businesses and individuals around the globe.

Benefits

Adsil manufactures and markets a family of coating formulations to preserve, prolong, and protect a range of surfaces. Trademarked as MicroGuard, there are products for anti-graffiti; anti-skid; heating, ventilation, and air conditioning (HVAC) and refrigeration applications; corrosion protection; and concrete or tile surface sealing.

As a testament to its value, MicroGuard has been used at hotels, banks, restaurants, schools, spas, retail stores, marinas, amusement parks, museums, power plants, water plants, on outdoor sculptures, and in sports stadiums.

Because MicroGuard can endure extremely high temperatures, the company's first commercial application was on welding tips. "Once it was on the welding tip, the slag from the welding process could be cleaned off easier," says Gibson. "From there, we went to air conditioning units and then to floor tile."

The tile floors of a hospital in Miami, Florida, are shown before and after being coated with Adsil Corporation's MicroGuard Clear Treatment System. According to Adsil, the coating will lessen the maintenance of the floors and improve the floors' appearance. Adsil's coatings are derived from John B. Schutt's work at Goddard Space Flight Center on durable coatings for spacecraft.

MicroGuard has proven particularly valuable for HVAC and refrigeration equipment, not only because it repels dust and dirt and reduces maintenance costs by approximately 13 percent, but because laboratory tests have shown that it completely inhibits the growth of mold, increases the energy efficiency up to 12 percent, and protects against corrosion even in the harshest of environments.

"It stays clean, and the metal can transfer heat without interference from dirt," says Gibson.

Another area where MicroGuard is beneficial is on floors made of grout, concrete, or tile. According to Gibson, the coating will last for years and treated surfaces will not support germs, are resistant to stains, and can be cleaned more easily. Due to benefits such as these, a popular use of MicroGuard has been in public rest stations and in hospital restroom facilities. For the University of Florida, MicroGuard coatings have reduced cleaning costs by 30 percent.

An added benefit of MicroGuard is its resistance to paints and inks. "We don't have a surface that graffiti can bite into. The coating, in essence, is just sitting on the surface. You can wipe graffiti off using a green solvent remover or a pressure washer," says Gibson.

MicroGuard also finds many uses on aluminum, brass, bronze, copper, and stainless-steel alloys to inhibit corrosion. For example, it has been applied on handrails and light poles in public parks in New York as well as in the Cayman Islands, where salty conditions wear away metal.

The coating also provides slip resistance, as has been shown in testing, and has been widely used on the floors of kitchens and medical facilities for such purposes. In fact, MicroGuard was applied to the floors in the water-attraction areas of Walt Disney World in 2011, and on exterior walkways and multiple bathrooms throughout Disney's All-Star Cafe and Disney's Contemporary Resort.

Even though Adsil's coating is not the only solution on the market, Gibson says the MicroGuard formulation stands out from others because of the way the film forms. "The molecules link together like a basket weave," he says. "It forms the film and makes it durable without any holes. It's not a solution that sinks in and dries. It's a film and it lasts a long time."

With 84 installers of MicroGuard across the United States, in Mexico, Asia, Brazil, Columbia, Spain, Canada, and India, Gibson says, "We wouldn't be doing this if it weren't for NASA. There's a total of about 150 people who are making a good living thanks to NASA." ❖

MicroGuard® is a registered trademark of Adsil Corporation.

Robots Spur Software That Lends a Hand

NASA Technology

Robonaut 2 flew aboard Space Shuttle Discovery to the International Space Station (ISS) in early 2011, but its development has been many years in the making. In 1997, Johnson Space Center engineers embarked on a mission to build a robot that could perform the same tasks as humans so it could assist astronauts in space.

In collaboration with the Defense Advanced Research Projects Agency (DARPA), Johnson aimed to build Robonaut 1—a humanoid robot complete with dexterous manipulation, or a capability to use its hands—to work alongside its human counterparts. In order to lend a helping hand, Robonaut needed to be able to use the same tools as astronauts to service space flight hardware, which was designed for human servicing.

Robert Ambrose, an automation and robotics engineer at Johnson, says the majority of research at the time on robotics autonomy (the ability to be self-governing) was focused on mobile robots that could avoid obstacles and drive over rough terrain. "There was a blind spot of sorts concerning manipulation," he says. "What had not yet been addressed was using a robot's arms and hands to interact with the world."

In addition, artificial intelligence—which uses computers to perform tasks that usually require human intelligence—was lacking for robots to be able to respond to unanticipated changes in their environment. This was a particular concern for Robonaut, since there can be delays or even failures in the communication between mission control and the ISS. Without commands, the robot would become useless.

Technology Transfer

In 2001, Johnson started seeking software for Robonaut 1 that could deliver automatic intelligence and learning. In cooperation with DARPA, the Center began working with Vanderbilt University, the University of Massachusetts, the Massachusetts Institute of Technology, and the University of Southern California. "We were looking for some simpler ways to teach robots and let them learn and internalize lessons on their own. We had some interesting approaches that we tested out using Robonaut 1," says Ambrose.

Robonaut 2 is checked before being packaged for launch to the International Space Station. NASA worked with partners to develop the ability for its humanoid robot to reason and interact with objects.

One of the approaches was from Dr. Richard Alan Peters, a professor at Vanderbilt, who was researching how mammals learn in order to write a program for robots to learn. He observed that people use their senses to acquire information about their environment and then take certain actions. He found this process critical to the formation of knowledge in the brain. After identifying some common patterns, he incorporated them into learning algorithms that could be used with a robot.

"We found there might be some really good approaches for teaching robots and letting them learn and develop capabilities on their own, rather than having to hard program everything," says Ambrose.

Previous generations of artificial intelligence required pre- or hard programming of rules in order for the robot to determine how to respond. All of the objects in an environment had to be labeled and classified before the robot could decide how to treat them. Peters aimed for software that could support robot autonomy by enabling it to sense a new object, determine its attributes, and decide how best to handle it.

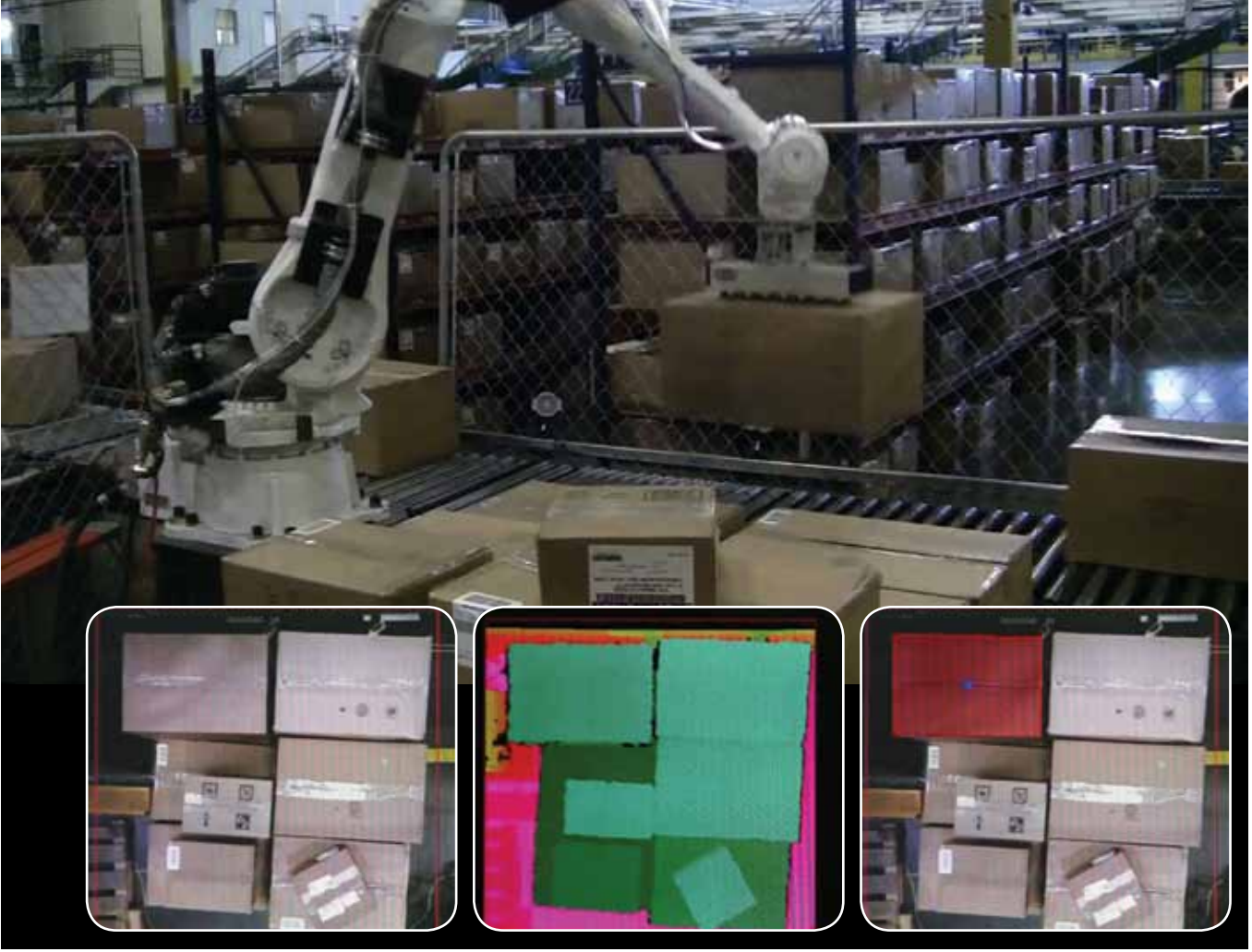
Under a Cooperative Agreement, testing on Robonaut 1 demonstrated Peters' algorithms were able to produce learned knowledge from sensory and motor control interactions—just like mammals, but without having a program written to tell it what to do.

By 2006, the group of partners developed the first robotic assistant prototype, Robonaut 1, and Ambrose says the results significantly informed the mechanical and electrical design of the second generation, or Robonaut 2. "We have several students who came from that collaboration who now work on Robonaut 2. They are doing things we could barely imagine back in the early 2000s. They took it to a new level and gave the robot the ability to reason about how to handle and interact with objects and tools. It is now running on Robonaut 2 in space."

For Peters, the work led to several patents related to robotics intelligence. Now, he serves as the chief technology officer at Universal Robotics, a software engineering company in Nashville, Tennessee, where the NASA-derived technology is available in a product called Neocortex.

Benefits

According to Hob Wubbena, vice president of Universal Robotics, Neocortex mimics the way people learn through the process of acting, sensing, and reacting. Just like the part of the brain that Neocortex is named after, the software provides insight on the data or processes acquired through sensing. This sensing data



This commercial robot is using software developed in partnership with NASA to identify boxes and move them from a pallet to a conveyer belt. The first inset shows the robot camera point of view, the middle inset shows the 3D depth map, and the last inset shows the view when the robot locates its next pick.

is captured through actual sensors in cameras, lasers, or other means.

Because Neocortex requires observation and interaction with the physical world, Universal Robotics created Spatial Vision to provide sight to see its surroundings. From its interactions with what it sees, Neocortex discovers what to do in order to be successful. A third product, Autonomy, is like the muscle control for Neocortex, and provides fast, complex motion for a robot.

According to the company, its ability to allow machines to adapt and react to variables and learn from experiences opens up process improvement opportunities. Neocortex provides a new option in places where automation can impact efficiency and worker safety, such as in warehousing, mining, handling hazardous waste, and vehicle use such as forklifts. The more Neocortex interacts with its environment, the smarter it becomes.

A popular logistics application of Neocortex is for placing, stacking, or removing boxes from pallets or trailers. The system can analyze factors such as shape and orientation to determine the best way to grasp, lift, move, and set down the items, as well as the fastest way to unload, all while compensating for weight, orientation, and even crushed or wet containers.

Wubbena says the product can improve productivity by providing information that an employee cannot necessarily perceive, such as load balancing during the stacking of items in a trailer. Also, because these tasks require repetitive lifting and twisting, the technology from Universal Robotics could help reduce the number of occupational injuries that occur. "Through the intelligence, new areas can be automated which contribute to safety as well as overall process efficiency," says Wubbena.

Working with Fortune 500 companies, Universal Robotics' technology is currently being installed to robotically stack and package frozen meat as well as to provide 3D vision guidance for automatically handling a variety of unusually-shaped bottles. The company has also worked on prototypes for automated random bin picking of metallic objects like automotive parts, as well as deformable objects like bulk rubber.

Not all applications of Universal Robotics' technology, however, employ a robot. For example, the software can help workers make faster decisions by recognizing and reading bar codes on packages and then projecting a number on each box to tell the handler where the package should go. Additionally, Wubbena says Neocortex has been tested for a significantly different application: analyzing electrocardiogram data to see predictive patterns in heart attack victims.

While the innovations from Robonaut 1 are in the process of improving life on the ISS, they are already benefiting life on Earth. "It's really a tribute to NASA that a partnership was created with such a significant impact for the space program as well as business," says Wubbena. "As we continue to help companies improve efficiency, quality and employee safety, we are proud to have worked with NASA to develop technology that helps the US maintain its competitive technical edge." ❖

Cloud-Based Data Sharing Connects Emergency Managers

NASA Technology

In a world that's increasingly interconnected, the effects of even smaller-scale natural disasters or other emergencies are often felt far and wide. Not all volcanic eruptions make the headlines, for example, but many of them create large plumes of smoke and ash that can interrupt commercial activities such as farming or air transport over wide areas. The eruption of Mount Redoubt in Alaska in 2009, though far from the continental United States, still caused the cancellation of over 200 commercial flights, disrupted cargo transport between Asia and North America, and temporarily suspended oil production in the area.

NASA's Earth Observing System (EOS), one of the Science Mission Directorate's core programs, is dedicated to collecting and making available data that among other things can improve preparations for and responses to catastrophic events. EOS currently conducts nearly two dozen Earth-observing missions, collecting continuous streams of data on conditions through the atmosphere from the ground up.

However, having accessible data, while helpful, isn't a panacea. Sharing and manipulating various data sources effectively is a major concern to public authorities, who in emergency situations are increasingly collaborating across agencies and are looking for technologies that enable those conversations.

Experts at Stennis Space Center know the importance of making NASA's valuable data resources usable in real time. "National, state, and local decision-makers need to anticipate, react to, and communicate about natural and manmade disasters, as well as cyber and homeland security events," says Bill Graham, scientist at Stennis and project manager on remote sensing and geographic information systems applications projects. Data collaboration increases the amount of expertise decision-makers can leverage in a given situation, potentially saving resources and even lives.

Software platforms are a primary component of sharing data, and most organizations and agencies currently use one of several proprietary geobrowsers, or software that displays data spatially, especially on maps. The tendency of these organizations is to use whichever program best fits their own in-house needs, not whatever software will best enable cross-agency data sharing. To encourage improved interchanges between organizations, Stennis wanted to facilitate the development of an interoperable data sharing platform.

Astronauts aboard the International Space Station photographed this striking view of Pavlof Volcano in Alaska as it erupted on May 13, 2013, sending an ash cloud more than 20,000 feet into the air. The volcano sits in the Aleutian Arc about 625 miles southwest of Anchorage. StormCenter's collaboration tools are especially suited for tracking the fallout from eruptions like these and managing resources accordingly.

Technology Transfer

Responding to a call from Stennis under the Small Business Innovation Research (SBIR) program, Baltimore-based StormCenter Communications Inc. began work on a software tool that would allow multiple, differing geobrowsers to communicate over the Internet, so that confusion and disruption caused by software incompatibility could be reduced.

"For many decision-makers today," says Dave Jones, founder and CEO of StormCenter, "their state of the art is sharing a link to a map on the web. The leader has to say, 'OK, now click on this button to display this data, click on that button to display that data.' And if you have multiple people on the call, you realize pretty quickly that it's going to get ugly."

StormCenter was a natural partner for Stennis, having previously worked with NASA Headquarters to enhance a geobrowser called the Envirocast Vision Collaboration Module (*Spinoff* 2012), which utilized a Google Earth interface to enable real-time data sharing over the Internet. Under this new partnership, StormCenter began developing an independent platform that could

give a group of users with multiple geobrowsers—including different proprietary software packages—a common interface for sharing and manipulating geospatial data.

Through Phase I and II SBIR contracts, StormCenter developed GeoSync and GeoCollaborate, two secure, 100 percent cloud-based technologies that enable data sharing on a large scale. GeoSync allows users to share data, whether with one person or thousands, by using a single web address and online interface. The leader of the session can display data sets on top of a navigable map while an audience follows in real time. GeoCollaborate adds the ability for participants in the session to "pass the baton around," Jones says, giving everyone with the proper credentials the ability to take the lead and add their own data sets into the mix. In this way, users can actually collaborate in real-time. "This is a very powerful capability with broad decision-making applications," he adds.

Benefits

The biggest value in StormCenter's new software, according to Jones, is its ability to allow different organizations to merge their data sets on GeoCollaborate regardless of what software they use in-house. "What these technologies do," says Jones, "is put everybody in the collaboration session on the same map, at the same time, with the same data. That enables a much greater degree of situational awareness and, ultimately, faster and better informed decision-making."

Because the sessions are cloud based, there is no need to rely on screen-sharing programs or to switch between computers as different people take control of the map. Additionally, the data also doesn't disappear once the leader relinquishes his or her control of the session—a significant problem with previous data-sharing technologies.

Jones says that StormCenter's tools can be applied in any situation where there is a map component to a collaborative decision-making process. In addition to the natural disasters StormCenter has consulted on, the software could potentially be used to track incidence of diseases that occur concurrent with specific environmental conditions, to help assess and build national infrastructure for situational awareness related to emergency response, to plan and execute military operations, to coordinate climate change research and adaptation planning, and more.

A StormCenter employee uses the company's geobrowser to lead a real-time collaboration session sharing geospatial data. The technology was expanded to a cloud-based, interoperable platform under StormCenter's SBIR Phase II contract with Stennis Space Center.

The company is even working to adapt its tools for use in multi-agency collaborative interfaces on space weather. "That's an entirely different effort, but we can share space weather data in the same way," says Jones. "We have the capability to connect NASA, the National Oceanic and Atmospheric Administration, the Department of Defense, and the Federal Aviation Administration for real-time situational awareness on space weather developments."

Volcanic ash monitoring is a disaster management field where StormCenter's innovative, NASA-funded collaboration technologies tools are currently enhancing decision-making capabilities and improving safety. The company is working with the Volcanic Ash Advisory Center in Anchorage, Alaska, to demonstrate how data sharing technologies can better protect the Nation's aviation industry during an eruption and save money by reducing the number of flights that need to be canceled. A recent meeting of the International Volcanic Ash Task Force—composed of the nine countries with volcanic ash advisory centers—resulted in an official document that recognized the importance of real-time collaborative tools: "The United States put forth our technology as one for consideration on global volcanic ash coordination," says Jones.

GeoSync and GeoCollaborate are currently available to commercial organizations and government agencies in need of their capabilities. And in 2013, StormCenter won a $1 million Phase III SBIR contract with the National Oceanic and Atmospheric Administration to continue improving the technology based on the company's work with NASA. "We are excited about the opportunities that are opening up as a result of our technology innovations," says Jones. "I see our NASA partnership as a tremendous success for the SBIR program."

Graham at Stennis agrees: "This is definitely a successful partnership for NASA. StormCenter's technology reduces the risk, cost, and time associated with preparing for and responding to emergencies, bringing a tremendous return to the taxpayers and benefiting society." ❖

Catalytic Converters Maintain Air Quality in Mines

NASA Technology

In the 1980s, Langley Research Center teamed up with the Federal Aviation Administration to develop a technology for the space-based detection of wind shears, which are rapidly changing wind currents occurring during thunderstorms. Downbursts in particular can wreak havoc on airplanes during take-off and descent and have caused several aircraft crashes over the years. One approach NASA tried was based on Lidar technology, which uses pulsed lasers to measure the distances and shapes of objects.

Carbon dioxide (CO_2) lasers were an ideal tool for the job because of their energy efficiency, stability, and relative safety. But during operation, the CO_2 is broken down by the laser into carbon monoxide (CO) and oxygen, leading both to CO_2 depletion and oxygen build-up that can eventually oxidize electrodes, causing arcing and power degradation, which can have disastrous effects on the optics.

To prevent this from happening, the laser can be periodically flushed out, or run "open" with a constant feed of fresh laser gas mix while bleeding spent gas, neither of which are viable options in space-based applications. So NASA conceived of another, more convenient method: a tin oxide-based catalyst applied to a washcoat, which is then deposited with platinum clusters. While the tin oxide gathers oxygen, CO attaches to the platinum and serves as a catalyst, causing the oxygen and CO to combine to form CO_2. In one fell swoop, CO_2 is conserved and the threat of signal degradation, arcing, optics damage, and the necessity of multiple tanks of make-up gas is averted.

This conversion process is similar to how a standard automotive catalytic converter would function, but with a key difference. A gasoline-powered automobile's converter functions best at high temperatures, or when the engine is operating at or near full capacity. It doesn't work well in the minutes after a car is started or when it's running idle. NASA's converter, by contrast, functions at low temperatures due to the special mixture of chemicals contained in the washcoat.

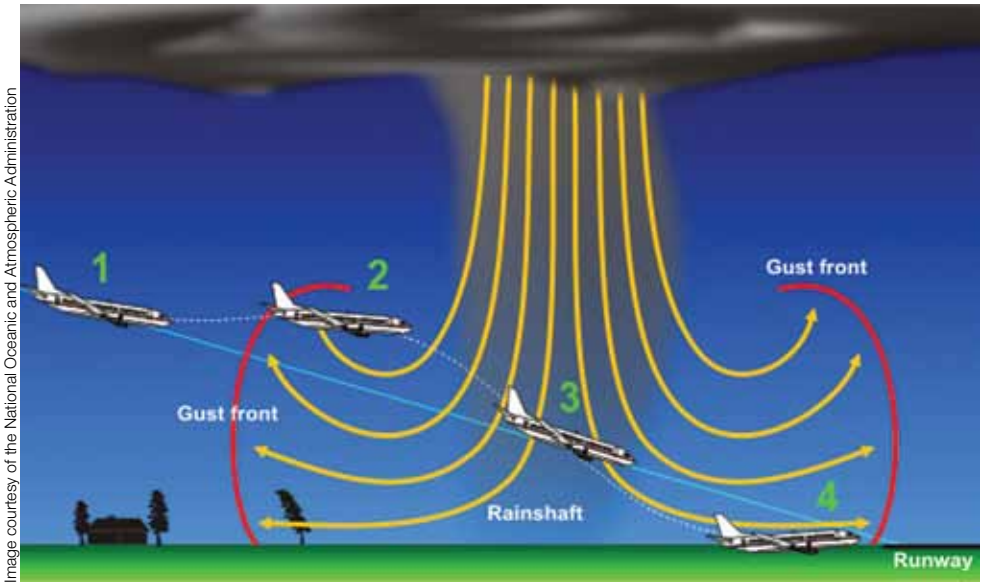


Image courtesy of the National Oceanic and Atmospheric Administration

NASA teamed up with the Federal Aviation Administration in utilizing carbon dioxide lasers for Lidar technology, which planes could use to account for dangerous downbursts of wind that can occur during storms.

Technology Transfer

Zaki Mustafa had worked many years as an executive for Corning Inc., a company that manufactures substrates for catalytic converters. He heard about the NASA-developed catalyst from friends working at Rochester Gas & Electric, which was licensing the technology for another application. After looking into it, Mustafa realized the technology's advantage: Its low-temperature capability meant it had the potential to function right from the moment a vehicle was started all the way to when it was switched off. There wouldn't be a downtime in performance that allowed for toxic gases to escape into the air. "I had a gut feeling that this technology had a lot to offer," he says, "so I went for it."

Soon after he helped found Airflow Catalyst Systems Inc. in Rochester, New York, in 1996. The company licensed the tin oxide-based catalyst technology from Langley in 1997 and started working in collaboration with NASA to adapt the technology for commercialization.

Changes were made to prime the technology for use in exhaust systems. Unlike the CO_2 laser NASA contended with, exhaust systems, in addition to CO, also release hydrocarbons from evaporated, unburned fuel, as well as oxides of nitrogen, which contribute to smog and acid rain. For that reason, automobiles typically have what are called three-way catalytic converters. The tin oxide-based catalyst was transformed into a three-way converter, first by adding certain rare metals to the washcoat, which catalyzed the reduction of nitrogen oxide into nitrogen and oxygen. As for the hydrocarbon, because it undergoes the same oxidation as CO and is converted to CO_2 and water, only minor tweaking was needed to the existing technology.

Following these improvements, NASA and the company worked together to stabilize the converter's performance at higher temperatures; the special washcoat

Airflow Catalyst Systems' EZ-series of converters, derived from technology developed and licensed by NASA, are used in the exhaust systems of underground diesel mining equipment to purge the air of potentially dangerous fumes. An EZ converter is installed for such an application (inset image).

that had allowed it to function at low temperatures didn't hold up as well when exposed to the piping hot conditions of full-capacity internal combustion engines. By adding various lanthanide metals, says Langley engineer Neal Watkins, "We managed to keep it working for 25,000 miles, which is on the order of where you need to be for an after-market catalytic converter."

In 2004, Mustafa reached a fork in the road: He could either attempt to enter the automotive market, which was saturated with large, established companies, or he could offer a new product for an industry ripe for innovation. He decided on the second approach and aimed to introduce the technology for use in off-highway diesel equipment. The goal was to replace high-maintenance archaic active paper filter devices with fully regenerative passive systems requiring practically no maintenance.

In 2010, after years of additional development, Airflow Catalyst Systems began selling its EZ-series passive filters—available in the EZCat, MinNoCat, and EZDOC models—for diesel-operated machinery, namely those used in the mining industry.

Benefits

The EZ-series filter is an entirely new technology for the mining sector, where safety regulations have become more stringent in recent years in recognition of the dangers in that environment. For example, the buildup of CO—a colorless, odorless, and tasteless gas that is toxic to humans—can be deadly and tends to happen especially in the wake of a disaster. The farther down a mine one goes, the more dangerous such a threat becomes.

"The deeper you go underground, the more difficult it is to circulate ventilation air through the mine," says Gary Robb, the company's director of development. "As much as possible, you need to reduce any form of pollutant directly at the source." That's where the NASA-derived three-way washcoat comes into play. It neutralizes CO, hydrocarbons, oxides of nitrogen, and particulate matter emissions (the toxic, black smoke that puffs out of trucks) from any diesel-operated equipment, such as scoops and roof bolters. EZ-series filters remove more of these toxins than the mechanical filters they replace, and they require much less maintenance.

"Those mechanical filters, which only remove particulate matter, may have to be replaced during the course of a work day," Mustafa says. "That can be costly and labor intensive." But because the EZ-series converts particulate matter into harmless gases, there is no buildup of residue, and therefore no filter replacements are needed. Says Mustafa, "The operator should never have to touch our system on a daily basis." In fact, EZ-series converters are projected to last for at least 7,000 hours, with appropriate duty cycles. The first products, which were sold in 2010, are still functioning and have yet to accumulate that much operating time.

Since the company started selling the filters, the response from industry has been strong, with business picking up every year. "Our reputation with customers is solid," says Umbereen Mustafa, the company's business manager, "and it's not just from a product standpoint, but also in terms of our customer service."

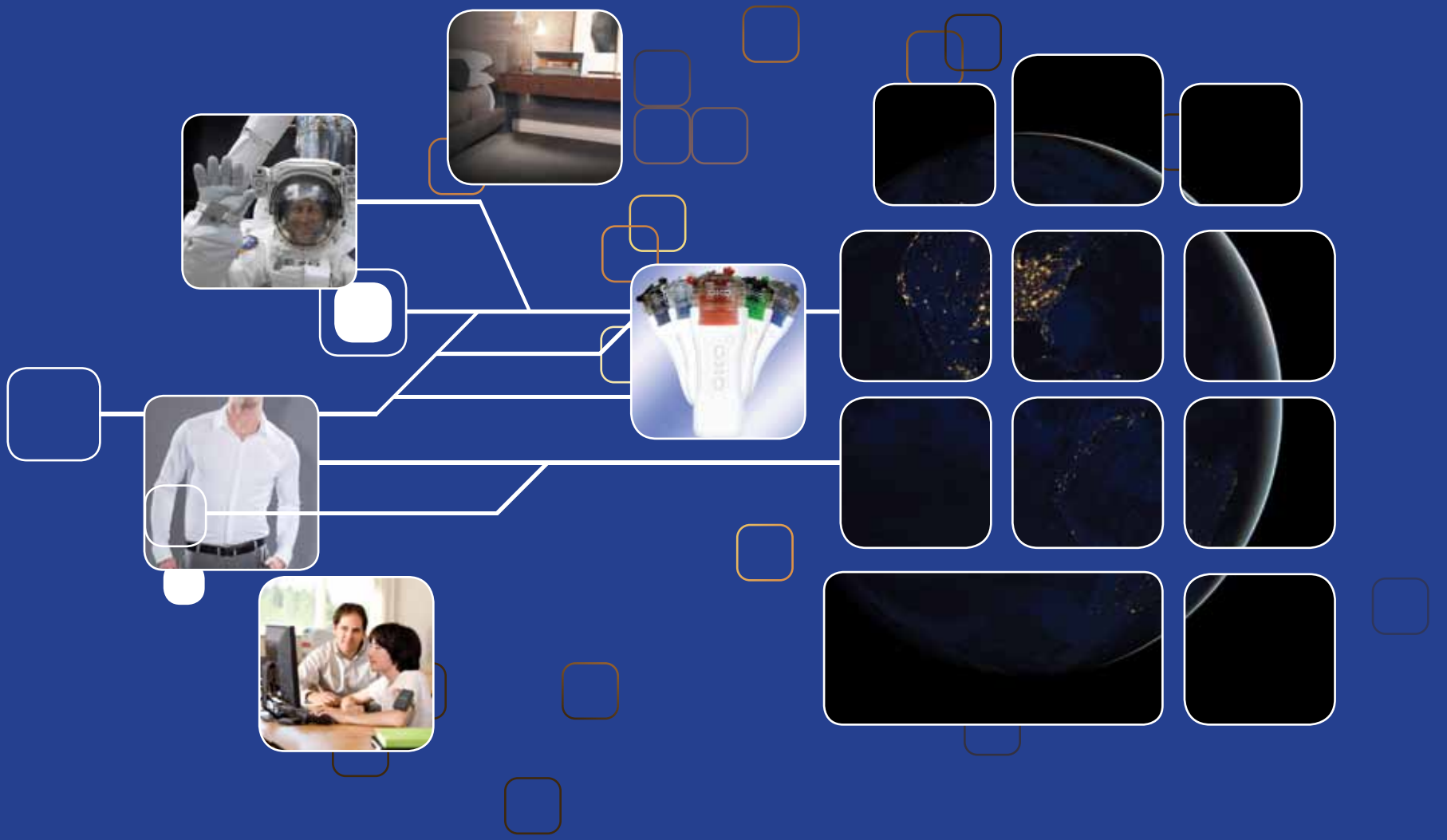
In addition, the Mine Safety and Health Administration, the federal agency that oversees mining regulations, commended Airflow Catalyst Systems for introducing to the industry the first substantial technology advancement of its kind in the last two decades.

For Mustafa, the long research and development phase that paved the way for the EZ-series was worth the wait. "With this NASA technology, we developed a product and we've found ourselves a niche that has set us up for success," he says. ❖

Consumer Goods

There's more space in your life than you think—especially in your home and among the products you use every day. NASA technologies often find their way into consumer applications, enhancing educational software, keeping those wearing business attire cool, and providing clean drinking water for weekend campers and adventurers. Spinoffs featured in this section:

- Filter Water on the Go
- Improve Distracted Minds
- Protect Priceless, Personal Keepsakes
- Eradicate Harmful Pathogens
- Drive a Professional Apparel Line
- Save Energy in Buildings



NASA-Enhanced Water Bottles Filter Water on the Go

NASA Technology

Thanks to NASA science missions, researchers are finding that water may be more plentiful in space than we previously believed. The Lunar Crater Observation and Sensing Satellite mission confirmed the presence of water on the Moon, and the Mars Reconnaissance Orbiter has returned images suggesting the flow of briny water in parts of the Martian landscape. Now that the Curiosity rover has landed on the Red Planet, it will search for the presence of water beneath the rust-colored soil.

Even so, space is practically a desert, where every drop of water is precious for the human explorers who brave that harsh environment. Complex systems onboard the International Space Station (ISS) collect and recycle moisture using powerful filtration technology developed by NASA and its partners—technology that transforms even urine and sweat into potable water for the ISS crewmembers. These systems are a model for those needed to make trips to distant destinations like Mars.

Even travelers here on Earth are benefiting from one such NASA-derived filtration innovation—part of a product that conveniently provides pure water for everyone from the international adventurer to the weekend warrior.

Technology Transfer

Mohssen Ghiassi, an entrepreneur with more than 30 years of experience developing products for the travel industry, was seeking technology that would enable his latest idea: a water bottle that would utilize an advanced filtration system, one that could be taken around the world, designed specifically for travelers. In selecting an effective filtration media, Ghiassi ran up against the problem of flow rate; water passed through the filter too slowly to provide convenient purification for consumers on the go. Soon, however, Ghiassi's research led him to a NASA-derived solution—NanoCeram.

NanoCeram originated at Sanford, Florida-based Argonide Corporation. In 2000, the company partnered with Johnson Space Center through the Small Business Innovation Research (SBIR) program, with the goal of advancing the company's unique filtration media for

Water filtration technology designed for use in space is now in the hands of athletes and travelers on Earth.

> “The materials that have been created for specific use by NASA are state of the art because of the extreme conditions they are subjected to. . . . They are superior to anything else out there.”
>
> —Mohssen Ghiassi, ÖKO

use in recycling water in space. With NASA support, Argonide developed the NanoCeram water purification technology, an innovation that won an R&D 100 Award and a place in the Space Foundation’s Space Technology Hall of Fame.

In 2006, Argonide exclusively licensed the filtration media to Ahlstrom Corporation, an international manufacturer that began mass producing the media for applications in countries around the world. Through Ahlstrom, Ghiassi found the key to his new product.

“We started purchasing from Ahlstrom and developing our product around this particular material because it really is the heart of the product,” says Ghiassi. He founded ÖKO, headquartered in Greenbrae, California, to market his spinoff technology.

Benefits

The ÖKO water bottle employs two filters: a carbon filter and the NASA-derived media. The bottle itself is made of a thin-walled version of a material similar to that used in most food containers. By simply squeezing the bottle, the consumer forces water through the two-level filter system, resulting in instant purified water.

ÖKO’s NASA-enhanced water bottle is rated effective in more than 120 countries.

Ghiassi notes the ÖKO bottle’s NASA-enhanced filtration eliminates multiple contaminates, including disease-causing microbes such as cryptosporidium and *E. coli*.

The Ahlstrom material, he says, activates when in contact with water, creating an electro-adsorptive charge field that, in addition to the media’s two-micron-wide pores, traps particles as the water is forced through. In a layer less than a millimeter thick, a bacterium would have to navigate through about 400 pores—called the “tortuous path”— while eluding silver ions in the media that kill microbes.

Ghiassi makes it clear that, while the ÖKO bottle is broadly effective, it is not universally so—environmental conditions play a major role. “You can say a product is going to remove 99.99 percent of this or that, but what is the saturation of that contaminate in the water? What is the ambient temperature? What is the pressure you are applying to the bottle? All of those factors are unknowns,” Ghiassi explains.

Drawing on sources such as the United Nations and the UNICEF World Health Program Organization, ÖKO provides its customers with information on the effectiveness of its water bottle in various areas of the globe. This information allows travelers to assess when their ÖKO bottles provide sufficient purification and when additional measures may be needed. The bottle is currently rated effective in more than 120 countries.

Ghiassi says that the ÖKO water bottle is experiencing demand outside of the travel industry. Consumers are buying the product for camping, sports, biking, and for children to use at school. ÖKO has other innovations in the pipeline, including a campground unit that can also be filled from a lake or stream, and a flashlight attachment that converts the water bottle into a nightlight. The filtration material developed through the NASA partnership is the core enabler of all of these products.

“The materials that have been created for specific use by NASA are state of the art because of the extreme conditions they are subjected to when they come into use by NASA,” says Ghiassi. “They are superior to anything else out there.” ❖

NanoCeram® is a registered trademark of Argonide Corporation.

Brainwave Monitoring Software Improves Distracted Minds

NASA Technology

Imagine moving an object using only your mind. Software company Unique Logic's Time on Task exercise makes that feat possible, at least on a computer screen. The game, which is designed to teach people how to sustain their attention in order to complete tasks, involves getting a forklift operator to transport a stack of crates from the ground onto the back of a big rig. It doesn't seem like a particularly interesting plot, except for the fact that, instead of using a remote control to dictate the action, you're using your concentration—measured by sensors that detect patterns of brainwave activity—to induce the operator to complete the job.

The inspiration for this attention-training game, one of many specialized software programs available under the company's Play Attention educational product line, began with NASA Langley Research Center scientist Alan Pope's research in the late 1980s on pilots and automated flight systems. Pope wanted to evaluate what degree of automation on flight decks was most beneficial. "Automation tends to free a person up to become bored and disengaged," he says. "Our purpose was to figure out when automation goes too far, based on brainwave activity."

To do this, Pope had pilots operate flight simulators that were installed on desktop computers. As they worked the controls, electrodes placed on their scalps gathered electroencephalographic (EEG) measurements, or neurofeedback, derived from electrical currents caused by neurons firing in the brain. The desktop simulator was programmed to react to the readings so that when a pilot was engaged, the degree of automation increased; a less engaged pilot prompted the simulator to increase manual controls. The experiment was the first example of what is now known as a biocybernetic loop system, which uses neurofeedback to influence the outcome of a computer program.

The methodology behind the experiment rests on the fact that electrical currents oscillate at various coexisting frequencies, with one frequency always being the strongest depending on a person's state of consciousness. When a person is sleeping, delta waves—the slowest of all frequencies—are dominant. Theta waves, which are a little faster, are indicative of daydreaming. Alpha waves prevail in a relaxed and unengaged person. Beta waves, with the fastest frequency, correlate with a brain that is actively engaged in a demanding task. So the experiment, in essence, matched each pilot up with a degree of automation that induced those concentration-maximizing beta waves.

Technology Transfer

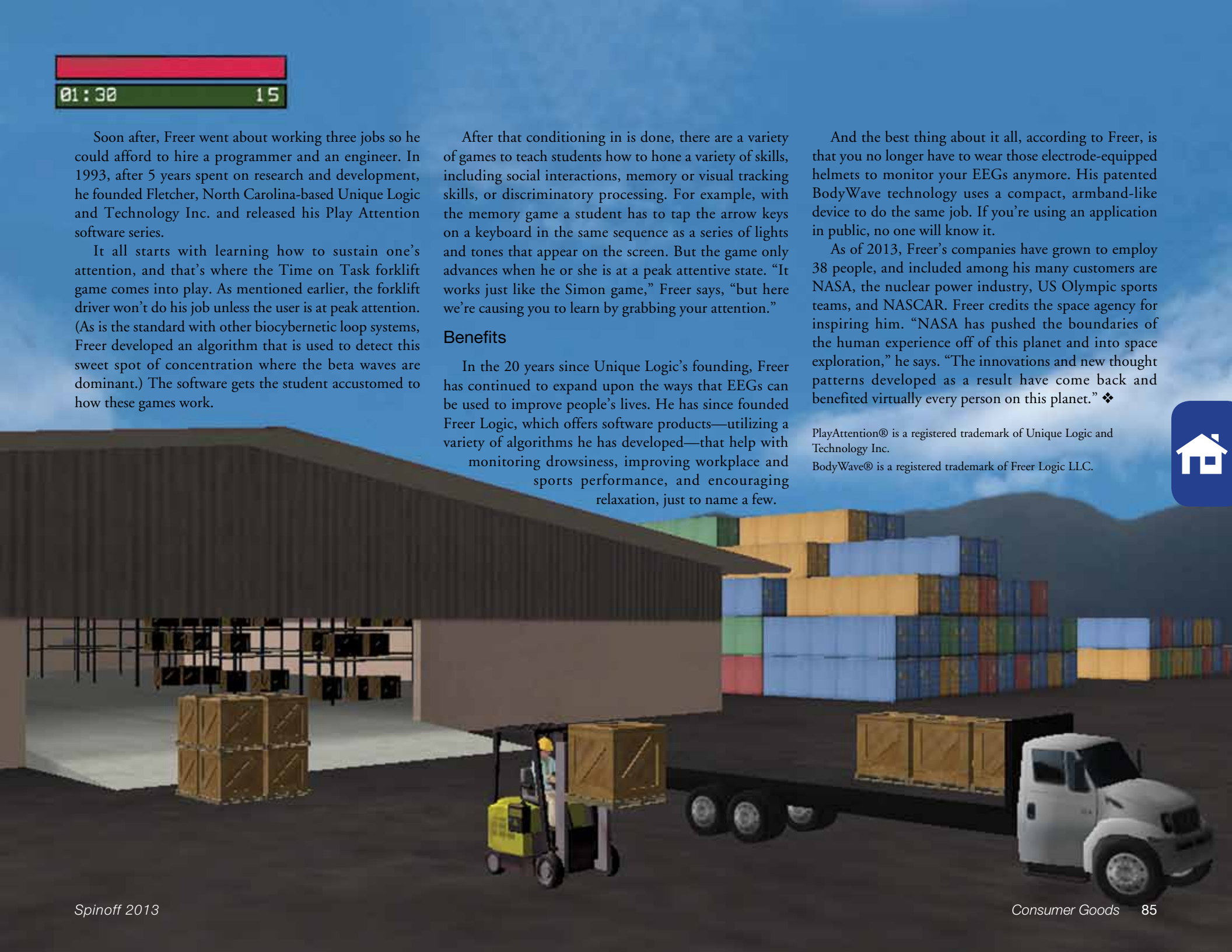
At around the same time as Pope's pilot experiment, Peter Freer was teaching math and science, mostly to sixth graders. He found the job challenging for one important reason: Some of the kids, no matter the degree of stimulation, had a hard time staying focused. Freer, who had earned a master's degree in education, pursued all the traditional tactics to reel them in: pull students closer to his desk so he has proximity control, start a reward program, give immediate feedback. None were very successful.

But something else also caught his attention. Whenever he would notice a student daydreaming, during breaks he'd ask him or her what was going on in class. He says that the answers he got were "phenomenal." They could tell him about what the bird was doing outside the window on a tree limb. They could point out little details, like the cobwebs in the corner of the room, or they had figured out when the air conditioner would turn on and off. They could even home in on what people nearby were whispering. And then maybe they could mention a little bit about the day's lesson.

This led Freer to the conclusion that people, on the whole, didn't have a lack of attention; rather, their attention was simply diffused or scattered. "The issue is the brain's inability to direct and sustain its attention at will," he says. "It's like taking a flashlight into a dark cave, and instead of looking at where you're going, you're just shining it all over the cave."

Unique Logic's BodyWave technology (above) allows users to wear armbands instead of helmets to measure brainwave activity. In the Time on Task game (opposite), a user must focus his or her attention in order to move a stack of crates from the ground to the back of a big rig.

Then he started reading about Pope's research using a biocybernetic loop system. He got to thinking that if EEG measurements could help pilots operate at what he calls their "peak attentive state," in which beta waves are the dominant frequency, then there wasn't any reason why he couldn't develop a similar software for helping students learn more effectively. "If I could take that technology, make it very simple to use, and then allow people to learn the skill sets that they drastically need—desperately need—then I would really have something."



Soon after, Freer went about working three jobs so he could afford to hire a programmer and an engineer. In 1993, after 5 years spent on research and development, he founded Fletcher, North Carolina-based Unique Logic and Technology Inc. and released his Play Attention software series.

It all starts with learning how to sustain one's attention, and that's where the Time on Task forklift game comes into play. As mentioned earlier, the forklift driver won't do his job unless the user is at peak attention. (As is the standard with other biocybernetic loop systems, Freer developed an algorithm that is used to detect this sweet spot of concentration where the beta waves are dominant.) The software gets the student accustomed to how these games work.

After that conditioning in is done, there are a variety of games to teach students how to hone a variety of skills, including social interactions, memory or visual tracking skills, or discriminatory processing. For example, with the memory game a student has to tap the arrow keys on a keyboard in the same sequence as a series of lights and tones that appear on the screen. But the game only advances when he or she is at a peak attentive state. "It works just like the Simon game," Freer says, "but here we're causing you to learn by grabbing your attention."

Benefits

In the 20 years since Unique Logic's founding, Freer has continued to expand upon the ways that EEGs can be used to improve people's lives. He has since founded Freer Logic, which offers software products—utilizing a variety of algorithms he has developed—that help with monitoring drowsiness, improving workplace and sports performance, and encouraging relaxation, just to name a few.

And the best thing about it all, according to Freer, is that you no longer have to wear those electrode-equipped helmets to monitor your EEGs anymore. His patented BodyWave technology uses a compact, armband-like device to do the same job. If you're using an application in public, no one will know it.

As of 2013, Freer's companies have grown to employ 38 people, and included among his many customers are NASA, the nuclear power industry, US Olympic sports teams, and NASCAR. Freer credits the space agency for inspiring him. "NASA has pushed the boundaries of the human experience off of this planet and into space exploration," he says. "The innovations and new thought patterns developed as a result have come back and benefited virtually every person on this planet." ❖

Thermal Materials Protect Priceless, Personal Keepsakes

NASA Technology

Most of us cannot comprehend the task of building something to withstand temperatures over 4,000 °F—but NASA can. The space shuttles endured such temperatures when returning to Earth's atmosphere because of aerodynamic heating, or heating due to the combination of compression and surface friction from Earth's atmosphere. For the vehicle to survive these fiery conditions, NASA scientists and engineers constructed a complex thermal protection system, or TPS, for the exterior of the shuttle.

The TPS consisted of various materials to radiate surface heat and inhibit any trace of heat from seeping inside the vehicle. The type of material used for the TPS depended on where it was placed. For example, reinforced carbon-carbon was used on the shuttle's spots that got the hottest, such as on the wing leading edges and nose cap; felt reusable surface insulation protected the areas where temperatures would remain below 700 °F.

Over the decades, the TPS proved to be extremely successful and withstood the harshest tests of temperature. Following the Space Shuttle Columbia accident in 2003, however, NASA began developing materials and techniques for the inspection and repair of the TPS, should it be damaged during flight. Dr. Scott Parazynski, a five-time NASA astronaut, was designated the Astronaut Office lead for space shuttle TPS inspection and repair.

"We figured out different inspection procedures to make sure nothing happened to the TPS," says Parazynski. "If it did, we had a series of repairs based on where the damage was located. We developed a suite of different tools and materials, and we developed confidence in them based on different test environments."

For the remainder of the Space Shuttle Program, astronauts had various methods available for repair of the TPS while in orbit, if they were ever needed.

Crewmembers on the International Space Station captured this image of the Space Shuttle Endeavour while checking the condition of the shuttle's exterior thermal protection system (TPS).

Technology Transfer

In 2009 Parazynski retired from NASA and met an entrepreneur with a hot idea for a NASA spinoff product incorporating concepts from the shuttle's TPS inspection and repair. Christopher Shiver wanted to build an enclosure to protect priceless and irreplaceable personal items like keepsakes and photos in the event of a fire or flood. Years before, a flood inundated his own home, and while Shiver's pictures and heirlooms remained safe, he wanted to ensure they would never be at risk again.

"When I dreamed of my new product, I knew there were people, materials, and designs at NASA that could help," says Shiver.

After meeting Parazynski, Shiver shared his ideas about a fire-, heat-, and water-proof enclosure to protect priceless personal belongings. Parazynski then contacted other experts on heat transfer prevention materials, and by 2011 Shiver and Parazynski collaborated with Clark Thompson, an engineer who had worked with Parazynski at NASA. The three agreed to partner as co-owners of a company that Shiver founded just years before: Houston-based DreamSaver Enterprises LLC.

Parazynski says he and Clark borrowed some general concepts from their work in the space program and



DreamSaver's Home Protection System was constructed with knowledge from a NASA astronaut and engineer who helped to develop the repair techniques for the Space Shuttles' TPS. In the images above, the box is shown before and after a 15-minute burn test at 3,400 °F.

> "DreamSaver shows that NASA engineers are excellent problem solvers."
>
> —Tim Budzik, Houston Technology Center

leveraged them for a commercial product. "We worked intently for 2–3 years after the Columbia accident to figure out ways to safely access and repair a damaged orbiter in space. The materials, general heat transfer background, and knowledge of different types of test environments fit nicely into the DreamSaver vision of using advanced materials for important purposes," he says.

The trio approached the Houston Technology Center (HTC), an organization that supports emerging technology companies in the Houston area, and DreamSaver was soon accepted into the HTC/Johnson Space Center Incubator Partnership Program. This new program aims to increase collaboration between public and private entities and find areas of common interest to foster new technologies.

DreamSaver became the first company in the Incubator Program, and soon graduated to the HTC Acceleration Program and became a resident of the HTC/Johnson campus, part of the Johnson Acceleration Center. This is an additional HTC/Johnson collaboration to enhance partnerships and spur technology development by providing office space at Johnson.

According to Tim Budzik, managing director of the HTC/Johnson Partnership, "DreamSaver shows that NASA engineers are excellent problem solvers. After the Columbia accident, Scott [Parazynski] gained experience with the methodology that NASA uses to come up with solutions. He took that same technique and applied it to something right here at home."

Benefits

DreamSaver's Home Protection System, available for purchase online, is a footlocker-sized box with lightweight, low cost, industry leading thermal protection. It's sealable and waterproof, made from the insulation technology developed by DreamSaver, and has been tested to 3,400 °F. According to the company, the product can withstand 98 percent of residential fires and 99 percent of water disasters.

As Shiver describes, the product is significantly different from a fireproof safe, which can get up to 300–400 °F inside, is made out of concrete and metal, and is relatively small. DreamSaver's product is bigger, lighter, lower cost, and with higher thermal properties. "We stop the transfer of heat long enough for the fire to burn out or to be extinguished," he says. "You can store 10 or 15 picture albums, scrapbooks, grandmother's wedding dress, videos, or your children's artwork inside of it."

The company plans to make the product in the United States and can create custom coverings for the box to match the décor in a room or to fit individual preferences. Possible options include everything from cedar to floral prints to the colors of a favorite sports team. The company is also considering a cushion for the top of the box so it can function like a bench. "At its core, it is highly functional, but on the outside, we can customize it," says Shiver.

The Home Protection System is just the beginning for DreamSaver, says Shiver. Ultimately, the company plans to offer multiple sizes of the product with various functions and features, such as a GPS chip on the inside. "The Home Protection System is just product number one," he says. "We see custom solutions, applications, and markets in multiple industries related to heat and fire problems."

Few of us can comprehend the pain of losing our priceless and irreplaceable personal keepsakes in a fire or flood. DreamSaver makes sure we will never have to—thanks to an innovative NASA-derived technology.

"Without a doubt, DreamSaver would not be in business if not for the HTC/Johnson Accelerator partnership," says Shiver. "NASA is the key aspect of making it happen." ❖

Home Air Purifiers Eradicate Harmful Pathogens

NASA Technology

In the 1990s, NASA scientists were thinking of what astronauts would need to survive long-term missions to the moon and even to other planets in the solar system. One important requirement was a dependable source of food, which could be accomplished by astronauts growing their own produce in space-age greenhouses. But cultivating crops in a sealed-off environment results in the buildup of an undesirable gas called ethylene. Plants release the odorless, colorless fume into the air, which has the unfortunate effect of accelerating decay, hastening the wilting of flowers and the ripening of fruits and vegetables.

Mizuna lettuce growing aboard the International Space Station before being harvested and frozen for return to Earth. NASA funded the development of Ethylene scrubbers to remove the plant-produced gas from the air, which help to keep vegetables fresh in space.

To address the problem, the Marshall Space Flight Center's Space Product Development Program funded the Wisconsin Center for Space Automation and Robotics, located at the University of Wisconsin–Madison, to develop plant growth chambers that included an ethylene reduction device. In this device, called a "scrubber," air is drawn into tubes coated with thin layers of titanium dioxide (TiO2). When an ultraviolet (UV) light source located in the tubes strikes the TiO2, the ethylene gets converted to water and carbon dioxide, both of which are beneficial for plants.

The ethylene scrubber was first used in 1995 aboard Space Shuttle Columbia mission STS-73, where it successfully preserved a crop of potato seedlings. Updated versions of the device were subsequently flown on several missions to the International Space Station.

Technology Transfer

While NASA's main objective in developing the technology was to get rid of ethylene, the scrubbers were capable of purging all kinds of unwanted organic particles from the air. Recognizing its powerful air purification abilities, KES Science & Technology, based out of Kennesaw, Georgia, licensed the technology from the University of Wisconsin (*Spinoff* 2001 and 2002). The company then partnered with Jacksonville, Florida-based Akida Holdings, which marketed the technology as Airocide (*Spinoff* 2009).

In 2013, Airocide finally found its way into people's homes when Akida Holdings adapted the technology for home use by developing an eye-catching portable unit with enough power to purge an entire room of pathogens.

The home Airocide unit made its public debut with an appearance on the *Ellen Degeneres Show*, immediately generating a great deal of attention for it. "It was a lot of fun putting that together and it was also great publicity for our product," said Barney Freedman, who is vice president at Akida Holdings.

Benefits

According to the company, Airocide is the only air purifier that completely destroys airborne bacteria, mold, fungi, mycotoxins, viruses, volatile organic compounds, and odors. And because of the technology's versatility, the product is now used in a variety of settings. Grocery stores and produce distribution facilities now use it, in addition to a host of wineries, distilleries, and floral businesses. The device has also found its way into refrigerators that are used for both homes and for distributing food aid to remote towns. In hospitals and clinics, Airocide's powerful germ-killing properties are on full display as it purges the air of harmful bacteria like methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Enterococcus*.

The home Airocide unit has a sleek, glossy, rectangular body accented with orange-peel-colored inside walls. The product, which can either be mounted on a floor stand or hung on a wall, could easily pass for a modern work of art. But, beyond its aesthetics, according to Freedman, the product will change consumers' quality of life. "You're going to sleep better, and you're going to feel better," he says.

> "In two days, you'll notice how the bedroom just feels different. And as you get the chance to breathe in the air, you'll start feeling better physically. You're going to wake up feeling refreshed."
>
> —Barney Freedman, Akida Holdings

Freedman notes that Airocide works differently from High-Efficiency Particulate Air (HEPA) filters, which are designed to capture particles that are 0.3 microns across and larger. If the strings on a tennis racquet represent the best of these filters, he says, and marbles represent dirt particles, the racquet's ability to capture them is how the filter collects dust. But if your aim were to capture particles smaller than dust—like viruses, bacteria, and volatile organic compounds—they would just slip right through the filter, as BB gun pellets would drop through a racquet's strings. Not so with Airocide. "We're able to eliminate those particles on contact," he says.

Airocide is simple to operate—just plug it into an outlet, turn it on, then forget about it. The only upkeep required is replacing the reaction chamber, which houses the UV light source, every 12-14 months. There's a high and a low-intensity mode, as well as automatic, which alternates from high in the day to low at night.

While the unit functions in any room, Freedman suggests putting your first one in the bedroom. With all the hours spent sleeping, it's the most important space to keep clear of contaminants. "In two days, you'll notice how the bedroom just feels different," he says. "And as you get the chance to breathe in the air, you'll start feeling better physically. You're going to wake up feeling refreshed. You're not going to be stuffy in the morning nor will you have any of the issues associated with air quality that you had before."

According to testimonials shared on the Airocide website, people credit the product with helping them and their loved ones attain relief from symptoms associated with asthma, allergies, and sinuses. Freedman isn't the least bit surprised by their claims.

"We know technology-wise that this device works," he says. "It was developed by NASA, it's FDA-approved, and it's been tested and vouched for by a host of universities. Not to mention the fact that we've been selling this for 10 years. We're very confident in what it can do." ❖

AiroCide® is a registered trademark of KesAir Technologies LLC.

The Airocide unit can be laid on a flat surface, hung on a wall, or mounted to a floor stand.

Thermal Materials Drive Professional Apparel Line

NASA Technology

From the time he was a Boy Scout, Gihan Amarasiriwardena had a fascination with performance materials. While growing up in the northeastern United States, he experienced the drastic twists and turns of the changing weather and says he needed a variety of outdoor gear to accommodate the fluctuations. Being the innovator that he is, he says, "I got into making my own gear."

NASA Astronaut Michael Massimino waves at the camera during a spacewalk. While designing astronaut gloves, NASA looked at phase change materials (PCMs) to keep an astronaut's hands from becoming too warm or cool.

In high school, Amarasiriwardena and his fellow Scouts would find their way onto construction sites where they would poke around for scrap pieces of Tyvek. They would take the material home and laminate it to ripstop fabric to make waterproof, breathable coverings. "I used to design waterproof jackets, climbing gear, and running apparel," remembers Amarasiriwardena.

By the time he got to college, Amarasiriwardena's passion for performance materials led him to pursue a degree in chemical and biological engineering at the Massachusetts Institute of Technology (MIT). There, he met students with similar interests, including Kevin Rustagi, who dreamed of innovative new product design in apparel; a classmate who sewed athletic socks into his dress socks to keep him comfortable (and stylish) throughout the day; and a colleague at MIT's Sloan School of Management, Kit Hickey, who wanted her office clothing to be as practical as her climbing gear.

Rounding out Amarasiriwardena's serendipitous group was Eddie Obropta Jr., a student working at the Man Vehicle Laboratory at MIT. Obropta was working on spacesuit designs for human travel to Mars, and had stumbled upon a technology that NASA had developed with industry many years before to help keep astronauts' hands at just the right temperature while working in space.

More than two decades ago, NASA's Johnson Space Center investigated phase change materials (PCMs) to use in spacesuit gloves. If the wearer became too warm or cool, the PCMs could automatically respond by absorbing or releasing heat. At a designated high temperature, PCMs absorb and hold heat to produce a cooling effect. At a designated low temperature, PCMs release stored heat to produce a warming effect in an area. Over the years, the NASA-derived PCMs have been applied to fabrics for a variety of uses, from bedding to undergarments (*Spinoff* 2009, 2012).

"When we became aware of PCMs to regulate body temperature," says Amarasiriwardena, "we saw it as an amazing opportunity."

Technology Transfer

In 2010, Amarasiriwardena and Rustagi joined forces to create a Boston-based company called Ministry of Supply (MOS). The name for the business came from a character in the James Bond movies who was based on a real person in the British Special Ops during World War II. Charles Fraser-Smith designed clothing and gadgetry for agents in the field, and his cover was British Ministry of Supply.

"We think of ourselves as creating the most advanced garments and gear for the Bonds and agents who we see as our customer," says Amarasiriwardena.

MOS set about to develop a brand new product: a professional dress shirt for men that felt and acted like active apparel. Working with a supplier in Los Angeles, MOS created a unique synthetic fabric that not only incorporated NASA-derived PCMs but could wick away moisture and control odors and bacterial growth.

"We wanted material that could help your body stay in that comfortable band—stay warmer or cooler—as well as be styled as a dress shirt," says Amarasiriwardena.

In 2012, MOS set out to raise $3,000 through KickStarter, an online platform for fundraising for creative projects, and the support started pouring in. By the close of its campaign, the team had raised a whopping $430,000 for its new dress shirt called Apollo.

Benefits

Available in white and oxford blue, everything from the Apollo shirt's fabric to its packaging is made in the United States. As a machine-wash only garment, the shirt will not wrinkle or absorb stains from perspiration. "Our goal is to inspire confidence in every man," says Amarasiriwardena. "That means allowing him to look and feel great."

In addition to the Apollo dress shirt, MOS has designed additional items for men, including an undershirt called Core, a short-sleeve shirt that can be worn alone or under another shirt called Atmos, and a pair of dress slacks called Aero.

Aside from using innovative materials , the company also employs innovative design and manufacturing techniques. "We are taking insight not only from the aerospace industry but from others, and we're using it to help educate others about a new design process for fashion," says Amarasiriwardena.

For example, MOS used strain analysis to understand how its material stretches, and as a result, where to place seams and stretch panels that help the shirts move with the wearer's body and stay tucked into trousers. MOS also employs infrared thermal imaging to see where heat is generated on the body, and uses the results to inform its designs. The crisp collar and cuff on Apollo are made using a process called thermal lamination, and lastly, robotic knitting is employed to make vented sections in the garments during the manufacturing process.

"We are different from the rest of the fashion industry because we are not about releasing new products every season. We are about putting a lot of thought, engineering, and great design into each garment before we launch it," says Amarasiriwardena. "We view ourselves as a sort-of Patagonia-J.Crew. It's performance wear designed to be office-wear appropriate."

Amarasiriwardena believes NASA's mission is as much about what happens in space as it is about bringing that knowledge back to Earth. "What NASA has enabled us to do is a powerful part of its mission," he says. "We're pushing the boundaries and making a big impact back here on Earth."

The Apollo and other MOS products are currently available on the MOS website, where, since its launch, has sold 12,500 tops and bottoms combined. The company expects even more success with some new styles coming in the future. ❖

The Apollo dress shirt from Ministry of Supply incorporates NASA-derived PCMs, which absorb and release heat depending on temperature, to keep the wearer comfortable.

Radiant Barriers Save Energy in Buildings

NASA Technology

It's a bird! It's a plane! It's—a satelloon?

That's what researchers and designers at Langley Research Center nicknamed Echo I, the first NASA communication satellite to orbit Earth and successfully relay signals from one spot on the planet to another. As a round, 10-story tall balloon, Echo looked like it had been wrapped in smooth aluminum foil. With a silly nickname and odd appearance, you can probably guess: Echo has an interesting story to tell.

It was the 1950s, and Langley engineers were looking for a thin, lightweight, reflective material to incorporate onto Echo's exterior to "echo" voice, radio, and television signals from Earth back to the ground. At the time, they were interested in using polyester (a plastic) coated with aluminum, but there were no existing techniques for applying the metal in a way that met NASA's specific needs.

The Echo I satellite waits in a hangar in North Carolina before its 1960 launch. The metallic coating on the outside of the satellite later launched into commercial success.

To create a new technique for coating plastics or other materials with an extremely fine mist of vaporized metal particles, the Agency collaborated with private industry. The result was a material similar in weight and feel to thin cellophane packaging, but with significant reflective properties. NASA utilized the technology on Echo, and in 1960 the satellite launched into orbit and successfully sent communication signals around the globe. Meanwhile, the vaporized metal technique also launched into success, and was used to create material for a myriad of space applications.

Alongside its ability to reflect communication signals, the material also reflected space radiation. It came to be known as "radiant barrier technology" and was used during the Apollo program to shield spacecraft and instruments from the harsh conditions in space. Since then, nearly every NASA mission has employed the shiny material to protect astronauts and equipment.

Technology Transfer

As the applications for radiant barrier technology took off in space, they also took off on Earth. The technology was made available in the public domain, and products across the world started incorporating the NASA-derived metallized material for everything from lightweight emergency blankets to insulation for homes and buildings. In 1996, the Space Foundation inducted the technology into its Space Technology Hall of Fame.

Recently, in 2010, entrepreneur Ryan Garrett learned about a new version of the radiant barrier that is manufactured by vapor phase encapsulation, a patented process from Sigma Labs in Tucson, Arizona. The difference between vapor phase encapsulation and the traditional technology is that, after the metal is vaporized, a coating

A spinoff technology called RadiaSource is installed in newly-constructed homes and buildings where it could save 46 percent on energy during the summer and 18–20 percent in the winter.

“In the **process** of **trying to** see **what’s** in **space,** we **discover technologies** that **benefit** us here **on Earth.”**

—Ryan Garrett, RadiaSource

A recreational gymnasium became too hot and uncomfortable to use during the summer months, but now with RadiaSource on the rafters, the owner says the gym stays cool. The image on the background of this page shows a close-up view of the perforated material.

encapsulates each particle of metal before it bonds to a material or fabric.

The big benefit, explains Garrett, is the oxidation factor. “There’s no penetration into the metal, and it is nearly impossible for the material to oxidize,” he says. In 2011, Garrett founded RadiaSource in Ogden, Utah, to share the benefits of the innovation with others through a unique product offering.

Benefits

Garrett was already aware of the benefits of radiant barrier technology for insulating homes and buildings, but he was also aware of a significant drawback. Aluminum, the basis of the technology, has a .03 E-value, which means that it reflects 97 percent of radiant heat and absorbs 3 percent. The problem, describes Garrett, is that aluminum begins to oxidize when exposed to moisture.

To paint a picture of oxidation, Garrett uses the example of an aluminum travel trailer. “Over time, they turn dusty gray and lose reflectivity. It happens quickly when exposed to the elements. When the metal oxidizes, the thermal emittance of the material goes up. Once it goes up, it is not reflective anymore,” he says.

Thanks to what Garrett calls the “oxidation factor” manufactured into RadiaSource material, the company’s insulation products have a lifetime guarantee. A case study in Toronto demonstrated a home with RadiaSource saved 18–20 percent on energy in the winter and 46 percent in the summer. When used on top of current insulation in a building or home, Garrett says, outside heat hits the material, and “It’s like water hitting a dam. It has nowhere to go.”

Aside from insulation, the company also produces radiant barrier garage doors, shipping materials, and wraps for water heaters. According to the company, RadiaWrap can save up to 20 percent on residential hot water heating costs.

With a variety of commercial opportunities in warehouses, gymnasiums, large buildings, and agricultural settings, RadiaSource insulation is currently being installed at a 2-million-square-foot poultry farm. The material is being incorporated in their livestock enclosures to save on the farm’s heating and cooling costs. “Temperature is an important factor to the development of chickens,” says Garrett. “Their growth rate, total body weight—all are impacted by temperature variations.”

Another area where Garrett sees beneficial use of RadiaSource is dairy farming. Cows produce milk at a certain temperature, he says, and fluctuation decreases milk production.

Still another industry is beekeeping. “Bees die when they are being transported because the temperature rises in the vehicles,” he says. “The bees flap their wings to cool down the hives, and they spend energy that could have been spent on making honey. If the temperature is regulated, honey production can go up.”

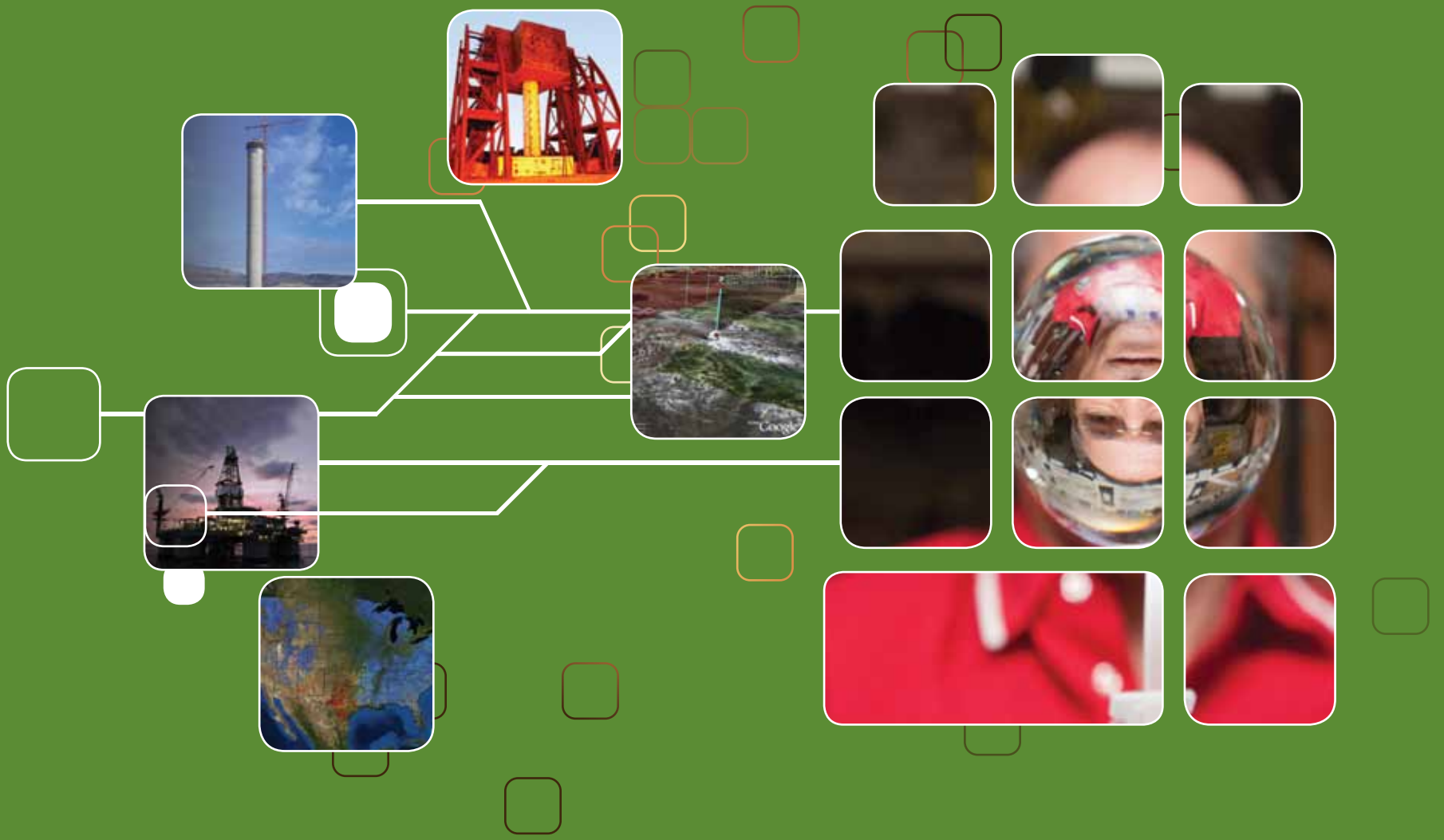
Considering the technology was enhanced more than 50 years ago for first-of-its-kind space applications, it’s no surprise it continues a legacy of unique applications here on Earth. As Garrett says, “We have to expand into space to continue to satisfy that craving to discover new things. In the process of trying to see what’s in space, we discover technologies that benefit us here on Earth.” ❖

RadiaSource™ is a trademark of RadiaSource.

Energy and Environment

Making the best and most efficient use of resources isn't a requirement only for space travel; NASA knows that the health of the planet depends on it, too. It should be no surprise, then, that the technologies created by NASA to make rockets burn efficiently, collect vital data from the field, and generate clean energy are now helping us to take good care of our world's precious resources. Spinoffs featured in this section:

- Power Real-Time Data Streams
- Revolutionize Solar Power
- Improve Safety on Oil Rigs
- Monitor the Nation's Forests
- Spawn Durable Wind Turbines
- Visualize Earth and Space for Interactive Education



Open Source Initiative Powers Real-Time Data Streams

NASA Technology

Let's say you are an academic researcher who needs to collect data over a long period of time, on a site hundreds of miles from your base of operation. You set up a variety of sensors in the field to continuously measure temperature, soil moisture, and capture visual imagery. All of that data needs to be stored securely so that it can later be extracted and analyzed.

But reliably acquiring and storing data is harder than it sounds. Sometimes sensors fail part way into a long-term experiment, and if they aren't communicating beyond their local network, a researcher might not know they have failed until he or she comes to retrieve the data and discovers that the experiment is lost.

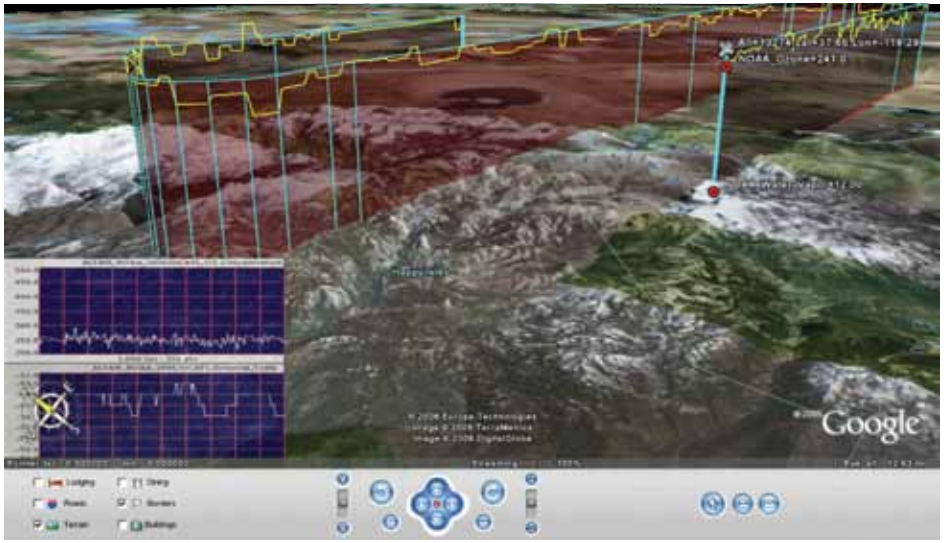
Obtaining timely and reliable data from another location is also a challenge. Some researchers want to set up equipment in a remote location solely to provide an alert when conditions are right—say, if a storm develops—so that a team can head out to the field only when it matters. Unreliable data feeds can ruin these plans.

In addition, many research setups incorporate sensors from several vendors, and it is often difficult to integrate heterogeneous proprietary software and hardware into one system. Without a uniform format, it can take extra time after data collection to organize a data set with appropriate tags and identifiers.

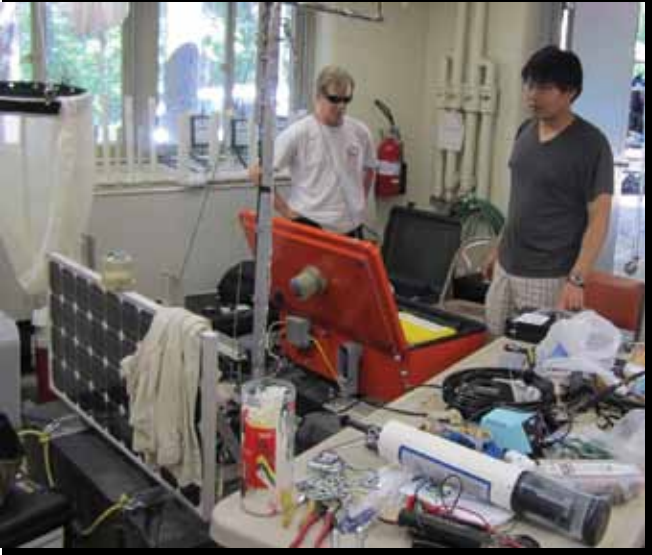
All of these problems and more are encountered not just in academic science but in hugely diverse settings, from structural analysis to manufacturing to medical health monitoring. Tony Fountain, director of the Cyberinfrastructure Lab for Environmental Observing Systems at the California Institute of Telecommunications and Information Technology, University of California, San Diego (UCSD), has long worked with researchers on securing good data. As he says, "The question is always: how do you move data between data sources, data repositories, and applications that use it? And how do you do that in near-real time, reliably, and over networks that may have various performance problems?"

At NASA's Dryden Flight Research Center, researchers have long faced the same questions. Dryden is NASA's primary center for research into every aspect of atmospheric flight and aircraft design. Many of the world's most advanced aircraft have graced the skies over the Center's location in the California desert, often with sensors attached to collect critical information.

In the mid-1990s, Matthew Miller was brought into the Dryden facility to discuss sensor data analysis software he had been developing. Miller was working as an engineer with Creare Inc. and became the principal inves-



NASA, the US Forest Service, and the National Oceanic and Atmospheric Administration teamed up to equip an unmanned aerial vehicle with sensors for detecting the severity of forest fires in California. Dryden Flight Research Center was responsible for transmitting flight data to the ground and used DataTurbine for the job.



A research team based out of San Diego releases a buoy equipped with sensors into Crystal Lake, Wisconsin. The hardware is running a version of DataTurbine ported to the Android platform, and the team has successfully streamed its real-time data across the country.

Images courtesy of Peter Shin.

tigator on a Phase I Small Business Innovation Research (SBIR) contract to apply wavelet-based mathematical analysis techniques to aircraft vibrations.

As Miller was discussing the project with the NASA technical monitor on the contract, Larry Freudinger, the two realized they had both spent time in data acquisition using devices manufactured by Hewlett-Packard (HP). "Larry happened to have some HP equipment, so we worked together to set up a demo of the software I had been working on," says Miller. "One of its key features was that you could take data from one place and stream it live over a network to another place." Having prepped a demo, the pair was able to get live data streaming from a test flight directly into the control room.

Technology Transfer

Both Freudinger and Miller were enthusiastic about the potential of the technology in more general applications beyond wavelet analysis and the particular equipment they had been using. Their continued efforts to develop the software resulted in a technology Miller named the Ring Buffered Network Bus (RBNB) (*Spinoff* 2000). A patent was filed by the co-inventors, and Dryden has since used the tool in many research flights.

The network streaming feature of RBNB was increasingly recognized as a significant enabling technology for distributed test and measurement applications. From its initial test run on specific machinery, RBNB soon became an open-ended tool, specializing in integrating input from any number of sources, in many kinds of formats, and moving that data to any number of end applications. A special emphasis was placed on making RBNB reliable for data storage and syncing, even when the sensor network giving it input became unreliable.

Miller, who is also a part-time contractor working for Dryden, used the partnership as a launchpad for further projects. He refined the technology through work with the Air Force, the National Institutes of Health, and the National Science Foundation (NSF), among others. All along, he had an eye on how the software could be commercialized, but he soon discovered that the tool could sometimes be a hard sell.

The challenge Miller faced was RBNB's status as "middleware"—that is, software that is by design agnostic with respect to its inputs and outputs and which doesn't specify how it must be used or what product it produces. Miller points out that many enterprises prefer dedicated, one-of-a-kind systems to tackle a given challenge rather than investing in reusable, general purpose tools. "If it had been just a self-contained, off-the-shelf product, it might have been easier to sell. As middleware, it took a lot of high-tech sales effort for the payoff. Companies were reluctant to purchase it."

Seeing "the writing on the wall," as he says, Miller began looking into how Creare might continue to benefit financially from the product other than by selling it as proprietary software. "I thought: In five years, who are you going to call for support if the software remains a privately owned commercial product that isn't actively being sold?"

One phenomenon Miller had noticed was that the software attracted attention from groups that were interested in open source tools. For example, the Network for Earthquake Engineering Simulation (NEES), a large project created by NSF, was building structures several stories high on giant shaker tables to create earthquake simulations, and planned on using RBNB to capture its data from sensors and cameras. NEES expressed interest in being able to use RBNB as open source software.

Another proponent for going open source was Fountain, who at the time was working with a number of academic researchers at UCSD. "I'm a computer scientist,

“DataTurbine has **benefitted** the **careers** of a widely **distributed** group **of people. . . . I call that a win.”**

— Matthew Miller, Dryden Flight Research Center

The Great Barrier Reef, here shown as imaged from space, is the world’s largest coral reef system and a subject of intense scientific research and study. One group in Australia is using DataTurbine to collect data gathered by sensor-laden buoys and send them to computers on shore. For a deeper look at the Open Source DataTurbine Initiative, scan this code.

but I work with ecologists, marine biologists, and others like that," he says. "They needed environmental monitoring, and I was given the responsibility of finding the right software to do that systems integration. Our evaluation came down to two products, one of which was Creare's."

Miller saw that Creare might have a better commercial opportunity in providing consulting services for users of the software rather than selling the software itself. Going open source would lower RBNB's cost, which could increase its user base—especially among the kinds of academic researchers Fountain was working with. That could in turn create demand for support services.

Miller worked with Creare to release the software under an open source license. Fountain, meanwhile, secured a grant from NSF to help its transition from proprietary software to open source and to create a website where the project could be hosted and organized. In 2007, the technology was officially rebranded as the Open Source DataTurbine Initiative—DataTurbine being an unofficial name RBNB had gone by for years.

Benefits

Today, anyone can freely use DataTurbine as a real-time streaming data engine; the software allows users to stream live data from sensors, labs, cameras, and even cell phones. The tool is as portable as the devices that carry it, and it can easily scale to match the volume of data generated by a project as it grows.

The initiative maintains a well-documented application programming interface—or the protocol required to extend the software with custom applications—so that users can adapt the program for any need. Australian researchers, for example, have adapted DataTurbine to keep track of conditions in the Great Barrier Reef, streaming live data from ocean buoys to computers on shore.

One of DataTurbine's unique features is its ability to allow applications to pause or rewind live data streams. Users can work with data as it arrives from a lab or the field without disrupting the process of collecting data from ongoing processes. And the data, whatever its source, comes in a uniform format. Says Fountain, "The user specifies the metadata, so once the data gets inside of DataTurbine, it all looks the same and can be relayed over continuous time periods."

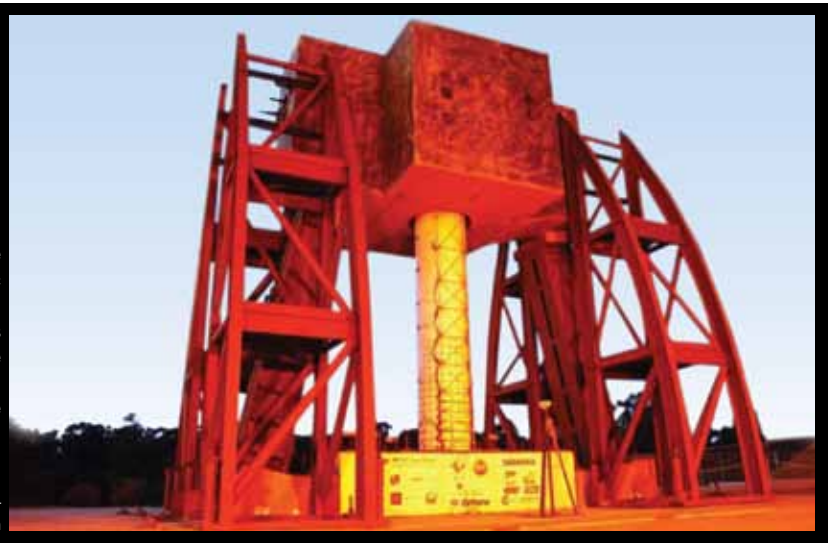
Although the software can easily be used in a variety of settings, Miller and Fountain have found that DataTurbine's biggest user base is among researchers in the Earth and environmental sciences. Fountain works with a number of groups that have placed sensors in coral reefs, lakes, forests, and agricultural sites. DataTurbine is also playing a key role in projects that conduct large-scale simulations of seismic activity on civil infrastructure.

The software has an active development community that continues to create extensions and complementary tools. DataTurbine has been ported to the Android platform, making it tablet- and phone-friendly, and in addition many new drivers have been programmed for various classes of sensors, cameras, microphones, and other kinds of devices. "There's also development on the backend for data analysis and cloud computing," adds Fountain, "so there's a lot of development going on with mobile support."

NASA still uses the software—for example, several years ago it equipped an unmanned aerial vehicle with it to gather information on the severity of forest fires in California. Miller continues to consult on a number of NASA projects using DataTurbine, sometimes enlisting the help of Fountain.

Both are happy to see the ways the project has grown. "Without the shift to open source, it would almost certainly be unused and unknown today," says Miller.

"DataTurbine has benefitted the careers of a widely distributed group of people and has helped generate research grants to support scientific work. It's been used in consulting services and has furthered other technologies," he says. "For me personally, I call that a win." ❖



A structure for large-scale validation of the seismic performance of bridge columns. This is one of the many projects run by the Network for Earthquake Engineering Simulation, which helped generate interest in the Ring Buffered Network Bus as an open source tool.

Image courtesy of the Network for Earthquake Engineering Simulation

Shuttle Engine Designs Revolutionize Solar Power

NASA Technology

One of the hottest solar energy plants in the world was developed with engineering expertise derived from one of the hottest space technologies ever engineered: the Space Shuttle Main Engine (SSME). For 30 years, the SSME operated in temperatures ranging from -423 °F to 6,000 °F—hotter than the boiling point of iron.

Built under contract to Marshall Space Flight Center in the 1970s by Rocketdyne, now part of Pratt & Whitney Rocketdyne (PWR), a United Technologies Company, the SSME was the most durable rocket engine that had ever existed.

Technology Transfer

After building the SSME and other engines at Marshall, PWR applied its knowledge and expertise to produce solar power technology. Randy Parsley, the business development manager for renewable energy at PWR, says that the company's NASA work allowed it to glean new expertise in handling high heat flux, extreme temperatures, and cyclic temperature gradients over long periods of time.

The Space Shuttle Main Engine (SSME) shown here was donated to the Smithsonian National Air and Space Museum.

In addition, PWR gained valuable welding expertise while working on the SSME. "There was so much welding knowledge that came out of the SSME development activity, it gave us the basis and knowledge of what we call thin-tube-welding," says Parsley.

With funding from the Department of Energy (DOE) and industry partners, PWR leveraged its NASA experience in the 1980s and '90s to assist in the development of large demonstrations of solar power tower plant technology in the Mojave Desert of California: Solar One and Solar Two. These plants used mirrors to reflect the Sun's energy onto a receiver at the top of a tower. Heated fluid flowing through the tower then carried the energy to a boiler on the ground where steam was created to spin turbines.

According to Parsley, the receiver assembly that sits on the top of the approximately 600-foot tower is like the combustion chamber of a rocket engine that is turned inside out. "If you can imagine, it's like a rocket chamber or a nozzle—like on the SSME—that has all the tubes being cooled with liquid, but instead of the tubes being heated from the inside by the rocket propellants, the tubes are heated from the outside by concentrated sun," he says.

By 1999, Solar Two proved to be a great success, and was generating enough energy to power 10,000 homes. Consequently, nearly a decade later, PWR granted an exclusive license of its NASA spinoff solar technology to Santa Monica, California-based SolarReserve.

SolarReserve uses its exclusively licensed PWR technology to develop large-scale concentrating solar power (CSP) projects. In a sunny area, SolarReserve installs mirrors called heliostats to reflect sunlight up to a central point—a receiver that sits on top of a 550-foot tower. Piping on the external walls of the receiver carries molten salt, which is heated by the concentrated sunlight. The hot salt maintains a liquid state at very high temperatures (above 1,000 °F), and after being heated by the Sun, flows down the tower into a holding tank where it will stay hot until the thermal energy is needed to make electricity.

To generate electricity, the salt goes from the hot storage tank to a heat exchanger to create steam, which is used to drive a standard turbine generator. Afterward, the cooled molten salt is released into a cold storage tank where it is held until it is cycled back up the tower to the receiver to be reheated and reused again.

Benefits

According to Tim Connor, the vice president of engineering and technology at SolarReserve, the steam generation process is the same as that used in conventional gas, coal, or nuclear power plants, except that it is 100 percent renewable with zero harmful emissions. Another major benefit of SolarReserve's technology is that it can provide electricity from the Sun on-demand, even after dark or on cloudy days, thanks to the storage capability of the molten salt.

"We can store the energy in the molten salt during the day and turn the turbine generator anytime, day or night, to create electricity. There is no other renewable technology out there that is as predictable and dispatchable as our technology. We are currently the only solar technology that can truly replace a nuclear power plant or fossil fuel plant," says Connor.

As of 2013, the company was developing a 110-megawatt plant called the Crescent Dunes Solar Energy Plant near Tonopah, Nevada, which will generate enough electricity to power 75,000 homes during peak electricity periods. The plant is situated on a 1,500-acre field with more than 10,000 heliostats directing the Sun's energy onto the receiver.

Every 10 seconds, specialized software controls and redirects the mirrors to capture the Sun's rays and redirect them to the receiver.

All of the power generated at the Crescent Dunes plant will be sold to NV Energy, the largest utility in Nevada. When commissioned in early 2014, Crescent Dunes will be the nation's first commercial-scale, molten salt solar power tower and the world's largest plant with a fully integrated energy storage system. Construction on the plant started in 2011, and has generated over 400,190 hours of on-site construction as of April 2013. More than 4,300 direct, indirect, and induced jobs are expected over the 30-month construction period. For the life of its operations, the plant will provide 45 full-time, permanent positions.

Aside from the Crescent Dunes plant, SolarReserve has a number of upcoming projects including the construction of a CSP plant near Blythe, California in 2014 and several others in the Southwest in the 2014–2015 timeframe. Beyond the United States, SolarReserve has projects in development around the world, in countries such as Spain, South Africa, Saudi Arabia, Morocco, Chile, Australia, and China.

Going forward, Connor believes molten salt solar power tower technology will become a dominant renewable energy technology. "As we build more and more projects, the economies of scale will allow us to decrease the price, which is currently the only drawback," he says.

Parsley agrees. "I believe this technology is a game-changer for solar thermal. It has a 20 percent cost advantage over other solar thermal technologies for cost of electricity, plus it has storage so you can make electricity even after the Sun goes down."

In the world of technology today, there are a number of hot items, but few get as hot as a rocket engine. Thanks to innovation from NASA and its contractors, companies like SolarReserve leverage the investments made in NASA technology to benefit life on Earth. As Connor says, "A lot of people don't understand the tremendous benefits, but NASA's continued investment in technology like this really does have a substantial payback in the form of local, National, and even global economic growth." ❖

Thousands of mirrors called heliostats (top inset) are being installed in a 1,500-acre field (middle inset) to direct the Sun's energy onto a receiver (bottom inset), which was built using expertise gained from constructing the SSME. The NASA spinoff receiver will sit on top of a 550-foot tower (background image). During construction, this solar power project will generate more than 4,300 jobs.

Procedure-Authoring Tool Improves Safety on Oil Rigs

During shuttle missions to the International Space Station, procedures were printed in notebooks and carried into space. The books were large and heavy, making them expensive to launch and cumbersome to handle. Here, STS-119 commander Lee Archambault looks over procedure checklists during flight activities.

NASA Technology

On May 11, 2013, two astronauts emerged from the interior of the International Space Station (ISS) and worked their way toward the far end of spacecraft. Over the next 5½ hours, the two replaced an ammonia pump that had developed a significant leak a few days before. On the ISS, ammonia serves the vital role of cooling components—in this case, a component on one of the station's eight solar arrays.

Throughout the extravehicular activity (EVA), the astronauts stayed in constant contact with mission control: every movement, every action strictly followed a carefully planned set of procedures to maximize crew safety and the chances of success. Though the leak had come as a surprise, NASA was prepared to handle it swiftly thanks in part to the thousands of procedures that have been written to cover every aspect of the ISS's operations.

The ISS is not unique in this regard: Every NASA mission requires well-written procedures—or detailed lists of step-by-step instructions—that cover how to operate equipment in any scenario, from normal operations to the challenges created by malfunctioning hardware or software. Astronauts and mission control train and drill extensively to ensure they know what the proper procedures are and when they should be used.

These procedures used to be exclusively written on paper, but over the past decade NASA has transitioned to digital formats. Electronic-based documentation simplifies storage and use, allowing astronauts and flight controllers to find instructions more quickly and display them through a variety of media. Electronic procedures are also a crucial step toward automation: once instructions are digital, procedure display software can be designed to assist in authoring, reviewing, and even executing them.

Technology Transfer

As a part of its development of electronic procedures, in 2006 Ames Research Center awarded Webster, Texas-based TRACLabs Inc. a Phase I Small Business Innovation Research (SBIR) contract to provide support for robotics and automation. That work soon grew into multiple Phase I and II SBIR contracts to develop a tool specifically for authoring procedures, and out of these efforts, the Procedure Integrated Development Environment (PRIDE) was born.

PRIDE is a suite of software tools that assists in authoring standard operating procedures to help astronauts in operating equipment that is complex and potentially dangerous. It provides an intuitive, drag-and-drop interface for the elements of a procedure (such as what equipment is needed and how it works) that reduces the labor and tedium of assembling instructions.

Says Jeremy Frank, a group lead in the Intelligent Systems Division at Ames, "At the time that you create your procedure, you want all the information about the equipment in the procedure tool. You don't want to have to spend time chasing down information in a reference manual just to figure out what this thing is. PRIDE takes care of that for you."

When executing a procedure, PRIDE assists the operator with a variety of tools to simplify and streamline the process of following instructions. It can format procedures for display in any number of media, for example, so that astronauts can use what they have on hand to read them, regardless of the platform used to write them. In electronic formats, an operator can check off steps as they are performed, which can be tracked (and later audited) by others managing the mission.

NASA has turned to PRIDE for a variety of needs: In 2008 it was used to author medical procedures for the ISS. Capabilities to write procedures for EVAs were integrated in 2011, and in 2012 it powered the procedure-writing for Morpheus, a rapid prototype lander project designed to test a range of capabilities. Perhaps most importantly, NASA is using PRIDE to author procedures for the prototype electronic procedure display for the Orion Multipurpose Crew Vehicle, the spacecraft scheduled to take astronauts beyond Earth's orbit for the first time since the Apollo Program.

Benefits

NASA may have been PRIDE's first user, but it won't be its last: in 2013 TRACLabs announced that it was marketing its software to private industry, starting with oil companies. As Dave Kortenkamp, president of TRACLabs, says, "We recognized pretty early on that procedures are ubiquitous, and any environment where there is some level of high dynamics and risk, people want to think things through. We live in Houston, where oil and gas is a very large industry, so it was a natural next step."

TRACLabs is now working with a number of large companies in the oil and gas industry—"names you see on gas station signs as you drive down the street," says Kortenkamp—as well as with companies that provide services to them. The company will sell both the software and support services and is already on pace to generate millions of dollars through its entry into the market.

On oil rigs with heavy machinery, any failure to strictly follow instructions can cause disaster. "After the Deepwater Horizon oil spill in 2011, these companies want to make sure that everything they're doing is according to best practices," says Kortenkamp. "Part of the problem in diagnosing what went wrong was that they weren't always sure who was doing what when. They're serious about making sure they're auditing procedures and keeping track of what's being done in the field."

Using procedures written with PRIDE, oil companies can better manage and audit oil rig operations. For example, when an expert authors procedures for a piece of drilling equipment, PRIDE captures that instruction in language the software understands. (Currently, such procedures are written in ordinary word processors.) "When the procedure is sent to the operator of that piece of equipment," says Kortenkamp, "the operator has some training but isn't necessarily an expert on that tool. With PRIDE, the operator can check off steps as he moves through them and use the software to branch off certain points in the procedure where there are questions that need to be answered."

At the same time, PRIDE can draw relevant sensor data coming from the equipment and display that an appropriate context both for the operator and anyone monitoring the work remotely. Using industry-standard interfaces that are compatible with PRIDE, multiple people can use the same procedure on multiple rigs, and as they carry out their instructions, all of their interactions are stored in a remote database so that the company can review what's happening. If an operator breaks from his or her given instructions, support software can send out alerts so that appropriate actions can be taken—whether that means halting the operation or flagging it for further review.

In the future, TRACLabs hopes to sell PRIDE in other markets, as it can easily be applied in many fields. For now, however, NASA's early adoption of PRIDE is helping the company get a foot in the door with an industry whose difficult environments and high risks sometimes resemble those of the space agency's.

"It's widely recognized that NASA is at the cutting edge of operating complex things safely," says Kortenkamp. "It's something NASA is well known for. The fact that this is the direction NASA is moving for its procedures tells the oil and gas industry that it's a direction they should be moving as well." ❖

Satellite Data Aid Monitoring of Nation's Forests

NASA Technology

Joe Spruce's last name is a fitting one: Spruce is a research scientist at NASA's Stennis Space Center working with the US Department of Agriculture (USDA) Forest Service to monitor forests and other vegetation across the country using NASA satellite data.

MODIS, or the Moderate Resolution Imaging Spectroradiometer, is an instrument onboard two Earth-observing satellites called Aqua and Terra. Each MODIS satellite collects data on the Earth's surface through 36 different spectral reflectance bands, typically every day. MODIS observes and gathers information to improve our understanding of global dynamics and processes on the land, in the seas, and in the atmosphere—not just for NASA Earth science, but also for the benefit of the natural environment.

Technology Transfer

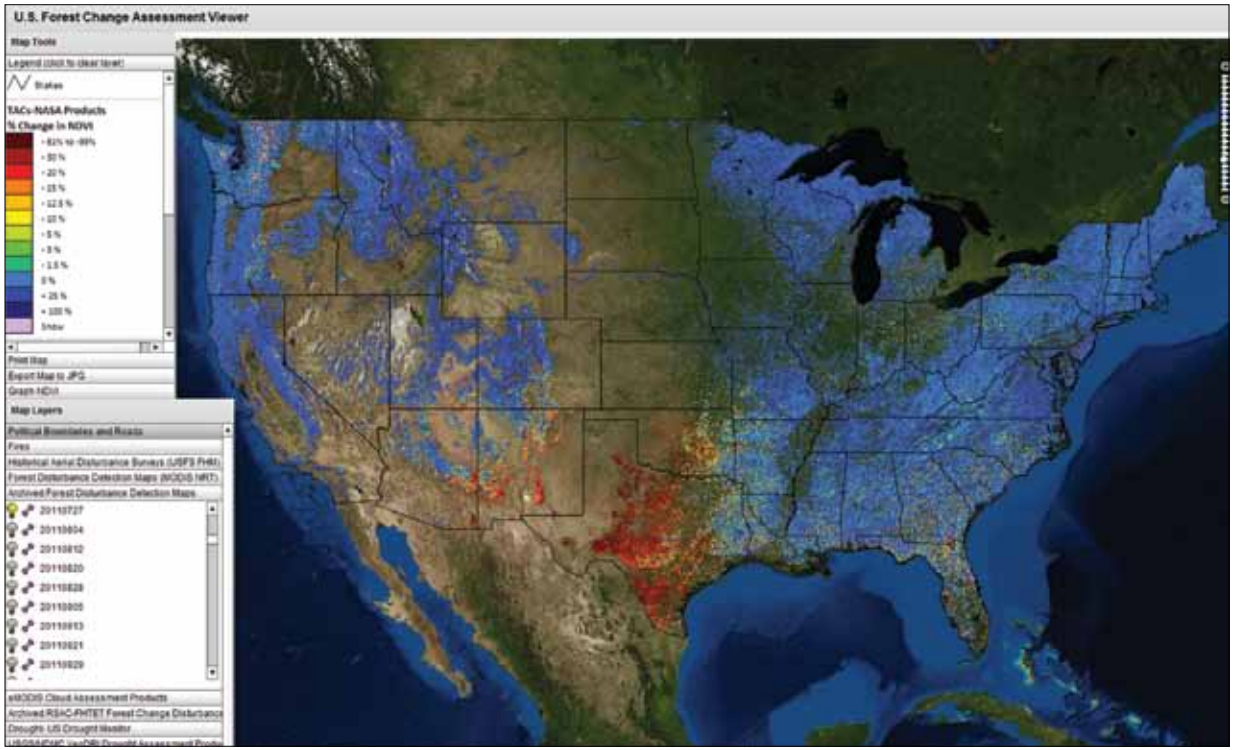
Detection and early warning of regionally evident disturbances of our Nation's forests is an important activity because forests provide societal, environmental, economic, and ecological benefits. Consequently, issues affecting forests can have a tremendous impact on the health of their associated ecosystems, watersheds, and forest-dependent communities. In 2003, the Healthy Forests Restoration Act called for the development of a National Early Warning System to detect potential threats to the United States' forests, such as those from insects, diseases, wildfires, extreme weather, and other events.

To this end, the USDA Forest Service's Asheville, North Carolina-based Eastern Forest Environmental Threat Assessment Center and the Prineville, Oregon-based Western Wildlands Environmental Threat Assessment Center partnered with Stennis, the US Geological Service (USGS) Earth Resource Observation System (EROS), and the Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL) to create a near real-time early warning system to identify, characterize, and track regional disturbances from potential forest threats.

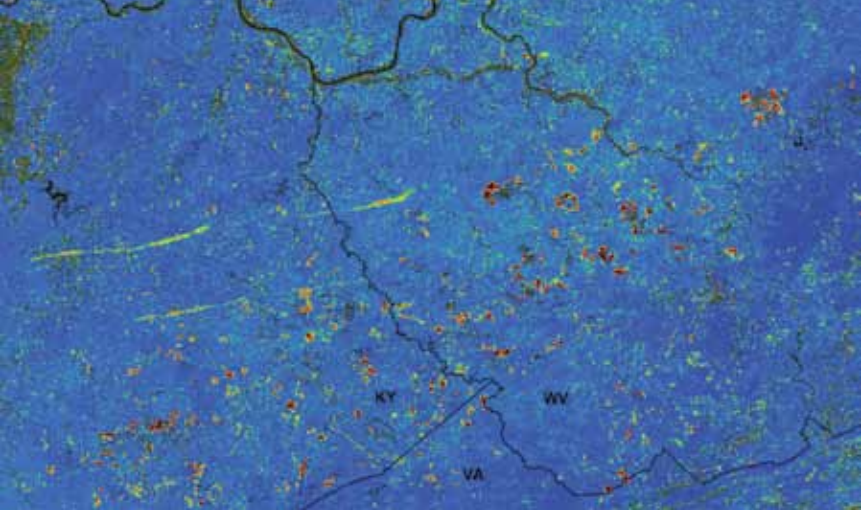
The result was ForWarn, a national forest monitoring system that utilizes the reflectance data obtained from MODIS to compute forest health indicator products. ForWarn's forest change assessment products have been used for a variety of applications from science to resource management to communication, education, and outreach.

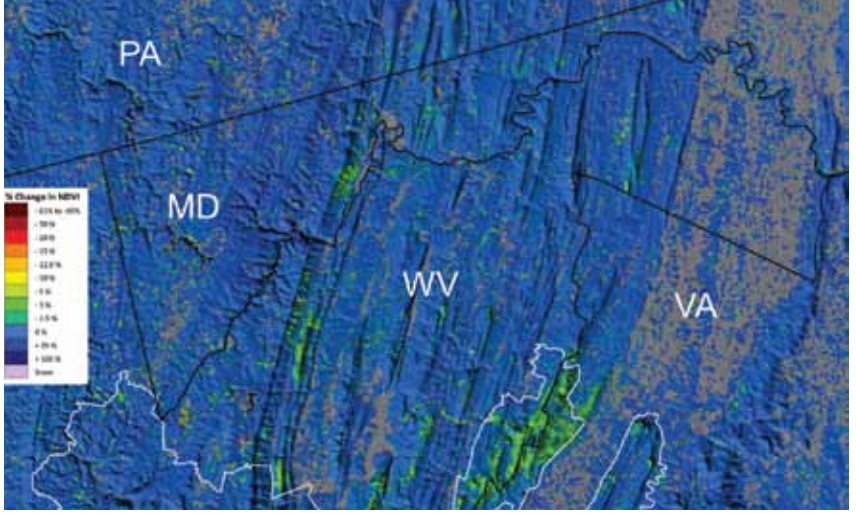
The imagery is processed and made freely available to the public through a user-friendly web-based geospatial data viewer called the Forest Change Assessment Viewer (FCAV), which was created and is maintained by the University of North Carolina Asheville's National Environmental Modeling and Analysis Center. DOE's ORNL assists with the statistical analysis of MODIS data and supercomputing efforts for the collaborative tool, and thanks to the contributions from the USGS's EROS Center, distribution of NASA's MODIS imagery is available for ForWarn as soon as possible after it is obtained.

"We can do this in near-real time, thanks to the EROS contribution," says William Hargrove, the Forest Service lead for ForWarn. The FCAV also allows users to easily share the disturbance maps that they are viewing. "Now when forest managers see something and are not sure what it is or if they should be worried about it, they can



This image from ForWarn, a forest monitoring system that utilizes NASA satellite data, shows where a drought hit the southern United States in 2011. An extreme loss of vegetation is shown in shades of red.





The first image on the far left shows tree and foliage losses from tornadoes in Kentucky and West Virginia. The second image shows where gypsy moths (a non-native species) defoliated and killed trees in Maryland, West Virginia, and Virginia.

share it with someone. It's a great way to speed up and aid communication," Hargrove says.

Spruce describes how, initially in 2006, the team began experimenting with MODIS data for forest disturbance detection and analysis and started developing a monitoring capability based mainly on satellite data. "Part of the MODIS mission involves efforts by NASA's Applied Sciences Program to encourage the use of NASA Earth science data for improving environmental monitoring and management capabilities," he says. "This project is a prime example of how MODIS satellite data can be processed and used to provide real, tangible societal benefits."

Hargrove adds, "If a particular forest is greener than we expected, then there's usually no problem. If the current view is less green than we expected, then that's the basis for our assumption that there is some kind of disturbance—something unexpected is going on."

Benefits

Today, ForWarn is being used by federal and state forest and natural resource managers across the country. Remotely sensed observations of vegetation life can contribute to a much broader-scale understanding of vegetation disturbances (including abiotic and biotic) not available from ground-based perspectives.

Abiotic disturbances are being detected and tracked, such as damage from hurricanes (such as Isaac in Mississippi and Louisiana, and Sandy in eastern US forests); drought in Texas and neighboring states including New Mexico, Texas, Oklahoma and Louisiana; hail in North Carolina; wildfires in Front Range forests of Colorado; as well as wind, river flooding ice, and frost. Biotic disturbances (such as forest defoliation and mortality) typically caused by multiple insect pests (like fall defoliation from fall webworm in Pennsylvania and summer foliage loss by western spruce budworm in Washington State) are also being observed.

Steve Running, Chair of the MODIS Land Science Team, appreciates the state-of-the-art capabilities enabled by ForWarn. "I find the ForWarn system to be the most innovative new use of MODIS data I have seen, and that finally has bridged the gap successfully from research to operations with MODIS land data. I am most impressed by how successful the ForWarn team has been at packaging and distributing this new information in a way that the land managers actively are using."

Overcoming typical organizational barriers, ForWarn is the direct result of a collaborative effort that produced a system that no single agency could have created on its own. The team is providing novel contributions toward understanding the Earth by means of remote sensing, and the value of this innovative cooperative effort has been further recognized: the ForWarn team was selected to receive the Federal Laboratory Consortium (FLC) Southeast Region's 2012 Partnership Award for technology transfer and the 2013 National FLC Interagency Partnership Award.

According to Hargrove and Spruce, the tool complements and helps focus existing forest monitoring efforts at more local scales, which will likely result in time and cost savings. In the future, they anticipate that ForWarn will be capable of automatically recognizing disturbances.

"Currently, our ForWarn team examines and interprets these disturbance detection maps manually by sight, which is labor-intensive. We're developing an automated disturbance recognition application for the tool so it can highlight forests with indications that something more particular is going on and call it to our attention," explains Hargrove.

ForWarn already examines all terrestrial vegetation of the contiguous United States, but its FCAV currently only shows forest change products. Based on recent experiments, Hargrove and Spruce believe a similar approach will have value in tracking agriculture and range vegetation disturbances, and are working to apply, evaluate, and potentially use capabilities of ForWarn for detecting disturbances in these nonforested landscapes as well.

Through this multi-agency partnership, ForWarn exemplifies how NASA's investment in Earth science data is bringing value back to public and private communities across the United States and, by doing so, directly benefitting regional forest health monitoring across the nation in new, unprecedented ways. ❖

Mars Technologies Spawn Durable Wind Turbines

NASA Technology

"It all started with ecological life support systems for exploration," says David Bubenheim, a senior research scientist at NASA's Ames Research Center. Sometimes referred to as regenerative life support systems, the concept includes an enclosed self-sufficient habitat that can independently support life for years on end. Such a system aims not only to produce its own food and water but to purify air and convert waste into useful byproducts.

Ames Research Center provided funding for Northern Power Systems to construct a wind turbine at the South Pole, a test environment for assessing technology for use on Mars.

In the early 1990s, NASA was planning for an extended stay on Mars, and Bubenheim and his Ames colleagues were concentrating efforts on creating a complete ecological system to sustain human crewmembers during their time on the Red Planet.

"The main barrier to developing such a system," he says, "is energy." Mars has no power plants, and a regenerative system requires equipment that runs on electricity to do everything from regulating humidity in the atmosphere to monitoring the quality of recycled water.

The Ames group started looking at maximizing energy use efficiency and alternative methods to make power on a planet that is millions of miles away from Earth. They turned to a hybrid concept combining two renewable sources: wind and solar power technologies. Large surface temperature swings on Mars produce windy conditions; extreme examples are the frequent dust storms that can block nearly all sunlight. "When there's a dust storm and the wind is blowing, the wind system could be the dominant power source. When the wind is not blowing and the sun is shining on the surface, photovoltaics could be the dominant source," says Bubenheim.

To develop and test the wind power technology, Ames turned to a remote, harsh environment here on Earth: the South Pole. "The South Pole was a really good analog for Mars," says Bubenheim. "The technology features for establishing a human habitat on Mars are very similar to the features needed to make something work at the South Pole."

Around the same time that NASA started investigating energy technologies for the Red Planet, the National Science Foundation (NSF) was working on a redesign of their station at the South Pole. To power its operations, NSF uses fuel that it flies to the remote location, but the Foundation recognized the benefits of also using onsite renewable energy technologies.

"In the winter they have small crews and their power requirements are less," says Bubenheim. "In the summers, they bring in larger groups and photovoltaics could supply the necessary additional power. Using renewable energy technology could be a way of reducing the amount of fuel they have to fly in."

Technology Transfer

To advance wind turbine technology to meet the requirements of extremely harsh environments like that on Mars, Ames partnered with NSF and the Department of Energy. "It was clear that a lot of the same features were also desirable for the cold regions of the Earth," says Bubenheim. "NASA took the leadership on the team because we had the longest-term technology—a Mars turbine."

Years before, NSF had worked with a company called Northern Power Systems (NPS), based in Barre, Vermont, to deploy a 3-kilowatt wind turbine on Black Island off the coast of Antarctica. The main purpose of this turbine was to power communications to the NSF's South Pole station. In 1993, Ames awarded the same company a Small Business Innovation Research (SBIR) contract to construct a similar wind turbine at the South Pole.

Jonathan Lynch, the chief technology officer at NPS, says the South Pole has less wind than Black Island but is significantly colder. "It's hard to have steels that work in those temperatures," he says. "The cold affects the parts and everything gets extremely brittle. We looked at which materials were appropriate for flexible wires, irons, and steels, and what lubrication systems were going to work and for what temperatures over a long period of time."

In 1997, NPS installed a 3-kilowatt turbine at the South Pole, and then began developing a 100-kilowatt turbine that could function in the same extreme conditions. The first prototypes of the larger turbine were successfully deployed in Kotzebue, Alaska and Golden, Colorado. "They were fully tested in loads to make sure

they worked, and we subsequently built them in batches," says Lynch.

By 2000, the wind turbine technology had won an R&D 100 Award from *R&D Magazine*, and since then, says Bubenheim, "It's been duplicated and put in a lot of places around the globe."

Benefits

Thanks to the public-private partnership, Lynch says NPS simplified the overall concepts of the turbine's function so it has few moving parts; improved the serviceability of the turbine by enabling access to the parts from inside the turbine's tower; and used materials including different types of metals, insulation, and fiberglass that can withstand extreme environmental conditions over long periods of time.

"Turbines traditionally have a hard time being employed in Alaska because they would typically freeze up and not work in the winter," says Bubenheim. "Nobody wanted to climb up on the wind turbine and work on it at 40-below zero in the dark."

Today, the NASA-derived NPS turbine is known as the Northern Power 100, and according to the company, the turbine's simplicity is what contributes to its durability in harsh, remote environments. "We designed a simple and elegant machine with as few moving parts as possible, to both minimize and simplify maintenance needs," says Lynch. "We also developed remote communication technology to support a growing fleet of widely distributed machines."

The Northern Power 100 begins generating power with winds as low as 6 mph, and each turbine produces enough energy for 25–30 homes. Over the years, NPS has adjusted the turbine's features to make it applicable for milder climates as well, and the technology has been installed for use in a variety of places, including school and university campuses, residential developments, farms, municipalities, and businesses ranging from candy factories to greenhouses.

Northern Power wind turbines pepper the landscape in Bisaccia, Italy.

Over 200 Northern Power 100s are currently in operation and have accumulated 2.5 million run hours—representing a significant energy savings for customers, and a reduction in carbon emissions of 50,000 tons annually. With a customer base across more than 25 states and 4 countries and a growing sales pipeline, NPS continues to expand the market reach of its turbines.

Currently, Lynch says the largest markets for the Northern Power 100 and its newer Northern Power 60, are in the United Kingdom and Italy. The company is also finding success in the Caribbean and Alaska. "Those are isolated grids where you provide energy that is cheaper than burning diesel," he says.

In the remote Alaskan communities of Kasigluk, Old Kasigluk, and Nunapitchuk, three of the Northern Power 100 turbines are saving $201,000 per year and 45,048 gallons of diesel fuel. The technology is especially valuable in these communities because the turbine's design requires minimal maintenance, a particular advantage for isolated locations.

On the opposite side of the United States, a Northern Power 100 installed at McGlynn elementary and middle school complex in Medford, Massachusetts, is yielding benefits of a different kind: the turbine provides an opportunity for students and teachers to learn about renewable energy technology. In combination with NPS's SmartView web monitoring program, the school tracks energy output, carbon-emission reductions, cost savings, and other historical data. Another installation on the East Coast, a 270-acre ski area at Burke Mountain in East Burke, Vermont, is satisfying approximately 15 percent of the mountain's electricity needs.

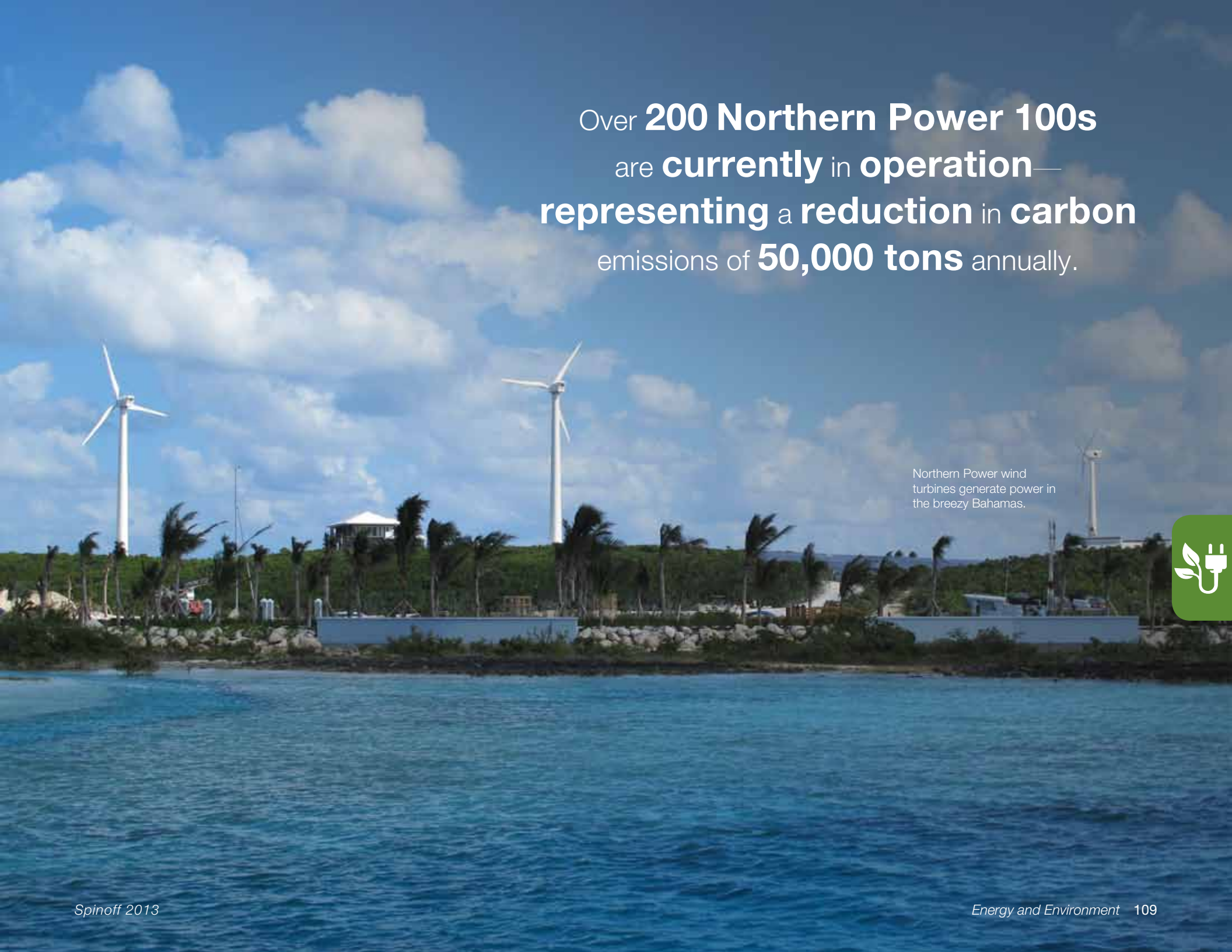
While the turbine has not yet made its way to Mars, Bubenheim says the partnership between NPS and other government entities has produced data and knowledge that NASA is building on for future Mars missions. Plus, thanks to more recent NASA missions to generate new information about the surface of Mars, Bubenheim says, "Now we have much better data and we can map the wind resources better than ever before. This way, we can get a very good idea as to how useful and applicable the wind technology will be."

In the meantime, a technology built for Mars continues to support the demand for clean energy back here on Earth. ❖

SmartView® is registered by Nothern Power Systems.

The Northern Power 100 wind turbine inherited its simplicity and materials, in part, from development efforts with NASA. Today, the Northern Power 100 functions successfully in diverse environments across the country—from Rhode Island (above left) to Alaska (above right).

Over **200 Northern Power 100s** are **currently** in **operation**— **representing** a **reduction** in **carbon** emissions of **50,000 tons** annually.



Northern Power wind turbines generate power in the breezy Bahamas.

Programs Visualize Earth and Space for Interactive Education

NASA's Eyes on the Solar System is a 3-D environment where users can explore the cosmos from their computer. This image is from the Eyes on the Solar System web site.

NASA Technology

Incredible sights are being seen, thanks to the development of technology both inside and outside of NASA. With just a few clicks, NASA's Eyes on the Earth web application lets you see what it's like to fly around Earth with a satellite. A separate program—Eyes on the Solar System—allows you to wander through space and stop at any planet or spacecraft you see. Last but not least, NASA's Eyes on Exoplanets provides a close-up view of the stars and planets inside the Milky Way. No longer do such sights have to come only from your imagination.

It all started in 2004 when Kevin Hussey, the manager of visualization technology applications and development at the Jet Propulsion Laboratory (JPL), was talking to a colleague who wondered, "Wouldn't it be cool if you could ride along with a spacecraft while it's doing its thing—especially if it is in a precarious situation or something noteworthy is going on?"

Fascinated by the idea, Hussey set out to collaborate with others at JPL to produce a prototype in the application programming interface called DirectX 9 to show the orbit insertion of Cassini, the first spacecraft to orbit Saturn, in real time. Soon after, Hussey's team used Unity3D, a game development program for creating interactive video-game style content, to advance the visualization and incorporate interactivity. Upon completion of the Cassini Saturn interactive explorer, Hussey received requests to develop similar programs encompassing all of the spacecraft in orbit around Earth and then all of the spacecraft in the Solar System.

Nearly a decade later, there are now 12 people in Hussey's group creating new ways of seeing what is happening in space and supporting the incredible tools that already exist. And Hussey is ecstatic about the results. "During the Mars Curiosity landing, over a 3-day period, there were approximately 1.2 million visitors to Eyes on the Solar System! During the asteroid DA14 close encounter in 2013, there were more than 350,000 users of Eyes on the Earth and over 84,000 people using Eyes on the Solar System! People are using it all over the world."

One of the many mind-boggling features of the programs is the capability to show real-time progress. Armed with information on the projected path of the spacecraft—what is going to happen and when—Hussey's team uses game engine technology to show what is predicted to happen in real time. "For Curiosity, our real time visualization, which is based on the predicted telemetry, was only .6 seconds early in landing than the real thing," says Hussey. "As people around the world were watching Curiosity touch down, it was less than a second off."

Technology Transfer

After completing Eyes on the Earth in 2008, Hussey was asked to assist in the redesign of an administrative lobby at JPL. His first idea was to use projected imagery to create a visual experience like being in space. He began researching companies online to help his idea come to life when he found Milwaukee, Wisconsin-based The Elumenati.

Hussey contacted the company and spoke with Hilary McVicker, the director of communications at The Elumenati, who explained how the company's domes, projection systems, and software can create immersive environments. Their patented optics fill ultra-wide screens in any shape and size with images, video, and interactive content, from fully-enclosed domes that create planetarium-like experiences to panoramas for simulating flight and exploring planetary surfaces. "Completely surrounding your audience with imagery creates a sense of presence in a virtual world that can't be replicated on a flat screen," says McVicker. "This makes our immersive environments uniquely effective in creating teachable moments, spaces for collaborative dialogue, and a 'wow' factor."

A version of Eyes on the Solar System was licensed by The Elumenati and is now available for use with the company's panorama and dome theaters to create immersive, interactive, educational experiences.

Even though Hussey's lobby project was cancelled, the relationship between JPL and Elumenati continued. Hussey's team worked with the company to rewrite Eyes on the Earth and Eyes on the Solar System using Elumenati's Omnity plugin for Unity3D, which enables interactive display of content on domes and spheres. McVicker says, "Our software performs geometry corrections so the content works on spherical displays. We worked with JPL so their code could be used in this way."

In 2009, the company debuted the Elumenati-adapted NASA program at the annual conference of the Association of Science-Technology Centers. Attendees used a videogame controller to fly through Eyes on the Earth inside an Elumenati GeoDome. "It was a real eye-catching and engaging display that brought people over to interact with our product," says McVicker.

After licensing the programs from JPL, Elumenati began offering its version to existing and potential customers. "More than 30 clients are using our GeoDome network for collaborative Earth and space science education in our immersive environments, and the network continues to grow. It was a perfect fit and a great way to get Eyes on the Earth and Solar System into wide use," says McVicker.

While Elumenati shares the benefits of NASA technology, NASA also benefits from Elumenati technology. JPL became the third NASA center, behind Goddard Space Flight Center and Marshall Space Flight Center, to purchase an Elumenati GeoDome for showing educational content. In fact, Goddard brought their GeoDome to the White House lawn in 2009 as part of the International Year of Astronomy celebration.

Benefits

The Elumenati officially launched the dome-enabled Eyes on the Earth and Solar System as a product in 2012. The markets for the software include schools, museums, science centers, and other institutions providing Earth and space science education. Inside the Elumenati GeoDome, people can explore data from NASA missions while surrounded by dynamic imagery. Using interactive controls, they can navigate to planets, asteroids, or satellites, and choose their speed through space and time. They can also launch "tours" curated by NASA staff.

Before the official product launch, the company included the NASA content in its Science Panorama at the grand opening of the North Carolina Museum of Natural Science's Nature Research Center. The responses were "Ooohs" and "Ahhs," says McVicker. "People are always excited to fly through space and see missions happening in real time. When you take this cool data and put it into a giant 28-foot screen like the one in North Carolina, you are surrounded by space, and you are driving the space ship."

One of the company's initial customers for the Eyes product was the School of Earth and Space Exploration at Arizona State University, in their 12-foot panoramic screen with a touchscreen interface. "Products based on real NASA data give us new dynamic tools to add to our product line," says McVicker. "This helps our clients realize their goals, and grows our business at the same time."

As part of the rollout, Elumenati GeoDome network clients will begin to incorporate the Eyes on the Earth and Solar System product for public engagement and professional development, starting with the 13 installations in the Minnesota Regional Planetarium Network.

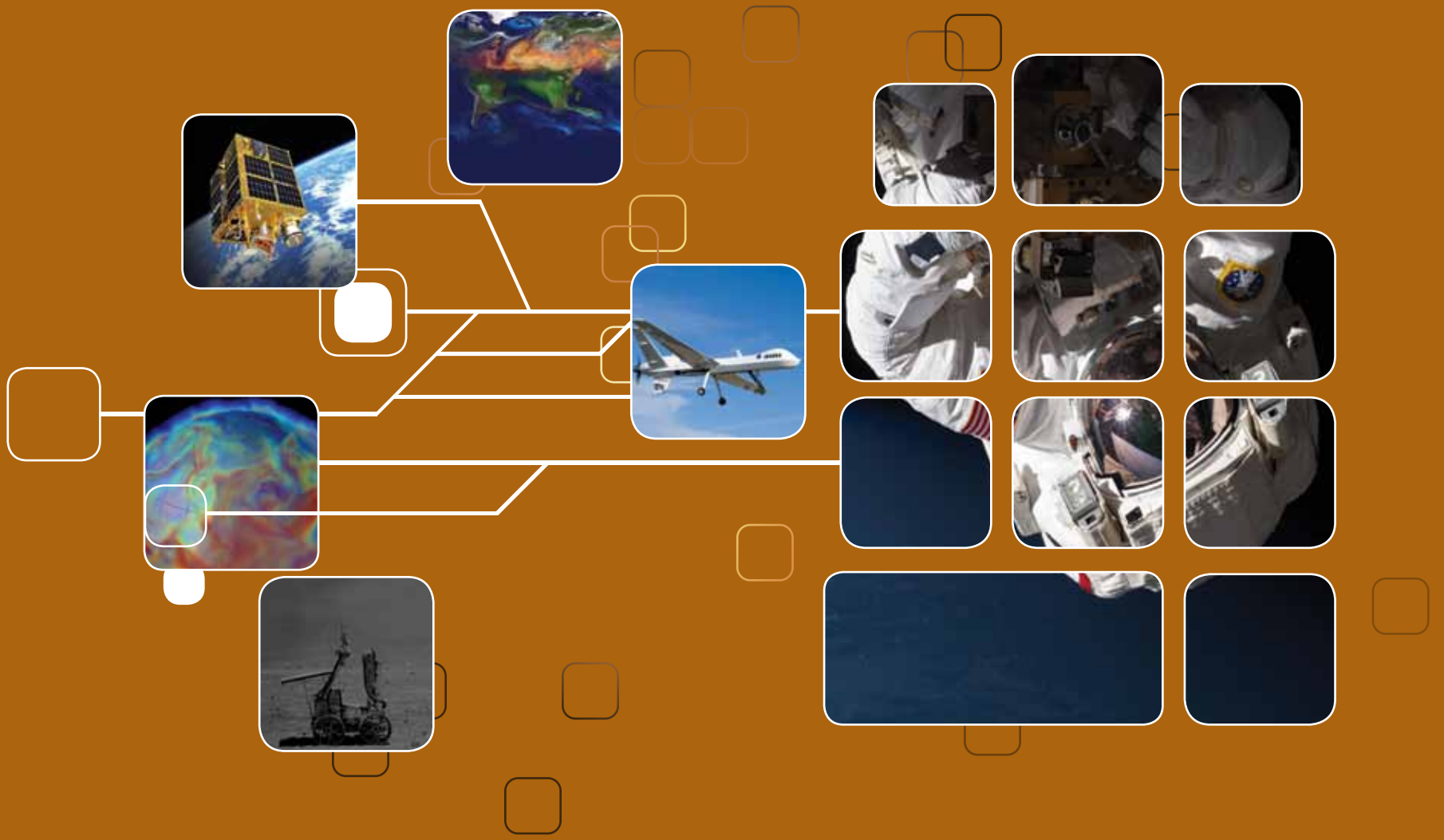
"Our relationship with NASA has been extremely beneficial," says McVicker. "Our clients leverage our expertise in creating immersive environments to tell stories based on NASA data, which really gets audiences excited about science in their lives. And hopefully, this gets younger audiences inspired to pursue careers in science in the field."

And that leaves us in a space where we can only imagine: What will we possibly see next? ❖

Information Technology

Powerful computing technology drives many of NASA's most ambitious missions. Many of the tools developed to support research in space can be found in private cloud-computing networks, electronic components for satellites and other spacecraft, and sensors that monitor important machinery. Spinoffs featured in this section:

- Reduce Satellite Construction Costs
- Accelerate Computing Time for Complex Math
- Prevent Signal Interference on Spacecraft
- Simplify the Sharing of Numerical Models
- Control Remote Devices
- Monitor Equipment Health



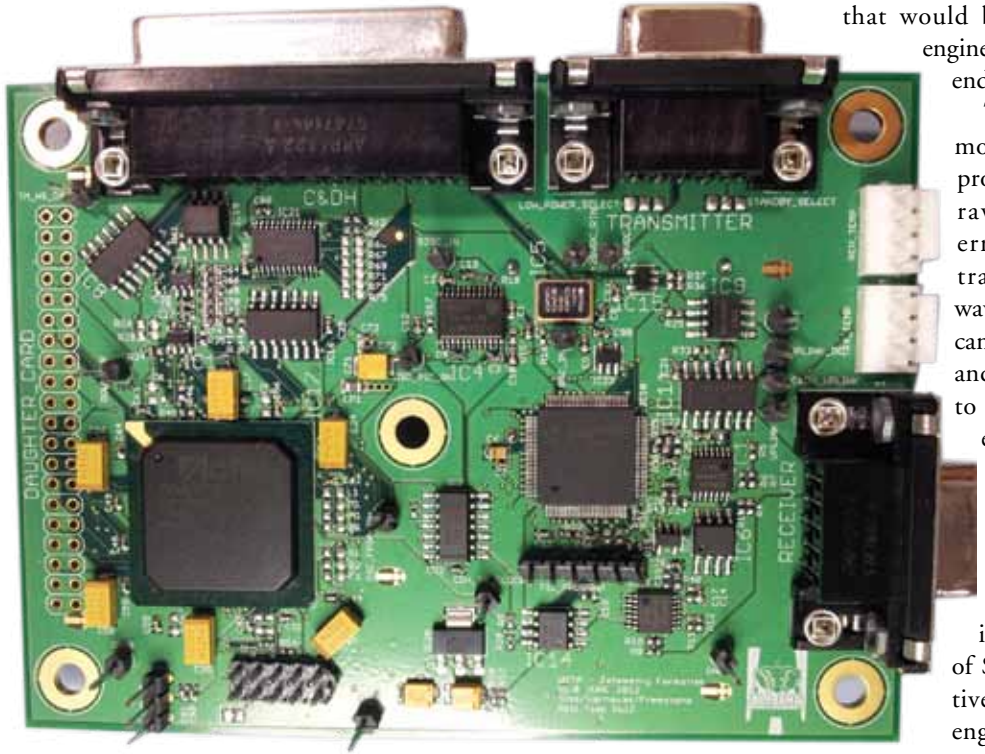
Processor Units Reduce Satellite Construction Costs

NASA Technology

In December 2008, NASA's Marshall Space Flight Center entered into an agreement with the Department of Defense and the Van Braun Center for Space Innovation to develop the Fast Affordable Science and Technology Satellite (FASTSAT). The satellite was designed to show that within 2 years it was possible to build a small, low-cost platform, launchable on any available rocket, that could successfully carry out experiments in space and return data back to Earth.

In a market where a single satellite can cost upwards of several hundreds of millions of dollars to build, constructing one that was constrained by a $4 million budget required reconfiguring and redesigning many components. One such piece was the telemetry module—a computer processor that plays a critical role in relaying information to and from a satellite and its receiving ground station.

A telemetry module can best be described as the flight computer's full-time interpreter. The flight computer is the satellite's "brain" and is tasked with carrying out any and all spacecraft functions, including handling power consumption and initiating and controlling experiments. But the way it communicates both internally and externally is through transmitting raw data—an error-prone, unformatted jumble of information that would be highly burdensome for engineers to process at the receiving end on Earth.



Orbital Telemetry's eponymous satellite component, which serves as a "translator" between the flight computer and the ground station, is a cost-effective alternative to traditional models.

That's where the telemetry module comes into play: The processor encodes all outgoing raw data into a special, error-corrected protocol—transmitted through radio waves—that the ground station can use. It also works in reverse and converts the protocol sent to space back into raw data, enabling the flight computer to receive instructions in its language.

Such an important piece of equipment was mandatory for the FASTSAT, but its commercial sticker price of $1 million was cost prohibitive. Instead, NASA electrical engineers Kosta Varnavas and Herb Sims constructed their own telemetry module by using commercial, radiation-hardened parts. They also modernized the electronics system with a simpler, more durable design. Its quality construction was confirmed when the washing-machine-sized, 400-pound FASTSAT launched from Alaska in November 2010 and the telemetry unit, along with the rest of the satellite, worked seamlessly.

In fact, its performance exceeded expectations. NASA extended its original yearlong mission—to prove that such a satellite could successfully carry out the six separate experiments it was equipped with—by an additional year.

Technology Transfer

In the Fall of 2011, as the FASTSAT was approaching its first anniversary of successful operation in low-Earth orbit, former NASA mechanical engineer Bruce Weddendorf had lunch with Varnavas, his old colleague. They had worked together on a number of missions involving sounding rockets, telescopes, and balloon flights. Weddendorf was still a consultant for the Agency, but in addition to owning his own design company, he was also an entrepreneur always on the lookout for the next hot idea.

When Varnavas explained his work developing the affordable but high-quality telemetry module, it got the wheels turning in Weddendorf's head. He recalled the rise in the use of satellite constellations, or a coordinated group of satellites that circle the Earth in low orbit. Each spacecraft monitors a section of the earth and works in tandem with other satellites to provide worldwide coverage for a variety of applications. This is in stark contrast to the larger geostationary satellites, which are positioned farther away from the Earth and, as a consequence, can provide global coverage with only two or three spacecraft.

One major advantage with using a constellation is that, if one satellite were to malfunction, the other satellites could compensate for the loss since their territories overlap. "I started thinking, this is the way the future is going," Weddendorf says. "This telemetry unit had a lot of market potential."

In April 2012 Weddendorf, as a result of working with Sammy Nabors from Marshall's Technology Transfer Office, entered into an exclusive licensing agreement with NASA to sell the technology and soon after founded Hunstville, Alabama-based Orbital Telemetry Inc.

Benefits

According to Weddendorf, the rise in the use of satellite constellations poses a challenge to companies, because the cost of installing the older model telemetry units in each of what can amount to dozens of satellites quickly becomes expensive even by aerospace standards. "If you're doing a constellation of 30 satellites in low-Earth orbit, suddenly a million dollars a telemetry module per satellite is just crazy," Weddendorf says.

Instead, Orbital Telemetry can provide NASA-developed units at a fraction of the price. The same manufacturer who built the FASTSAT unit also produces the commercial units, and as a part of the Space Act Agreement reached with the Agency, Marshall engineers test the model afterward to make sure it meets a customer's specifications and is reliable enough to launch into space. With his background in mechanical engineering, Weddendorf can also customize the casing. In other words, he can see the process through from beginning to end.

"All the customer has to do is hook it up to their flight computer and the radio inside their satellite, and they're ready to launch," he says.

Varnavas believes there's a lot of potential in the telemetry unit, as he sees the market exploding for cheap but reliably built satellites like the FASTSAT, which concluded its operations in November 2012 after 2 successful years in orbit. "We try to keep our eyes open for any competition out there to see if there is anything comparable," he says, "and we're convinced that there will be a huge demand for this technology now and in the years ahead." ❖

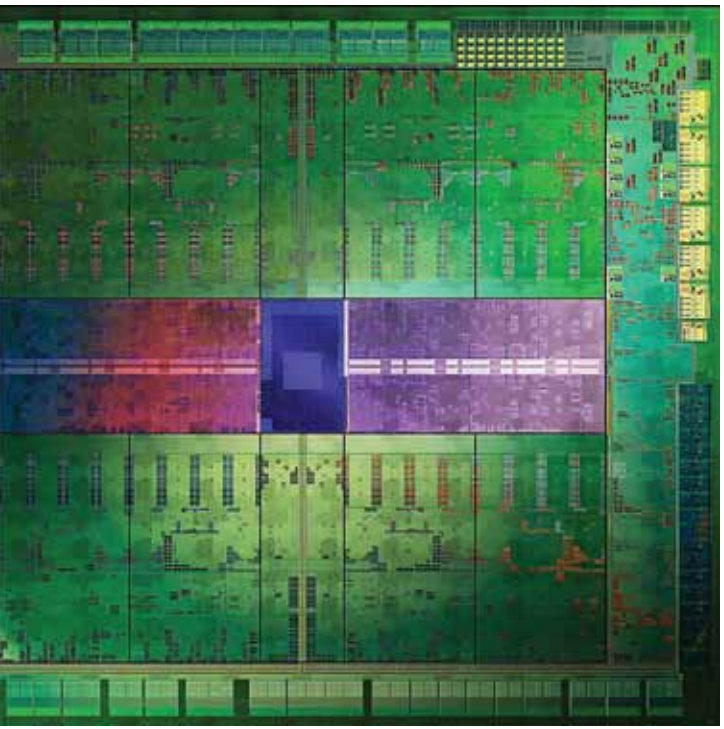
The Fast Affordable Science and Technology Satellite (FASTSAT) was launched in 2010 to prove that a small, low-cost platform could successfully execute experiments in space. The NASA-developed telemetry unit used in FASTSAT saved the mission hundreds of thousands of dollars.

Software Accelerates Computing Time for Complex Math

NASA Technology

The 19th century mathematician Carl Friedrich Gauss, the astronomer par excellence of his day, called mathematics "the queen of the sciences." If Gauss were alive now, he would likely marvel at the kinds of scientific breakthroughs and insights NASA scientists are now achieving through a number-crunching technology that was not possible during his time.

Our advantage in the modern age is the supercomputer: a souped-up, multiprocessor machine capable of churning out calculations at the rate of billions, trillions, or even quadrillions of operations per second. (The technical term used for these calculations is floating-point operations per second, or FLOPS.)



NVIDIA's GeForce GTX 680 consists of 3.54 billion transistors.

With nearly 100 active missions, NASA has no shortage of data, and the Agency is always looking for ways to better process and manage the results of its scientific endeavors. NASA has even built one of the world's most powerful supercomputers at Ames Research Center, Pleiades, which allows researchers to comb through vast swaths of data and model everything from the interaction of atoms to the formation of entire galaxies.

While supercomputers are the thoroughbreds of the processing world, not all scientists have access to such machines, which can cost hundreds of millions of dollars to build and millions more per year in maintenance and electric bills. For some, their only recourse is a desktop or laptop, whose FLOPS performance is often massively lower than its supercomputer counterpart. The same calculation that takes a supercomputer a day or two to solve could very well take a standard PC over a month to complete.

One company caught NASA's attention by finding a way to connect ordinary scientists and ordinary machines with extraordinary processing power. Doing so would give the Agency access to a new technology, allowing researchers to complete some projects locally on their PCs rather than calling on the Pleiades supercomputer to do the same job remotely.

Technology Transfer

If you've played a video game lately on a console or a computer, you've probably noticed how lifelike and smooth the graphics appear. The industry has come a long way since the days of Pong, and a crucial moment in its development was brought about by the invention in the late 1990s of what's called a graphics processing unit (GPU)—an electronic chip that can accelerate the processing of a massive number of computations at an astonishing speed.

GPU accelerators are critical to creating the realism of today's video games, as they not only perform the vector calculations needed to accelerate the rendering of millions of triangles, which in combination comprise the images seen on a screen, but also do so at a rate of 60 times per second. The result is real-time action. But beyond ushering in a new era of electronic entertainment, the new technology also meant there was now a faster way of solving scientific problems that utilized parallel computing, a kind of super computing which, like video game graphics rendering, functions by solving a great many calculations simultaneously.

One of the first companies to recognize the potential applications for GPUs other than delivering video game graphics was Newark, Delaware-based EM Photonics Inc., a company that specializes in high-performance computing software. In the mid-2000s they began to develop code designed not for graphics rendering but for solving complex algorithms used in the modeling of antennas and optical devices. But programming GPUs at first, according to EM Photonics CEO Eric Kelmelis, was not easy.

"The hardware was initially designed for rendering graphics," he says, "so you made it think it was rendering graphics. But in truth, it was doing a scientific computing operation for you—running an equation."

That all changed in 2006, when NVIDIA, the company that invented GPUs, released the CUDA parallel computing platform and programming model to make developing software for the powerful processor chip more user friendly.

With the added ease of use provided by the CUDA platform, EM Photonics set its sights on completing an ambitious, first-of-its-kind project: programming a family of GPU-accelerated linear algebra libraries, including an implementation of the de facto industry standard LAPACK. These solvers often have to deal with an enormous amount of data, and traditional versions require supercomputers in order to run in a timely manner. Moving these tools to GPU accelerators was the kind of innovation that could benefit scientists who use laptops or desktops to run these solvers.

A portrait of global aerosols at a 10-kilometer resolution, simulated by the Goddard Earth Observing System Model (GEOS-5) on NASA's Discover supercomputer. The GEOS-5 is capable of simulating worldwide weather at resolutions of 10 to 3.5 kilometers.

To accomplish its goal, the company applied for Small Business Innovation Research (SBIR) funding, which Ames granted to them. NASA researchers, like other scientists, are constantly running linear algebra equations to accomplish mission objectives. Says NASA computer scientist Creon Levitt, who sat on the evaluation committee, "There was an obvious utility in having this kind of software, and nobody else was doing it. EM Photonics had the appropriate background in related technologies, so it seemed quite likely that they could pull it off."

It is clear by now that he was right. In 2007 the company's programmers cracked their knuckles and got to work. In August 2009 the CULA Dense package was commercially released.

Benefits

Running CULA Dense on a regular computer can be compared to accessing higher gears on a car—gears that you never knew existed. That's because, before CULA Dense arrived, a scientist's computer would run LAPACK solvers on its central processing unit (CPU). While CPUs are more adept at solving sequential problems, or problems that each require step-by-step processes, they are not as fast and efficient as GPUs when programmed for parallel computing, especially when it involves using localized data.

EM Photonics, in creating CULA Dense, removed that formidable programming barrier, providing a simple and accessible tool for solving these types of problems that any scientist without computer expertise could use.

According to Henry Jin, a researcher in the supercomputing division at NASA Ames, the difference in aggregate calculating power between the two chips is staggering. "A modern CPU can give you about 20 gigaflops at its peak," he says. "A single GPU accelerator can easily give you up to one teraflop, so that's a thousand gigaflops. So from the FLOPS point of view, there is a big advantage with GPUs."

Put another way, it means that CULA Dense can solve parallel calculations, on average, 6 to 10 times faster than CPU-based LAPACK applications. In some cases, processing times are reduced by more than 100-fold. The same projects that used to take weeks to complete now take days; those that took days are now processed in hours. Whether it's modeling the interactions between distant galaxies or simulating a model fighter jet landing on an aircraft carrier, performing complex algorithms on a personal computer has never been faster.

In the 3 years since the software has been on the market, CULA Dense has acquired more than 12,000 users working in government agencies, the private sector, and academic institutions all over the world. Even Titan, the fastest supercomputer in the world as of November 2012, which is housed at Oak Ridge National Laboratory in Tennessee, runs the application to increase its already astronomical computing speed.

Kelmelis notes that, as a result of the product's success, both revenues and the number of company employees are up by 10 percent. And through a separate SBIR contract with Ames, EM Photonics more recently developed and commercialized another library of linear algebra solvers called CULA Sparse, which provides scientists with a further assortment of mathematical tools that have access to GPU processing power.

According to NVIDIA's general manager of GPU computing software, Ian Buck, "The success of solvers like CULA demonstrates the broad applicability of GPUs to address a range of scientific challenges. Today there are hundreds of CUDA-based applications in use around the world to enable new breakthroughs in everything from brain tumor and HIV/AIDS research, to the search for cleaner, renewable energy."

Regarding the company's collaboration with NASA, Kelmelis says, "It helped us launch into a whole new product area. In the past we were very special-purpose-application focused, but CULA has allowed us to reach a much broader audience and deliver on some very advanced technology." ❖

Simulation Tools Prevent Signal Interference on Spacecraft

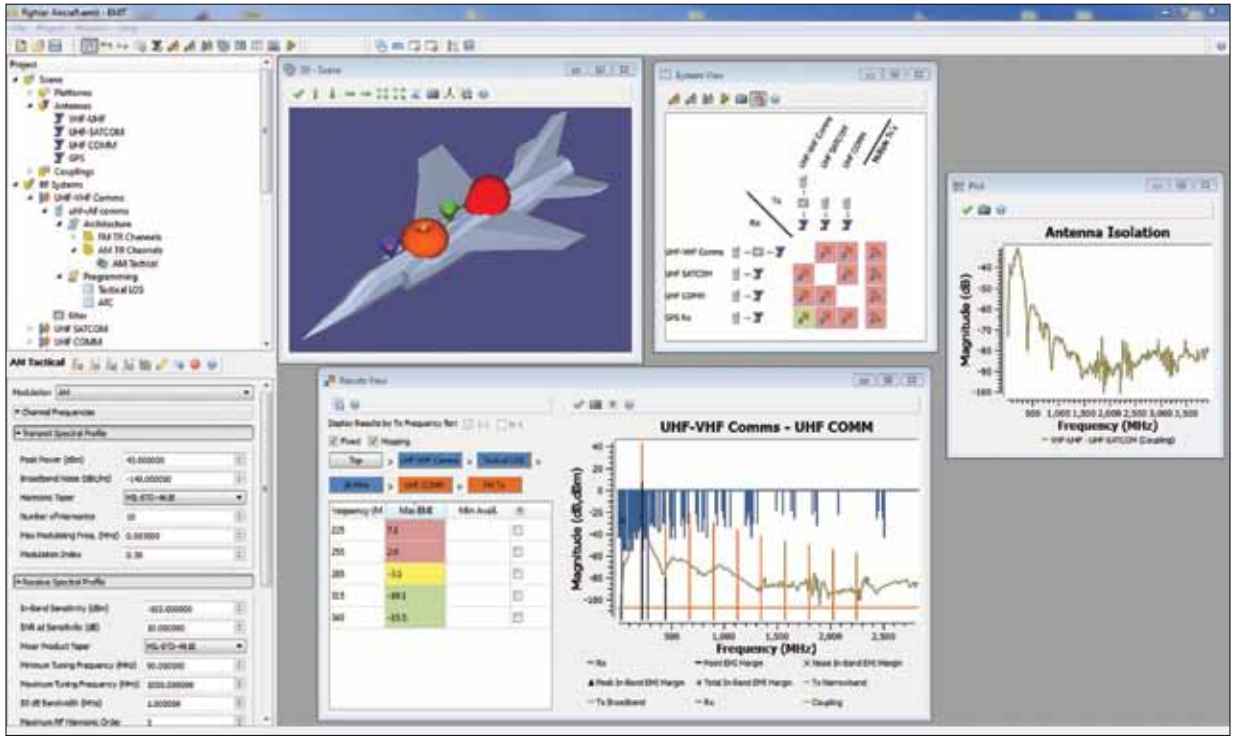
NASA Technology

Launching a satellite into space requires painstaking preparation, not only to make sure that a multitude of technologies are functioning, but also to ensure that critical components are working together in unison. A great example: the communication systems onboard satellites and the rockets used to launch them.

A number of receivers and transmitters are installed into both satellites and rockets so that engineers on Earth can use radio signals to track and control their every movement and function and troubleshoot problems that may arise during ascent. Once securely in orbit, satellites also send data back to Earth for telecommunications and scientific research.

But having a smorgasbord of equipment sending and receiving radio signals within close proximity causes cosite interference: transmitters meddle with the signals being sent to receiving systems, preventing critical communications from reaching their desired targets. If the signal interference is severe enough, a launch mission could fail. So before installing radio frequency (RF) systems, NASA engineers use simulation software to analyze and correct for any interference that would occur between a satellite and its launch rocket. They also analyze other RF systems near the launchpad, such as antenna towers and radars, which may also interfere with data transmission.

If the simulator detects the potential for any interference, various measures can be implemented to correct for it. For one, technicians could move antennas to different areas of the spacecraft to reduce the inter-system coupling. Engineers can also engage in frequency planning, which means carefully coordinating when each system operates on specific channels, thereby lessening the chance of interference between devices.



Delcross' EMIT interference simulation software analyzes for cosite interference between different radio frequency systems.

Because there are many systems at play in any launch, and because they all need to be accounted for, staging a computer simulation can be tedious and time-consuming. In the past it was even more painstaking because, in many cases, specifications for each RF system had to be manually inputted before running each individual analysis. That is, until engineers at the Launch Services Program at Kennedy Space Center collaborated with the private sector to customize software that would streamline the work.

Technology Transfer

In March 2012 Kennedy entered into a Small Business Innovation Research (SBIR) contract with Champaign, Illinois-based Delcross Technologies LLC to enhance the company's EMIT interference simulation software by developing a more robust library of RF systems.

The company had already created such a library for EMIT, which allows users to simply drag and drop whichever equipment is being considered for a rocket and satellite. Once all the prospective RF systems are in place, the software assesses whether there is any potential for interference between components. With the new contract, the goal was to increase the number of equipment items to choose from by adding a number of key systems of particular interest to NASA engineers, which would further lessen the amount of time needed to manually input specifications into the program.

Filling out the library, says Dr. Fred German, the company's lead strategist for product development and senior scientist, was accomplished by tapping every publicly available source for all the data parameters needed, such as start and stop frequencies and channel spacing,

to identify specific radios. “We’ve become quite adept at ferreting data out,” he says.

They were so adept that by January 2013, Delcross completed the contract, having added hundreds of RF system specifications to the EMIT library.

Having a more robust library, says Kennedy flight analyst Dr. Gabriel Vazquez, will be an enormous help to the Launch Services Program. “Once you have some experience with the software, it can help tremendously,” he says. “And another thing that gives EMIT a lot of potential is that it takes into account harmonics magnitudes and other factors that aren’t always taken into account during a quick intermodulation analysis.”

Vazquez also stresses that, throughout the project, NASA never divulged any third-party or proprietary information for any of the RF systems it had on hand. “We only provided Delcross with the make and model of the transmitters and receivers, and they worked with what they had,” he says. “And in our opinion they succeeded in getting enough relevant information for the successful completion of the SBIR objectives.”

Benefits

For Delcross Technologies, the collaboration has also been a success. Since the new library was introduced, sales to the US military, telecommunications companies, and other outfits whose success depends on clear radio transmission signals, have increased. German says it is because creating the RF system models is one of the biggest bottlenecks in using a simulation program like EMIT. The database developed under the project goes a long way to removing that bottleneck by providing ready-to-go models, which can shave days off the analysis time.

Sometimes it takes a partnership with an agency like NASA to move a technology forward. “Support for the continued development of EMIT allows Delcross to maintain a strong team of developers to ensure the ongoing improvement to future releases of EMIT,” German says. “Without these collaborations, Delcross would not be able to maintain the development team necessary to ensure regular, high-quality releases of our software tools.” ❖

EMIT™ is a trademark of Delcross Technologies LLC.

NASA uses interference simulation software to prepare for launches. Here, NASA's Mars Science Laboratory spacecraft, sealed inside its payload fairing atop the United Launch Alliance Atlas V rocket, launches from Cape Canaveral Air Force Station in Florida.

Software Simplifies the Sharing of Numerical Models

NASA Technology

Scientists at NASA not only focus on advancing space exploration; they study what is happening in the Earth's atmosphere as well. The Global Climate Modeling program at Goddard Space Flight Center's Institute for Space Studies, for instance, is tasked primarily with developing paired atmosphere-ocean models that simulate Earth's climate system when influenced by a variety of variables, including greenhouse gases, aerosols, and solar effects. Given how critical this work is, NASA frequently shares its models and simulations with graduate students and other researchers outside the Agency. But the traditional way that this has been done—by sending the code to the recipient to deploy on his or her own computer—is fraught with potential problems.

The two main issues, configuration and reproducibility, both stem from the fact that computers perform differently. First of all, configuring complex modeling software correctly is challenging, even for experts, especially on platforms different than those on which the code has been built and tested. New users of such models must often resort to asking model developers for help, which is inefficient for everyone involved. Second, differences between computing platforms can cause outcome discrepancies and prevent numerical simulations from being accurately reproduced. In a simulation-driven field like climatology, reproducibility of results is critical for scientific integrity.

"Climate models are plagued by discrepancies like these because they're so delicate," says NASA Program Manager Michael Seablom. "Any little numerical discrepancy will grow and grow as the forecast model runs. So it is important to have the same computing environment wherever possible."

And that's what the space agency was looking for: a technology that made possible the seamless sharing and reproducibility of models and simulations by running them as web-accessible services.

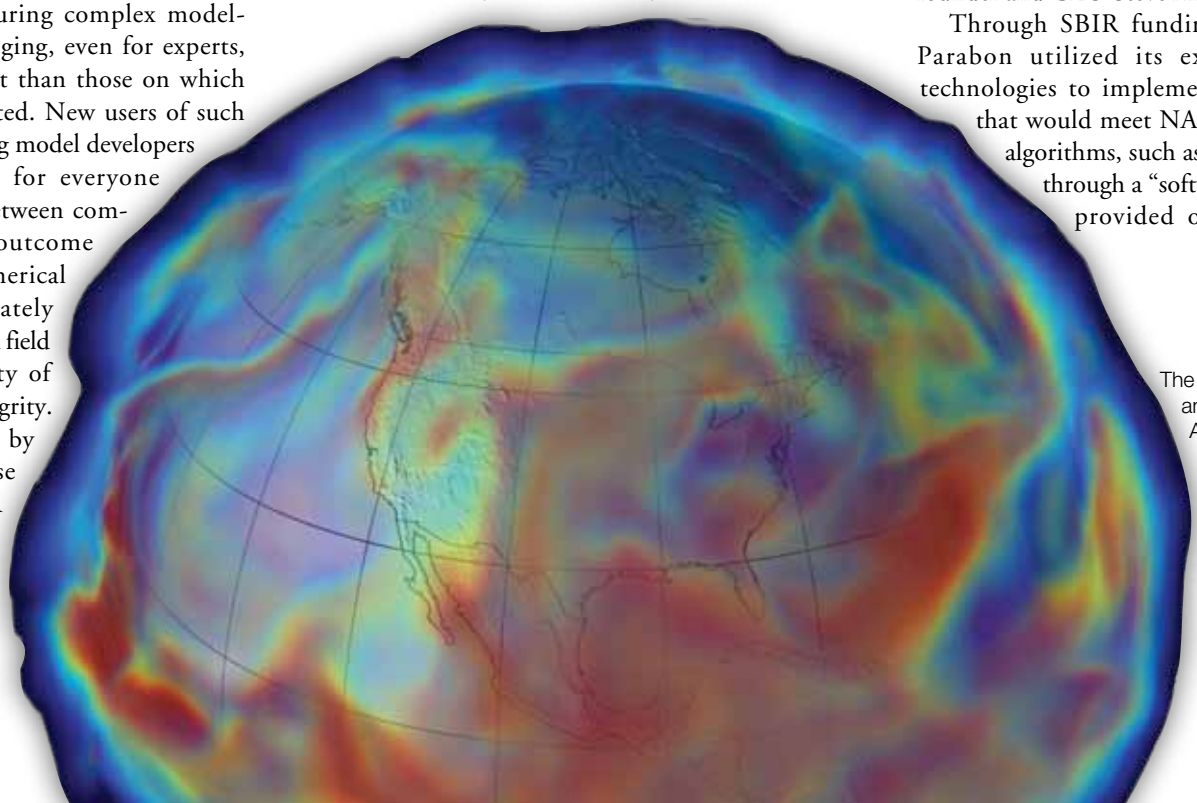
Technology Transfer

Answering that call was Reston, Virginia-based Parabon Computation Inc. Founded in 1999, the company is known for its Frontier Compute Platform, a distributed software environment that allows customers to access high-performance computing (HPC) as a service. HPC calculations can be utilized for many types of applications, such as models and simulations, data mining, financial forecasting, and code decryption. Many fields of science utilize HPC capacity, including bioinformatics, nanotechnology, robotics, genome sequence processing, and climatology.

> "Now students can simply go to a web page to set up and run these models, carry out experiments, and edit portions of the code."
>
> —Michael Seablom, Goddard Space Flight Center

The Frontier Compute Platform is essentially a cloud computing system, specialized for HPC-scale processing, that aggregates the processing capacity of both dedicated and idle computers within a network to run complex calculations. "What Frontier is doing, basically, is allowing any computer within a company or organization to work on pieces of HPC problems when they're not otherwise being used," says Parabon Computation's founder and CEO Steve Armentrout.

Through SBIR funding from Goddard in 2009, Parabon utilized its expertise with cloud-based technologies to implement a software infrastructure that would meet NASA's needs: the ability to run algorithms, such as the Agency's climate models, through a "software as a service" environment provided over the Internet. In other



The Modern Era Retrospective-analysis for Research and Applications at Goddard Space Flight Center is producing a comprehensive record of Earth's weather and climate from 1979 up to the present. This visualization depicts specific atmospheric humidity on June 17, 1993, during the Great Flood that hit the Midwestern United States.

words, NASA researchers, and those they share their work with, can access NASA's computing power using any standard web browser.

"Now students can simply go to a web page to set up and run these models, carry out experiments, and edit portions of the code," NASA's Seablom says. "This new approach really makes things easier for everyone." And seeing that it could apply its new software tools to more than just climate simulations, Parabon commercialized the result of its NASA work as the Frontier Collaborative Online Development Environment (Frontier CODE).

Benefits

As with any service provided over the Internet, the primary advantage of web access for end users is that it keeps them from having to acquire and install the entire software package and run it on his or her machine. In place of these individual installations, a central server—whose hardware can execute all the idiosyncrasies inherent in that particular set of code—is responsible for carrying out all of the processing, ensuring that the simulations are more reliable and less error prone.

The result is an application that runs smoothly and makes life easier both for model developers and those who use their code. "The modelers don't have to spend an inordinate amount of time troubleshooting end users' problems," Armentrout says. "An application can stand on its own, and people can access it as they need to."

Adding to the simplicity provided by Frontier CODE is the ease with which users can interact and collaborate. Using Frontier's collaboration environment, scientists can adapt models, share code repositories and wikis, and initiate trouble ticketing systems, which are all requirements of what Armentrout calls "a code-centric community."

Further enabling that community is Frontier CODE's ability to accommodate different operating systems by providing the option to use so-called "virtual machines" to perform scientific calculations. For example, if someone uses a Windows operating system, but a certain model they're working with only runs on Linux, Frontier can invoke a software version of a Linux computer within Windows to run the model. This means that all types of computers, from laptops to Linux clusters, can lend their processing power for any computation.

The NASA Center for Climate Simulation Data Exploration Theater features a 17-by-6-foot multi-screen visualization wall for engaging visitors and scientists with high-definition movies of simulation results. Here, the wall displays a 3.5-kilometer-resolution global simulation that captures numerous cloud types at groundbreaking fidelity. Parabon Computation's Frontier Collaborative Online Development Environment, or Frontier CODE, can facilitate both in the development and processing of such a simulation.

As the company's NASA-funded product continues to roll out into the market, Armentrout says those same industries that have used the Frontier Compute Platform—financial sectors, oil and gas companies, and biotechnology and nanotechnology firms—will be interested in using the software-as-a-service capabilities as well, because of how much easier it is for scientists to collaborate with each other and form code-centric communities. "Frontier has a unique set of features in an easy-to-use, tightly integrated package," Armentrout says, "and it's ideal for any group that's tackling big science problems."

As for his company's collaboration with NASA, he couldn't be any more pleased. "NASA had a need for this technology and our software development team delivered," he says. "The result is a great commercial product that's going to make a positive impact for us and our customers. It's a win-win situation." ❖

Virtual Machine Language Controls Remote Devices

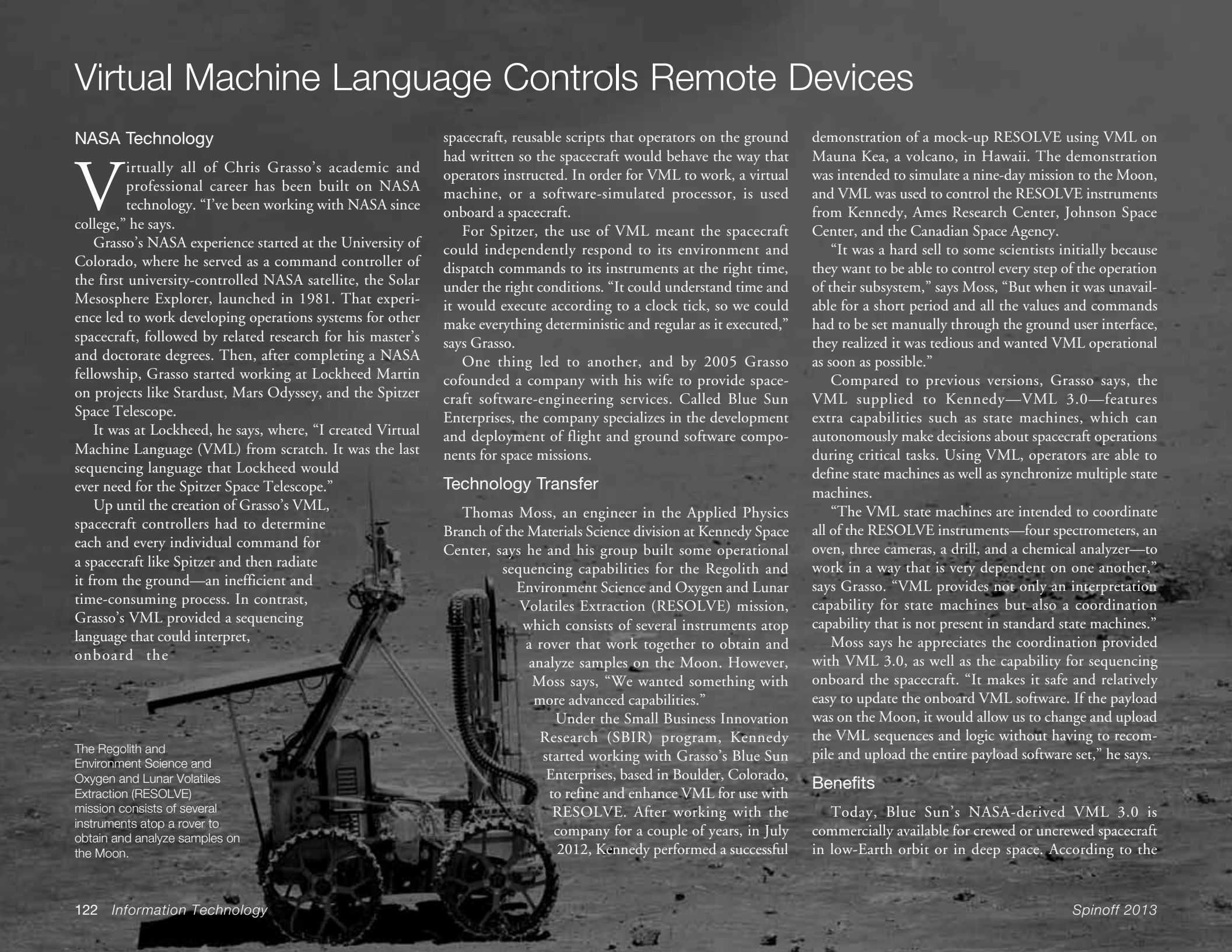
NASA Technology

Virtually all of Chris Grasso's academic and professional career has been built on NASA technology. "I've been working with NASA since college," he says.

Grasso's NASA experience started at the University of Colorado, where he served as a command controller of the first university-controlled NASA satellite, the Solar Mesosphere Explorer, launched in 1981. That experience led to work developing operations systems for other spacecraft, followed by related research for his master's and doctorate degrees. Then, after completing a NASA fellowship, Grasso started working at Lockheed Martin on projects like Stardust, Mars Odyssey, and the Spitzer Space Telescope.

It was at Lockheed, he says, where, "I created Virtual Machine Language (VML) from scratch. It was the last sequencing language that Lockheed would ever need for the Spitzer Space Telescope."

Up until the creation of Grasso's VML, spacecraft controllers had to determine each and every individual command for a spacecraft like Spitzer and then radiate it from the ground—an inefficient and time-consuming process. In contrast, Grasso's VML provided a sequencing language that could interpret, onboard the spacecraft, reusable scripts that operators on the ground had written so the spacecraft would behave the way that operators instructed. In order for VML to work, a virtual machine, or a software-simulated processor, is used onboard a spacecraft.



The Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction (RESOLVE) mission consists of several instruments atop a rover to obtain and analyze samples on the Moon.

For Spitzer, the use of VML meant the spacecraft could independently respond to its environment and dispatch commands to its instruments at the right time, under the right conditions. "It could understand time and it would execute according to a clock tick, so we could make everything deterministic and regular as it executed," says Grasso.

One thing led to another, and by 2005 Grasso cofounded a company with his wife to provide spacecraft software-engineering services. Called Blue Sun Enterprises, the company specializes in the development and deployment of flight and ground software components for space missions.

Technology Transfer

Thomas Moss, an engineer in the Applied Physics Branch of the Materials Science division at Kennedy Space Center, says he and his group built some operational sequencing capabilities for the Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction (RESOLVE) mission, which consists of several instruments atop a rover that work together to obtain and analyze samples on the Moon. However, Moss says, "We wanted something with more advanced capabilities."

Under the Small Business Innovation Research (SBIR) program, Kennedy started working with Grasso's Blue Sun Enterprises, based in Boulder, Colorado, to refine and enhance VML for use with RESOLVE. After working with the company for a couple of years, in July 2012, Kennedy performed a successful demonstration of a mock-up RESOLVE using VML on Mauna Kea, a volcano, in Hawaii. The demonstration was intended to simulate a nine-day mission to the Moon, and VML was used to control the RESOLVE instruments from Kennedy, Ames Research Center, Johnson Space Center, and the Canadian Space Agency.

"It was a hard sell to some scientists initially because they want to be able to control every step of the operation of their subsystem," says Moss, "But when it was unavailable for a short period and all the values and commands had to be set manually through the ground user interface, they realized it was tedious and wanted VML operational as soon as possible."

Compared to previous versions, Grasso says, the VML supplied to Kennedy—VML 3.0—features extra capabilities such as state machines, which can autonomously make decisions about spacecraft operations during critical tasks. Using VML, operators are able to define state machines as well as synchronize multiple state machines.

"The VML state machines are intended to coordinate all of the RESOLVE instruments—four spectrometers, an oven, three cameras, a drill, and a chemical analyzer—to work in a way that is very dependent on one another," says Grasso. "VML provides not only an interpretation capability for state machines but also a coordination capability that is not present in standard state machines."

Moss says he appreciates the coordination provided with VML 3.0, as well as the capability for sequencing onboard the spacecraft. "It makes it safe and relatively easy to update the onboard VML software. If the payload was on the Moon, it would allow us to change and upload the VML sequences and logic without having to recompile and upload the entire payload software set," he says.

Benefits

Today, Blue Sun's NASA-derived VML 3.0 is commercially available for crewed or uncrewed spacecraft in low-Earth orbit or in deep space. According to the

company, the technology provides operational cost reductions for spacecraft by carrying out autonomous actions instead of relying on instructions relayed from the ground.

By using VML, Grasso says operations technicians can now perform many of the tasks that flight software engineers typically perform because the product can interpret the scripts that operators compile. Plus, the VML sequences are easier to develop than flight software, and relatively smaller and safer. "We provide an easy-to-write language for the operators," says Grasso.

Currently, Red Canyon Software of Denver, Colorado is using VML 3.0 in an SBIR project for spacecraft automation to perform the interpretation of the automation scripts running on state machines. VML 3.0 is also part of a recently released Phase II SBIR technology demonstration for the Reactive Rendezvous and Docking System (RRDS), overseen by the Jet Propulsion Laboratory. RRDS is a technology that will enable autonomous retrieval of an orbiting sample canister around Mars. VML 3.0 may also be used in conjunction with JPL's AutoNav spacecraft navigation technology development for the autonomous navigation necessary to visit a comet or asteroid.

Meanwhile, back at Kennedy, Moss says VML is playing a significant role in the RESOLVE payload operations as part of the Resource Prospector mission. "We are becoming more dependent on it for our flight design. It is managing the payload software and how the payload functions. VML is key to the payload's mission success."

In the future, Grasso sees potential applications with various remote systems including those in the air, underwater, or on land. Specifically, these could include unmanned aerial vehicles, remote sensing devices, and autonomous vehicles like submarines, weather balloons, and telescopes. "Any application that requires remote autonomy could use VML to implement that autonomy and decision-making," he says.

Grasso says he is extremely appreciative for his career built on NASA technology. "Working with NASA has been the driving force for our company," he says. "It has given us an opportunity to have a substantial impact on space operations." ❖

Kennedy Space Center worked with Blue Sun Enterprises to refine and enhance the company's virtual machine language (VML) to control the instruments on RESOLVE. Now the NASA-improved VML is commercially available for crewed and uncrewed spacecraft, and has potential future applications on remote systems such as weather balloons, unmanned aerial vehicles, and submarines.

Micro-Accelerometers Monitor Equipment Health

NASA Technology

Objects that orbit the Earth, such as the International Space Station (ISS), provide a unique environment called zero-g, or more correctly, microgravity. All objects in orbit are pulled by Earth's gravity, but they achieve the lack of gravity when they move at just the right speed (in the case of the ISS, around 17,500 miles per hour) so that the curve of their fall matches the curve of the Earth. The result is a perpetual free fall, creating weightlessness.

Scientists at NASA perform a host of experiments in microgravity in order to ascertain the effects of gravity on biological, chemical, and physical systems. For example, biotechnology research in space has focused on protein crystal growth to see how cells interact with one another, and combustion experiments examine how weightlessness affects the processes of ignition, flame spreading, and flame extinction. Researchers have even gleaned insight into how dangerous pathogens, such as *Salmonella* bacteria (the infamous food-poisoning agent) spread and thrive upon entering the human body.

But even in space, objects are not always free from gravitational effects. Acceleration forces, brought about by anything from performing orbital maneuvers and firing thrusters to opening and closing pumps, will cause a spacecraft to vibrate, causing small accelerations. These disturbances affect the microgravity environment. Despite their very low magnitudes, such vibrations may affect experiment outcomes. Protein crystals may uncharacteristically branch off into different directions; in flame propagation, fires may burn unevenly.

NASA astronaut Karen Nyberg conducts a session with the Capillary Flow Experiment—designed to observe the flow of fluid, in particular capillary phenomena, in microgravity—in the Harmony node of the International Space Station. Accelerometers onboard measure slight gravitational disturbances, which, if left unaccounted for, can skew experiment outcomes.

> "Evigia [shrunk] the low-frequency accelerometer from a device the size of a desk telephone or tabletop to a microchip the size of a dime.

To measure these forces, devices called accelerometers are kept onboard to measure them. A traditional accelerometer contains a suspended round or cube proof mass. When the proof mass is excited and tries to move, the magnetic forces that suspend the mass increase and decrease to hold it in place. The current required to hold the mass in place is used to calculate the proportionate force. The forces are matched up with a log of documented actions performed on the spacecraft in a given period, allowing scientists to attribute inconsistent results to acceleration blips.

The drawback to these accelerometers is that they're large and bulky—ranging from the size of a small desk telephone to a tabletop—and also very expensive, sometimes costing hundreds of thousands of dollars. NASA wanted access to accelerometers that were smaller, lighter, and more cost-effective. "Every time you reduce your payload by a pound, you're reducing the cost of flying these instruments," said Bill Foster, an engineer at Glenn Research Center. "And because this is a support instrument and not the main science, you really want to have it be as small as possible."

Technology Transfer

The space agency's call was answered by Ann Arbor, Michigan-based Evigia Systems. Founded in 2004, the company specializes in developing wireless sensing and tracking technologies. In 2005, Glenn awarded Evigia Systems Small Business Innovation Research (SBIR) funding to develop an accelerometer based on microelectromechanical systems (MEMS) technology.

In describing MEMS technology, one should just think of very, very small machines. Components in these devices measure between 1 and 100 micrometers, or between 1- and 100-millionths of a meter. So when Evigia transformed the technology, it did so drastically, shrinking the low-frequency accelerometer from a device the size of a desk telephone or tabletop to a microchip the size of a dime. That meant that the enclosed proof mass was also made much, much smaller.

But shrinking that proof mass also necessitated that the sensor technology be that much more sensitive. "As soon as you start reducing its size, you're losing the amount of gravitational force that you're picking up," said Navid Yazdi, founder and president of Evigia Systems. The company compensated for that by placing the sensors closer to the proof mass, allowing them to perceive its movements more accurately. At the same time, the microchip's compact design stabilized the measurements against sensor drift, which can cause errors in the readings.

While it's evident that the MEMS accelerometer is considerably smaller and lighter than its traditional counterpart, the cost savings are also substantial: They are produced for less than $1,000 each. It's because the device is manufactured in a similar fashion to the integrated circuit chips that are used to run computers and cell phones. "We are able to place our sensors on top of these chips, which have become inexpensive to make because of the economies of scale," says Yazdi. "You can build many units at the same time, which cuts down on costs."

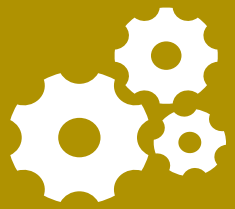
Evigia's line of prognostic sensors, which incorporate NASA-funded technology, are used to monitor the performance of industrial equipment like the machinery used in this automotive plant.

Benefits

While NASA hasn't yet integrated the MEMS accelerometers on the ISS or other spacecraft, Evigia Systems has transferred technical knowledge gained from the partnership to its commercial products. For instance, the company uses a lower-fidelity version of the accelerometer in its line of prognostic sensors, which are designed to monitor the integrity of industrial machinery by keeping track of various data, such as vibration (which uses the accelerometer technology), temperature, humidity, and mechanical shock. Sales from these products have led to the hiring of 5 employees, and Yazdi expects to hire 30 more in the next 5 years.

Meanwhile, the company has also been working in collaboration with other government agencies to advance the technology. Through a contract with the Air Force, Evigia Systems added a gyroscope component to function alongside the accelerometer, resulting in an instrument capable of improving the navigation of air and space vehicles and robotic devices. The Department of Defense is also now working with the company to develop the technology even further.

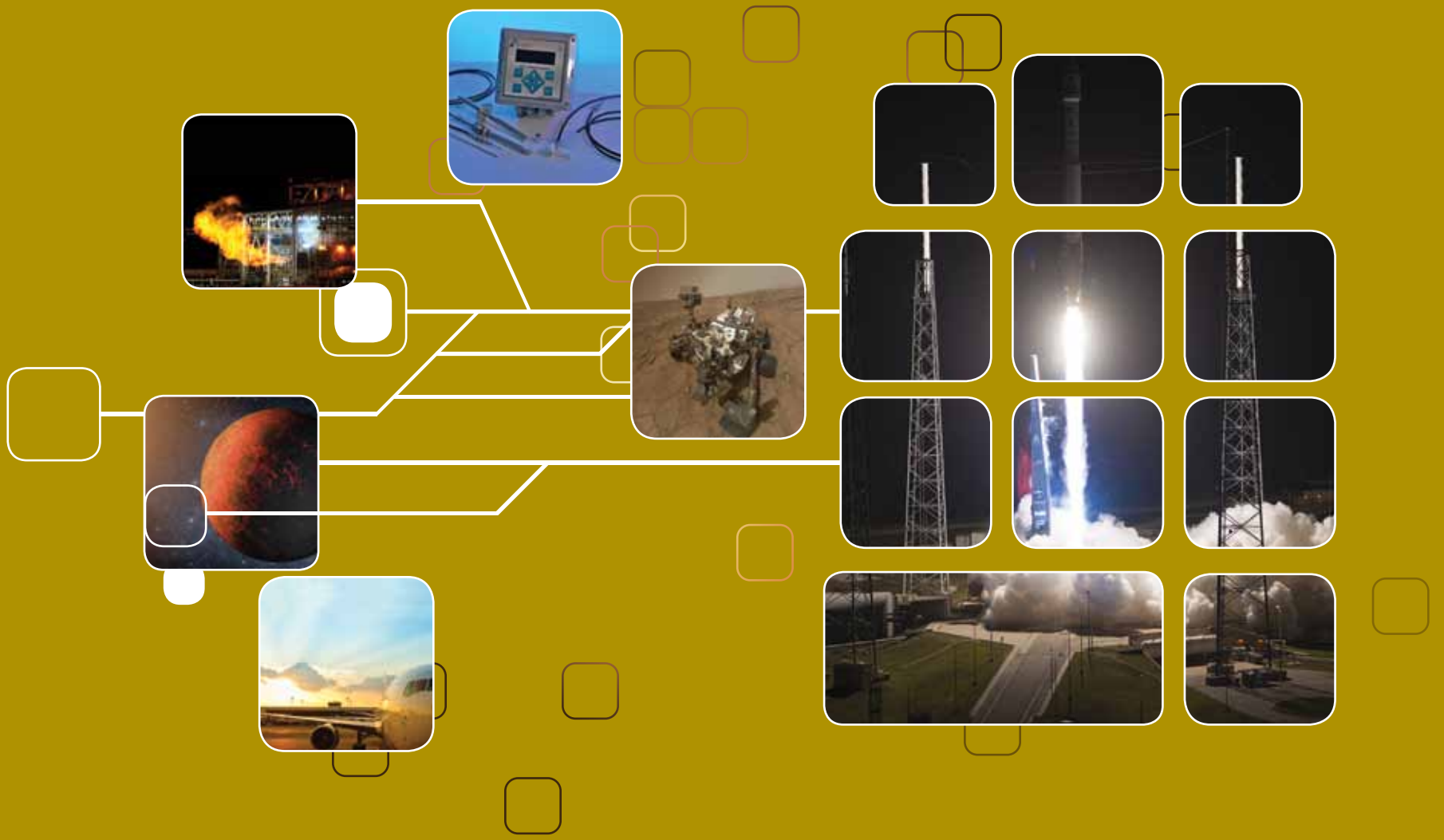
Yazdi says that the company's partnerships with NASA and other agencies has been very beneficial because they have allowed Evigia Systems the opportunity to develop technologies that are risky and solve very specific, challenging problems. Once matured, these technologies can be incorporated into new and improved products for the public. "Without these initial public-private partnerships, a lot of these innovations will not leave the labs," he says. "They will stay here and not even get off the ground, much less to the market." ❖



Industrial Productivity

When faced with unprecedented challenges, NASA literally builds its own future, leading to advances in manufacturing. Many of these have gone on to improve our Nation's industrial capacity, including cryogenic testing devices, smarter sensors, precision machining, and more. Spinoffs featured in this section:

- Save Energy, Costs for Hydrogen Production
- Monitor Spacecraft Integrity to Prevent Failures
- Garner Data on Insulation Performance
- Gather Information for Machine Diagnostics
- Monitor Bioreactors and Ensure Health and Safety
- Catch Defects in Screen Displays
- Capture Exoplanet Data, Reflect Lasers



Reactors Save Energy, Costs for Hydrogen Production

NASA Technology

When flying, do you ever wonder how the electronics—lights, air vents, or WiFi—continue to function as you glide across the sky? Commercial aircraft supply their own power with batteries; auxiliary power units (APUs, or small engines); and large jet engines.

To save energy and reduce pollution, NASA's Glenn Research Center examined alternative methods of producing electricity—including fuel cells—onboard commercial aircraft in the early 2000s. APUs are traditionally powered by jet fuel to generate electricity, but Glenn turned to fuel cell APUs, which use hydrogen and oxygen instead. By using fuel cells, the Center estimated a 2-hour commercial flight could save 20 percent on energy.

In looking at fuel cell technology, Glenn also had to look at fuel reforming technology. A fuel reformer uses fuel, air, steam, and a catalyst (reactor), to produce hydrogen for the fuel cell to make electricity. For Glenn's purposes, the reformer needed to be small, lightweight, and capable of reforming jet fuel to produce hydrogen and carbon monoxide.

Thomas Tomsik, an engineer in the fluid systems branch at Glenn, recalls the work. "When you compared the fuel cell power source versus the current APU, it reduced emissions during taxi, boarding, and while the aircraft was being serviced. Contemporary APUs continuously burn jet fuel, but if you can convert and use hydrogen as a source, it's cleaner and quieter."

These catalytic reforming technologies have been studied by Glenn not only for onboard generation of auxiliary power but for other mobile applications as well.

Technology Transfer

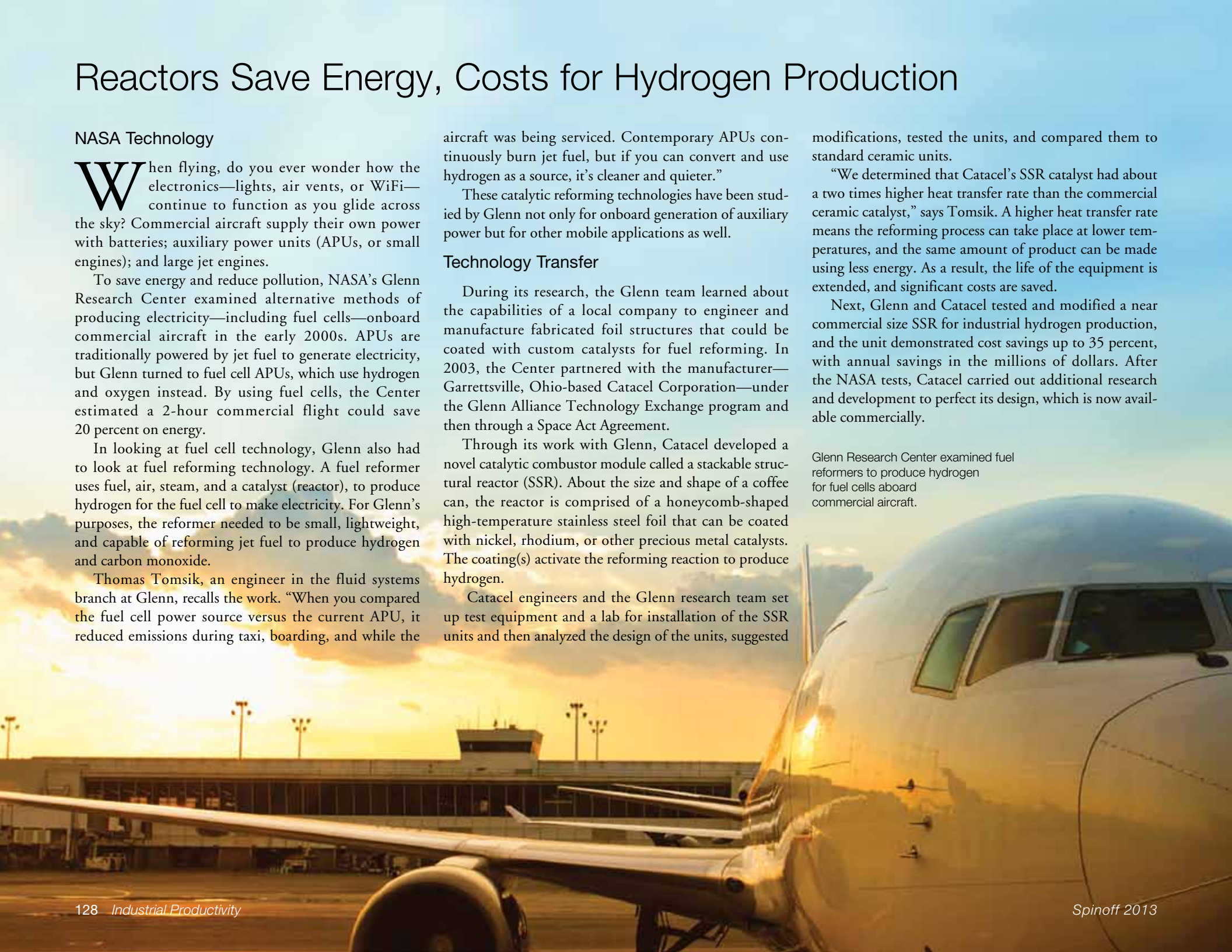
During its research, the Glenn team learned about the capabilities of a local company to engineer and manufacture fabricated foil structures that could be coated with custom catalysts for fuel reforming. In 2003, the Center partnered with the manufacturer—Garrettsville, Ohio-based Catacel Corporation—under the Glenn Alliance Technology Exchange program and then through a Space Act Agreement.

Through its work with Glenn, Catacel developed a novel catalytic combustor module called a stackable structural reactor (SSR). About the size and shape of a coffee can, the reactor is comprised of a honeycomb-shaped high-temperature stainless steel foil that can be coated with nickel, rhodium, or other precious metal catalysts. The coating(s) activate the reforming reaction to produce hydrogen.

Catacel engineers and the Glenn research team set up test equipment and a lab for installation of the SSR units and then analyzed the design of the units, suggested modifications, tested the units, and compared them to standard ceramic units.

"We determined that Catacel's SSR catalyst had about a two times higher heat transfer rate than the commercial ceramic catalyst," says Tomsik. A higher heat transfer rate means the reforming process can take place at lower temperatures, and the same amount of product can be made using less energy. As a result, the life of the equipment is extended, and significant costs are saved.

Next, Glenn and Catacel tested and modified a near commercial size SSR for industrial hydrogen production, and the unit demonstrated cost savings up to 35 percent, with annual savings in the millions of dollars. After the NASA tests, Catacel carried out additional research and development to perfect its design, which is now available commercially.



Glenn Research Center examined fuel reformers to produce hydrogen for fuel cells aboard commercial aircraft.

> “Government agencies enable industry to innovate and incubate big ideas that they could not possibly approach on their own.”
>
> –Don Lensner, Catacel Corporation

Benefits

In 2008, Catacel installed the first commercial version of the NASA spinoff SSR in a hydrogen production plant in Turkey to supply hydrogen for a steel mill. As of 2012, the early-version SSR was continuing to perform just as well as traditional catalytic technology. According to Catacel, the life of the SSR is expected to be as long as the life of the industrial plant in which it is used.

In 2012, a food oils processing plant in Mexico installed Catacel’s newest version of the SSR for hydrogen production. The plant requires large amounts of hydrogen to make sorbitol, a food ingredient, out of corn. According to Catacel, the plant saw an immediate 13.5 percent natural gas cost reduction after installing the technology, which increased to a nearly 30 percent fuel reduction when the plant was run at typical production rates. Thanks to the savings, the plant expects to see a return on its investment in less than 3 years.

Don Lensner, the manager of sales and marketing at Catacel, says the results are impressive. “That plant is producing the same amount of hydrogen as it did before, but using 30 percent less combustion fuel. When you turn down your burners by 30 percent, there’s a significant environmental and economic benefit,” he says.

Lensner believes the SSR will enable new efficiency in commercial hydrogen production across the world in the petrochemical, steel, food, silicon chip, glass, ammonia, and methanol industries.

On average, the technology results in energy savings of about 20 percent. It also enables longer lifetimes for the equipment as well as capital cost savings in new plant designs. “The coating technology is where the heart of our intellectual property is. Our coatings exist under very severe, heavy-duty cycles over long periods of time,” says Lensner.

In the future, the same technology could potentially be used for carbon capture, explains Lensner. Instead of using catalysts to promote a reaction, the coating would contain materials to absorb carbon. Catacel is currently working with the Department of Energy on this application.

As Lensner says, “Government agencies enable industry to innovate and incubate big ideas that they could not possibly approach on their own. They have enabled so many companies, like Catacel, to get involved with the building blocks of new technology.”

The next time you fly, remember how NASA spinoff technology is saving energy—not only for industrial processes but for the Nation as a whole. ❖

The stackable structural reactor (SSR) shown on the right, was installed in 2012 at a food oils processing plant in Mexico for hydrogen production to make sorbitol. Thanks to the SSRs, the plant is producing the same amount of hydrogen as it previously did, but using 30 percent less fuel.

Cameras Monitor Spacecraft Integrity to Prevent Failures

NASA Technology

Is there—or was there ever—life on Mars? In August 2012 NASA's Curiosity rover touched down on the surface of Mars in an attempt to answer what has become one of modern science's most burning questions.

In preparation for such an endeavor, the rover had to be equipped with the latest technologies, one of which was a set of high quality, radiation-hardened cameras able to capture sharp, vibrant images of the Martian terrain time and time again. Scientists at the Mars Science Laboratory (MSL) mission use the cameras as their "eyes" to survey the landscape, guide the rover's movement, and select rock and soil samples for further investigation.

To develop these critical components, the Jet Propulsion Laboratory entered into a contract with San Diego, California-based Malin Space Science Systems Inc. (MSSS), a small, privately owned company with big experience providing camera equipment for space missions.

The ECAM imaging system is an off-the-shelf, cost-effective method of monitoring a spacecraft's performance from Earth. Cameras can also be custom-built to meet the needs of the customer.

Technology Transfer

Since its founding in 1990, MSSS has collaborated with NASA on a number of Agency missions, starting with developing and operating the ground data system of the Mars Observer Camera (MOC), which launched in 1992. When the MOC was rebuilt for use on the Mars Global Surveyor in 1996, the company oversaw the camera's operations for the next decade. In the mid-1990s MSSS also began developing smaller, more modular camera systems for other spacecraft such as the Mars Climate Orbiter and the Mars Polar Lander.

When NASA put the call out for a firm to develop Curiosity's cameras in 2004, the company once again stepped up and set about developing imagers that were both compact and cutting edge, mainly by implementing the latest technology used on consumer digital cameras. For MSSS, that meant installing focusable lenses in some of the cameras. It also meant using sensors with Bayer Pattern Filters for applying color to the imagery: compared to traditional filter wheels, these filters require less work and take up less data volume to transmit back to Earth.

By the time Curiosity launched in November 2011, the company had successfully fulfilled its contract and had equipped the car-sized rover with four cameras that would help scientists retrieve clues that would shed some light on the Red Planet's natural history.

The images retrieved have since become part of both NASA and national lore. The Mars Descent Imager (MARDI)—purposed with orienting the spacecraft during its early operations—recorded the now famous video of the rover's nerve-racking landing inside Gale Crater. The two Mast Cameras (Mastcams for short), which are mounted on a mast extending from Curiosity's deck and charged with capturing the expansive Martian terrain in varying focal lengths, have revealed the dry and mountainous majesty of its landscape. The Mars Handheld Lens Imager (MAHLI)—capable of zooming in on features thinner than the diameter of a human hair—has sent the internet abuzz with images that keep people guessing as to what they might be.

In short, the cameras are performing well. "The hardware is working great, and the internal software, the controls, and the camera are all working well," says Jeff Simmonds, the MSL payload manager who oversaw the cameras' development. "And they're taking images that are helping the science team do their science."

Leveraging the experience gained in designing Curiosity's cameras, combined with years of developing cameras for other space missions, MSSS has commercialized an affordable, off-the-shelf imaging system called ECAM that is meant to help in another way: by monitoring spacecraft functionality. Comprised of four cameras and a Digital Video Recorder (DVR) that serves as a central processing unit, the system is designed for installation onto satellites in order to probe and troubleshoot any issues that may arise in orbit.

Benefits

According to Michael Ravine, MSSS's advanced projects manager, there is a big potential benefit in having the ECAM system installed onboard a spacecraft. He says there were some missions where, during a malfunction, if engineers back on Earth had been able to view images of the satellite, they would have been able to diagnose and

"The images retrieved have since become part of both NASA and national lore.

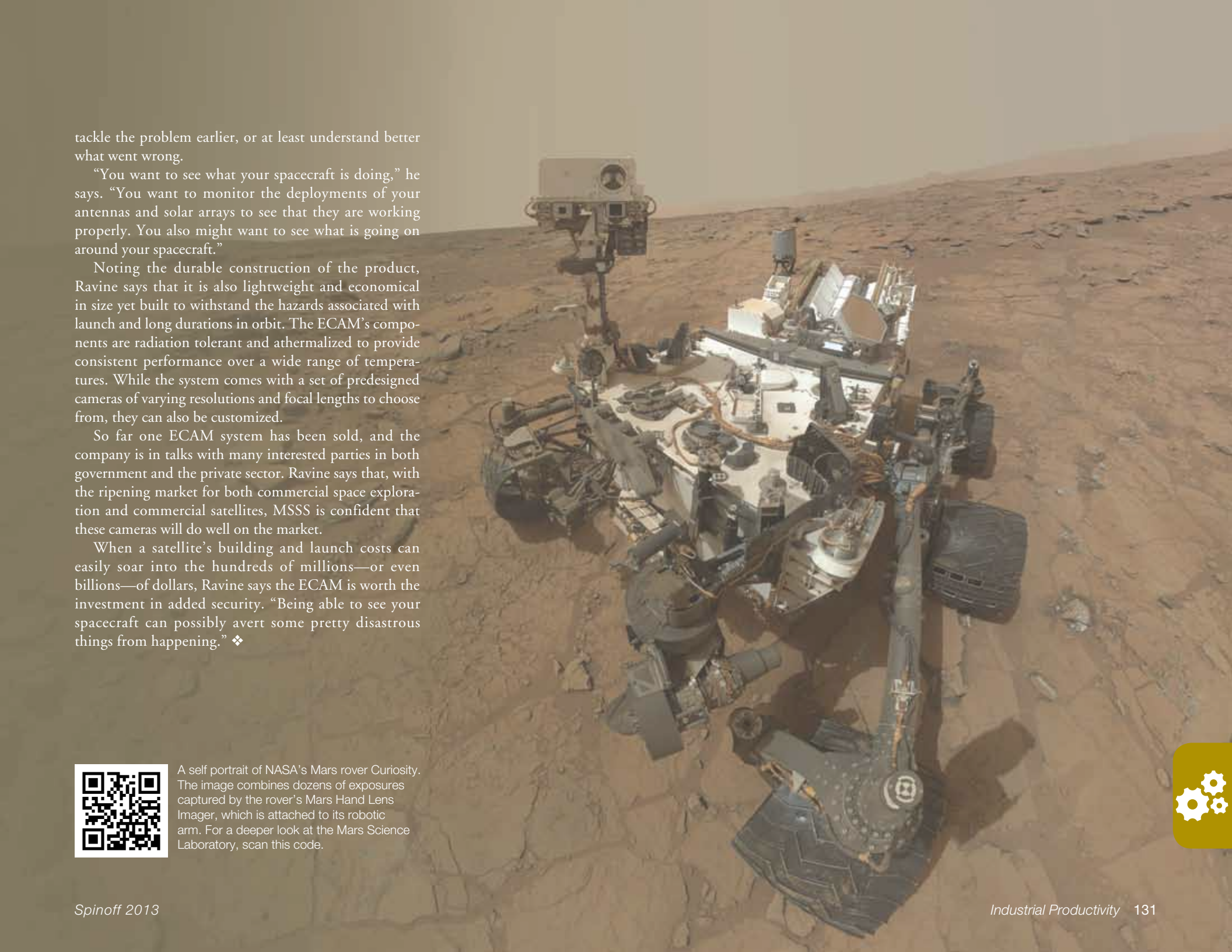
tackle the problem earlier, or at least understand better what went wrong.

"You want to see what your spacecraft is doing," he says. "You want to monitor the deployments of your antennas and solar arrays to see that they are working properly. You also might want to see what is going on around your spacecraft."

Noting the durable construction of the product, Ravine says that it is also lightweight and economical in size yet built to withstand the hazards associated with launch and long durations in orbit. The ECAM's components are radiation tolerant and athermalized to provide consistent performance over a wide range of temperatures. While the system comes with a set of predesigned cameras of varying resolutions and focal lengths to choose from, they can also be customized.

So far one ECAM system has been sold, and the company is in talks with many interested parties in both government and the private sector. Ravine says that, with the ripening market for both commercial space exploration and commercial satellites, MSSS is confident that these cameras will do well on the market.

When a satellite's building and launch costs can easily soar into the hundreds of millions—or even billions—of dollars, Ravine says the ECAM is worth the investment in added security. "Being able to see your spacecraft can possibly avert some pretty disastrous things from happening." ❖



A self portrait of NASA's Mars rover Curiosity. The image combines dozens of exposures captured by the rover's Mars Hand Lens Imager, which is attached to its robotic arm. For a deeper look at the Mars Science Laboratory, scan this code.

Testing Devices Garner Data on Insulation Performance

Kennedy Space Center's Wayne Heckle fills a cryostat instrument, developed at the Cryogenics Test Laboratory at Kennedy, with liquid nitrogen. The cryostat instrument tests the thermal performance of insulation materials in a standard, repeatable way.

NASA Technology

Whether you wanted to know how certain insulation would work on a Mars-bound spacecraft or on an Earth-based refrigerator, you would want to test its performance in the very same way: accurately. At least that is how James Fesmire, senior principal investigator of the Cryogenics Test Laboratory at NASA's Kennedy Space Center, sees it. "If you don't have accurate data, you have nothing," he says.

"When we talk about cryogenic tanks and deep spacecraft protection, we can easily talk about hot water heaters and engine compartments for NASCAR at the same time," he says. "Heat goes from the hot side to the cold side. It's the same energy on Earth or in space and that heat always goes in the same direction."

For Fesmire, the accuracy of the technique used for evaluating insulation is at least as important as what the insulation is used for. In the 1990s, while working on the idea of a flexible aerogel, a NASA-derived high-performance insulation material (*Spinoff* 2010), Fesmire's team was at a loss: they didn't have an effective way to verify its performance. "We realized there wasn't anything to test the stuff," he says. "The machines we used didn't have the sensitivity to get meaningful results under the right conditions."

Together with a team at Kennedy's lab, the origin of the future Cryogenics Test Laboratory, Fesmire began developing a test instrument that could garner measurements of the true thermal performance of aerogel insulation as well as other types of insulation under extreme conditions. "We made it really simple," he says. "We didn't invent boil off calorimetry, but we incorporated it into a standardized instrument that anybody can use."

The test instrument uses a cold cryogenic fluid, which boils at a very low temperature, inside a cylindrical chamber. Surrounding the cryogenic chamber is another cylindrical, vacuum environment container. The test material is placed around the cold chamber, and as heat from the outer vacuum container passes through the insulation to the inner container, it causes the fluid to boil. The rate of boil off, or how much liquid is vaporized, is directly related to the insulating performance of the test material.

Through many years in the development process, the team encountered a number of challenges that they had to address, including how to control the environmental conditions, how to maintain a special stability of the cryogenic liquid, and how to ensure the insulation inside the enclosures was installed the same way for each test.

Putting their heads together, the group overcame each one of the issues. The result was Cryostat 1, an absolute thermal measurement instrument that proved capable of testing any insulation material that the team threw at it. This instrument quickly led to a simplified, comparative-type instrument named Cryostat 2, which was complimentary to the Cryostat 1. Over time, the Cryostat 1 and the rest of the Cryostat family became a cornerstone capability for the laboratory. "Now," says Fesmire, "thermal properties can be measured in a standard, repeatable way for both practical and extreme applications."

Technology Transfer

In 2010, the Cryostat 2 (now called Cryostat 200) was being used for testing under a Space Act Agreement with a private industrial materials manufacturing company, which showed interest in acquiring the technology for use in its own business. At the same time, a private aerospace company expressed interest in having its own test capability for product development and certifications. A contractor at Kennedy—McLean, Virginia-based QinetiQ North America (QinetiQ NA)—saw a business opportunity and soon applied for a license to make and sell one of several versions of the NASA Cryostat that was developed over the last two decades.

As Fesmire describes, "The Cryostat 200 is the simplest of the cryostats to operate. The cost and design

> As cryogenic technologies advance, energy needs grow and efficiency standards increase. Reliable, precise, and versatile testing devices will be required."
>
> —Jeff Kohler, QinetiQ NA

make it reasonable and affordable, which is why we are beginning to license and sell those first."

Benefits

According to Jeff Kohler, a business manager for QinetiQ NA, only a handful of manufacturers offer testing devices focused on insulation for extreme temperatures, and of those, none are equipped to handle the low temperature ranges like the Cryostat 200. More important, most current equipment cannot handle the higher performance materials and systems that are now beginning to proliferate in industry. "As cryogenic technologies advance, energy needs grow and efficiency standards increase. Reliable, precise, and versatile testing devices will be required," he says.

While QinetiQ NA already sees interest from companies that want to purchase the NASA-licensed technology, including the original company that used it under the Space Act Agreement, Kohler says the technology will initially attract aerospace and energy customers. The company plans to market the technology to organizations doing research and development for new materials for industrial and medical uses, as well as new product development for things like piping and storage tank insulation, appliances, and consumer goods.

Another likely application, describes Kohler, is to test insulation that is being used in the food refrigeration industry. "Food is transported in refrigerated containers, and the better you insulate the containers, the better you can maintain cold temperatures and the better your food stays," he says.

QinetiQ NA licensed the Cryostat 2, shown here, from Kennedy Space Center. Manufacturers now have an option for testing high-performance insulation materials in relevant conditions on-site at their production or lab facilities.

The Cryostat may also prove beneficial in evaluating the materials used to insulate pharmaceuticals when they are being shipped for the medical industry. "We're looking at all of these industries," says Kohler. "Any industry that needs to keep things cold can benefit from the device."

For insulation manufacturers, the commercialization of the technology will allow on-site tests at production or lab facilities. It will also enable the evaluation of thermal performance over a range of pressures and temperatures—something that has not been previously attainable. "Researchers can quickly test 10 different insulation materials and get the results to see what insulation is better. Manufacturers can use it for quality control. If they make hundreds of insulation products, they might want to test every tenth one for quality or consistency," says Fesmire.

The most important benefit, according to Fesmire, is that the technology can test high performance insulation in relevant conditions and provide the real-world engineering data that are needed for aerospace, energy industries, and building construction. "If it's a really good insulation, then commercial instruments start having a hard time. If it's a high performance thing, you need something like this," he says. And that is why Fesmire is leading the development, in accordance with ASTM International, of a comprehensive new ASTM standard for testing high-performance, low-temperature insulation materials and systems.

With a valuable NASA spinoff technology in hand, QinetiQ NA's Kohler supports Fesmire's idea wholeheartedly. "We saw the opportunity to not only license the technology and sell it, but we also saw an opportunity for NASA, which is looking to take these cryostats into the world and establish a new standard for testing." ❖

Smart Sensors Gather Information for Machine Diagnostics

NASA Technology

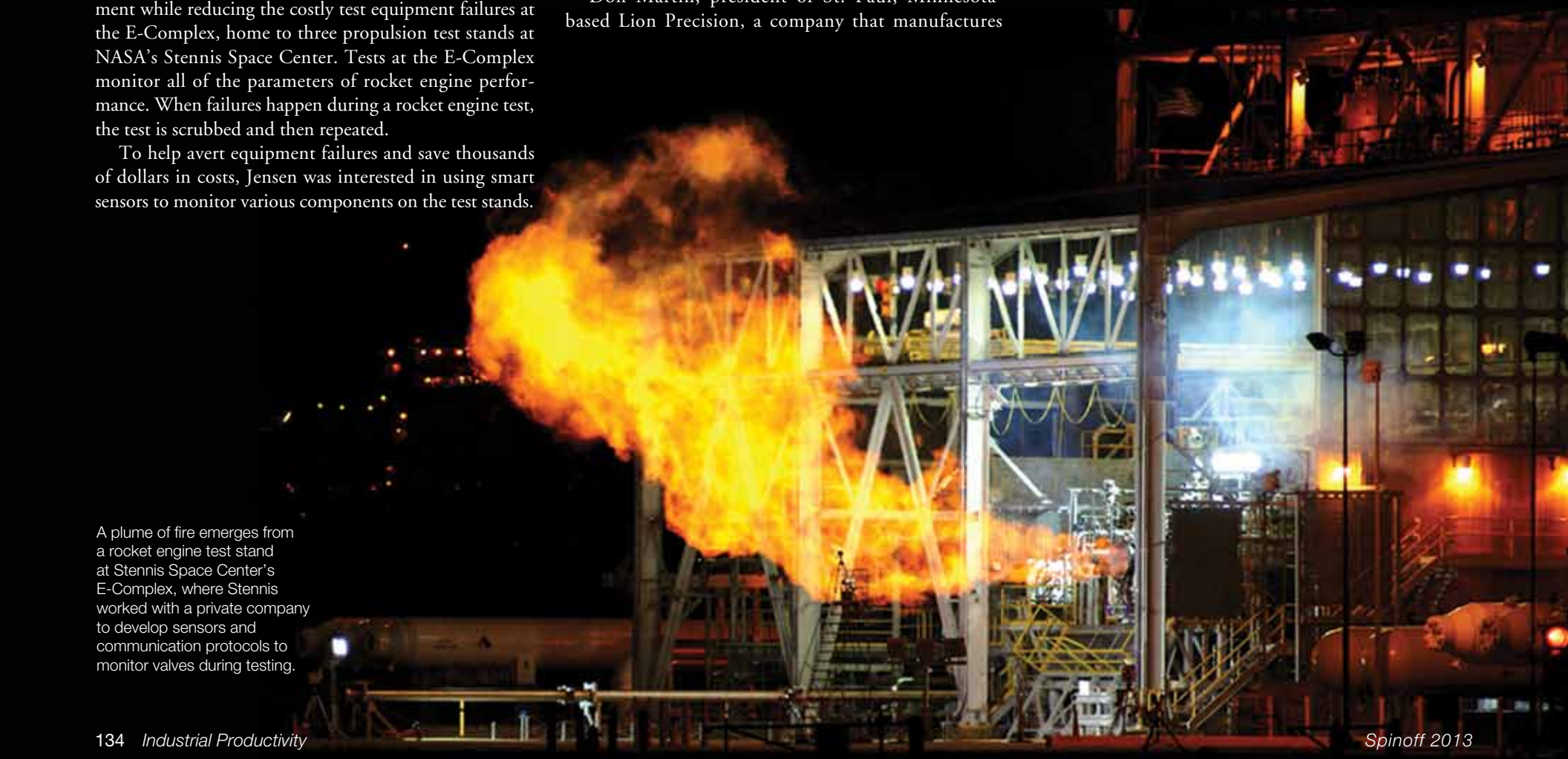
Surrounded by electronics and hovering over a work bench in the Data Acquisition and Control Systems (DACS) Laboratory, Scott Jensen startles when he hears the phone ring. He had been focused on what he was doing. After answering the phone—and a couple of questions about cooperative agreement opportunities—he returns to his work where he has his own questions to answer.

Jensen wonders how to engage technology development while reducing the costly test equipment failures at the E-Complex, home to three propulsion test stands at NASA's Stennis Space Center. Tests at the E-Complex monitor all of the parameters of rocket engine performance. When failures happen during a rocket engine test, the test is scrubbed and then repeated.

To help avert equipment failures and save thousands of dollars in costs, Jensen was interested in using smart sensors to monitor various components on the test stands. Smart sensors can process information on their own, are capable of two-way communication, and can, in some instances, even make their own decisions. At Stennis, such sensors could quickly report a problem and inform operators when something on a test stand requires maintenance. When issues are revealed during an engine test, a minor problem can be addressed before it becomes a major one.

Technology Transfer

Don Martin, president of St. Paul, Minnesota-based Lion Precision, a company that manufactures displacement sensors to measure small distances, learned about NASA's interest in smart sensors while reading a NASA *Tech Briefs* publication. At the time, Martin was working with the MTConnect Institute on an industry standard to integrate devices from different manufacturers and communicate information through a standard interface. Martin knew NASA's systems would be a good match with Lion Precision's sensor technology as well as with his development work on MTConnect.



A plume of fire emerges from a rocket engine test stand at Stennis Space Center's E-Complex, where Stennis worked with a private company to develop sensors and communication protocols to monitor valves during testing.

Lion Precision developed a smart sensor, which is now commercially available, through its work with Stennis.

Martin contacted the Agency, and in 2010 Lion Precision partnered with Stennis through a Cooperative Agreement to develop a smart sensor and the associated communication protocols for use at the E-Complex. The partners' goal was to monitor the valves responsible for the flow of liquid oxygen and liquid hydrogen during rocket engine tests. At the time, the sensors used on the valves were limited in the type of information they could obtain.

As Jensen explains, what is happening with these valves is critical. "The valves regulate highly combustible fluids under extreme pressure to supply the propellants for the test articles. Something could vibrate loose or the valve could get stuck and not close completely. Circumstances like that have caused problems, even shutdowns, during testing," he says.

Because the duo also wanted to pursue technical advancements that were deployable within the explosive propulsion test environment, as part of the agreement, the measurements from Lion Precision's sensors were transmitted using MTConnect.

"MTConnect allows you to get information from a lot of different machines and monitor different variables. The goal is to be able to take that data and look for trends so you can see if certain equipment was down, and what the causes were," Martin says.

As a result of the partnership, Lion Precision produced sensors for the test stand valves that were able to obtain the precise rates at which the valves closed; whether the valves were sticking; and how near to open or closed the valve plugs were. The partnership was also the first implementation of the sensor protocols of MTConnect, an implementation that proved to be a significant contributor to the development of the larger MTConnect standard.

Benefits

The same smart sensor developed for NASA is now commercially available, and Lion Precision is incorporating the same diagnostic capabilities into its next generation of sensor products. "Even if you don't use the MTConnect protocol, you can still get information from the sensors through the embedded software that provides diagnostic information," says Martin. "The sensors can be used with or without MTConnect."

In addition, the company has used its NASA experience to create a battery-powered wireless device that can transmit data on battery voltage, battery current, and temperature. So far, Lion Precision has built two prototypes of the wireless device for measuring the position of a machine tool that is used to make metal parts. The projected use is for manufacturing high-cost parts in the aerospace industry.

Martin says future applications for the sensor protocol for MTConnect also include the manufacturing or machining of metal parts. "It can track the wear on a cutting tool, how much the machine is running, or why it isn't running," says Martin. "It can also be used to sense vibration or temperature. The sensors plug on to a network and the data gets combined with other data from other devices. The real advantage is being able to combine data from all the different sources and figure out what the root causes of the problems are or when things are running smoothly."

Martin compares MTConnect to the diagnostic device that a mechanic uses when working on an automobile. The device relays information from all the different sensors on a vehicle to see what is going on with each component. The same interconnectivity is the goal of MTConnect, but for devices on a manufacturing floor. Ultimately, the goal is to link technologies and move toward seamless manufacturing operation.

Thanks to the partnership, Jensen will be able to obtain some answers to his own questions about seamless operation. "You can show a failure with the test stand valves in a preventive manner," he says. "And the same MTConnect protocol can be used for all types of equipment at NASA. There are a lot of different areas that could benefit." ❖

Oxygen Sensors Monitor Bioreactors and Ensure Health and Safety

Bioprocess Engineer Tony Rector prepares one of the reactor vessels on the Aerobic Rotational Membrane System (ARMS) bioreactor for initial testing in the Space Life Sciences Lab. ARMS was designed to help treat wastewater onboard the ISS by using beneficial bacteria, which rely on a stable supply of gaseous oxygen to thrive.

NASA Technology

In the mid-1990s scientists at NASA Kennedy Space Center were experimenting with an unusual substance: cow digestive bacteria. Could it break down leftover dead plant matter in space into usable organic matter?

To find out, the scientists were cultivating the bacteria in bioreactors and had to constantly check and make sure that appropriate amounts of oxygen were being dispensed. Without enough oxygen, aerobic bacteria (like those of the vast majority of living organisms) would be incapable of their normal metabolism, or harnessing the biochemical energy that enables them to subsist and reproduce. But conversely, exposure to too much oxygen would be toxic and deadly, particularly for anaerobic bacteria.

Researchers at the time were using two sensors, but without satisfaction. The first, an electrochemical sensor, consumes molecular oxygen as part of its measurement. However, when immersed in thick, viscous biologicals (as was the case with the cow bacteria), biofilms develop on the sensor, which can slow the intake of oxygen, resulting in calibration drift, or inaccurate readings.

The second sensor, a fluorescent-quenching sensor, measures oxygen levels by analyzing the fluorescent intensity of an indicator substance while exposed to the testing sample. The calculations derived from the two events have an inversely proportional relationship: The more oxygen there is in a given sample, the less the fluorescent intensity, and vice versa. But this tool is also prone to calibration drift. For example, if during a measurement the light source became inadvertently brighter, then the readout would erroneously suggest a lower level of oxygen was actually present.

Technology Transfer

After learning about the Kennedy scientists' sensor deficiencies, Needham Heights, Massachusetts-based Polestar Technologies Inc., a company that specializes in high-tech monitoring equipment, conceived an idea to develop a more reliable sensor: one that uses fluorescent quenching in a novel way to determine how much oxygen is present in a given medium.

In 1997 the company received SBIR funding to develop a new sensor. With additional financial backing from the National Institutes of Health the following year, and after a few years of research and development, Polestar had manufactured its own line of optical oxygen sensors.

What makes the company's sensing technology unique is that the fluorescent lifetime of the indicator polymer, in this case a Ruthenium complex, is used to calculate oxygen levels. Like other fluorescent chemical compounds, the Ruthenium complex emits light when excited by external radiation. (For this purpose, Polestar employs an LED light.) The fluorescence lifetime—for which each compound has its own distinct rate, often in

the order of microseconds—is the time after radiation exposure when the compound's light intensity drops to a little over one-third of its initial emission.

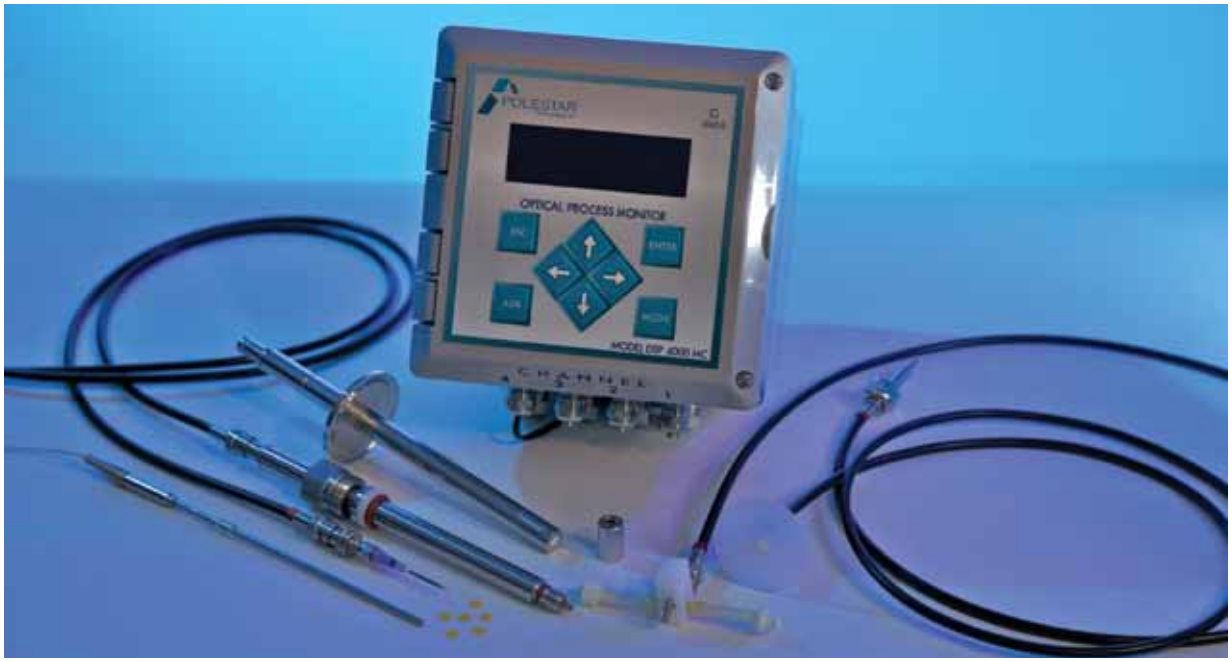
But external factors can quench, or decrease, the fluorescent lifetime of a compound, and such is the case when the Ruthenium complex is exposed to oxygen. Oxygen will take the energy from the compound that would be given off as a photon of light and instead releases it as heat, so the more oxygen there is, the shorter the Ruthenium's fluorescent lifetime.

Polestar's optical sensor technology takes this phenomenon into account in order to determine the amount of oxygen that is present in a given sample. What makes this sensor more reliable than previous models is that the underlying math works independently of variables that can affect the accuracy of the readings.

"Our sensors are not prone to calibration drift due to light signal intensity or photo bleaching of the indicator molecule," says James Kane, the company's vice president of technology and product development. "It delivers precise measurements time and time again."

And repetition is something these sensors are able to do on a grand scale. A typical sensor can record about 4 million readings before a red light on the instrument indicates it needs to be replaced. At that point, all the researcher or technician does is screw off the old sensor tip and replace it with a new one—a simpler process than is typical with many electrochemical sensors, which require skilled handling to replace the membrane, refill the electrolyte, and polish the electrode.

"Ours is a very user-friendly system that anyone can operate and maintain," Kane says.



Polestar Technologies' suite of sensors can monitor oxygen, carbon dioxide, and pH levels. All three sensors plug into a single hardware unit.

Benefits

Since entering the market in 2000, Polestar's oxygen sensors have become very popular with pharmaceutical companies and medical research universities that work with cell culture, fermentation, and tissue regeneration. Drugs that need to be sealed in blister packages that are kept inert are tested with tiny sensors for quality control, and companies are using Polestar's sensors for this task.

When gas companies started adding ethanol to petrol to create hybrid fuels, they found that their pipes had become more prone to erosion cracking because of the increase in oxygen. Many now use the fluorescent sensors as a safe, electrically inert way of testing in highly flammable environments.

But the company didn't stop at oxygen detection. In the last several years, Polestar utilized the same optics and electronics technology they originally pursued with NASA SBIR funding to develop carbon dioxide and pH sensors. All three sensors can be plugged into the same instrument, which can house the necessary software for each tool. With other models on the market, one would have to buy a separate instrument for each sensor.

Polestar Technologies continues to grow, and at a prodigious rate: In 2013 alone the company estimates that its workforce increased by 50 percent. Its expertise has also resulted in a contract with the US Army to develop transcutaneous sensors for measuring arterial carbon dioxide in soldiers wounded with traumatic head injuries. Another contract that is underway with the US Navy involves developing a sensor for monitoring the same gas in tankless rebreather SCUBA gear.

It all began, says Kane, with that initial SBIR funding from the space agency. "The knowledge that we acquired in optics and electronics from the NASA grant set the foundation for this entire product line," he says. "It has worked out really well for us." ❖

Vision Algorithms Catch Defects in Screen Displays

NASA Technology

NASA has sent more than a few robotic missions into space, but it never loses sight of its goal to enable human exploration of the cosmos. A core component of planning for future manned missions is the Human Systems Integration Division, headquartered at Ames Research Center, which focuses on advancing our understanding of how people process information and interact with mechanical and electronic systems.

Andrew Watson is Ames' senior scientist for vision research and the director of the Vision Group at the Human Systems Integration Division. "Many NASA missions in both space and aeronautics rely on vision," he says, "either to monitor the environment around us or to gather information from visual displays. It is important to understand how the limits and capabilities of vision constrain and enable human performance in these missions."

Part of Watson's research focuses on optimizing vision technology, including the design of robotic vision systems. One of the long-standing problems in robotic vision is predicting the visibility of arbitrary targets, so Watson coordinated an international effort involving 10 research labs to collect data on it and developed a computer model that could predict those data.

"I also knew of many applied problems that would benefit from a simple model of target visibility," he says, "so to serve that need, I converted the science model into an applied tool."

Watson named his tool the Spatial Standard Observer (SSO), which has since been patented. The SSO is a simplified model of human vision, focusing on how contrast is perceived by the human eye. According to Watson, the SSO has potential applications in many areas, including vision for unmanned aerial vehicles, predicting outcomes for laser eye surgery, evaluating the legibility of text, and more.

Technology Transfer

One of the SSO's applications soon caught the eye of Radiant Imaging—a company that would later merge with Zemax Development Corporation to become Redmond, Washington-based Radiant Zemax LLC. The company developed systems and software for testing light and lighting display systems and at the time was developing software tools to support its imaging colorimeter, a camera that measures color and brightness in accordance with the International Commission on Illumination's standards for human visual performance.

A typical high-definition display, like that on a flat-panel television, contains approximately 2 million pixels, any one of which could be defective—what are termed "dead" or "stuck-on" pixels. Dead pixels and defects like them are relatively easy to catch when testing manufactured units, whether the inspector is a camera, sensor, or human being. But there is another class of defect called blemishes—or mura—which are areas of changing brightness or color that could be anywhere on the display and rather subtle. As mura have no necessary, fixed qualities, they tend to be difficult to predict or find.

Says Hubert Kostal, vice president of sales and marketing at Radiant Zemax, "As we researched this problem, we asked, 'How can we find these floating defects, which can be anywhere in the display image and be any shape?' If you know what you're looking for, you can do a scan for it, but you get to a point where you're not even sure whether it will be oval-shaped, square-shaped, or a bunch of dot defects clustered together."

What Radiant Zemax needed was an objective way to classify the shape of luminance and color differences

In 2013 Radiant Zemax introduced the ProMetric I Imaging Colorimeter, designed especially for high-volume manufacturing customers, which utilizes the company's NASA-improved TrueTest inspection software.

as human beings see them, in a way that could be incorporated into its image analysis software. The industry-standard method of grading differences in color is the use of a just noticeable difference (JND) scale, with one unit of JND representing the minimal change in color between two areas that is required before an average human observer could notice the difference between them. And, says Kostal, "as it turned out, one of the outputs from Watson's approach allowed us to use JND to assign numerical values to the severity of blemishes."

Satisfied that it had found the right tool for the job, the company licensed the technology from NASA, combined some of the SSO algorithms with the company's own software, and created a new product called TrueMURA (*Spinoff* 2008).

Benefits

Manufacturers of television, laptop, tablet, and phone displays usually operate on razor-thin profit margins and face a dilemma when inspecting their product: On the one hand, an inspection process that doesn't detect flawed units will result in returns, repairs, and unhappy customers unlikely to buy from the company again. On the other hand, imaging colorimeters can be more sensitive to flaws than the human eye, and manufacturers lose a lot of money when they throw away good product that could have satisfied consumers—even if the inspection flagged it as defective.

"That's the conundrum," says Kostal. "When is a mura meaningful to a human observer? How severe is it?" With its NASA-improved software, Radiant Zemax helps display manufacturers ensure that they are catching enough of the right kind of mura. "The most important thing is not what defects you can get a camera to detect," says Kostal. "What's really important is what customers see; it's only a defect when a customer can see it."

Since its debut several years ago, TrueMURA has been tightly integrated with Radiant Zemax's software tools. In 2012, the company announced its TrueTest software system, which incorporated TrueMURA along with a suite of other quality and defect detection tests into one package designed to better automate display inspections. The technology powers the company's newest line of high-performance imaging colorimeters, which are particularly suited for use by high-volume manufacturers of flat panel displays.

The speed, resolution, and accuracy of these newer imaging colorimeters is increasingly allowing the company's system to take over inspection functions that have traditionally required human technicians, who can sometimes produce imprecise or inconsistent judgments. "All kinds of variables come into play with human inspection," says Kostal. "If I'm giving you 1,000 displays to inspect, you might only have 5–10 seconds to look at each one. A defect that barely reaches the level of human perception might not be seen by an inspector, but a consumer watching hours of television and movies on that display is definitely going to notice it." Kostal also points out that, when compared to the cost of using human inspectors, companies using Radiant Zemax's product will end up saving money within 1 year.

Radiant Zemax's products are now being used by a large number of companies producing common consumer electronics like smartphones, tablets, laptops, and televisions. According to the company, TrueTest is deployed on hundreds of production lines and is testing millions of flat-panel displays. "I can guarantee you," says Kostal, "that if you go into a major electronics store, you will find products there that were either tested or designed using this capability."

One challenge facing display manufacturers is that their customers spend so many hours looking at the screen. Barely noticeable blemishes that pass inspection can over time become major distractions to the consumer.

The company has been very pleased with its experience licensing NASA technology. "We do really cool things at Radiant Zemax, but we're fundamentally an engineering company," says Kostal. "We want to develop and provide solutions to our customers. The information that we were able to get from NASA enabled us to move quickly to the forefront of the industry in terms of analysis, methodology, and techniques." ❖

Deformable Mirrors Capture Exoplanet Data, Reflect Lasers

NASA Technology

We have always wondered: Is there other life out there? Are there other planets like our own, orbiting other stars like our Sun? In the early 1990s, astronomers began to discover that there are other planetary systems around other stars in our galaxy. Referred to as exoplanets (to distinguish them from planets in our own solar system), more evidence is being accumulated to reveal whether these systems do indeed resemble our own.

In 2009, the Kepler telescope launched to survey part of our galaxy in an effort to find Earth-size planets in or near zones around other stars where liquid water and life might exist. Because exoplanets are small and distant, and because the stars they orbit are so bright, it is difficult to observe exoplanets directly. Instead, Kepler uses sensitive instruments to measure light and looks for subtle dips in the brightness of a star caused by a planet crossing in front of it.

While Kepler has gazed at more than 156,000 stars in its field of view, NASA has planned new missions to image exoplanets around particularly bright stars. One such mission, the Balloon Exoplanet Nulling Interferometer (BENI), could be ready to fly in 2016 at 135,000 feet above Earth to image exoplanets in a matter of hours.

The BENI mission will require the use of a new instrument called a visible nulling coronagraph (VNC) to detect, image, and characterize exoplanets. Rick Lyon, a scientist at Goddard Space Flight Center, says, "Coronagraphs absorb, reflect, diffract, or interfere starlight to make the planet appear brighter than the star."

An issue associated with the coronagraph, however, is that starlight can seep through and lower the contrast in an image. To address the problem, Goddard turned to deformable mirrors (DMs), which can adjust their shape or position to correct for the unwanted light.

Technology Transfer

In 2005, Berkeley, California-based Iris AO, Inc. started working with Goddard through the Small Business Innovation Research (SBIR) program to improve the company's microelectromechanical (MEMS) DMs for the purposes of imaging and characterizing exoplanets. According to Lyon, "It is considered the most critical technology within the VNC."

Michael Helmbrecht, president of Iris AO, says NASA wanted positioning accuracy down to the nanometer level and sub-nanometer resolution and stability—areas where little work had been done before. "It led us to design low-noise drive electronics that allow you to precisely position the mirror. We increased the precision and stability of the device significantly."

Iris AO's technology consists of hexagonal segments closely packed together to form the surface of the DM. This is much different from a traditional DM consisting of a single, continuous surface. "Each segment is articulated with 3 actuators to move up and down and tip and tilt, and each segment operates independently," says Lyon.

This artist's rendering shows Kepler-20e, the first planet smaller than the Earth discovered to orbit a star other than the sun. The planet always shows the same side to its host star, and could have large temperature differences between its permanent night and day sides.

> “Without the commitment to cutting edge research, the technology would not be anywhere close to where it is today.”
>
> —Michael Helmbrecht, Iris AO

For nearly a decade, Iris AO and Goddard have made great strides, and the improved DMs were tested and found to achieve “the best result of any nulling coronagraph to date,” says Lyon. Next up for Iris AO and Goddard is to increase the number of segments and actuators to get an even better optical correction.

Benefits

NASA is not the only organization interested in Iris AO’s successful technology. Unlike other manufacturers, Iris AO calibrates all of its DMs, which, according to Helmbrecht, “opens up a lot of applications where precise mirror positioning without feedback is required. Being able to precisely position the DM increases adaptive optics (AO) system performance as well.”

Outside of NASA, the technology is being both evaluated and used for biological research and industrial applications. In fact, the company has received funding from the National Eye Institute (NEI) and the National Science Foundation (NSF) to advance the technology for such applications.

The New England College of Optometry, the University of California, and Davis and Simon Frasier University in Canada are also using the spinoff technology in existing ophthalmic instruments to improve images of the eye. For retinal imaging, “It gives insights to researchers when they are studying diseases and helps to understand the processes of the eye and the human visual system. You can see the effects of diseases at fine details that would not be seen without AO technology,” says Helmbrecht.

In the near future, he finds, prescription drug manufacturers could use the technology to track the efficacy of drugs and see what is taking place in the back of the eyes of test animals during the course of treatment.

Along similar lines, the technology can be incorporated into biological microscopes to get a better view of tissues either on a slide or in vivo. “As you try to look deeper and deeper into the tissue, aberrations severely degrade imaging resolution and contrast. The deformable mirror technology can correct these aberrations and thus enable biologists to see further into tissue,” says Helmbrecht.

In an entirely different application, the technology also sees promise in shaping laser beams more precisely for manufacturing. Lasers are used in industrial laser micromachining to machine tiny electrical components for things like smart phones. Funding from NSF is enabling testing of the DMs to be able to handle large amounts of laser power.

“Increased power handling means higher throughput for laser micromachining systems,” says Helmbrecht. “In laser machining applications, the DM can be used to track focus, correct optical system aberrations, and to dynamically shape the beam intensity profile. Incorporating the DM greatly enhances the flexibility of laser micromachining systems to handle various materials and feature sizes. The industry needs techniques that are able to make very precise cuts into different materials.”

Whether it is helping to get a better look at exoplanets or the human eye, or to make laser beams more precise, Iris AO’s spinoff technology is sure to reveal things not seen before. Helmbrecht says it is only because of NASA and other government funding that the technology exists. “These kinds of partnerships have been absolutely invaluable for us. Without the commitment to cutting edge research, the technology would not be anywhere close to where it is today.” ❖

The deformable mirror developed by Iris AO and improved through work with NASA is in use for applications ranging from NASA imaging systems for planet detection to state-of-the-art retinal imaging and microscopy.

Partnership News

Inspiring the fabrics of the future. Rethinking aircraft design. Predicting floods and fires. Empowering civic hackers to solve global challenges. The space agency knows that collaborative partnerships are as crucial as they are beneficial for tackling some of the most pressing problems our society faces. Working with government, business, industry, academia, and people like you, NASA employs its unmatched facilities and unique expertise to help save lives, improve public health and safety, grow commercial space efforts, and stimulate the economy in a variety of ways.

INTERNATIONAL SPACE APPS CHALLENGE

There's a Space App for That

What's the weather like on Mars right now? The world's first interplanetary weather app can tell you right on your phone or tablet. The app, called Sol, is one of 770 projects created by more than 9,000 people during the second annual International Space Apps Challenge, an event organized by NASA that took place on April 20–21, 2013.

Participants gathered in 83 cities across 44 countries for the event, with many others collaborating over the Internet. More than 480 organizations lent support, and hacker-scientists and astronauts also participated from locations as remote as a research station in Antarctica and the International Space Station (ISS).

This year's Space Apps Challenge is believed to be the largest organized hackathon event of any kind ever held. Citizen programmers, scientists, designers, artists, and others from all seven continents took on 52 challenges posed by various government organizations—including 25 from NASA—that are relevant to both space exploration and community needs on Earth.

Said Nick Skytland, lead of the Space Apps Team, "The International Space Apps Challenge was the culmination of months of planning, years of experimentation, and thousands and thousands of hours of hard work from people across the globe who share in the excitement of building our collective future. It is a shining example that transparency, participation, and collaboration are alive and well at NASA."

Sol, the Mars weather app, won the event's award for Best Use of Data, one of several global award winners selected among 134 nominated projects. The award was granted to Sol as "the solution that best makes space data accessible or leverages it to a unique purpose or application." Other global award-winners included:

- Best Use of Hardware: ISS Base Station, a hardware and software design project that expands NASA's Spot the Station web service and app. ISS Base Station uses a mechanical arm, guided by software, that points to the location of the ISS as it passes overhead. It includes an iOS app that uses an icon and an augmented reality feature to assist users in spotting the ISS in the sky. Using the phone's camera, the app allows users to take and tweet photos of the station.
- Best Mission Concept: Awarded to "the solution that developed the most promising mission concept," the Popeye on Mars team won the honor. Popeye on Mars addressed the Deployable Greenhouse challenge by creating a reusable spinach greenhouse for Mars. The system relies on aeroponics and can harvest oxygen produced by the plants as they grow.

More than 9,000 people gathered in 83 cities around the world for what became the largest organized hackathon ever held.

- Galactic Impact: The NASA Greener Cities project won the award in recognition of its "potential to significantly improve life on Earth or in the universe." The app complements NASA satellite data with crowd-sourced microclimate data, in effect providing higher resolution information for monitoring the environment.
- Most Inspiring: A prototype called T-10, which aims to connect people on the ISS with those on the ground and save astronauts time, was recognized as particularly inspirational. Astronauts often take photos of the ground from the ISS; the T-10 app allows astronauts to choose where they wish to photograph and receive alarms ten minutes prior to when the ISS will pass over that area. If the weather is good (something the app automatically checks), and the astronaut confirms that he or she will take a photo, T-10 users on the ground in the to-be-photographed location receive an alert so they can look up, smile, or wave as the photo gets taken.

Enthusiasts worked on a total of 770 projects in response to 52 challenges posted by government agencies, taking the form of everything from new software and hardware to mobile apps.

The makers of Sol, the world's first interplanetary weather app, are hoping to inspire mass consumer interest in science through an appealing and easy-to-use app.

A Window through Time

Astronauts have often remarked that seeing the Earth from space is a profound, life-changing experience, one that gives them a new perspective on the fragility of our home planet floating in space. Now Google, the US Geological Survey, *Time* magazine, and NASA are hoping to recreate that experience for Internet users. The organizations have partnered to release more than a quarter-century's worth of images as part of *Time*'s new Timelapse project, resulting in a zoomable map of the entire globe that reveals changes in the Earth's topography over a span of 28 years.

Working with data from the Landsat program, the images display a historical perspective on changes to Earth's surface from 1984 through 2012. "The Landsat data record—humanity's longest continuous record of our planet from space—has been an invaluable tool for scientists and decision-makers in many fields, from natural resources to agricultural productivity and climate change," said NASA's associate administrator for communications David Weaver.

"The release today on Google's Earth Engine of new Landsat time-lapse data animations shows key changes across our planet and helps share this remarkable US resource with the public in an engaging new way," he said.

Timelapse provides imagery for nearly every part of the world, but the project is being used to draw particular attention to areas where humanity's impact on the globe is most easily seen. Users can watch the urban sprawl of Las Vegas creep into the surrounding desert, a humble fishing village's transformation into Dubai, receding glaciers on the move, deforestation in the Amazon, and much more.

In its announcement of the project, Google said it used its Google Earth Engine to incorporate data from Landsat, processing more than 2 million images, or nearly a petabyte of data. After picking the best data available, the images were stitched together and converted into a single, navigable HTML5 animation.

Said Google, "Much like the iconic image of Earth from the Apollo 17 mission—which had a profound effect on many of us—this time-lapse map is not only fascinating to explore, but we also hope it can inform the global community's thinking about how we live on our planet and the policies that will guide us in the future."

NASA launched the newest Landsat satellite in February of 2013. A few months later, the space agency handed over operations of the mission to the US Geological Survey. Said Weaver, "NASA is looking forward to beginning the work to extending this critically important national resource."

Left: Images taken by NASA and processed by Google show the retreat of the Columbia Glacier in Alaska over a 27-year period.

The city of Dubai, once a humble fishing village, is now famous for its grandiose architecture, including manmade archipelagos that are easily visible from space—in this case, photographed by a crewmember onboard the ISS.

"We believe this is the most **comprehensive** picture of our **changing planet** ever made **available** to **the public."**

— Google, Official Blog

The newest Landsat satellite on the launchpad, before its February 2013 trip into orbit. The Landsat program has provided the world's longest continuous global record of the Earth's surface. For a deeper look at the program, scan this code.

NASA's PhoneSat prototype (left) is small and inexpensive and demonstrated that consumer-grade hardware could be flown successfully on a space mission. Two of the satellites sent back photos taken by the smartphones in the spacecraft (right).

A Picture-Perfect Commercial Liftoff

On April 21, 2013, NASA commercial space partner Orbital Sciences Corporation launched its Antares rocket from a pad at the Agency's Wallops Flight Facility in Virginia. The test flight was the Wallops pad's first ever launch and was also the first flight of Antares, which delivered the equivalent mass of a spacecraft, a so-called mass simulated payload, into Earth's orbit.

"Today's successful test marks another significant milestone in NASA's plan to rely on American companies to launch supplies and astronauts to the International Space Station (ISS), bringing this important work back to the United States where it belongs," said NASA Administrator Charles Bolden. "Congratulations to Orbital Sciences and the NASA team that worked alongside them for the picture-perfect launch of the Antares rocket."

Orbital is building and testing its Antares rocket and Cygnus spacecraft under NASA's Commercial Orbital Transportation Services (COTS) program. Following the successful completion of a COTS demonstration mission to the station, Orbital will begin conducting eight planned cargo resupply flights to the orbiting laboratory through NASA's $1.9 billion Commercial Resupply Services contract with the company.

NASA initiatives, such as COTS, are helping to develop a robust US commercial space transportation industry with the goal of achieving safe, reliable, and cost-effective transportation to and from the ISS and low-Earth orbit. NASA's Commercial Crew Program also is working with commercial space partners to develop capabilities to launch US astronauts from American soil in the next few years.

NASA took advantage of the launch to send three small satellites powered by smartphones, called PhoneSats, into orbit. The trio of PhoneSats might be the lowest-cost satellites ever flown in space. The goal of the mission was to help determine whether a consumer-grade smartphone can be used as the main flight avionics of a capable, yet very inexpensive, satellite.

NASA engineers kept the total cost of the components for the three prototype satellites between $3,500 and $7,000 by using primarily commercial hardware and by keeping the design and mission objectives to a minimum. The PhoneSats utilized Google-HTC Nexus One smartphones running the Android operating system and, among other functions, successfully took photos of Earth from space.

Dryden's "Bittersweet" Success

All good things must come to an end, as the saying goes.

After flying the remotely-piloted X-48B and X-48C Hybrid / Blended Wing Body research aircraft for nearly 6 years, the joint NASA-Boeing X-48 project team successfully completed its last flight test project at NASA's Dryden Flight Research Center in 2013.

The manta-shaped X-48 Hybrid Wing Body technology demonstrator flew a total of 122 flights, 30 of them as the C-model. "Both very quiet and efficient, the hybrid wing body has shown promise for meeting all of NASA's environmental goals for future aircraft designs," said Fay Collier, manager of NASA's Environmentally Responsible Aviation project.

The aircraft, designed by Boeing and built by Cranfield Aerospace Limited of the United Kingdom, was flown in partnership with NASA. The X-48C model, which was formerly the X-48B Blended Wing Body aircraft, was modified to evaluate the low-speed stability and control of a low-noise version of a notional, future Hybrid Wing Body (HWB) aircraft design. The HWB design stems from concept studies being conducted by NASA's Environmentally Responsible Aviation project of future potential aircraft designs 20 years from now.

"Our team at NASA Dryden has done what we do best, flight test a unique aircraft and repeatedly collect data that will be used to design future 'green' airliners," said Heather Maliska, NASA Dryden's X-48C project manager. "It is bittersweet to see the program come to an end, but we are proud of the safe and extremely successful joint Boeing and NASA flight test program that we have conducted."

NASA's Aeronautics Research Mission Directorate and Boeing funded the X-48 technology demonstration research effort, which supported NASA's goals of reduced fuel burn, emissions, and noise.

The Boeing-NASA X-48C Hybrid Wing Body research aircraft, pictured here during two of its many test flights over Dryden Flight Research Center at Edwards Air Force Base in Edwards, California.

Rain Boots on the Ground

Scientists at NASA and the Iowa Flood Center are at work developing the methods for turning satellite observations into practical tools. The two organizations are partnering to measure rainfall using existing satellite data and rain gauges in the field, studying how such data can be used in applications such as flood forecasting and the monitoring of water resources.

"We're trying to figure out how well our satellites estimate rainfall," said Walt Petersen, a ground validation scientist in NASA's Global Precipitation Measurement satellite mission at NASA's Wallops Flight Facility in Virginia. "This study is unique in that it takes space-borne observations, it takes ground-based observations, and it brings those things into a modeling framework that should further our ability to predict flooding."

Rainfall estimates of water content and intensity are vital inputs for forecasters who need that information to determine whether or not streams and rivers will flood and impact people living in the floodplain. Many variables go into flood prediction, said Witold Krajewski, the center's director, including soil type and moisture, stream and river geography, and land use. Some variables are difficult to measure, such as how water flows underground after it soaks into the ground. Rainfall is one of the easier variables to measure and validate.

The field campaign, called the Iowa Flood Studies experiment, or IFloodS, collected data from a vast network of ground instruments as well as instruments on satellites passing overhead. The results of these comparisons mean a better interpretation of the raw rain data and improved understanding of the rainfall estimates provided from space. For the Iowa Flood Center, Krajewski said, the benefits are close to home: "Our hope is that with all that information, we can really improve our flood forecasting models."

NASA and Iowa Flood Center staff install instrumentation in eastern Iowa for the IFloodS campaign.

Image courtesy of the Iowa Flood Center

Spying on Fire

Airborne imaging technology developed at NASA and transferred to the US Department of Agriculture's Forest Service (USFS) in 2012 helped prepare for the 2013 wildfire season in the western United States. The Autonomous Modular Sensor (AMS) is a scanning spectrometer designed to help detect hot-spots, active fires, and smoldering and post-fire conditions. Scientists at Ames Research Center and USFS engineers installed the NASA technology on a Cessna Citation aircraft that belongs to the Forest Service.

Developed by NASA's Airborne Sciences Program, the AMS acquires high-resolution imagery of the Earth's features from its vantage point aboard research aircraft. The sensor transmits nearly real-time data to ground disaster management investigators for analysis. NASA is collaborating with USFS firefighters to use the data in fire management to help mitigate dangers.

The AMS will not only provide an unprecedented amount of data on wildfires but will also support other Agency objectives, such as vegetation inventory analysis and water and river mapping. "I see tremendous opportunity for my agency and other land management agencies to benefit from the application of NASA-developed technology," said Everett Hinkley, national remote sensing program manager with USFS.

A California wildfire as seen from Harkness Fire Lookout at Lassen National Park. Right: A natural color image of the slough mouth and salt ponds near Ames Research Center, taken by the Autonomous Modular Sensor.

Image courtesy of the National Park Service

New Materials to LAUNCH a New Future

In May of 2013, more than 150 materials specialists, designers, academics, manufacturers, entrepreneurs, and nongovernmental organizations met at Nike headquarters in Portland for the start of the LAUNCH Systems Challenge 2013. The group discussed innovations that could improve one of the toughest global and spaceflight challenges: materials and how they are made.

LAUNCH is a partnership among the United States Agency for International Development (USAID), Nike, the US State Department, and NASA that brings innovative thinkers together with other people who can help make change happen. Together, they come up with solutions to transform our existing human systems into new ones that are more sustainable, accessible, and show promise for making tangible impacts on society in the developed and developing worlds. These systems are equally important to enable humans to travel to destinations beyond Earth, like to an asteroid or Mars.

The innovations presented at the Systems Challenge forum may lead to new, stronger, lighter, and more affordable fabrics and materials made with a focus on positive societal and environmental impacts. These types of materials are vital to the design of next-generation spacecraft and spacesuits.

On Earth, innovations spurred from LAUNCH could identify, showcase, and support new approaches to fabrics that can stimulate economic growth, drive human prosperity, and replenish the planet's resources. According to Nike, by 2015, the global apparel industry is expected to produce more than 400 billion square meters of fabric every year—enough to cover the state of California.

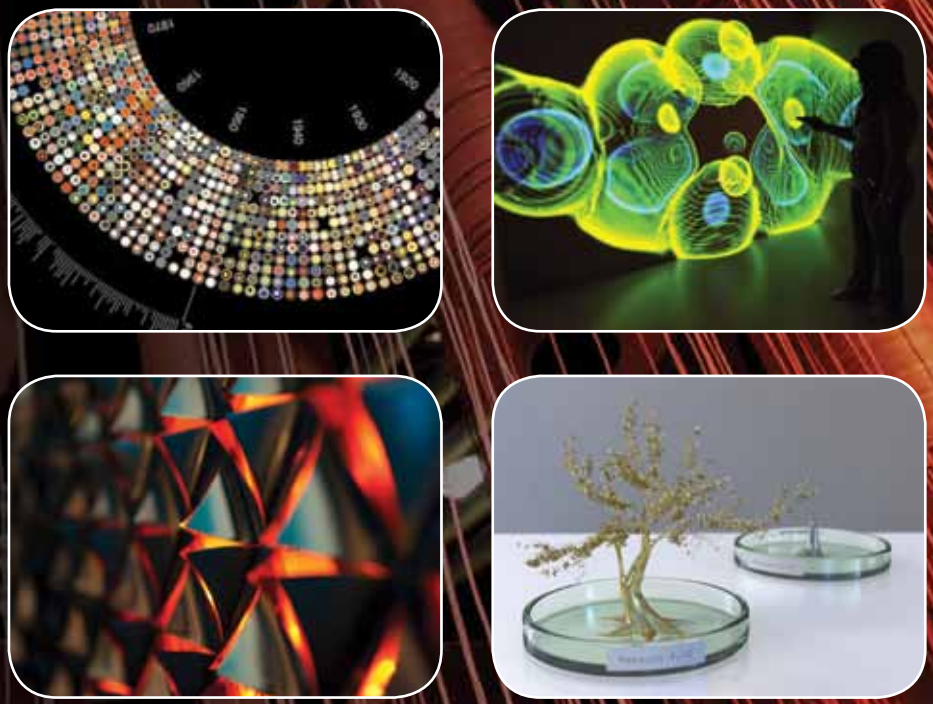
NASA and the LAUNCH Council—leaders representing a diverse and collaborative body of entrepreneurs, scientists, engineers, and others from government, media, and business—participated in the event and will help guide the innovations forward. Ten selected LAUNCH innovators will receive networking and mentoring opportunities from influential business and government leaders.

Previous LAUNCH forums have focused on water, health, energy, and waste management. These forums have resulted in many innovations, including:

- technology that enables irrigation using brackish, saline, and even polluted water;
- a handheld lab-in-a-box that can diagnose a variety of diseases in a matter of minutes;
- a modular, flexible smart-grid distribution technology to provide access to power for those in need; and
- a simple, affordable fuel cell that converts biomass directly to electricity.

The partnerships fostered by LAUNCH allow NASA to promote and share the emergence of transformative technology to solve global problems.

The 2013 LAUNCH Summit, hosted by Nike in partnership with NASA and other agencies, focused on the sustainability of manufacturing materials.



LAUNCH solutions include (clockwise, from top left): decision support and educational tools that guide choices of chemistries and materials; open technology platforms to enable sharing and collaboration on the analysis of sustainability impacts; multi-purpose synthetic and bio-synthetic materials; and technology to increase energy, water, and raw material efficiency.

20 Years of Moon Racing—On Earth

In late April, NASA hosted the 20th annual Great Moonbuggy Race at the US Space & Rocket Center in Huntsville, Alabama. The race fielded over 90 teams from 23 states, Puerto Rico, Canada, India, Germany, Mexico, and Russia. Approximately 600 students took part as drivers, engineers, and mechanics, along with team advisors and cheering sections.

Organized by Marshall Space Flight Center, the race challenges students to design, build, and race lightweight, human-powered buggies. Traversing the grueling half-mile course, which simulates the cratered lunar surface, race teams face many of the same engineering challenges dealt with by Apollo-era lunar rover developers at Marshall in the late 1960s.

Sponsors presented the first-place high school and college teams with cash awards of $3,000 each. Individuals on the winning teams also received commemorative medals and other prizes.

Eight college teams participated in the first NASA Great Moonbuggy Race in 1994. The race was expanded in 1996 to include high school teams, and student participation has swelled each year since. The race has been hosted by the US Space & Rocket Center since 1996.

Hot Engine, Cold Problem

How does ice accumulate inside hot turbofan jet engines during flight? NASA scientists, working with engine manufacturers, are closer to answering that question thanks to a unique test facility at Glenn Research Center.

Over the last 20 years, more than 200 incidents have been documented of turbofan jet engines losing power during high-altitude flights, even though pilots observed little to no inclement weather. Investigators have developed a theory that the aircraft are flying through dense clouds of small ice crystals. The crystals are ingested into the engines where they melt on the warm surfaces inside the engines. The surfaces eventually become cold enough during flight that ice can begin to build up, or accrete, which can affect the normal operation of the engine.

Understanding how a constant flow of warm air inside the engine interacts with a constant flow of ice crystals has challenged conventional theories. Up until recently, engine manufacturers could only perform component tests to investigate their theories, as recreating the desired conditions and measuring the results was difficult and expensive.

Earlier this year, however, Glenn researchers were able to re-create the high-altitude ice-crystal cloud environment in the Propulsion Systems Laboratory during a full-scale engine test, which resulted in a loss of engine power. For the first time ever, scientists calibrated to a very fine degree ice-crystal clouds found at the high altitude and pressure conditions typical in flight.

Glenn is working with industry to address this aviation issue by using its unique capabilities. The information gained through the tests will be used to establish methods and techniques for the study of engine ice-crystal icing in new and existing commercial engines. It will also help develop validation data sets required for advanced computer codes that can be specifically applied to assess an engine's susceptibility to ice-crystal icing in terms of safety, performance, and operability.

Judy Van Zante, an icing cloud specialist at NASA's Glenn Research Center, was the first person to calibrate the high altitude ice crystal cloud environment necessary to cause a loss of engine power during an engine test at the Center's Propulsion Systems Laboratory.

Open Data for Public Benefits

Data collaboration is an increasingly important function among public health authorities, who strive to track large-scale phenomena such as the trail of natural disasters or the nation-wide spread of diseases. In an effort to keep researchers and public health officials better informed, the interagency US Global Change Research Program launched an online tool and website called the Metadata Access Tool for Climate and Health (MATCH).

MATCH brings together data and expertise from several federal institutions, including NASA, alongside academic researchers and professional organizations like the American Public Health Association and the American Meteorological Society. In its announcement, the Office of Science and Technology Policy noted that "many of the metadata records now retrievable through MATCH . . . were previously in difficult-to-access agency archives or stored in non-interoperable formats."

The website will help users access the best and latest information from many data sets to increase situational awareness and inform decision-making. The tool is expected to be especially helpful in dealing with natural disasters of increasing intensity attributed to climate change, such as floods and hurricanes.

Moving from Earthquake Warnings to Forecasts

Scientists have no proven, reliable method for predicting an earthquake before it happens. At the moment, the best alert systems provide only seconds of warning to populated areas after an earthquake has already started, allowing individuals to take emergency action where possible. One company, Palo Alto, California-based Stellar Solutions Inc., is hopeful that it has found a way to move from alerts to short-term predictions that can give authorities and civilians days to prepare rather than seconds.

Tom Bleier manages QuakeFinder, a humanitarian research and development project by Stellar Solutions, and oversees the installation of sensor stations designed to catch clues of impending earthquakes. The theory is that rocks deep underground release electromagnetic pulses when stressed and crushed, especially during the increased movement that precedes earthquakes. Those pulses then migrate to the surface and ionize the air, says Bleier, and QuakeFinder's sensors look for those ions.

QuakeFinder has received a portion of its funding from NASA's Earth Science Division, and Bleier has collaborated with scientists from Ames Research Center, the Jet Propulsion Laboratory, and Langley Research Center to develop the system. Stellar Solutions has also received funding from the state of California and the Musk Foundation, among other organizations.

The project, which began in 2000, hit several important milestones in 2013—most importantly, the team installed the last of its sensors that make up a network running along the San Andreas fault line. Bleier reports that QuakeFinder has also performed retrospective analysis on three significant earthquakes that occurred in the past year within range of its sensors, discovering apparent earthquake signatures that occurred two weeks prior to each of the events.

Although QuakeFinder currently publishes the data it collects, the project is not yet considered operational. Bleier hopes that the project will soon begin to monitor real-time data for signs of imminent earthquakes using finely tuned algorithms, the next step in testing the theories behind the system.

Left: One of QuakeFinder's sensor installations. Background: The San Andreas Fault.

Image courtesy of Ian Kluft

Driving Clean Transportation Forward

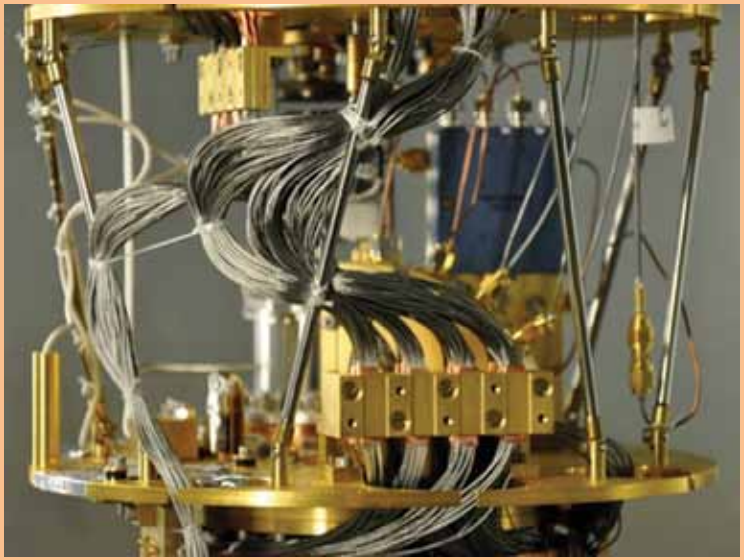
What drank Lake Erie water, motored quietly through the streets of Cleveland, and expelled water good enough to drink from its tailpipe? A cutting-edge Greater Cleveland Regional Transit Authority (RTA) bus, part of a NASA demonstration of clean, alternative transportation.

Glenn Research Center supported the community-based partnership with RTA, the Cleveland Foundation, the Ohio Aerospace Institute, and several technology development companies to add a hydrogen-fueled demonstration bus to the RTA fleet. It aimed to transport passengers 60–80 miles a day along various routes with emissions of only water and heat, and to refuel at a station at RTA's Hayden bus garage equipped with technologies developed at Glenn.

"What makes this project unique is that Glenn has installed the first electrolysis-based refueling station in Ohio," says Carolyn Mercer, manager of the Space Power Systems Project. "This means we don't have to transport hydrogen tanks; we make the fuel on site, which is safer and more cost-effective."

The electrolysis unit takes in city water, purifies it via an internal de-ionizing process and uses electricity to split the water into hydrogen and oxygen gases. The generated hydrogen is then stored in tanks ready for use. The dispenser operates similar to a typical gas pump.

Research at Glenn is focused on improving the reliability and efficiency of fuel cells and electrolysis systems. NASA's Space Power System supported the hydrogen bus effort, which is a NASA Space Technology Game Changing Development project.


The D-Wave quantum computer at Ames Research Center.

Solving the Unsolvable

NASA, the Universities Space Research Association, and Google are partnering to assess the potential of quantum computers to perform calculations that are difficult or impossible using conventional supercomputers. A quantum computer leased from D-Wave Systems was installed in the NASA Advanced Supercomputing facility at Ames Research Center in 2013.

Quantum computing is based on quantum bits, or qubits. Unlike traditional computers, in which bits must have a value of either zero or one, a qubit can represent a zero, a one, or both values simultaneously. For certain types of optimization problems, the quantum properties of a qubit allow researchers to effectively try all possible solutions at once, arriving at the best solution much more quickly.

The potential benefits to NASA include dramatically improved algorithms for optimization tasks, with possible applications in air traffic control, autonomy, robotics, navigation and communication, system diagnostics, pattern recognition, and mission planning and scheduling. The research team at Google will focus on how the quantum system may help build more accurate models for a variety of fields, including speech recognition, web searches, and protein folding. The collaboration also includes computing time set aside for the broader academic community to utilize the machine and to work with researchers at both NASA and Google.

Staying Ahead of the Pack

One of the world's longest migrations of zebras occurs in the African nation of Botswana, but predicting when and where zebras will move has not been possible until now. Using NASA rain and vegetation data, researchers can track when and where arid lands begin to green, and for the first time anticipate if zebras will make the trek or, if the animals find poor conditions en route, understand why they turn back.

Covering an area of approximately 8,500 square miles, Botswana's Okavango Delta is one end of the second-longest zebra migration on Earth. Zebras walk an unmarked, 360-mile route following the best places for grazing, while late October rains overhead drive new plant growth. In a matter of weeks, the flooded landscape yields ecosystems flush with forage for the muscled movers.

High above, Earth-orbiting satellites capture images of the zebras' movements on this epic trek, as well as daily changes in environmental conditions. Pieter Beck, research associate with the Woods Hole Research Center in Falmouth, Massachusetts, and three collaborators studied animal migration in a novel way, combining GPS movement data with NASA satellite imagery of environmental conditions taken during the months of the migration.

To track the greening of leaves, the researchers relied on the Normalized Difference Vegetation Index data acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) on board NASA's Terra and Aqua satellites. The MODIS sensors capture growing conditions by measuring the reflectance of near-infrared light from plants. The team also used NASA's Tropical Rainfall Mission data to map daily rainfall.

Beck and his team learned that zebras do not follow an internal clock and do not migrate at a steady pace. By examining daily rainfall and weekly vegetation data from satellite images and entering the data into migration models, the researchers were amazed at how well they could predict when zebras started migrating and how fast they migrated.

Having access to NASA's free satellite images that shed light on the environmental conditions migratory animals face is something that Beck finds invaluable. The models provided the team with the means to think like a zebra, which has practical applications in management issues that concern humans. "We're getting close to the stage where for some organisms, we can use satellite data in management," he said.

He sees the capability of using the team's research in the future to design models that will help game managers, conservation managers, farmers, and tour operators predict animal migration, whether it's zebras or other migratory animals. Understanding the mechanisms that drive migratory behavior is increasingly important, Beck said, in terms of climate change, as migrating animals rely on multiple habitats.

For the study, zebras were collared with GPS devices to track their location along the migration route.

Image courtesy of Botswana Herbivore Research

Image courtesy of T. Geberth

Sizing Up a National Resource

A new NASA airborne mission has created the first maps of the entire snowpack of two major mountain watersheds in California and Colorado, producing the most accurate measurements to date of how much water they hold.

The data from NASA's Airborne Snow Observatory mission will be used to estimate how much water will flow out of the basins when the snow melts. The data-gathering technology could improve water management for the 1.5 billion people worldwide who rely on snowmelt for their water supply.

"The Airborne Snow Observatory is on the cutting edge of snow remote-sensing science," said Jared Entin, a program manager in the Earth Science Division at NASA Headquarters in Washington. "Decision-makers like power companies and water managers now are receiving these data, which may have immediate economic benefits."

The mission is a collaboration between NASA's Jet Propulsion Laboratory (JPL) and the California Department of Water Resources in Sacramento. A Twin Otter aircraft carrying NASA's Airborne Snow Observatory will be making weekly flights over the Tuolumne River Basin in California's Sierra Nevada and monthly flights over Colorado's Uncompahgre River Basin, which supplies water to much of the western United States.

The mission's principal investigator, Tom Painter of JPL, said the mission fills a critical need in an increasingly thirsty world, initially focusing on the western United States, where snowmelt provides more than 75 percent of the total freshwater supply.

"Changes in and pressure on snowmelt-dependent water systems are motivating water managers, governments and others to improve understanding of snow and its melt," Painter said. "The western United States and other regions face significant water resource challenges because of population growth and faster melt and runoff of snowpacks caused by climate change. NASA's Airborne Snow Observatory combines the best available technologies to provide precise, timely information for assessing snowpack volume and melt."

Painter plans to expand the airborne mapping program to the entire Upper Colorado River Basin and Sierra Nevada. "We believe this is the future of water management in the western United States," he said.

The Airborne Snow Observatory in operation over Yosemite National Park, California. The observatory is creating comprehensive data sets that will be used to estimate how much water will flow out of the river basins when the snow melts.

Manufacturing the Future

In partnership with five federal agencies—including the departments of Defense, Energy, and Commerce, the National Science Foundation, and NASA—the Obama administration launched a nationwide competition in 2013 to create three new manufacturing innovation institutes.

The institutes are being created following an open and competitive selection process headed by the departments of Energy and Defense. The government will invest $200 million in the new institutes, which competition winners will match with private investment and funding from state and local governments. In the long-term, the institutes are expected to become financially self-sustaining.

The new effort is part of Obama's larger goal of creating a network of 15 manufacturing innovation institutes across the country, known collectively as the National Network for Manufacturing Innovation (NNMI), which aims to increase the United States' ability and capacity to compete on a global scale. According to the administration, areas of focus for the first three NNMI institutes will include digital manufacturing and design innovation, lightweight and modern metals manufacturing, and next-generation power electronics manufacturing.

NASA Associate Administrator for Space Technology Michael Gazarik applauded the announcement, saying that it "continues the momentum needed to address a crucial competitiveness challenge—the need to close the gap between research and development activities and the deployment of technological innovations that benefit American manufacturers and American-made goods."

Gazarik noted that NASA's participation in NNMI will signal to the aerospace and manufacturing communities that they will continue to have access to cutting-edge technologies and capabilities for creating new inventions and better products. "Advanced manufacturing, for and in space, holds great promise for NASA as we move forward with our exploration efforts," he said.

Prior to the President's announcement, NASA had also been an active partner in the NNMI pilot program in Youngstown, Ohio. There, the National Additive Manufacturing Innovation Institute focuses on creating a collaborative, open infrastructure for exchanging ideas and technology in additive manufacturing and research.

"We look forward to working with the other stakeholders in these new institutes," said Gazarik, "recognizing they will provide the fuel for America's innovation engine. NASA is proud to help keep that engine running."

Hack Your City

In the summer of 2013, thousands of service-minded hackers from around the country joined virtual hands to meet the challenges faced by ordinary Americans in their communities and in government. The National Day of Civic Hacking took place in more than 80 cities around the country, putting citizens to work on specific challenges issued by nearly 20 government partners, including NASA.

The government agencies involved made dozens of data sets and other resources available to enable the project, aiming to empower developers to build applications for the web and on smartphones. Said Nick Skytland, manager of the Open Innovation Program at NASA Headquarters and leading participant in the event, "Civic Hacking Day is an opportunity for software developers, technologists, and entrepreneurs to unleash their can-do American spirit by collaboratively harnessing publicly-released data and code to create innovative solutions for problems that affect Americans."

Skytland noted that, while small communities of civic hackers have long worked with public data to improve the world, this summer marked the first time a nationally organized event adopted a "shared mission" to address and solve challenges facing communities and government from the local to the national level.

Among the many solutions created over the weekend were an app that connects people in so-called food deserts (urban areas with few or no grocery stores offering fresh foods) with sources for healthy food; a mobile app that allows neighbors to report storm damage in their community; and an app that uses public and user-submitted data sources to track murals and help address their danger of being destroyed.

Research trees were whitewashed and black dots were applied so computer-imaging equipment could capture the stress points as the tree was pulled by a winch. Matt Melis (bottom right), an engineer at Glenn Research Center, designed the demonstration.

If a Tree Falls, Does Anyone Measure It?

It all started when two trees began to die in Matt Melis' front yard. Melis, an engineer at Glenn Research Center, began working with a local arborist to save his trees. Soon after, he devised a plan for understanding the biomechanics of tree failure generally due to hurricanes, ice, and snow loads.

Tree failure has caused many billions of dollars in damage to buildings and the infrastructure of utilities. Understanding how trees fail under the strains of extreme weather is critical for arborists as they work with businesses to find solutions to reduce damage.

Melis' idea involved stereo photogrammetry, a technology he used during the Space Shuttle Columbia accident investigation. "Stereo photogrammetry is the science of analyzing sets of stereo images with computer software to accurately calculate full-field 3D deformation and strains in the structures we test," he explains. "We use it for measuring structural response on a great many things we test in our day-to-day work."

To demonstrate the technique's applicability to tracking tree deformation, Melis painted black and white dot patterns on trees to enable the software to better track their structural motion. Melis and some of his coworkers then conducted a demonstration to a nationwide group of foresters and arborists to show how the technique could be used to measure deformations in the root, trunk, branch and canopy elements of a tree.

The project worked so well that the Morton Arboretum near Chicago proposed a grant to the Tree Fund, an organization devoted to funding tree research, which in turn awarded the grant to Morton. The grant was used to fund a Space Act Agreement to bring Melis and NASA engineer Justin Littell of Langley Research Center to the arboretum to conduct a week-long collaborative photogrammetry research study.

The success has gained additional attention from the biomechanics community. A consulting firm, Bio-Compliance, is working with utility companies on the East Coast and wants Melis and his team to look at branch structures. Falling branches account for a high degree of damage to property and have also been responsible for human fatalities.

"Our work on these projects is an example of how NASA can make a difference in advancing the science of the environment by spinning off capabilities used in its day-to-day operations," says Melis. "We now have demonstrated stereo imaging to be a valuable tool which can lead to greater understanding of tree biomechanics, creating safer communities and infrastructure during extreme weather." ❖

Award-Winning Technologies

NASA's remarkable successes in technology, innovation, and leadership are regularly honored with awards granted by government and industry alike. This year, award-winning Agency achievements in technology transfer, robotics, new materials, spacesuit design, sustainability efforts, and more show the ongoing returns our Nation receives for its investment in space.

Award-Winning Technologies

A Three-Peat at Ames

A tiny sensor that can detect chemicals in the air, invented at Ames Research Center, has won the 2012 NASA Government Invention of the Year. "High Sensitive, Low Power and Compact Nano Sensors for Trace Chemical Detection" was invented by Jing Li and Meyya Meyyappan of Ames and Yijang Lu of the University of California, Santa Cruz.

The invention includes methods and systems for estimating one or more unknown parts of a gas using carbon nanotubes. The electronic sensors developed from these carbon nanotubes are inexpensive, lightweight, and consume very little power.

The sensors have been deployed by NASA to detect trace gases in the crew cabin on the International Space Station (ISS). Other federal agencies are using sensors based on this technology to detect trace gases in various environments. Specific applications for which the innovative sensors have been tested and used include trace chemical detection in planetary exploration, air monitoring, leak detection, and hazardous agent detection using cell phones. Potential future applications may include environmental monitoring, industrial process monitoring and control, and biomedical diagnosis.

"We're very pleased to have Ames inventiveness recognized with this award for the third consecutive year," said S. Pete Worden, Ames' center director. "With this invention, our people have basically created the insides of a tricorder, and based on the uses we've already demonstrated, I can't wait to see the fantastic applications that NASA and industry are going to devise for it."

Each NASA field center submits nominations for the awards, which are evaluated by NASA's Inventions and Contributions Board. The board determines which nominations qualify for each category, ranks the nominees, and makes recommendations to the NASA Office of the General Counsel for review and approval.

This year Ames also won Commercial Invention of the Year runner-up recognition for its Rehydration Beverage, a patented water-electrolyte beverage that results in significantly higher body-hydration levels than similar beverages available on the market. Invented by Ames' John Greenleaf, it has been used by astronauts before, during, and after spaceflight, including missions to the ISS.

The technology became a popular spinoff and is now used by athletes who require rapid rehydration after strenuous activity (*Spinoff* 2000). Marketed as The Right Stuff and sold by Wellness Brands Inc., the concentrate contains the original sodium chloride and sodium citrate blend developed by NASA, along with flavoring and sweetener to counter the saltiness of the electrolytes. Users add a small vial of the product to their water—or any training beverage—in order to significantly enhance rehydration.

The award-winning, tiny, ultra-sensitive sensor developed at Ames Research Center has a huge range of potential applications, from detecting hazardous gases to industrial uses to medical care.

Goddard's Tech-Transfer Team Recognized for Innovation

The Innovative Partnerships Office (IPO) and the Information Technology and Communications Directorate at NASA's Goddard Space Flight Center accepted *InformationWeek* magazine's Best Innovative Government Agency Award. The award was presented during the InformationWeek 500 Conference, held annually to honor the most innovative US-based users of business technology.

Goddard's IPO is responsible for the identification, review, and evaluation of advanced aerospace technologies and innovations, including a determination of the commercial potential for patenting and/or licensing those technologies. Goddard's IPO has negotiated licenses that have resulted in hundreds of thousands of dollars in royalties shared among NASA, civil-servant inventors, and the US Treasury.

The IPO also manages the Center's Small Business Innovation Research (SBIR) program, which awards small businesses more than $9 million per year. Thanks in part to the IPO's efforts, Goddard innovators have recently won numerous awards, including recognition from *R&D Magazine*, Women in Aerospace, the Space Technology Hall of Fame, NANO 50, and the Federal Laboratory Consortium.

Said Ted Mecum, a senior technology manager at Goddard, "It is an honor for Goddard to be recognized for being innovative in technology transfer activities and IT applications related to open source cloud-computing solutions. We have a great team and this means a lot." Adrian Gardner, chief information officer at Goddard, added, "Goddard Space Flight Center's selection among Information Week's 500 is a tribute to its leadership and frontline workers' commitment to the task of developing and implementing new ways to deliver the Center's mission."

"Given the current fiscal climate," Gardner said, "it will take an infusion of innovative tactics, techniques, technologies, and business practices to meet the growing demands of a tech-savvy workforce at a drastically reduced cost. As the Goddard CIO, I believe that we must invest in cloud, mobile, and big data analytics to deliver customer-facing and timely IT services."

Ted Mecum (left) and Adrian Gardner (right), both of Goddard Space Flight Center, accept the *InformationWeek* magazine's Best Innovative Government Agency Award.

NASA Software has Earthshaking Implications

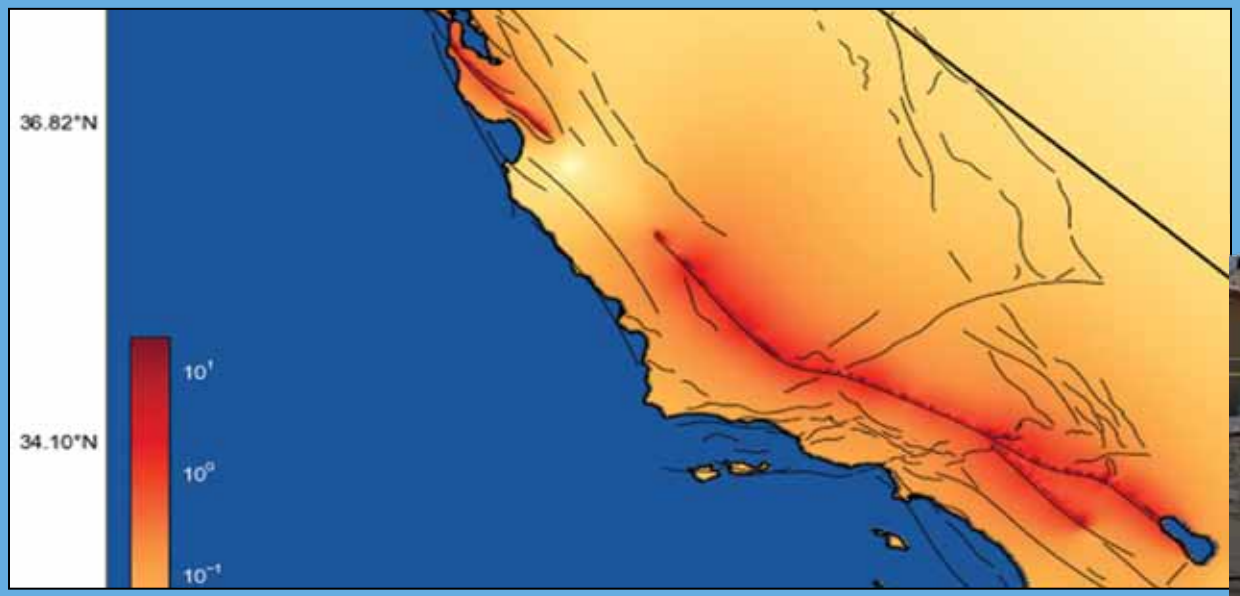
QuakeSim, software that models the behavior of earthquake faults to improve earthquake forecasting and our understanding of earthquake processes, was a co-winner of NASA's 2012 Software of the Year Award. The award recognizes innovative software technologies that significantly improve the Agency's exploration of space and maximize scientific discovery on Earth.

Developed at the Jet Propulsion Laboratory (JPL), QuakeSim is a comprehensive, state-of-the-art software tool for simulating and understanding earthquake fault processes and improving earthquake forecasting. It uses NASA remote sensing and other earthquake-related data to simulate and model the behavior of faults in 3D, both individually and as part of complex, interacting systems. This provides long-term histories of fault behavior that can be used for statistical evaluation.

QuakeSim is also used to identify regions of increased earthquake probabilities called hotspots. Studies have shown QuakeSim to be the most accurate tool of its kind for intermediate earthquake forecasting and detecting the subtle, transient deformation in Earth's crust that precedes and follows earthquakes. Its varied applications include scientific studies, developing earthquake hazard maps that can be used for targeted retrofitting of earthquake-vulnerable structures, providing input for damage and loss estimates after earthquakes, guiding disaster response efforts, and studying fluid changes in reservoirs.

The software has had a number of notable accomplishments to date: It produced the first readily accessible set of digital fault models of California and was used to identify regions in southern California at risk for earthquakes; QuakeSim helped to rule out tectonic deformation of Earth's surface as a factor when a spate of water pipe breaks afflicted Los Angeles in 2009; and it was used in several recent government earthquake response exercises, including the 2008 California ShakeOut, the 2011 National Level Exercise, and the 2012 Golden Guardian Exercise.

QuakeSim approaches are also being adopted by numerous organizations, including the Southern California Earthquake Center, United States Geological Survey, and the California Geological Survey.



The best forecasts of earthquakes are roughly 10 times more accurate than a random prediction, according to a study by scientists at the University of California, Davis. The researchers compared several forecasts, including those made by a NASA-funded group under the QuakeSim program, and results of the study will be used to help researchers develop better forecasts and tools to assess them.

Studies have shown **QuakeSim** to be the **most accurate tool** of its kind for **intermediate earthquake forecasting.**

Officials from the Federal Emergency Management Agency inspect structures following a 7.2 earthquake that struck downtown Calexico, California on June 14, 2010.

Former NASA astronauts Mark Polansky (left) and Michael Lopez-Algeria (right) awarded the medals, shown here with president and CEO of GATR Technologies and inductee Paul Gierow.

ceremony. The DistanceDoc, which allows remote ultrasound users to transmit images securely in real time over the internet, and MedRecorder, which captures diagnostic-quality images for future reference, both allow for telemedicine ultrasound procedures to be performed in previously inaccessible locations by minimally trained individuals.

The enabling technologies were derived from the Advanced Diagnostic Ultrasound in Microgravity project, which produced a specially designed ultrasound machine currently installed on the International Space Station. It was developed through collaboration among Johnson Space Center, the Henry Ford Hospital in Detroit, and Houston-based Wyle Laboratories Inc. (*Spinoff* 2009).

Space Technology Hall of Fame Celebrates 25 Years—with NASA Technology

During the Space Foundation's 2013 National Space Symposium, two NASA-developed technologies were honored by being inducted into the Space Foundation's Space Technology Hall of Fame, which has for 25 years recognized exceptional examples of space technology making a practical impact on Earth. An inflatable antenna communication device and an ultrasound system capable of remote operation, both developed through NASA partnerships, were celebrated at the event.

Glenn Research Center was honored alongside GATR Technologies for its role in developing an inflatable antenna system—a highly portable and easily deployed communication device that relies on geostationary satellites to secure high-bandwith communication links nearly anywhere in the world. The technology was originally intended to be used as a tool for power generation by an engineering firm working under a Small Business Innovation Research (SBIR) contract with Glenn. But in 2004 GATR licensed the device, made improvements to it under a series of Space Act Agreements, and launched it as a commercial communication product (*Spinoff* 2010).

GATR's antenna can provide Internet access and enable a wide variety of communication, including voice and video connections. Because of its reliance on satellites, it provides coverage even in remote areas and is thus popular with US military forces and emergency first responders, among others. The complete system takes only minutes to set up or tear down, and it packs into two suitcases that weigh less than 90 pounds each. The antenna has played a role in humanitarian aid following natural disasters, including Hurricanes Katrina, Ike, and Sandy, and the 2010 Haiti earthquake.

Two ultrasound devices commercialized by Mediphan, a remote diagnostics company, following technology advances made by Johnson Space Center, were also inducted at the Space Technology Hall of Fame

The honored organizations and individuals received engraved trophies at the ceremony.

The 2013 inductees to the Space Technology Hall of Fame were two NASA spinoffs: an inflatable communication antenna (top) and portable ultrasound technology (bottom).

Aided by software and guidance from experts on the ground, the new system allows crew members with minimal technical training to image a wide range of body parts to track the effects of spaceflight on various systems. Applications on Earth include telemedicine ultrasound diagnosis, remote training and instruction for medical students, and rapid diagnosis in sports medicine.

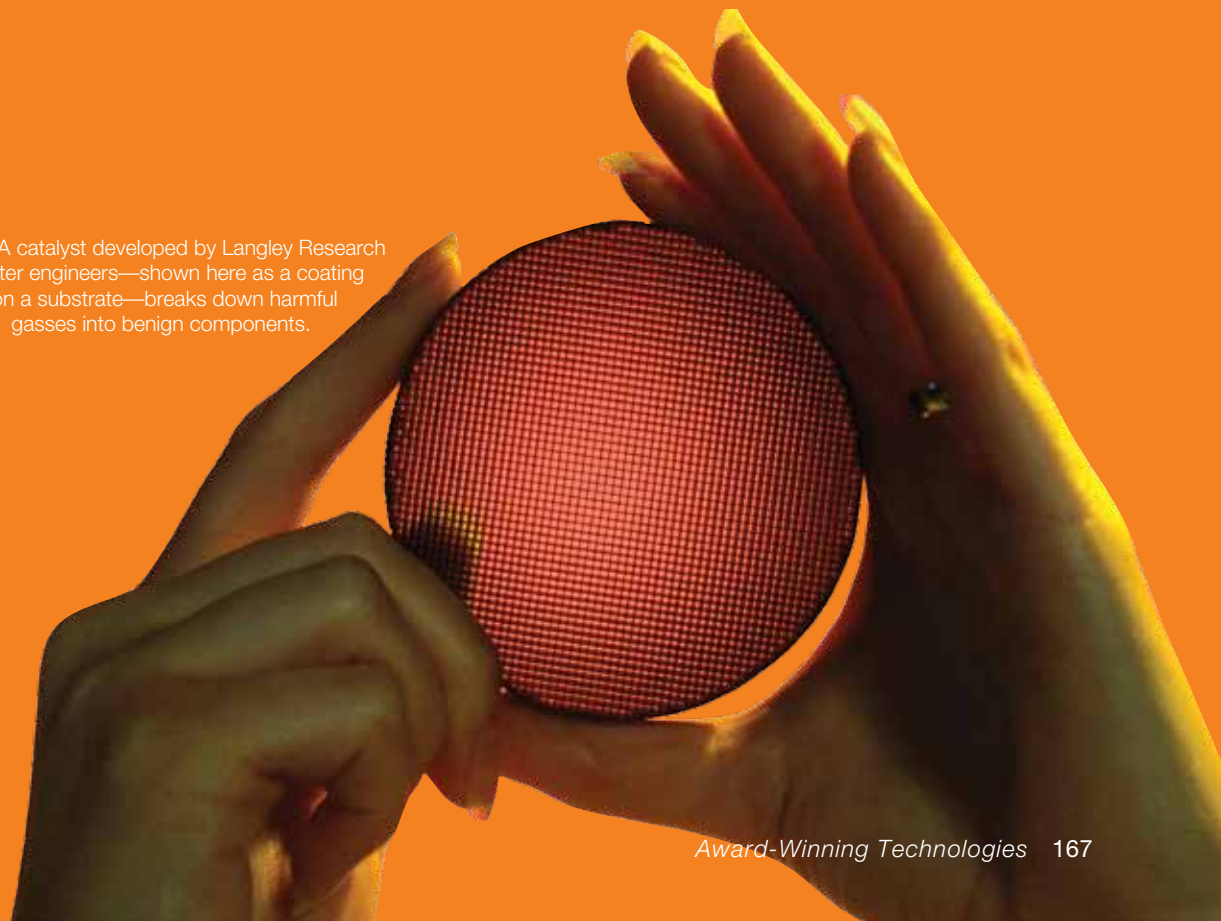
An Eclectic Team Combines for Success

All of the right elements came together for a seven-person team at Langley Research Center, who were presented with the 2012 NASA Commercial Invention of the Year Award for "Methodology for the Effective Stabilization of Tin Oxide-Based Oxidation/Reduction Catalysts." This method can stabilize a catalyst in virtually any application that requires the removal of toxic compounds, including carbon monoxide. Unlike a conventional catalyst, this technology has low, near-room-temperature oxidation capabilities that are maintained up to temperatures greater than about 1,472 °F.

The technology has spun off in industrial equipment that keeps air pure in mining operations (page 68). It also has potential use in power generation, construction, locomotive, forestry, and marine applications.

Current catalyst systems cannot change the state of carbon monoxide and hydrocarbons in such a wide range of temperatures, but the Langley-developed technology can. Plus, it is capable of removing additional volatile compounds, such as formaldehyde, and nitrogen oxides from exhaust streams.

"The team worked very well together and was made up of chemists, engineers, technicians, as well as experts in automotive catalyst formulations and materials science," said Neal Watkins, one of the inventors. "It was an eclectic gathering of talents that was essential for the success of the program."



A catalyst developed by Langley Research Center engineers—shown here as a coating on a substrate—breaks down harmful gasses into benign components.

A Prototypical Success

NASA's next-generation spacesuit is still only in its prototype phase, but its unique design—which many have compared to the outfit worn by *Toy Story*'s Buzz Lightyear—caught the attention of *Time* magazine, which named the Z-1 spacesuit one of its Best Inventions of the Year 2012.

Describing the protoype's features, *Time* remarked that the suit "provides go-anywhere garb featuring more-flexible joints, radiation protection for long stays in space and a hatch on the back that allows the suit to dock with a portal on a spacecraft or rover so an astronaut can crawl through without letting dust in or air out." The "hatch," known as a suitport, will allow wearers to quickly get into the spacesuit from the interior, detach it from the spacecraft, and begin exploring on the exterior of the spacecraft or rover.

The prototype was successfully tested in a vacuum chamber at Johnson Space Center—an important step, as the vacuum environment allows engineers to test the suit's hardware under conditions found in space. Z-1 will eventually be followed by a Z-2 model, with improvements and refinements that will ready the concept for use by NASA—first on the International Space Station, and eventually in crewed missions beyond Earth orbit.

"With this suit, the subject **crawls in** through the **back,** and **then we just shut** the **door."**

— Amy Ross,
Johnson Space Center

NASA's next-generation spacesuit, shown here in its prototype phase, is being designed with long-term, deep-space missions in mind.

Award for Former Director Inspires Future Plans at Johnson

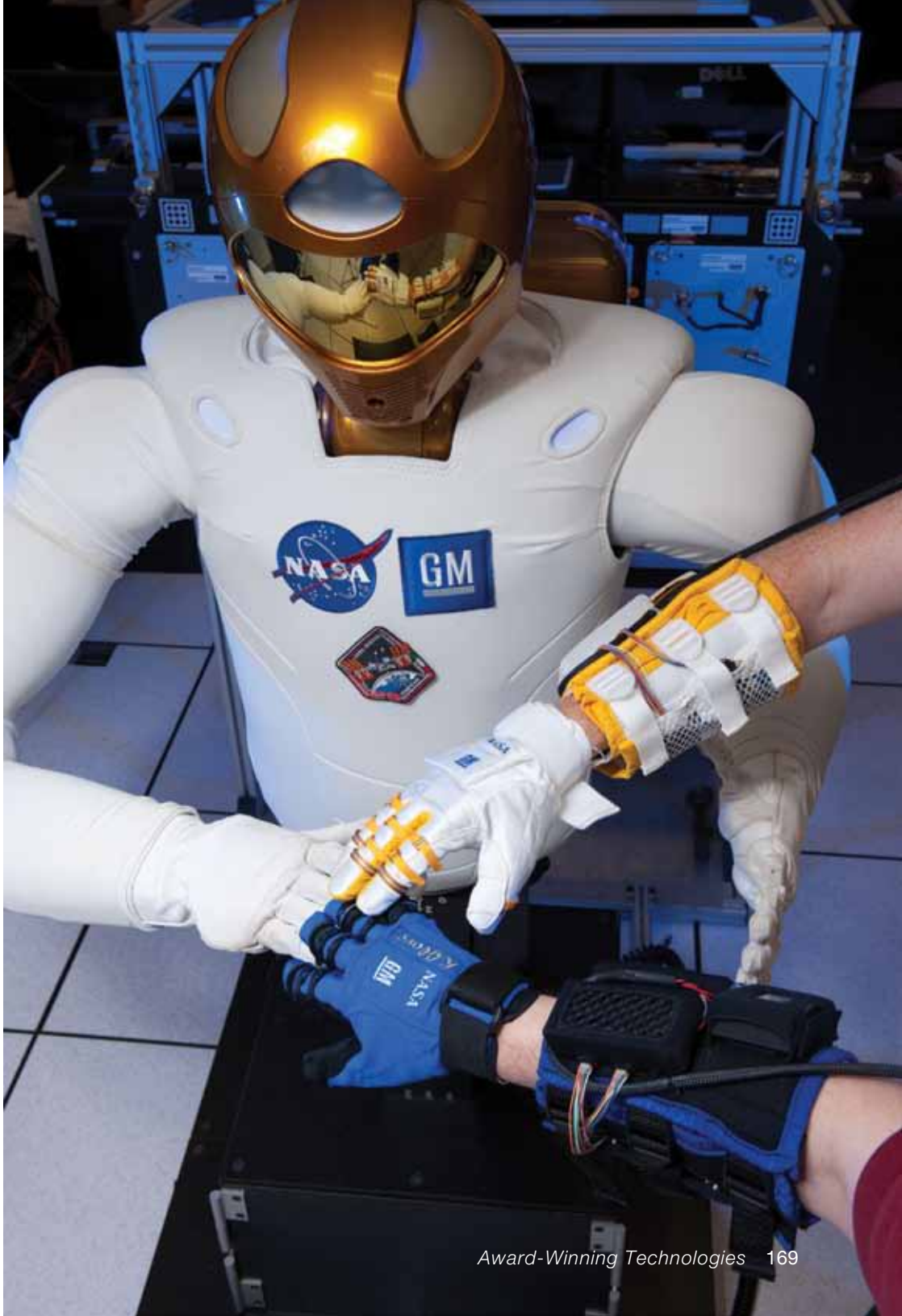
Following closely on the heels of awards given to Johnson Space Center on behalf of the Federal Laboratory Consortium (FLC) Mid-Continent Region for Notable Technology Development and Outstanding Laboratory, former Johnson director Mike Coats was recognized by the FLC as the 2012 Laboratory Director of the Year.

This recognition reflects Johnson's outstanding leadership and numerous technological achievements. Some of the notable accomplishments under Coats that led to the award include:

- medical support provided by Johnson in the efforts to rescue the trapped Chilean miners;
- Johnson and commercial partner SunDanzer's solar-powered refrigerator, now enabling the storage of vaccines in remote areas without electricity (*Spinoff* 2003, 2013);
- the Johnson-GM partnership to develop a robotic glove to alleviate repetitive stress injuries; and
- the partnership with Meridian Health Systems to use NASA-patented microwave and millimeter wave technology to treat the hardening of heart arteries.

Some of these technologies represent the beginning of new commercialization activities for Johnson, which is exploring opportunities for transferring NASA technology. "We're putting more emphasis on getting our technologies out there," said Jack James of Johnson's Technology Transfer Office, which falls under the Strategic Opportunities and Partnership Development Office. "We're strengthening our partnerships with the Houston Technology Center and BayTech, and there are a few other ones we're looking to pursue."

Johnson's success, as well as this most recent award for its former director, is now part of a legacy—one that current Johnson director Ellen Ochoa says she seeks to continue. Under Ochoa's leadership, Johnson will combine efforts in human exploration, science, and space technology to meet President Obama's challenge to send astronauts to an asteroid by 2025 and to Mars by the 2030s.



NASA partnered with General Motors to develop a robotic glove that will strengthen its wearer and help users to avoid stress injuries.

Curiosity's Team Recognized for Historic Achievements—Twice

Two prominent aerospace industry organizations are recognizing the contributions of NASA, especially the achievements of the team that landed NASA's Curiosity rover on Mars in August 2012, with coveted awards.

In early May 2013, the National Aeronautic Association (NAA) presented its Robert J. Collier Trophy to the Mars Science Laboratory (MSL) Team of NASA's Jet Propulsion Laboratory (JPL) at an event in Arlington, Virginia. The previous week, the team received the American Institute of Aeronautics and Astronautics (AIAA) Foundation Award.

"It's wonderful to see NASA's people and their accomplishments recognized by the aerospace community," NASA Administrator Charles Bolden said. "In particular, the Curiosity landing was the hardest NASA mission ever attempted in the history of robotic planetary exploration. These prestigious awards are a testament to the dedication and hard work of the entire worldwide team."

The NAA established the Collier Trophy in 1911 and presents it yearly to recognize the greatest achievement in aeronautics or astronautics in America. The AIAA awards recognize the most influential and inspiring individuals in aerospace, whose outstanding contributions merit the highest accolades. Past honorees have included Orville Wright, Neil Armstrong, the team that designed the space shuttle, and the astronauts who carried out the first Hubble Space Telescope repair mission in 1993.

The NAA's Collier citation notes the MSL team's "extraordinary achievements of successfully landing Curiosity on Mars, advancing the Nation's technological and engineering capabilities, and significantly improving humanity's understanding of ancient Martian habitable environments."

More than 7,000 people in at least 33 US states and 11 other countries have worked on the Mars Science Laboratory mission. Curiosity, the laboratory's centerpiece, carries 10 science instruments to investigate the environmental history inside Gale Crater on Mars. In March 2013, rover scientists announced that an analysis of a rock sample shows Mars could have supported living microbes in an ancient freshwater environment. Curiosity's mission is expected to last at least 2 years.

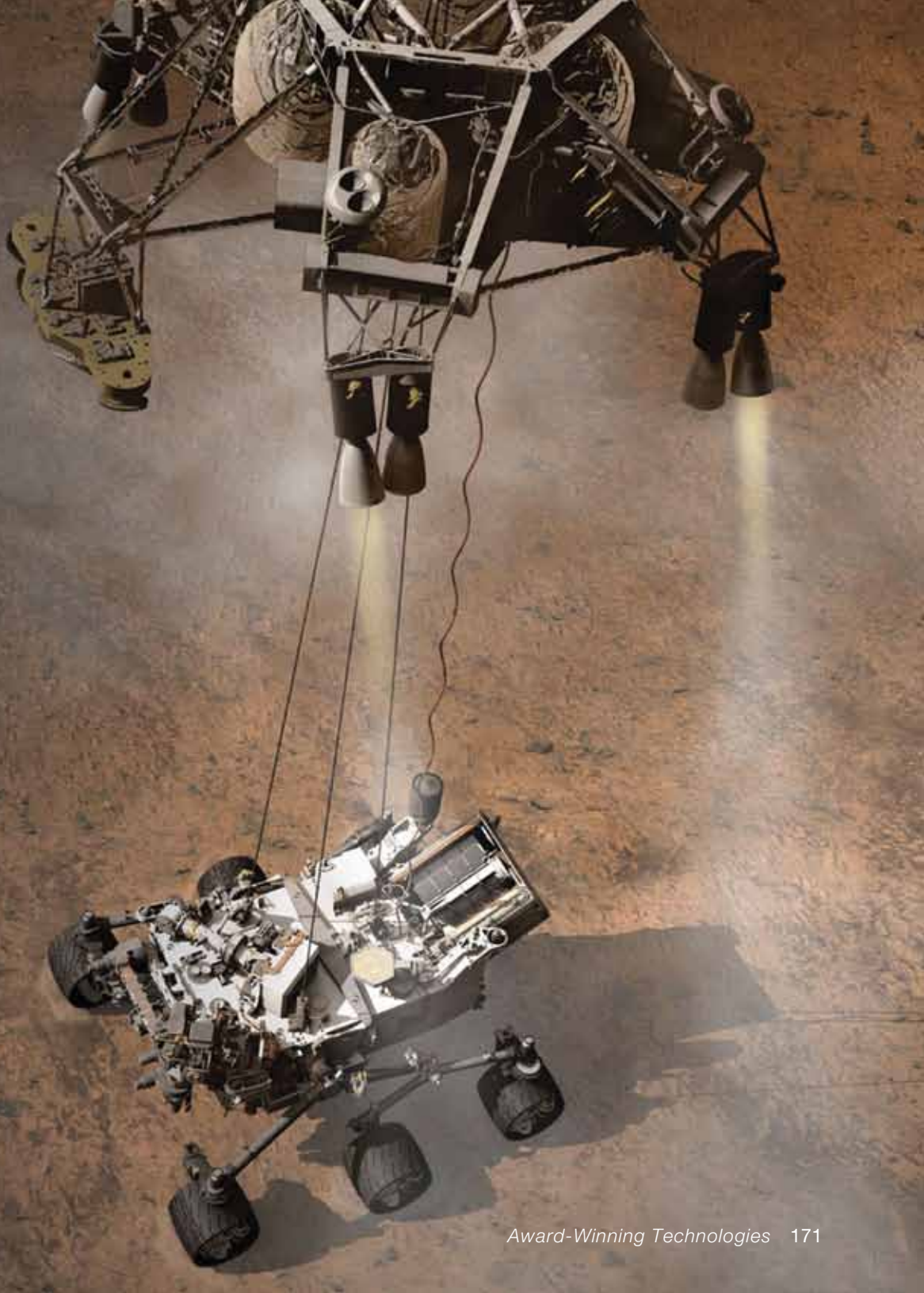
"The prestigious Collier Trophy is a wonderful recognition for Curiosity, a phenomenal engineering and science achievement that has captured the hearts and minds of children and adults across America and around the globe," said Charles Elachi, director of JPL. "It's an honor to do missions like this one on behalf of NASA and the Nation."

NASA researchers work with full-scale models of various rovers, including Curiosity, in the Jet Propulsion Laboratory's Mars Yard testing area.

In 2013, the men and women behind the dramatic landing of NASA's Curiosity rover were honored with the Robert J. Collier Trophy from the National Aeronautics Association and an award from the American Institute of Aeronautics and Astronautics.

"The Curiosity landing was the hardest NASA mission ever attempted in the history of robotic planetary exploration."

— Charles Bolden, NASA Administrator



The Curiosity Rover has captivated the imagination of millions around the world. A Jet Propulsion Laboratory video explaining its daring landing mission, called "Curiosity's Seven Minutes of Terror," was extremely popular and created a great deal of anticipation on the part of the public. To watch the video, scan this code.

NASA Facilities Earn Green Honors

The US Environmental Protection Agency (EPA) has recognized NASA's White Sands Test Facility in Las Cruces, New Mexico, and Johnson Space Center in Houston as Federal Green Challenge National Award winners.

White Sands received the National Award for Overall Achievement for outstanding efforts in 2012 to advance sustainability efforts and for its leadership in reducing the environmental footprint of federal government activities. "In 2012, concrete and asphalt debris piles were safely recycled into 10,712 tons of reusable materials," said Michael Jones, environmental project manager at White Sands. "As an alternative to purchasing new road base materials, White Sands now has reusable resources for future projects. This truly was a team effort between the White Sands facilities engineering, environmental, and safety organizations."

Johnson was recognized for the highest progress over the previous year. The center increased municipal solid waste composted from 16 tons in 2011 to 250 tons in 2012, which represents a 1,449-percent improvement. "Through our composting program, we no longer need to purchase mulch and compost, we don't have to pay to get rid of yard debris, and we're reducing greenhouse gas emissions—it's a win-win situation all around," said Michelle Fraser-Page, recycling manager at Johnson.

These achievements were made by NASA facilities while participating in the Federal Green Challenge, a national effort under EPA's Sustainable Materials Management Program that challenges federal agencies to lead by example in reducing environmental impact. Federal agencies are recognized for outstanding efforts that go beyond regulatory compliance and for annual improvements in selected areas.

Above: Building 12 on the campus of Johnson Space Center sports an environmentally friendly roof that is home to nearly 70,000 plants. Below: A series of images shows before, during, and after a major White Sands Test Facility effort to clear debris and asphalt piles, recycling them into nearly 11,000 tons of reusable materials.

Goddard Engineer Joins NASA Greats with Lovelace Award

NASA engineer Tom Flatley of Goddard Space Flight Center received the William Randolph Lovelace II award at the 51st Robert H. Goddard Memorial Symposium. The American Astronautical Society (AAS) award was presented to Flatley in recognition of his outstanding contributions to space science and technology through his work with SpaceCube.

SpaceCube is a compact, reconfigurable hybrid-computing platform that is being used for flight science data processing applications. It was designed for space applications that require extreme processing capability at a much higher level than current radiation-hardened space technology can handle. SpaceCube uses radiation-tolerant processing components and can collect and process 100 times more data than traditional radiation-hardened flight processors.

"SpaceCube technology is truly cutting-edge," said Chief Technologist Peter Hughes of Goddard. "This processor provides long-needed radiation-tolerant, high-performance computing from a smaller, more energy-efficient platform. These attributes are allowing spacecraft to become increasingly more autonomous and capable, particularly important today because of the massive amounts of data collected by our instruments."

The AAS award was created to honor the lifetime achievements of Lovelace (1907-1965), NASA's director of space medicine. Flatley joins other NASA notables who previously received the Lovelace award, such as astronaut Buzz Aldrin, the second man to ever walk on the moon; Neil Gehrels, chief of Goddard's Astroparticle Physics Laboratory and a gamma ray researcher; and Noel Hinners, who was Goddard's center director before becoming NASA's associate deputy administrator and chief scientist.

SpaceCube, pictured here, deployed on the International Space Station to test special software techniques that can make computers more immune to the problems caused by radioactive particles in space.

Robonaut Team Honored for Game-Changing Technologies

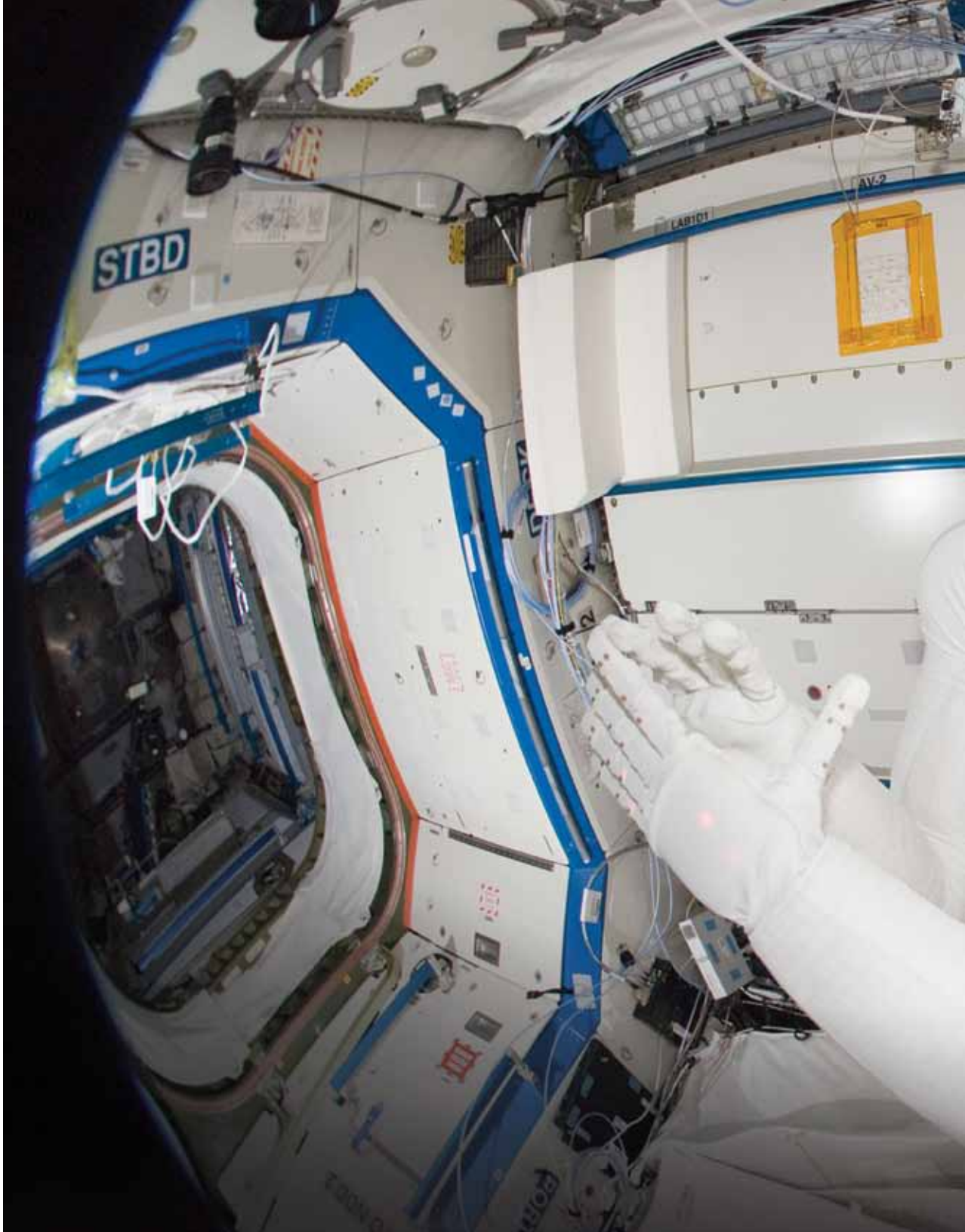
The NASA team behind Robonaut 2, the first humanoid robot in space, has been awarded the American Institute of Aeronautics and Astronautics' (AIAA) Space Automation and Robotics Award for 2013. AIAA is the world's largest technical society dedicated to the global aerospace profession.

Robonaut 2, or R2, is a dexterous humanoid robot built and designed at Johnson Space Center. Sent to the International Space Station (ISS) in 2011 with the intention of aiding astronauts on dangerous tasks and freeing them from some of their more mundane work, upgrades to the R2 system continue to produce novel advances in the field of robotics.

"The R2 development team is an incredible group of talented people and I am so proud that the team has been recognized with this prestigious honor," said Myron Diftler, Robonaut principal investigator at Johnson. "To be acknowledged this early in our planned activity on the ISS is especially notable. This award from our peers gives us increased confidence that R2 is on a track to even more success as we move towards mobility inside, and then outside the ISS."

Technologies developed by the R2 team have debuted in multiple potential spinoffs as wearable robotic devices. The Robo-Glove, codesigned by NASA and General Motors to reduce the risk of repetitive stress injuries and provide additional gripping strength to astronauts, is a direct descendant of the actuators and controls found in R2's hands. Also drawing from the robot's design team, the X1 exoskeleton device is a robot that a human could wear over his or her body either to assist or inhibit movement in leg joints.

R2 is part of NASA's Game Changing Development Program, which seeks to quickly mature innovative technologies that will have cross-cutting applications throughout Agency missions and may also be of benefit to the American aerospace industry. NASA's game-changing efforts are part of the Agency's Space Technology Program, which is innovating, developing, testing, and flying hardware for use in future science and exploration missions. ❖



The X1 Robotic Exoskeleton is a wearable device based on robotics technology developed during the Robonaut project. The X1 can either inhibit or assist movement in leg joints and has potential applications both in space exploration and on Earth.

Spinoffs of Tomorrow

In addition to its many spinoffs already benefitting society, NASA has a host of technologies that are available for licensing and partnership opportunities. Each of the 10 field centers is making unique advances in a variety of fields, from aeronautics and information technology to biomedical devices. This section features just a few examples of industry-ready technology on offer thanks to NASA's investments in research. For a complete listing of all available NASA technologies, visit http://technology.nasa.gov.

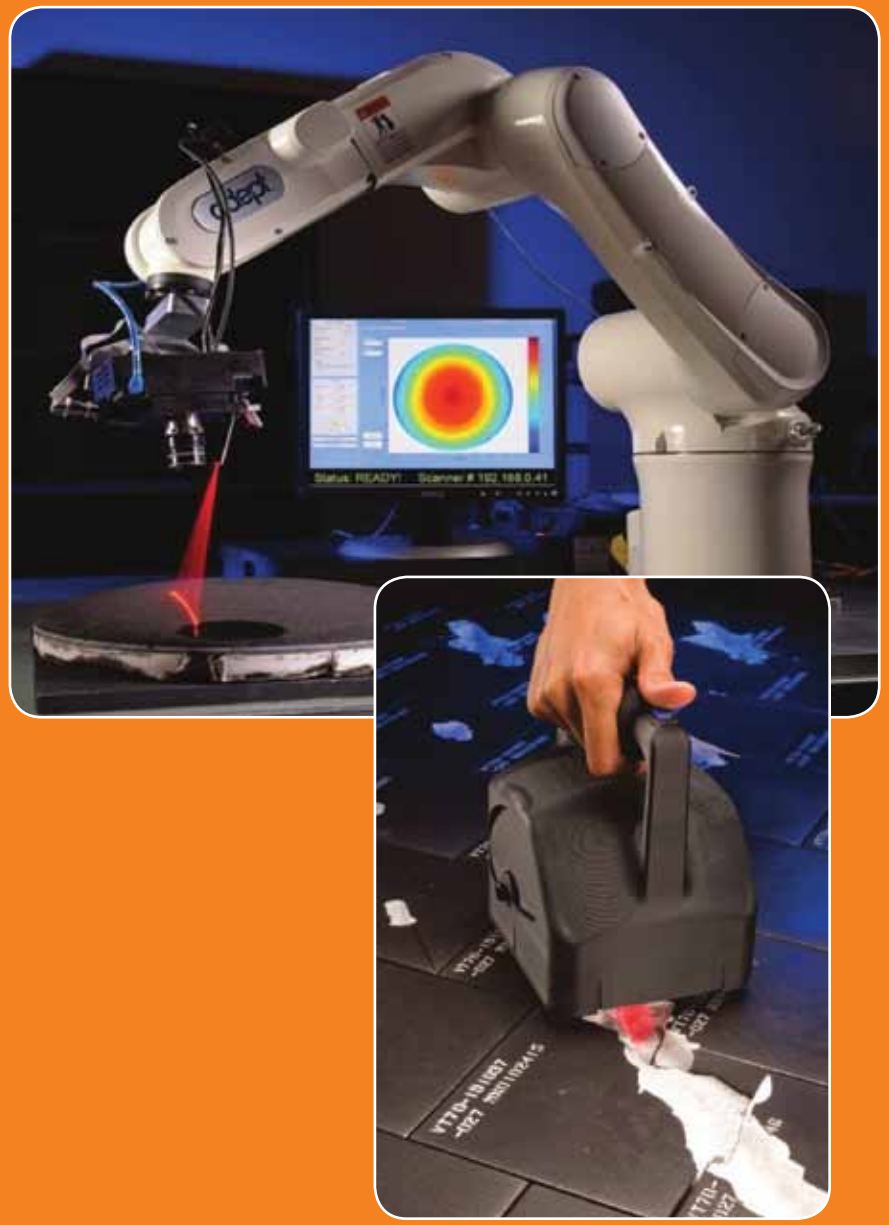
Ames

High-Speed 3D Laser Scanner

Versatile, fast 3D scanning with Internet connectivity and a small footprint

Ames Research Center now offers its patented 3D Laser Scanner surface scanning and profiling technology for license, a technology that won the 2008 NASA Government Invention of the Year Award. Originally developed for critical, real-time inspection of damage to the thermal protection tiles of the space shuttle, this advanced system can be used for a wide range of commercial applications from product quality control to autonomous navigation.

Powered by the onboard Surface Profiling and Characterization Engine (SPACE) processor, the 3D Laser Scanner provides real-time analysis of surfaces ranging from the small (such as circuit boards) to the large (such as panels or roads). No other 3D scanner offers the same combination of speed, resolution, size, power efficiency, and versatility. In addition, it can be used wirelessly, unencumbered by cables. Results of a scan are available in real time, whereas conventional systems scan over the surface, analyze the scanned data, and display the results long after the scan is complete.



Benefits

- High-speed, 3D scans create more than 600,000 3D points/second—among the highest available
- Provides results in real-time from the integrated SPACE processor
- Can scan areas sized from square centimeters to square meters
- Detects details smaller than .001 inches
- Small, lightweight, and power efficient: over 1,000 scans from the rechargeable lithium battery
- Offers wireless or gigabit ethernet wired connectivity

Applications

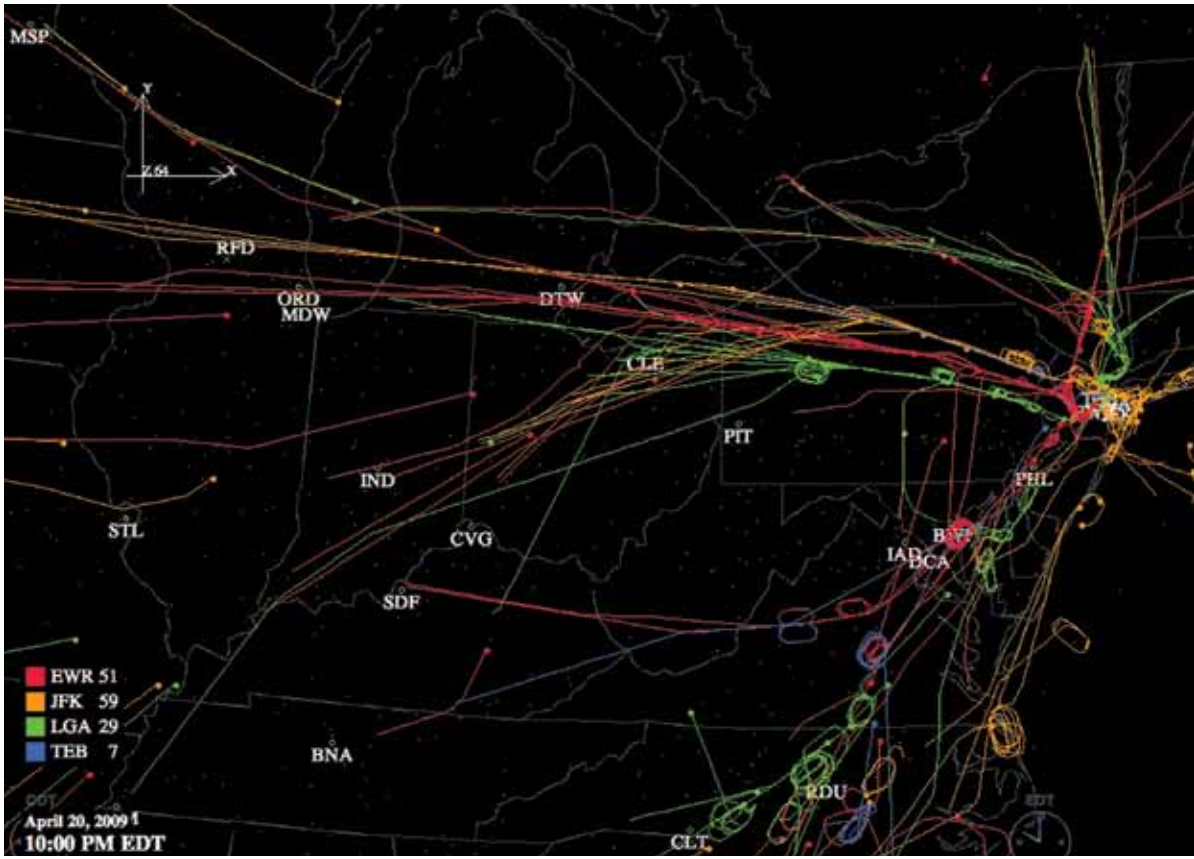
- Inspection of aircraft and spacecraft fuselage surfaces, wings, and more
- Autonomous navigation by mobile robots
- Inspection of pipelines (oil, natural gas, water) for corrosion-related defects
- Optical 3D scanning of printed circuit boards for inspection and positioning
- Dental scanning and inspection of orthodontic devices
- Dermatology/healthcare scanning (inspection and tracking of moles)
- Road surface profiling

Future Air Traffic Management Concepts Evaluation Tool

Comprehensive software eases air traffic management

With thousands of planes flying overhead in the United States at any given time, there is an urgent need for tools that help avoid air traffic incidents and delays. Ames Research Center is offering the opportunity to license and codevelop the Future Air Traffic Management Concepts Evaluation Tool (FACET). FACET performs powerful computational simulations for evaluating advanced concepts of air-traffic management. It includes a program that generates a graphical user interface, plus programs and databases that implement computational models of weather, airspace, airports, navigation aids, aircraft performance, and aircraft trajectories.

Actual air traffic data and weather information are utilized to evaluate an aircraft's flight-plan route and predict its trajectories for the climb, cruise, and descent phases. The dynamics for heading and airspeed are also modeled by FACET, while performance parameters such as climb/descent rates and speeds and cruise speeds can also be obtained from data tables. Resulting trajectories and traffic flow data are presented in a 3D graphical user interface. The software is modular and written in the Java and C programming languages. Its potential applications include reroute conformance monitoring algorithms that have been implemented in one of the Federal Aviation Administration's nationally deployed, real-time operational systems.



Benefits

- Decreases airline accidents
- Swiftly generates as many as 15,000 aircraft trajectories on a single desktop or laptop computer
- Provides trajectories and traffic flow data presented in an easy-to-use, 3D graphical user interface

Applications

- Air traffic management
- Development of enhanced flight routing strategies that can
  - save fuel
  - preserve airline schedules
  - reduce passenger delays and missed connections

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Global Elevation Data Adaptive Compression Algorithms

Greater compression and faster decompression of digital terrain maps

Dryden Flight Research Center is offering its patent-pending Global Elevation Data Adaptive Compression Algorithms to provide compression and rapid decompression of digital terrain maps (DTMs) in constrained computing environments. The primary purpose of these algorithms is to create and utilize highly compressed digital terrain data representing the geographical areas of the entire world to enable Automatic Ground Collision Avoidance Systems (Auto-GCAS) for high-performance fighter aircraft. The data is formatted to be accessible anywhere in the world in real-time and also allows for control of data resolution to support the complete range of high-performance aircraft operations. Other uses include applications that require large databases of graphical information to be deployed through restricted environments such as tablets and smartphones.

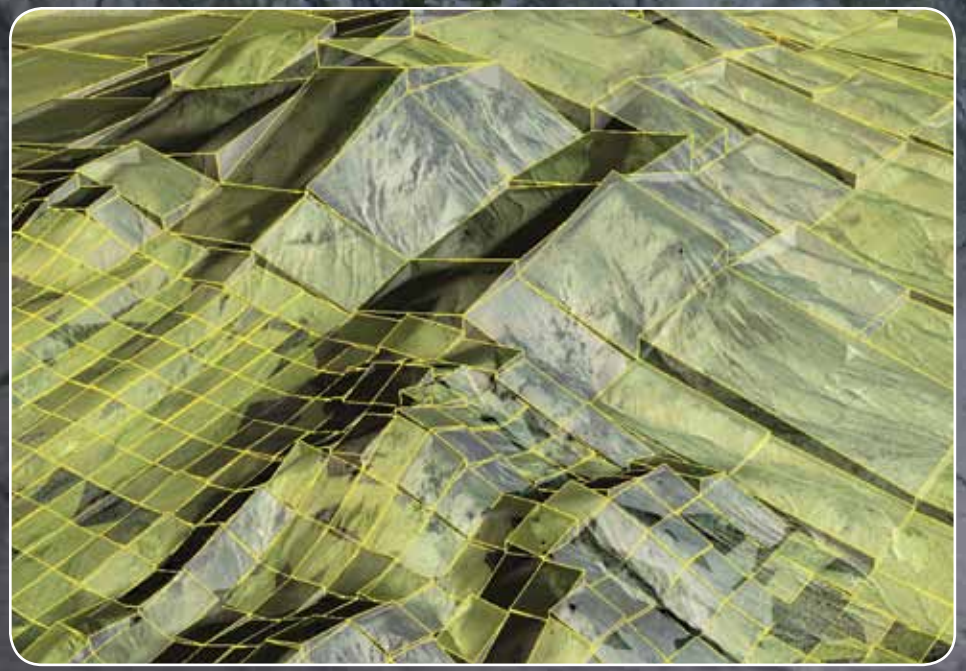
The software provides an extensive and highly efficient compression capability for continental and global-scale DTMs, along with a real-time decompression capability to locally decompress and render map data in the vicinity of a fast-moving airplane. A key feature of the innovation is its ability to render local terrain maps in real time for an Auto-GCAS in a high-performance airplane that may need to deviate from a planned flight path due to unexpected and dynamic events.

Benefits

- Controls error induction maximums for user-defined geographical areas from lossless to infinite and incorporates different areas seamlessly in a single compressed DTM
- Performs rapid, high-performance decompression in real-time constrained computing environments
- Integrates more than 250 billion separate pieces of terrain information into a single compressed file
- Features technology flown and tested on several different platforms including high-performance fighter aircraft
- Enables implementation on existing aircraft systems without upgrading computer hardware; offers industry standard C, C++ code base and map formats

Applications

- Commercial and military aircraft Auto-GCAS
- Marine electronic charting systems
- Weapons guidance systems
- Software that analyzes terrain routes or continual surfaces
- Gaming systems
- Medical software



Battery Monitoring System

Assessing real-time battery health wirelessly with commercial, off-the-shelf parts

Battery health monitoring is an emerging technology field that seeks to predict the remaining useful life of battery systems before they run out of charge. Such predictive measures require interpretation of large amounts of battery status data. Engineers at Dryden Flight Research Center have developed a battery data acquisition and logging system that processes and reports analog sensor data in real time for wireless transmittal. When used in combination with customized, NASA-developed algorithms, the Dryden innovation provides a means to collect, process, and transmit this critical remaining useful life data.

Constructed with commercial, off-the-shelf parts, this low-cost and novel battery monitoring system is adaptable to multiple types of battery chemistry, creating cross-platform capabilities for a wealth of sensing needs. Measurements taken include voltage, temperature, and state of health for multiple batteries simultaneously. The methodology not only provides time-to-failure estimates but also generates a probability distribution over time that best encapsulates the uncertainties inherent in system models. Such information enables a real-time monitoring capability beyond that which is currently available, particularly for applications where unanticipated battery performance may lead to catastrophic failures, such as aerospace and medical device systems.

Benefits

- Prevents occurrence of catastrophic battery failure by predicting the remaining useful life of battery systems
- Processes large amounts of data and reports results wirelessly
- Effectively monitors the health of multiple batteries simultaneously
- Reliable, critical, real-time monitoring capability that allows an immediate and controlled response to avoid battery failure
- Uses commercial, off-the-shelf parts, increasing affordability and contributing to a lightweight, compact footprint
- Provides a rugged, robust platform with the potential for miniaturization

Applications

- Electric unmanned aerial vehicles
- Electric, hybrid, and plug-in hybrid electric vehicles
- Light rail systems
- Medical devices
- Robotics
- Industrial instruments
- Grid stationary power systems
- Portable power packs

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 Dryden technologies, scan this code or visit http://www.nasa.gov/offices/ipp/centers/dfrc.

Glenn

High-Temperature, Low-Melt Viscosity Imide Resins for Liquid Molding

Fabricating resin transfer molding composites for aerospace components

Glenn Research Center is inviting companies to license or establish partnerships to develop its patented high-temperature, low-melt viscosity imide resins for composite fabrication into aerospace components. Produced by a solvent-free melt process, these resins exhibit high glass transition temperatures, low-melt viscosities, long pot-life, and are amenable to resin transfer molding (RTM) and vacuum-assisted resin transfer molding (VARTM).

RTM imide resins can be melted and injected into fiber preforms under pressure or vacuum. The resins also can be made into powder prepregs with unlimited out-time by melting the resin powders so that they fuse onto fibers. RTM imide resins display high softening temperatures (370–400 °C) and excellent toughness. This technology was developed to make polyimide resins from novel asymmetric dianhydrides (a-dianhydrides) and kinked diamines to achieve low-melt viscosities that are amenable to low-cost RTM and VARTM, while retaining high-temperature performance above 300 °C. These a-dianhydride-based RTM imide resins display low-melt viscosities that cannot be achieved using normal symmetric dianhydrides.

Benefits

- High-temperature capability, performing above 300 °C, which exceeds conventional RTM resins for aerospace applications
- Can be cured in 2 hours without releasing any volatiles
- Offers a 30 percent cost savings by fabricating complex parts more economically
- Improved safety and eliminates the need for hazardous organic solvents

Applications

- Aircraft propulsion
- Airframe vanes, ducts, and bushings
- Missiles
- Rockets
- Polymer laser sintering

Spinoff 2018

Nickel-Titanium Ball Bearings

Shockproof, super-elastic, and corrosion-immune bearings

Many aerospace bearing and mechanism failures can be traced back to the inadequacy of currently available materials: conventional hardened bearing steels are prone to corrosion, and bearings made from corrosion-resistant alloys and plastics are relatively soft and prone to wear. To address these issues, NASA has developed rolling element (ball) and sliding bearings utilizing NiTiNOL 60 (60NiTi), a nickel-titanium alloy that offers a broad combination of physical properties that make it unique among bearing materials.

NASA partnered with Abbott Ball Company Inc. to develop the basic material and shared expertise in using powder metallurgy for a new material production technique. Glenn Research Center is now offering an innovative ball bearing made with an advanced intermetallic alloy for licensing.

60NiTi is hard, electrically conductive, readily machined prior to final heat treatment, easily lubricated, and nonmagnetic. It is also highly resistant to corrosion because it contains no iron and cannot rust. Furthermore, it belongs to the family of super-elastic materials and exhibits the uncanny ability to withstand extreme loads and stresses without incurring permanent damage such as Brinell dents.

Benefits

- Low friction and high hardness properties make bearings wear-resistant and long-lasting
- Better and more easily lubricated, as oils without corrosion inhibitors can be used
- Bearings are lower-weight and more efficient than alternatives
- A unique combination of properties increases the dent resistance of the bearings
- Fully commercialized production process with many standard ball sizes available

Applications

- Spacecraft and satellite mechanism bearings subjected to high static and shock loads
- Corrosion-resistant mechanical components (bearings, gears, and mechanisms) for medical, marine, and food processing machinery
- Air, surface, and marine transport systems

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Goddard

Estimated Spectrum Adaptive Postfilter Algorithm

Improve the quality of images and video sequences

Goddard Space Flight Center invites companies to license a new, patented technology proven to enhance the image quality of compressed grayscale or color JPEG images and MPEG video clips commonly used on websites, online applications, and streaming media. The Estimated Spectrum Adaptive Postfilter (ESAP) algorithm helps to improve the objective and subjective quality of these images as well as enhance their perceptual visual quality, as compared to baseline JPEG images.

Default video and image encoding algorithms for JPEG, MPEG, and HDTV files produce many quality-reducing blocking effects when operating at low bit rates. Previous techniques to overcome this problem were mostly nonlinear filtering methods based on limiting, local pixel statistics rather than on more accurate local frequency content. These techniques offer lower subjective quality than the techniques based on Goddard's algorithms. In addition, ESAP can be cost-effectively implemented in firmware to enable real-time image results. The algorithm can be commercially developed to enable enhanced video and image quality that is superior to previous techniques and the default JPEG or MPEG compression parameters.

Benefits

- Minimizes the loss in image quality that occurs in compressed images
- Yields minimal blurring of an image's true edges while significantly reducing the blocking artifacts resulting from high image compression
- JPEG-compliant, adhering to the coded stream syntax of the Independent JPEG Group
- Can be implemented in firmware or a fast processor, eliminating the need for additional overhead expenses

Applications

- Web-ready images
- Streaming video
- Moderate-rate HDTV broadcasts

Modulated X-ray Source

Bringing X-ray tubes to the digital age

While medical imaging has advanced over the years, X-ray sources have remained relatively unchanged. Much like old vacuum-tube technology, standard X-ray tubes are driven by a hot filament that emits electrons that strike a target to generate radiation. Hot filaments require warm-up time and are not conducive to rapid switching. Like vacuum-tube designers before the advent of the transistor, most X-ray equipment designers have not considered how a more functional X-ray source could enable other imaging and therapy innovations.

Originally developed for deep-space astronomy and communication applications, Goddard Space Flight Center's patent-pending Modulated X-ray Source (MXS) technology replaces the hot filament with simple light-emitting diode (LED), photocathode, and electron multiplier components. Any electrical signal delivered to the LED generates UV light that triggers the photocathode to generate electrons that can be optionally amplified by an electron multiplier.

Benefits

- By moving from a hot to cold cathode, the MXS enables X-rays to be switched on and off in less than a nanosecond
- More robust than standard X-ray sources, with decreased warm-up times and increased device life
- Easy to manufacture, as all designs and functioning prototypes are based on commercial off-the-shelf components that are small and low cost
- Allows for customized dose controls to minimize radiation exposure in medical settings—particularly advantageous for children and pregnant women
- Enables X-ray communication that is secure, fast, long-range, and more energy efficient than current or next-generation laser-based space communication

Applications

- Precise and low-dose medical imaging
- Dynamic imaging
- X-ray based communications
- Chemical and material identification and analysis

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Johnson

Hypoxia Detection and Warning System

Method and apparatus for monitoring oxygen partial pressure in air masks

Johnson Space Center has developed an innovative oxygen warning system capable of detecting and preventing oxygen deprivation, or hypoxia, in the user. If oxygen partial pressure dips below a safe, predefined level, the sensor's alarm and aggressive vibration are capable of arousing an individual who may have become impaired by symptoms of hypoxia such as drowsiness, slowed reaction times, and blackouts. The partial pressure warning system can be incorporated into virtually any commercially available oxygen mask.

This sensor measures the product of oxygen concentration and total ambient pressure, or oxygen partial pressure. The alarm's circuitry can be triggered by any combination of low oxygen concentration and low total pressure that drops the product below a user-defined set point. Vigorous tactile and aural stimulation allows the user to take corrective action before succumbing to the dangerous, and potentially fatal, effects of hypoxia.

Benefits

- An effective "nose beater" vibration and high-pitched alarm alerts an individual who may otherwise be too groggy to respond
- Measures the partial pressure of oxygen, which correlates more highly with hypoxia than oxygen concentration, which is what other oxygen sensor systems typically measure
- Precisely monitors oxygen partial pressure within the air mask rather than within the supply air, allowing for more accurate analysis of the air the user is actually breathing
- Sensor functions independently of the oxygen or air system, so it can provide accurate detection and warnings in the event of an oxygen system failure
- Easy-to-implement system relies on communication wiring already present in oxygen masks and therefore requires minimal modifications and production costs

Applications

- Military aviation
- Firefighting
- Respiratory and life support systems
- Scuba diving
- Underwater welding
- Mountain climbing
- Industrial sites with hazardous breathing environments

X1 Robotic Exoskeleton

Wearable device that can inhibit or assist movement

Derived from the Robonaut 2 project at Johnson Space Center and designed in partnership with the Florida Institute for Human and Machine Cognition and Houston-based Oceaneering Space Systems, NASA's X1 robotic exoskeleton may someday help astronauts stay healthier in space and assist paraplegics and others in walking on Earth.

The device is a 57-pound robot that a person can wear over his or her body to assist or to inhibit movement in his or her leg joints. The X1 legs are worn with a harness that reaches up a person's back and around his or her shoulders. There are 10 degrees of freedom, or joints: four motorized joints at the hips and the knees, and six passive joints that allow for sidestepping, turning, and pointing and flexing a foot on the robot. There are also numerous adjustment points that allow the apparatus to be used in many different ways. While still in the research and development phase, the X1 is functioning. NASA's primary focus is continued development, evaluation, and improvement of the technology.

Benefits

- Device is lightweight and proven to be more comfortable and easier to wear and adjust than other exoskeleton devices
- High-performance capabilities offer mobility assistance and can expand rehabilitation programs
- When combined with NASA-developed walking algorithms, X1 can potentially produce high torques to allow for assisted walking over varied terrain, including stair climbing
- Coupled with a spacesuit, X1 can provide additional force when needed during exploration

Applications

- Space exploration
- Long-term astronaut health
- Assistive walking devices
- Rehabilitation
- Gait modification
- Offloading large amounts of weight from wearer

Kennedy

Regolith Advanced Surface Systems Operations Robot

Teleoperated robotic platform excavates in hard-to-reach locations

Kennedy Space Center is soliciting licensees for its Regolith Advanced Surface Systems Operations Robot (RASSOR) excavator. RASSOR is a teleoperated mobile robotic platform with a unique space regolith excavation capability. Its design incorporates net-zero reaction force, thus allowing it to load, haul, and dump space regolith under extremely low gravity conditions with high reliability. RASSOR could also be scaled up and used for terrestrial mining operations in difficult-to-reach or dangerous locations.

Regolith excavation is desired in future space missions for the purpose of in situ resource utilization to make local commodities (such as propellants and breathing air) and to pursue construction operations. The RASSOR excavator can traverse steep slopes and rough terrain, and its symmetrical design enables it to operate in reverse so that it can recover from overturning by continuing to dig in the new orientation. RASSOR has wireless control, telemetry, and onboard transmitting cameras, allowing for teleoperation with situational awareness. The unit can be programmed to operate autonomously for selected tasks.

Benefits

- Lightweight materials and foldable design reduce launch weight and payload dimensions
- Can operate in extremely low gravity conditions
- Platform can traverse steep slopes and rough terrain, and reversible design allows continued operation even if unit is overturned
- Wireless control, telemetry, and onboard cameras provide teleoperation and situational awareness
- Platform design can be scaled up or down to meet project requirements: smaller sizes are suitable for space missions, and larger designs could be used for terrestrial mining in hazardous or hard-to-reach locations

Applications

- Extraterrestrial in situ resource utilization
- Extraterrestrial construction operations
- Space mining of regolith and water ice
- Robotic terrestrial mining operations
- Autonomous and teleoperated sand mining

Activated Metal Treatment System

Environmentally friendly remediation treatment for contaminated paints

Kennedy is seeking partners interested in the commercial application of the Activated Metal Treatment System (AMTS) for treating polychlorinated biphenyls (PCBs) in paints. PCBs have been shown to cause cancer in animals and to have other adverse effects on immune, reproductive, nervous, and endocrine systems. Although the production of PCBs in the United States has been banned since the late 1970s, many surfaces are still coated with PCB-laden paints.

Current physical removal methods are able to strip off PCB-containing paint from surfaces; however, these methods typically create a new waste stream that must be treated according to Toxic Substances Control Act regulation. In contrast to these methods, AMTS extracts PCBs and breaks them down into benign byproducts while on the structure. Therefore, no additional treatment for PCBs is required. Also, because the treated surface can be reused following application, AMTS has advantages over other methods and often opens up recycling opportunities that would not have been possible prior to the application of AMTS.

Benefits

- No impact on the structure or the material beneath the paint, and the surface can be repainted on reused following application
- Treats PCBs in place and requires none of the costs associated with transporting, treating, or disposing of a secondary waste stream
- Total costs are anticipated to be less than comparable costs for media blasting
- Has been shown in lab-scale and field-scale tests to remove approximately 80 percent of PCBs from paint within 4 hours, and approximately 100 percent of PCBs within 48 hours
- Produces benign byproducts

Applications

- Painted structures such as buildings and ships
- Concrete surfaces contaminated by PCB-laden transformer oil
- Caulks and other adhesives
- Electrical equipment
- Soils (ex situ)
- Other PCB-contaminated debris

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Langley

Game and Simulation Control

Adapting controls to users' physiological state

Langley Research Center has developed a technology at the forefront of a new generation of computer and video game environments that trains mental skills beyond eye-hand coordination and that encourages the personal improvement—not just diversion—of the user.

The technology is derived from previous research on automatically adapting flight deck controls based on user feedback, performed under Langley's Intelligent Integrated Flight Deck Technology (IIFDT) program. New research has enabled modulation of the manual inputs that a player makes to joysticks, controllers, and image recognition video input devices. The new input device allows a player to control inputs to a video game by adjusting his or her physiological state, such as heart rate and breathing, in addition to standard controller or video inputs.

The current capability has been successfully prototyped using the Nintendo Wii console and wireless Wii remote as well as the Xbox console and Kinect motion-sensing device. Prototypes have been designed and are being developed to extend the current capability to the PlayStation Move and other similar game platforms.

Benefits

- Introduces, for the first time, user-control interaction with the Wii video game system via the user's physiological signals
- Can be used with several physiological signal-measuring devices (heart rate, muscle tension, and brainwave activity)
- Wireless operation with third-generation gaming consoles
- Use of LED infrared communication reduces device power consumption
- Encourages health-enhancing physiological self-regulation skills and therapeutic amplification of healthful physiological characteristics

Applications

- Consumer brain-computer interface devices
- Biofeedback equipment
- Third-generation video game systems
- Third-party video game peripherals
- Physical therapy
- Athletic training
- Mind-body medicine

Advanced Actuators and Transducers

Hybrid actuator systems can recover environmental energy to power devices

Actuators and transducers are deployed in devices to harvest mechanical energy as electrical energy and to convert stored electrical energy into mechanical energy. By developing a transducer based on advanced electroactive materials, NASA has produced a design that can harvest orders of magnitude more energy in a given application than traditional solutions, yielding more power to drive devices and to store in batteries. The hybrid actuator system (HYBAS) uses both an electroactive polymer and an electroactive ceramic, achieving enhanced displacement performance from a single power supply and greatly reducing electrical consumption while simultaneously improving mechanical displacement compared to current state-of-the-art actuators.

Langley's technology applies a new design for improved performance and maintains the ability to capitalize on future gains from breakthrough materials. Generated power could be simply stored in a battery or serve as a compact power source for wireless sensor networks for applications such as health monitoring, biomedical applications, and environmental safety alert systems.

Benefits

- Low-volume, lightweight, high mechanical-to-electrical power conversion efficiency
- Superior performance compared to single-element designs
- Harvests orders of magnitude more power than existing technologies while requiring no power supply
- Custom design specifications possible due to configurable material selection
- Advanced materials further enhance the system's characteristics

Applications

- Precision machinery, optical devices, drug delivery, underwater navigation, and microphones
- For aerospace: active noise-vibration control, aerodynamic control, and surveillance
- For defense: surveillance, remote sensor networks, and deploy actuators
- Mobile consumer electronics and power supplies
- Power supplies and actuation for implants and wearable medical devices

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Marshall

Advanced Magnetostrictive Regulator and Valve

Offering all-electric, highly accurate, and low setpoint drift properties

Marshall Space Flight Center is offering for license a set of unique magnetostrictive (MS) technologies. The components are lightweight, compact, highly precise, and can operate over a wide range of temperatures and pressures. MS materials used in valves developed at Marshall allow the valve to be opened and closed via application of a magnetic field to the outside of the valve envelope. This all-electric design enables highly accurate and highly reactive regulation. As the current changes, the magnetic field strength adjusts, causing the valve poppet to reposition, bringing the pressure back to the setpoint.

This process contains all moving parts inside the pressure shell, eliminating the need for feedthroughs or mechanical seals. Typical valves used in many applications suffer from leaks and failures and are often considered unreliable. In contrast, Marshall's approach using MS materials eliminates the issues of seal leakage, friction, and wear. It uses fewer moving parts, offering greater reliability, safety, and longer life. The components are also at least one order of magnitude faster in response time in reacting to transients in supply pressure when compared to current control regulation methodologies.

Benefits

- Reduces the number of valves used in typical regulated pressure systems
- Offers precise operation and control with fast responses
- Uses fewer moving parts and no external or dynamic seals for increased reliability
- Continuously senses ambient conditions and self-adjusts to maintain precise control
- Capable of operating over a wide range of pressures, temperatures, and harsh environments
- Features a compact, lightweight design that allows alternate redundant, parallel pathways to be implemented without substantially increasing cost or weight

Applications

- Pressure-fed rocket propulsion systems
- Aircraft engines
- Automotive fuel systems
- Manufacturing and processing for petrochemicals, plastics, and pharmaceuticals
- Industrial machinery and power equipment
- Biomedical devices and drug metering systems

Benefits

- Does not require the removal of soft goods or part disassembly for testing
- Offers a streamlined method of leak detection with minimal, lightweight components
- Detects large, medium, and very small leaks
- Adapts easily for rapid in-line or batch testing
- Operates without the need for a vacuum pump, gas spectrometer, or chemical bath

Applications

- Specialized military and aerospace sensors and equipment
- Automotive components
- Electronic equipment such as semiconductors, thermostats, switches, and optical devices
- Consumer goods packaging
- Pharmaceuticals

Hermetic Seal Leak Detection

Nondestructive testing of container and instrument seals

Innovators at Marshall Space Flight Center have developed a unique apparatus ideal for use in nondestructive testing of hermetic seals of containers or instrumentation. The device is capable of detecting both large and small leaks and can be calibrated to characterize the relative leak rate. Its simple design does not require specialized gasses and eliminates the need for expensive instrumentation such as a mass spectrometer. The leak detection system chamber can be of any size or shape to accommodate any type of sealed object.

The technology offers a highly sensitive method of detecting leaks in airtight seals that is more streamlined and lower in cost than other available methods with similar sensitivity. Low in cost and simple to manufacture, the patent-pending technology is ideal for use in many industries, from aerospace applications to food packaging and commercial goods.

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Stennis

Piezoelectric Sensor Monitoring System

In situ measurement particularly suited for accelerometers

Stennis Space Center is soliciting partners interested in the commercial application of a patented in situ measurement system for monitoring the performance of piezoelectronic sensors, particularly accelerometers. With this technology, characteristics such as resonant frequency, response, cable status, connectivity, bonding, and linear range can be determined. Sensors can be tested in a very wide frequency range without removing them from their mounted locations and without requiring specially constructed transducers or special wiring. Assessments can be performed in situ and can be conducted with handheld test equipment or integrated into instrumentation systems.

Using this monitoring system, degraded sensor performance can be quickly and economically identified. The testing system is not limited to identifying degraded performance in the sensor's piezoelectric elements; it can detect changes within the entire sensor and sensor housing. Physical contact with the sensor is not necessary; therefore, monitoring can be done as far away as 250 feet, or longer if certain provisions are made.

Benefits

- Allows simplified testing that does not require physical contact
- Does not require removing mounted sensors or sending them to a calibration lab, which reduces costs
- Increased testing parameter range; provides both normal and as-mounted resonant frequencies
- Improved accuracy, providing entire frequency response over the range of the device (unlike commonly used shaker tables)
- Illuminates in situ problems; can identify degraded sensor bonds, faulty cabling, and sensor damage

Applications

- Accelerometers
- Automotive sensors
- Structural sensors
- Sensors for manufacturing equipment
- Any application where vibration is monitored
- Any piezoelectric sensor
- Nondestructive testing

Conical Seat Shut-Off Valve

Unique hardware design eliminates the need for an actuator

A novel, moveable valve that controls the flow of pressurized working fluids is now being offered by Stennis for partners interested in the technology's potential commercial applications. This valve consists of a hollow, moveable floating piston pressed against a stationary solid seat, and it can use the working fluid or an external pressure source to seal the valve.

This open/closed valve has a novel balanced piston so it can be designed to always seat with the same amount of force, allowing the use of metal-to-metal seats as well as soft seats. Additionally, this valve design, even when used in large, high-pressure applications, does not require large conventional valve actuators, and the valve stem itself is eliminated. Actuation is achieved with the use of small, simple solenoid or hand valves. This design also eliminates the need for many seals used with existing ball valve and globe valve designs, which also commonly cause failure. Coupled with the elimination of the valve stem and conventional valve actuator, valve reliability and seat life are greatly improved, reducing downtime and maintenance costs.

Benefits

- Allows for a wide range of design parameters, including pressures from ambient to 15,000 psi and sizes from less than 1 inch to greater than 10 inches
- Can be manufactured from a variety of metals and operate on cryogenic gas lines
- Constructed using only five major parts without stem seals or packing glands that can leak
- Does not require an external large pneumatic, hydraulic, or motor actuator
- Stationary metal-to-metal seat improves valve reliability
- The combination of features eliminates the actuator, reducing the physical size and cost of the valve

Applications

- Power plants
- Petrochemical plants
- Refineries
- Pressurized storage tanks

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