



SPINOFF



2012

SPINOFF

2012

Office of the Chief Technologist

NASA Headquarters

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On the Cover:

Background: *A view of the aurora borealis—or northern lights—as seen from the International Space Station.*

Front Insets: *Images representing NASA spinoff technologies and their benefits in the areas of (from left to right) information technology, health and medicine, consumer goods, and energy and the environment.*

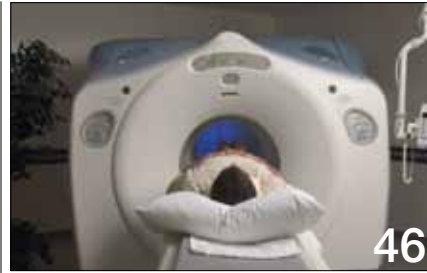
Back Insets: *Images representing NASA spinoff technologies and their benefits in the areas of (from left to right) public safety, transportation, and industrial productivity.*

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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.



The Inflatable Reentry Vehicle Experiment (IRVE-3) is a technology created by the Game Changing Development Program in NASA's Space Technology Program. A large, inflatable heat shield, IRVE-3 is designed to survive a trip through Earth's atmosphere while travelling at hypersonic speeds up to 7,600 miles per hour. For a deeper look at the project, scan this code.

Foreword

NASA continues to be an investment in the future of American innovation. As a nation of explorers and trailblazers, we lead the world in space, achieving breakthroughs that make our challenging missions possible, all the while pushing the boundaries of frontiers in aviation, space travel, and science.

NASA's renewed focus on technology development and the capabilities to reach higher in the future is yielding real dividends as we find new uses for exploration technology on our home planet. Every dollar spent on space exploration is spent here on Earth, and in the case of our spinoff technologies, those benefits continue to multiply. Entrepreneurs and researchers are continuously developing new ways to improve life around the world by building on our ongoing work to send humans to new destinations, launch scientific spacecraft for breathtaking discoveries, and improve our Nation's air travel system.

At the Agency's field centers across the Nation, NASA's dedicated workforce and its many skilled contractors continue to push the envelope of what is possible. The Agency's academic and industry partners are transforming these innovations to produce wide-ranging applications and inventions from the technologies we originally pursued with mission-specific objectives.

We are always delighted at the exponential value the American public and people around the world derive from our investment in exploration. As we uncover the secrets of the universe and raise the bar of our human potential, we are also making an impact on people's daily lives.

Each year in *Spinoff*, we tell some of the amazing stories that have come about from NASA technologies being adapted for uses on Earth. Among the many incredible examples this year are:

- An invisible coating, developed by a NASA Dual-Use Technology partner and tested at NASA facilities, that is capable of breaking down pollutants, eliminating odors, and inhibiting the buildup of grime. The

technology's many applications include enhancing the efficiency of solar cells, sanitizing air in the homes of those suffering from cystic fibrosis, and even transforming buildings and towering modern art sculptures into massive air purifiers. (page 104)

- A robot assistant now found in the halls of hospitals around the country, helping with everything from registering patients to logging vital signs. The robot has been dubbed "a Mars rover in a hospital" by one of its developers, who employed the expertise he gained working on Mars robotics for NASA to create the technology. The robot is not only easing the workload of hospital staff but also providing an economic return, creating 20 new jobs for its manufacturer. (page 40)
- A recreational trailer designed using the same principles that supplied comfortable living quarters for the crew of the International Space Station. The trailer's creator used his experience as a NASA architect to create a unique, eco-friendly means for reconnecting with nature and revitalizing interest in our Nation's parks. (page 80)
- A solar concentration technology that, for the same amount of silicon, can provide many times the power of conventional panels benefited from innovations developed through a NASA Small Business Innovation Research (SBIR) partnership. The company founded to commercialize these NASA-derived sustainable energy installations now employs 30 workers, all with a mission to move renewable solar power into true mainstream use. (page 100)
- A worldwide search and rescue system was founded through NASA innovation. Enabled in part by satellite ground stations developed and constructed by a NASA partner, the true value of this spinoff is inestimable. To date, more than 30,000 lives have been saved, on average more than 6 a day, from the highly publicized 2010 rescue of teen sailor Abby Sunderland to the rescue

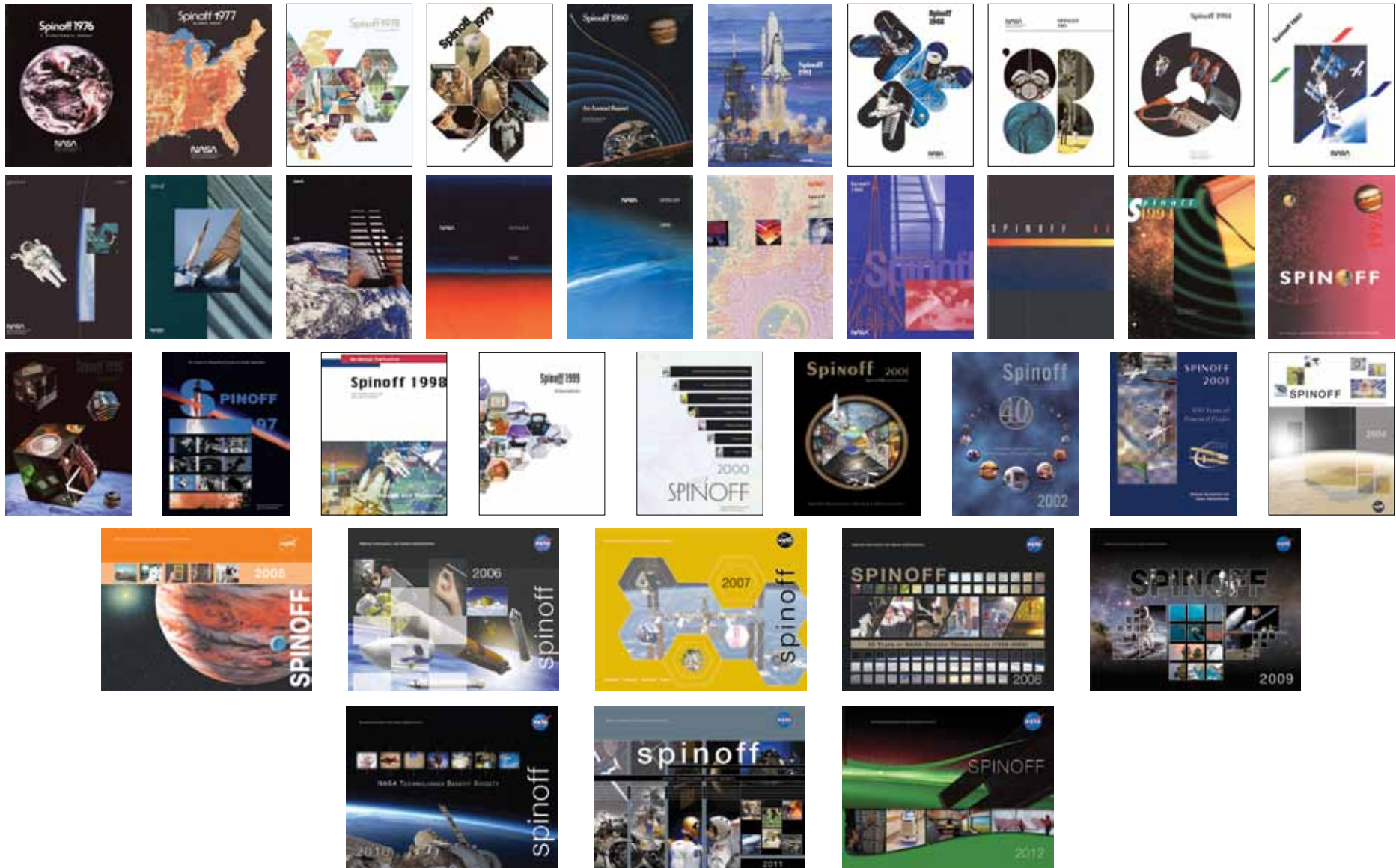


Charles F. Bolden, Jr.
Administrator
National Aeronautics and
Space Administration

A handwritten signature in black ink, appearing to read "C. Bolden". The signature is stylized and written in a cursive-like font.

of fishermen, hikers, and adventurers around the world. (page 68)

From life-saving technologies to those that make our lives easier, the true value of NASA spinoff technologies is hard to calculate. What is obvious is that the value of our Nation's charge to explore space and pursue the goals that may at first seem impossible is broader and deeper than we ever dared hope when first we look to the skies and dream about the road to tomorrow.



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

NASA and the Nation are embarking on an ambitious program of space exploration that builds on new technologies as well as proven capabilities as we expand humanity's reach into the solar system. While reaching for new heights in space, NASA is creating new jobs right here on Earth—especially for the next generation of American scientists and engineers—by supporting cutting edge aeronautics and space technology innovations, research and development that will help fuel the Nation's economy for years to come.

NASA provides America with unique capabilities simply because of how we ask questions about our universe. By taking humans to inhospitable places we learn more about how Earth sustains us, because we have to recreate that environment for our astronauts to survive. NASA solves difficult technical problems and thereby inspires Americans to invent technologies that make life better right here on Earth.

Investments in space and aeronautics technology stimulate the economy and contribute to the Nation's global competitiveness through the creation of new products and services, new business and industries, and high quality, sustainable jobs. A technology-driven NASA will maintain the Nation's aerospace community as a global technological leader for many years to come. NASA innovation also serves as an inspiration for young people to pursue science, technology, engineering, and mathematics education and career paths.

Whether we're developing needed technologies for space exploration or advancing the Nation's aeronautics capabilities, great ideas from NASA have a way of spreading, to everyone's benefit. So, it should come as no surprise that the technologies powering NASA missions are used by pioneering individuals and organizations to create and improve products and services that make life better here on Earth. Those benefits include everything from life-saving medical devices to improved solar power, fuel-saving aircraft designs and enhanced manufacturing techniques.

Increasingly we are finding that NASA's technological needs for space exploration overlap with our everyday needs. The partnerships we form to achieve NASA's objectives often make an immediate economic impact, with technologies being commercialized as spinoffs.

Every spinoff is a tangible reminder of NASA's commitment to investing in the future. The spinoffs featured in this book are inspiring examples of how NASA and its commercial partners have used space technology to solve everyday challenges—solutions that are being deployed in communities across America right now. These technologies are generating jobs, increasing productivity, creating revenue, cutting costs, and even saving lives. *Spinoff* 2012 presents 44 of these technologies, each with its own story. Here are just a few:

- A NASA partnership to develop a multivitamin regimen for astronauts resulted in a range of supplements for enhancing nutrition on Earth. Consumers have reported reduced healthcare costs and the elimination of allergies thanks to this spinoff. (page 38)
- One company received funding from NASA's SBIR program to investigate a superconductor material for future aircraft propulsion systems. The material is now helping enable lower cost MRI medical imaging devices. Thanks to its NASA partnership the company has created 16 jobs and has generated \$3 million in revenue from its spinoff products. (page 46)
- A NASA partnership produced unique instruments for measuring ocean color—essential data for understanding our planet's marine ecosystems. These innovations not only provide scientists with new tools for studying our oceans, but they also have resulted in more than \$2 million in contracts for the partner company. (page 94)
- Building on a patented innovation originally designed to create a unique marker for Apollo 11's mission to the Moon, a company has created silicon-based archiving technology that now preserves essential



Mason Peck
Chief Technologist
National Aeronautics and
Space Administration

records in a format resistant to fire and water damage. The 4-year-old company has grown from 2 to 10 employees and has now opened an international office. (page 126)

- Set to launch in 2018, the James Webb Space Telescope is already yielding spinoffs in health and medicine and industrial productivity. Now innovations designed to perfect the telescope's massive mirrors have been incorporated into technology for mapping the eye and diagnosing sight-threatening conditions. (page 44)

These and the other spinoffs in this book show that yesterday's investments in technology continue to repay the public today.

Pushing the boundaries of aerospace and taking informed risks, NASA and our Nation remain at the cutting edge. By making steady investments in technology, we will enable future human and robotic exploration of near-Earth asteroids, the Moon, and Mars just as current and past mission successes were supported by decades of vital technology investments.

A NASA focused on advancing technology helps ensure that high-tech jobs will be available for young people when they complete their studies. And in sponsoring this sort of research and development, it will do its part to encourage the next generation of aerospace engineers, ensuring that our Nation retains the critical capabilities in advanced technology that will ensure its economic competitiveness.

Spinoffs in Manufacturing

Spinoff has documented more than 350 NASA technologies that have been commercialized to enhance the Nation's industrial productivity. From innovative manufacturing techniques to materials that allow for entirely new structures, higher performance electronics, and improved energy efficiency—these spinoffs have created hundreds of jobs while ensuring that American companies remain world leaders across industries.





Built to Last

Using NASA technologies, American manufacturing grows stronger

How do you build a space shuttle when no one has built one before? How do you build a probe to study the moons of Saturn? A rover to traverse the red soil of Mars? A space station orbiting the Earth? How do you create the next generation of vehicles that will carry human explorers farther into space than ever before?

NASA's aeronautics and space exploration missions require the Agency to continually push the boundaries of technology in order to answer questions like these and many more. Challenges such as landing rovers on Mars or sustaining human life in space for months at a time necessitate not only innovative ideas but the means to realize them. This often involves the creation of new or enhanced manufacturing technologies, materials, and processes that allow spacecraft, instruments, and capabilities without precedent to make the leap from the minds of NASA engineers to the skies and stars.

Inside the Spacecraft
Assembly Facility at NASA's
Jet Propulsion Laboratory



The Office of the Chief Technologist (OCT) and Space Technology Program (STP) lead the Agency's efforts to create the technologies that will enable NASA and the Nation to pursue its ambitions as the world's leader in aeronautics and space exploration. OCT and STP recognize that a technologically advanced American manufacturing sector is essential not only to NASA's missions but to the economic strength of the country as a whole. Through initiatives such as the NASA Manufacturing Innovation Project—a part of the Game Changing Development Program—the Agency seeks to drive the creation and evolution of manufacturing technologies critical to future missions and the Nation's global competitiveness.

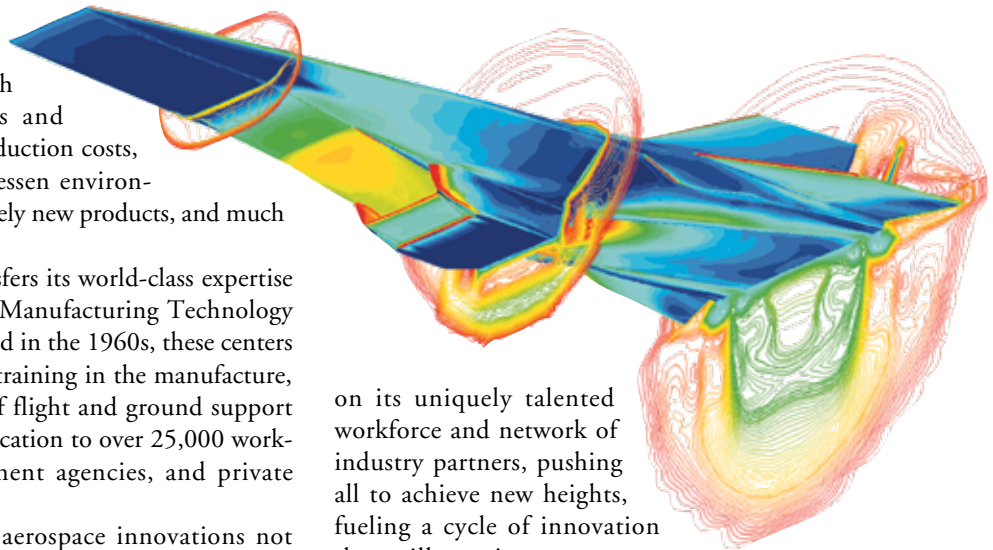
Building on its congressional mandate to transfer its technologies whenever possible to benefit the public, NASA has from its earliest days worked to nurture and advance American manufacturing. These efforts take many forms. Through licensing, Space Act Agreements, the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, and other partnerships, the Agency provides the Nation's

industrial leaders with cutting-edge technologies and capabilities that reduce production costs, preserve and create jobs, lessen environmental impacts, enable entirely new products, and much more.

NASA also actively transfers its world-class expertise through venues such as its Manufacturing Technology Transfer Centers. Established in the 1960s, these centers continue to offer technical training in the manufacture, assembly, and inspection of flight and ground support hardware—providing certification to over 25,000 workers from NASA, Government agencies, and private industry.

The transfer of NASA aerospace innovations not only benefits American manufacturers but returns to the Agency by providing its partners with the means to create technologies that enable missions, lower costs, and extend space exploration in ways previously only dreamed of.

A nation that stops building starts stagnating. By driving deeper into space, NASA is placing demands



on its uniquely talented workforce and network of industry partners, pushing all to achieve new heights, fueling a cycle of innovation that will continue to generate spinoffs in manufacturing.

NASA and its partners have commercialized more than 350 documented spinoffs relating to industrial productivity and manufacturing. These technologies have ranged from cutting-edge design software to advanced construction tools to industry-launching innovations in materials and fabrication techniques. By supporting a healthy industrial sector, NASA spinoffs also result in job creation and help drive the economy as a whole.

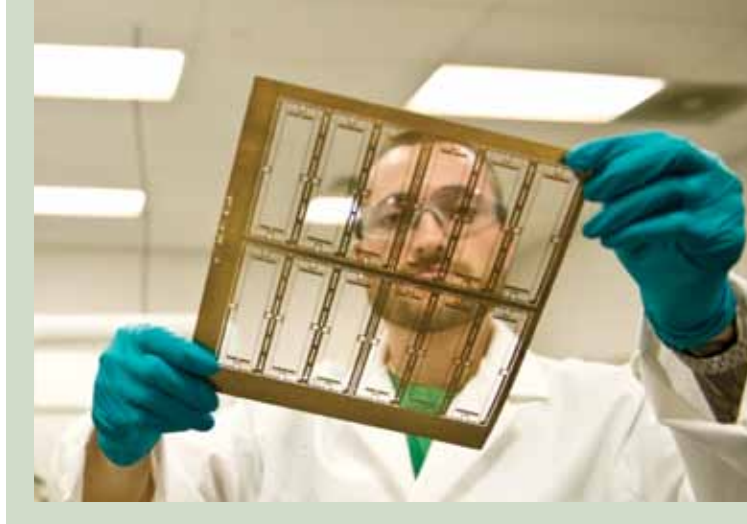
The following are just a few of the recent spinoffs from the Space Program that are helping build the Nation's future.

NASA has a long history of innovation in manufacturing, including advances in computer modeling (top) and cutting-edge technologies such as electron beam freeform fabrication (left), which was used to create the structural metal part to the right.



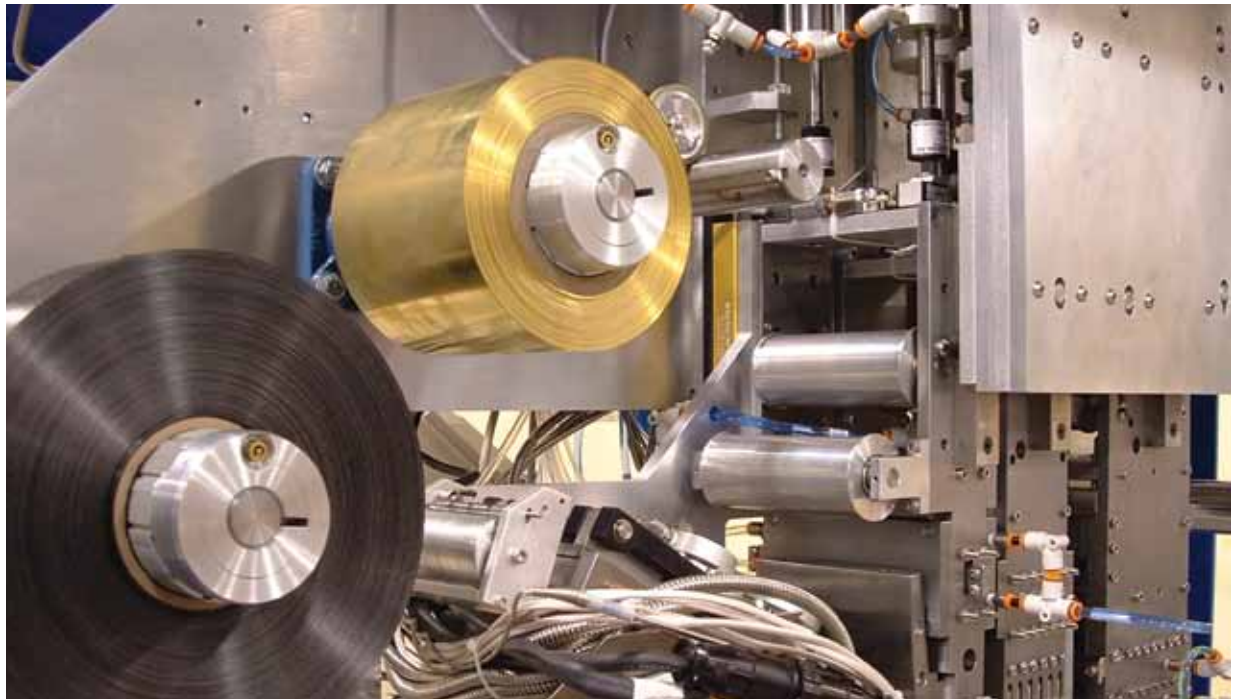
Improving a Revolutionary Weld Technique

Nova-Tech Engineering LLC, of Lynnwood, Washington, received a co-exclusive license for Marshall Space Flight Center technology that significantly improves an advanced welding technique called friction stir welding (FSW). While the technique creates a superior weld to traditional fusion methods, FSW leaves a hole when the welding machine's rotating pin, which creates the weld, exits the weld joint. It also has difficulty welding materials of tapering thicknesses. Marshall invented an auto retractable pin tool that solves these problems. The innovation now allows Nova-Tech's FSW machines to perform effective welds for offshore drilling rig piping, armor plating, and rocket manufacturing.



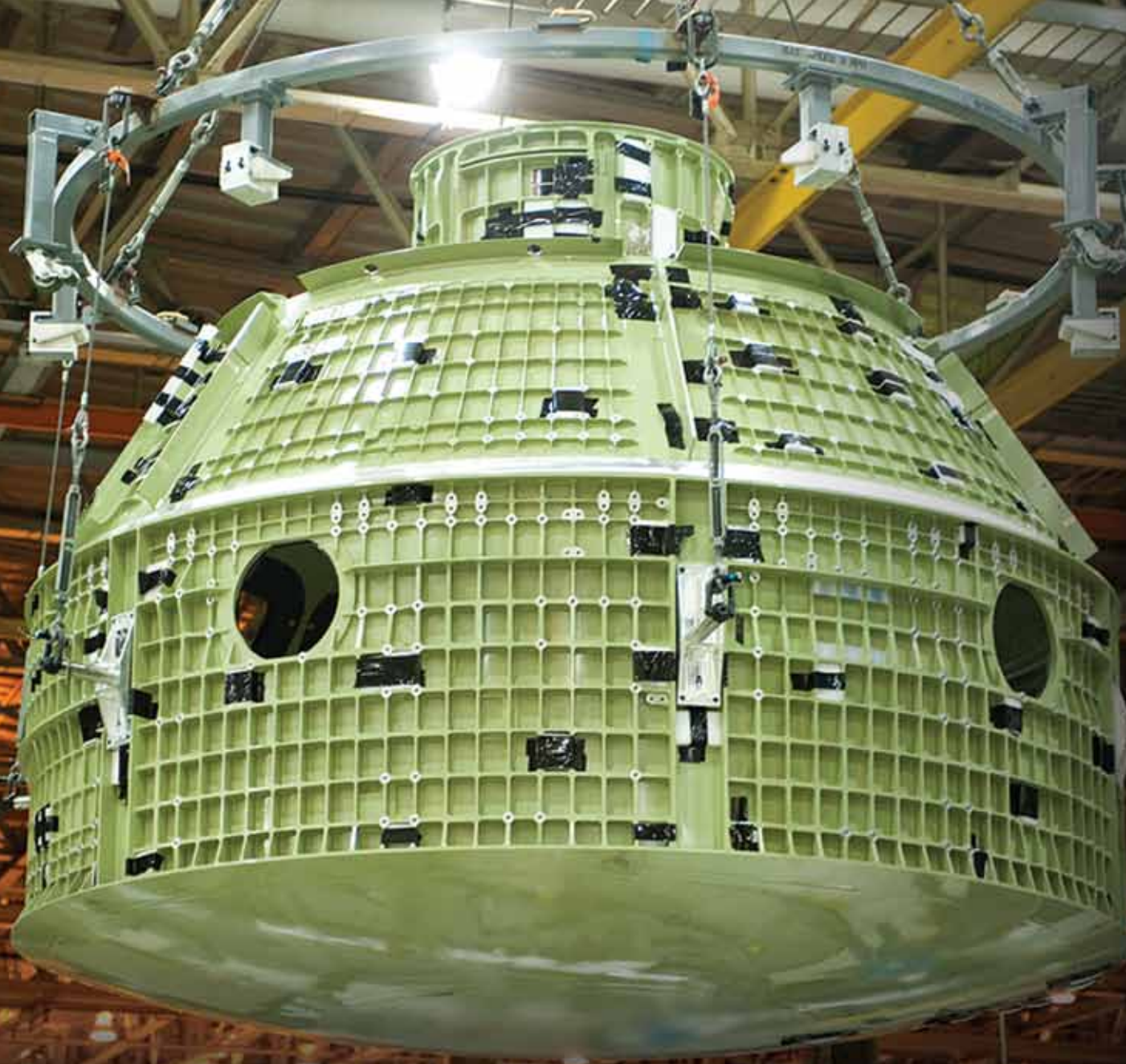
Enhancing Medical Imaging

Collaborating with Goddard Space Flight Center, Mike Appleby developed a manufacturing process to create specialized components for a NASA Sun-imaging satellite. Through SBIR funding, Appleby's company, Mikro Systems of Charlottesville, Virginia, perfected the process now used to fabricate advanced parts for medical and security imaging devices. The company added 37 jobs as a result of its NASA work.



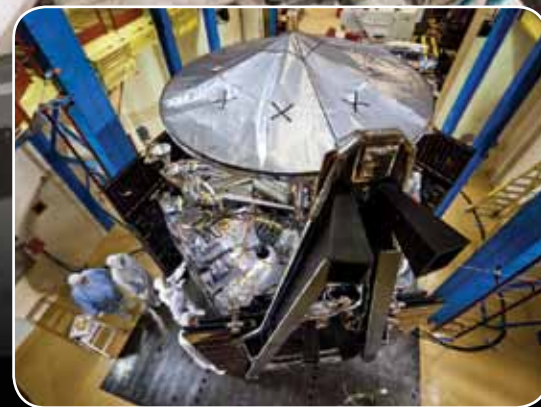
Advancing Composite Manufacturing

Through the SBIR program, Accudyne Systems Inc. of Newark, Delaware, developed a device for creating thermoplastic composite structures without the use of an expensive autoclave. The partnership yielded technology for the company's commercial, custom-built composite manufacturing machines, helping advance composite part fabrication. The company's automated solutions enable the production of higher quality parts at lower costs, while not threatening the jobs of the workers who previously fabricated the composite parts by hand.



In order to build spacecraft unprecedented in their times, NASA had to invest in the development of new materials and manufacturing techniques. From the Saturn V rockets of the Apollo Program (top inset), to the space shuttle (middle inset), to the US modules of the International Space Station (ISS, bottom inset), the Agency created the means to realize human exploration of space. NASA's latest exploratory vehicle, Orion (a test vehicle shown above, during assembly), is the latest example of that endeavor.

Developed through a partnership between NASA and General Motors, Robonaut 2, now onboard the ISS, may one day assist workers in auto factories on Earth. Chief Technologist Mason Peck (left inset) oversees NASA's efforts to create the remarkable new technologies that will carry the Agency's missions forward, while facilities like NASA's Michoud Assembly Facility (middle inset)—one of the world's largest manufacturing plants—remain the site of creation for the next generation of American manned space vehicles. Meanwhile, NASA continues to build and launch the world's most innovative spacecraft, such as Juno (right inset), currently on its way to study Jupiter.





Lightening Components

Leveraging its private resources with SBIR contracts with NASA, WebCore Technologies LLC, of Miamisburg, Ohio, developed a lightweight, fiber-reinforced foam sandwich panel that can be used for a wide variety of industrial and consumer applications. The patented and trademarked material has found use in the manufacture of structures and vehicles including marine and ground transportation, mobile shelters, bridges, and most notably, wind turbines.

Simplifying Circuit Board Manufacturing

Glen Research Center's extensive knowledge of polyimide chemistry and its expertise in the synthesis of ultraviolet light curable polyimides was the critical component that allowed Advanced Coatings International, of Akron, Ohio, to prototype the platform chemistry for a polyimide-based, liquid coating ideal for the manufacture of printed circuit boards. These coatings are environmentally friendly, enhance worker safety, and reduce manufacturing and operating costs.

Upgrading Optics Manufacturing

Because NASA depends on the fabrication and testing of large, high-quality aspheric (nonspherical) optics for applications like the James Webb Space Telescope, it sought an improved method for measuring large aspheres. Through SBIR awards from Goddard Space Flight Center, QED Technologies of Rochester, New York, upgraded and enhanced its stitching technology for aspheres. QED's spinoff technology earned the company an R&D 100 Award, and the company also developed a breakthrough machine tool called the aspheric stitching interferometer. The equipment is applied to the manufacture of advanced optics in telescopes, microscopes, cameras, medical scopes, binoculars, and photolithography.



Reducing the Cost and Enhancing the Quality of Nanotubes

SBIR contracts with Johnson Space Center supported the development and demonstration of a nanotube production method pioneered by SouthWest Nanotechnologies Inc. (SWeNT), of Norman, Oklahoma. SWeNT's scalable, efficient process results in mass-produced nanotubes that are customizable to client needs and more pure than those created by other methods. These enhanced manufacturing capabilities may soon allow for nanotube-enabled technologies like advanced body armor, ultra-conductive wiring, printable electronics, and green innovations like more affordable solar panels and low-energy, solid-state lighting products. SWeNT's NASA-supported process has allowed the company to increase production a hundredfold while lowering cost tenfold.



NASA seeks to drive the creation and evolution of manufacturing technologies critical to future missions and the Nation's global competitiveness.

NASA partnerships in commercial space are building an entire new industry, creating jobs and supporting the private, US-based manufacture of commercial spacecraft that are central to NASA's plans for supplying and staffing the ISS for years to come. Seen here is the manufacturing floor of SpaceX's Hawthorne, California facility, with a Dragon capsule at center.

Developing UAVs for Science, Military

A Space Act Agreement with Goddard Space Flight Center and West Virginia University enabled Aurora Flight Sciences Corporation, of Manassas, Virginia, to develop cost-effective composite manufacturing capabilities and open a facility in West Virginia. The company now employs 160 workers at the plant, tasked with crafting airframe components for the Global Hawk unmanned aerial vehicle (UAV) program. The company also develops advanced UAV technologies that are redefining traditional approaches to unmanned aviation. Since the company's founding, Aurora's cutting-edge work has been supported with funding from NASA.



Advancing Aerospace Manufacturing

The 2008 NASA Commercial Invention of the Year, PETI-330, is a polyimide matrix resin that performs well at high temperatures and is easily processed into composites in a simple, short-curing cycle. Invented by scientists at Langley Research Center, PETI-330 is now licensed to Ube Industries, based in Japan with American headquarters in New York. In addition to being durable and lightweight, the resin is also nontoxic, which makes it safe for workers to handle. PETI-330 was created specifically for heat-resistant composites formed with resin transfer molding and resin infusion, which formerly could only be used with low-temperature resin systems. ❖

Enhancing Architecture around the World

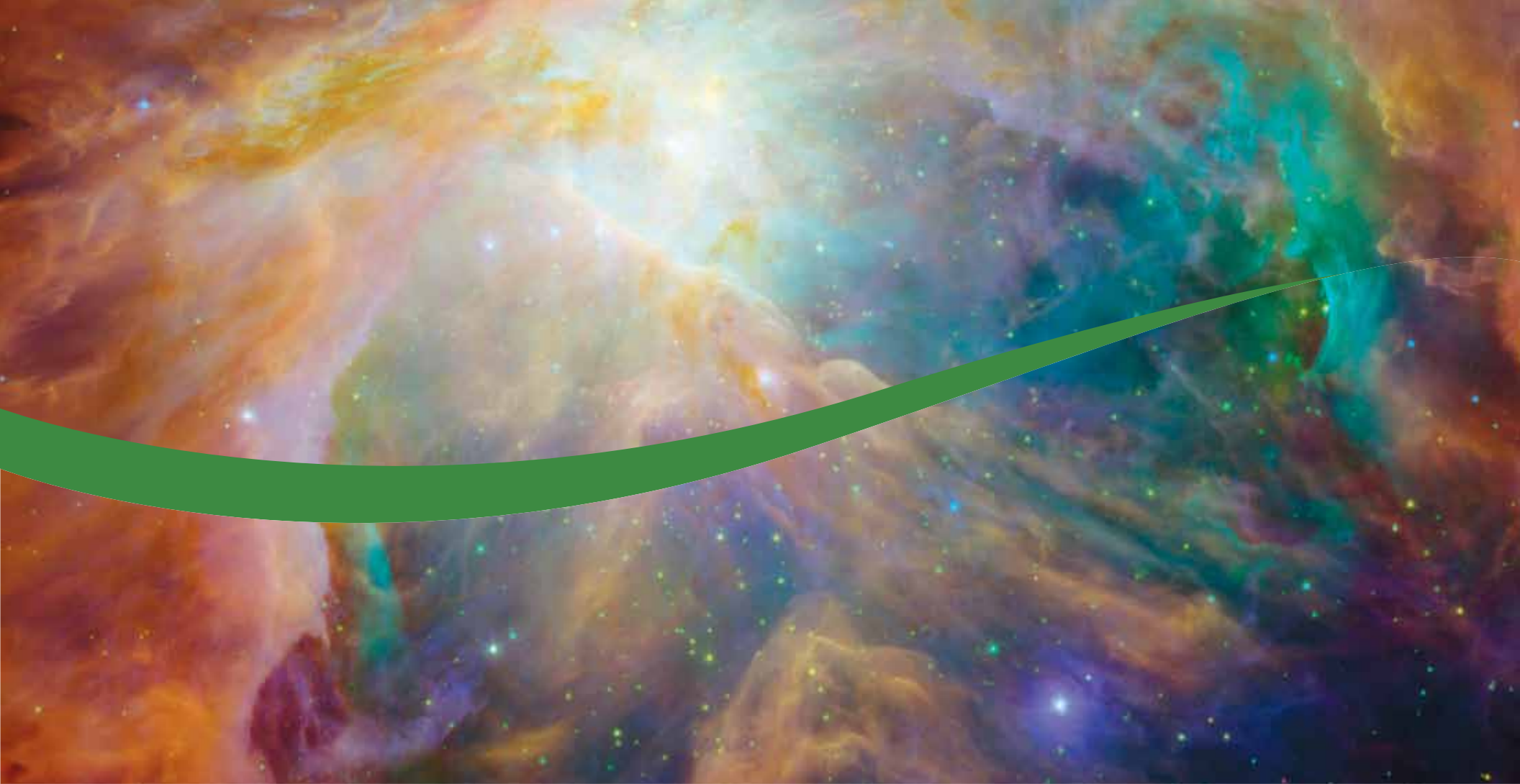
Using a remarkable fabric originally developed to protect Apollo astronauts, Birdair Inc., of Amherst, New York, has crafted highly durable, safe, environmentally friendly, and architecturally stunning tensile membrane roofs for over 900 landmark structures around the world. Travelers in airports, sports fans at stadiums, and shoppers in malls have all experienced the benefits of the Teflon-coated fiberglass fabric that has enabled Birdair to grow from a small company established in its founder's kitchen in 1955 to a multimillion-dollar specialty contractor today.



Executive Summary

Since 1976, NASA *Spinoff* has featured over 1,800 of the most compelling, beneficial technologies to emerge from the Agency's innovative technology transfer initiatives. The stories of these spinoffs begin with NASA's world-class scientists and engineers, who, in the course of guiding and supporting space exploration and Earth observation missions, develop new technologies and capabilities with uses that extend beyond NASA. Through partnerships with private industry, academia, Government agencies, and others, NASA transfers these innovations for the public good, creating jobs and advancing the fields of health and medicine, transportation, public safety, consumer goods, energy and environment, information technology, and industrial productivity.





Executive Summary



36 Water Treatment Technologies Inspire Healthy Beverages

Mike Johnson, a former technician at Johnson Space Center, drew on his expertise as a wastewater engineer to create a line of kombucha-based probiotic drinks. Unpeeled Inc., based in Minneapolis-St. Paul, Minnesota, employs 12 people and has sold more than 6 million units of its NASA-inspired beverage.



38 Dietary Formulas Fortify Antioxidant Supplements

As NASA plans for long missions, it explores ways to provide astronauts with

nutrition equivalent to fresh produce. Johnson Space Center entered into a Space Act Agreement with Houston-based AmeriSciences LP to develop a multivitamin and other supplements for astronaut health. By 2011, the company commercialized its NASA-derived products in multivitamins, antioxidants, and omega-3 fatty acids.



40 Rovers Pave the Way for Hospital Robots

The Jet Propulsion Laboratory provided funding for the Massachusetts Institute of Technology to develop capabilities for robotics like Rocky 7. 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.



42 Dry Electrodes Facilitate Remote Health Monitoring

Johnson Space Center collaborated with Blacksburg, Virginia-based NanoSonic Inc. through the SBIR program to devise a sensor to replace the traditional electrodes used for an electrocardiogram in space. In 2011, NanoSonic started marketing the dry electrodes as well as an EKGear Sensor Shirt, which is being considered for use in hospital garments, athletic apparel, and dive suits.



44 Telescope Innovations Improve Speed, Accuracy of Eye Surgery

To polish the Webb telescope mirrors, Goddard Space Flight Center enlisted

the help of several contractors. WaveFront Sciences, later acquired and renamed Abbott Medical Optics, developed a system for testing the mirrors. The Santa Ana, California-based company now offers a laser vision product, enhanced by the telescope innovations, to measure a patient's eye and create a map for the treatment.



46 Superconductors Enable Lower Cost MRI Systems

Hyper Tech Research, a Columbus, Ohio-based company, received funding from Glenn Research Center's SBIR program to investigate a magnesium diboride (MgB_2) superconductor for future aircraft propulsion systems. The company advanced MgB_2 to a point where it is now used in prototype MRI devices, has been able to add 16 employees, and has generated \$3 million in revenue.



50
Anti-Icing Formulas Prevent Train Delays

Because an airplane must be snow- and ice-free to fly safely, researchers at Ames Research Center devised a solution that prevented ice from sticking to the surface. Midwest Industrial Supply Inc. of Canton, Ohio, licensed the technology for use in anti-icing products for train tracks and switches. Now the products increase the company's revenue by \$300,000-\$600,000 a year.



52
Shuttle Repair Tools Automate Vehicle Maintenance

When paperwork generated by shuttle repairs gets out of hand, Kennedy Space

Center developed software that would streamline the maintenance, repair, and overhaul (MRO) process. The result was SMART, a tool that automates MRO, cutting repair times by 45 percent. Orlando, Florida-based Diversified Industries Inc. licensed SMART and now offers it commercially.



54
Pressure-Sensitive Paints Advance Rotorcraft Design Testing

Partnering with Langley Research Center through the SBIR program, Innovative Scientific Solutions Inc. of Dayton, Ohio, developed enhanced pressure-sensitive paint technology for gathering essential aerodynamic data from high-speed, unstable surfaces such as rotorcraft blades. The efficient, cost-effective spinoff innovation has generated approximately \$200,000 in revenue for the company.



56
Speech Recognition Interfaces Improve Flight Safety

Entering a flight plan into a GPS is time-consuming and poses a safety hazard for pilots. VoiceFlight Systems LLC, in Troy, New York, created a speech recognition interface to replace manual inputs. With support from an SBIR contract from Langley Research Center, the VSF101 became the first Federal Aviation Administration-certified speech recognition product for use in civilian aircraft.



58
Polymers Advance Heat Management Materials for Vehicles

Under NASA funding, Alliant Techsystems Inc. contracted with Starfire

Systems Inc. in Schenectady, New York, to supply a polymer material to incorporate into a formula to repair damage on the exterior of the space shuttle. Called SMP-10, the polymer converts into a ceramic at high temperatures. Starfire now manufactures NASA-derived heat management products for military, aerospace, aviation, and automotive markets.



60
Wireless Sensors Pinpoint Rotorcraft Troubles

With the help of SBIR contracts from Glenn Research Center, Tucson, Arizona-based Ridgetop Group Inc. has pioneered wireless sensors that can function inside of rotorcraft transmissions. The sensors have a large number of applications, and the data they provide can improve mean time to repair by as much as 50 percent.



64
Ultrasonic Detectors Safely Identify Dangerous, Costly Leaks

To allow inspectors to scan the space shuttle's hydrogen fuel systems from a safe distance, Kennedy Space Center engineers developed a long-range attachment for an ultrasonic detector. Elmsford, New York-based UE Systems licensed the NASA invention, which allows workers to safely and accurately pinpoint leaks in factories and other industrial applications, providing savings in the millions of dollars.



66
Detectors Ensure Function, Safety of Aircraft Wiring

To help inspect electrical bundles and wires on the space shuttle, Pedro

Medelius at Kennedy Space Center invented the standing wave reflectometer. Corona, California-based Eclipse International licensed the technology, which is now used on wiring in aircraft, submarines, sea vessels, and helicopters. The company has grown to 30 employees and the technology has saved more than \$2 million on development costs.



68
Emergency Systems Save Tens of Thousands of Lives

To improve distress signal communications, NASA pioneered the Search and Rescue Satellite Aided Tracking (SARSAT) system. Since its inception, the international system known as Cospas-Sarsat has resulted in the rescue of more than 30,000 people. Techno-Sciences Inc., of Beltsville, Maryland, has been involved with the ground station component of the system from its earliest days.



72
Oxygen Assessments Ensure Safer Medical Devices

A team at White Sands Test Facility developed a test method to evaluate fire hazards in oxygen-enriched environments. Wendell Hull and Associates, located in Las Cruces, New Mexico, entered a Space Act Agreement with NASA and now provides services including fire and explosion investigations, oxygen testing and training, and accident reconstruction and forensic engineering.



76
Collaborative Platforms Aid Emergency Decision Making

Though NASA collects a great deal of real-time data, it cannot always be put to

use in a single platform. Baltimore-based StormCenter Inc. has partnered with NASA Headquarters to make real-time collaboration a reality, greatly enhancing emergency decision-making efforts by public authorities.



80
Space-Inspired Trailers Encourage Exploration on Earth

Architect Garret Finney joined Johnson Space Center's Habitability Design Center to work on creating comfortable, efficiently designed crew quarters for the ISS. Drawing directly on that experience, Finney founded Houston-based Cricket and set about creating unique, versatile recreational trailers that incorporate space habitat principles and features.



82
Ultra-Thin Coatings Beautify Art

Early in the space program, Johnson Space Center developed a vacuum-deposition method for applying ultra-thin coatings of metal to substances. The technology spun off into commercial applications, such as the manufacture of dichroic glass. Jan Lewczenko, owner of Mount Pleasant, Pennsylvania-based JL Crystal Artistry LLC makes use of dichroic glass in his crystal sculptures.



84
Spacesuit Materials Add Comfort to Undergarments

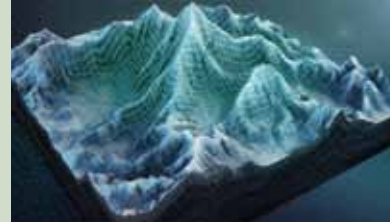
Phase change materials (PCMs) were one of the technologies NASA used to help astronauts maintain a “just right”

temperature in their space gloves. To incorporate PCMs in spacesuit fabrics, Johnson Space Center collaborated with Outlast Technologies Inc. In 2011, Jockey International, headquartered in Kenosha, Wisconsin, released a line of men’s and women’s undergarments incorporating the NASA technology.



86
Gigapixel Images Connect Sports Teams with Fans

Technology developed at Ames Research Center to take high-resolution imagery on Mars is now being used in baseball stadiums across the country. New York City-based Major League Baseball Advanced Media LP customized the 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.



88
Satellite Maps Deliver More Realistic Gaming

When Redwood City, California-based Electronic Arts (EA) decided to make SSX, its latest snowboarding video game, it faced challenges in creating realistic-looking mountains. The solution was NASA’s ASTER Global Digital Elevation Map, made available by the Jet Propulsion Laboratory, which EA used to create 28 real-life mountains from 9 different ranges for its award-winning game.



90
Elemental Scanning Devices Authenticate Works of Art

To better detect aluminum compounds, Marshall Space Flight Center partnered

with KeyMaster Inc. (later acquired by Madison, Wisconsin-based Bruker AXS Inc.) to develop a vacuum pump system that could be attached to X-ray fluorescence (XRF) scanners. The resulting technology greatly expanded XRF scanner capabilities, and hundreds of museums now use them to authenticate artifacts and works of art.



94
Microradiometers Reveal Ocean Health, Climate Change

Partnering with Goddard Space Flight Center through the SBIR program, Biospherical Instruments Inc. of San Diego created modular radiometer instruments that allow scientists to customize the technology for their research needs. The spinoff is now used to monitor the planet’s oceans, climate change, and more. The company has garnered more than \$2 million in contracts thanks to its NASA collaboration.



98
Sensors Enable 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. Berthoud, Colorado-based AgriHouse Brands Ltd. has commercialized the technology, which allows “thirsty” plants to send text messages to farmers asking for more water.



100
Efficient Cells Cut the Cost of Solar Power

Glenn Research Center engineer Bernard Sater spent his spare time developing a solar concentrator that would use less silicon, making solar arrays cheaper. After retiring from NASA, Sater and his son formed Oberlin, Ohio-based GreenField Solar and, under a Space Act Agreement

with Glenn, moved the technology toward commercialization. GreenField Solar now employs 30 people thanks to its NASA partnership.



102
Shuttle Topography Data Inform Solar Power Analysis

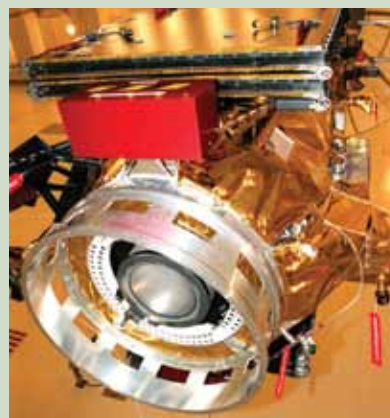
In 2000, the Jet Propulsion Laboratory spearheaded the Shuttle Radar Topography Mission, which created a high-detail global elevation map. The data sets were later processed to produce shading models, which are now part of New York City-based Locus Energy LLC’s commercial offerings. Locus Energy’s solar power prediction packages help companies save millions of dollars in costs by avoiding expensive hardware.



104
Photocatalytic Solutions Create Self-Cleaning Surfaces

A Stennis Space Center researcher investigating the effectiveness of pho-

tocatalytic materials for keeping the Center’s buildings free of grime turned to a solution created by PURETi Inc. of New York City. Testing proved successful, and NASA and the company now share a Dual Use Technology partnership. PURETi’s coatings keep surfaces clean and purify surrounding air, eliminating pollution, odors, and microbes.



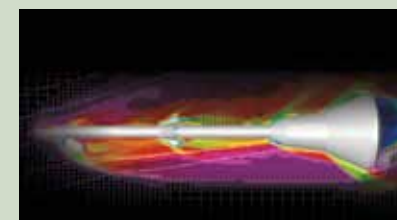
108
Concentrators Enhance Solar Power Systems

Glenn Research Center and Fort Worth, Texas-based Entech Solar partnered through the SBIR program to adapt Entech’s solar concentrator. Soon after developing the Solar Concentrator Array with Refractive Linear Element Technology, Entech and NASA worked on a version called the Stretched Lens Array (SLA). Recently, Entech incorporated elements from the SLA into a solar concentrator for Earth applications.



110
Innovative Coatings Potentially Lower Facility Maintenance Costs

Through extensive testing at Stennis Space Center, Nanocepts Inc. of Lexington, Kentucky, received key validation of the effectiveness of its photocatalytic coatings. Now a NASA Dual Use Technology partner, the company’s commercial coatings offer unique environmental and medical benefits, and their self-cleaning properties help limit grime buildup on buildings.



114
Simulation Packages Expand Aircraft Design Options

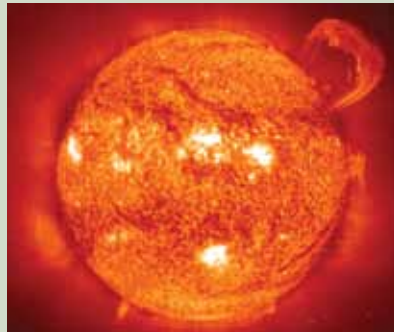
In 2001, NASA released a new approach to computational fluid dynamics that

allows users to perform automated analysis on complex vehicle designs. In 2010, Palo Alto, California-based Desktop Aeronautics acquired a license from Ames Research Center to sell the technology. Today, the product assists organizations in the design of subsonic aircraft, space planes, spacecraft, and high speed commercial jets.



116
Web Solutions Inspire Cloud Computing Software

An effort at Ames Research Center to standardize NASA websites unexpectedly led to a breakthrough in open source cloud computing technology. With the help of Rackspace Inc. of San Antonio, Texas, the resulting product, OpenStack, has spurred the growth of an entire industry that is already employing hundreds of people and generating hundreds of millions in revenue.



120
Behavior Prediction Tools Strengthen Nanoelectronics

NASA's electronics must resist the effects of extreme temperature and radiation. Huntsville, Alabama-based CFD Research Corporation received funding from Marshall Space Flight Center's SBIR program to refine software to predict the behavior of electronics in space. Now used by the Department of Defense, nuclear laboratories, and commercial satellite designers, the software has generated approximately \$2 million in revenue.



122
Power Converters Secure Electronics in Harsh Environments

In order to harden power converters for the rigors of space, NASA awarded multiple SBIR contracts to Blacksburg, Virginia-based VPT Inc. The resulting

hybrid DC-DC converters have proven valuable in aerospace applications, and as a result the company has generated millions in revenue from the product line and created four high-tech jobs to handle production.



124
Diagnostics Tools Identify Faults Prior to Failure

Through the SBIR program, Rochester, New York-based Impact Technologies LLC collaborated with Ames Research Center to commercialize the Center's Hybrid Diagnostic Engine, or HyDE, software. The fault detecting program is now incorporated into a software suite that identifies potential faults early in the design phase of systems ranging from printers to vehicles and robots, saving time and money.



126
Archiving Innovations Preserve Essential Historical Records

The Apollo 11 mission left on the Moon a silicon disc inscribed with

microscopic recreations of messages from 73 countries. NanoArk Corporation of Fairport, New York, built on that NASA technology to develop a fire and water resistant archiving innovation that provides cost savings and security in preserving documents. Since its launch, NanoArk has grown from 2 to 10 employees.



130
Meter Designs Reduce Operation Costs for Industry

Marshall Space Flight Center collaborated with Quality Monitoring and Control (QMC) of Humble, Texas, through a Space Act Agreement to design a balanced flow meter for the Space Shuttle Program. QMC founded APlus-QMC LLC to commercialize the technology, which has contributed to 100 new jobs, approximately \$250,000 in yearly sales, and saved customers an estimated \$10 million.



132
Commercial Platforms Allow Affordable Space Research

To help realize the potential of the US National Laboratory on the ISS, NASA Headquarters partnered with NanoRacks LLC of Houston through a Space Act Agreement to provide a cost-effective, versatile system for facilitating space-based research. NanoRack's platforms have allowed major research institutions and even high schools to conduct experiments on the ISS—expanding the scope of the commercial space industry.



136
Fiber Optics Deliver Real-Time Structural Monitoring

To alter the shape of aircraft wings during flight, researchers at Dryden Flight Research Center worked on a fiber optic sensor system with Austin-based 4DSP LLC. The company has since commercialized a new fiber optic system for monitoring applications in health and medicine, oil and gas, and

transportation, increasing company revenues by 60 percent.



138
Camera Systems Rapidly Scan Large Structures

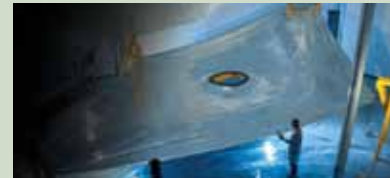
Needing a method to quickly scan large structures like an aircraft wing, Langley Research Center developed the line scanning thermography (LST) system. LST works in tandem with a moving infrared camera to capture how a material responds to changes in temperature. Princeton Junction, New Jersey-based MISTRAS Group Inc. now licenses the technology and uses it in power stations and industrial plants.



140
Terahertz Lasers Reveal Information for 3D Images

When Kennedy Space Center started looking for new capabilities to inspect the thermal materials for future space vehicles, it solicited proposals through the STTR program. NASA worked with Boston-based LongWave Photonics LLC

on a source of terahertz radiation called the quantum cascade laser (QCL). By 2011, LongWave started selling the Easy QCL to academic, industrial, and government researchers.



142
Thin Films Protect Electronics from Heat and Radiation

While Anne St. Clair worked on high performance polyimides at Langley Research Center, she noticed that some of the films were nearly colorless. The polyimides became known as LaRC-CP1 and LaRC-CP2, and were licensed by NeXolve Corporation, based in Huntsville, Alabama. Today, NeXolve provides polyimide film products to commercial customers for spacecraft, telescopes, and circuit boards.



144
Interferometers Sharpen Measurements for Better Telescopes

NASA worked with 4D Vision Technology—later acquired by Tucson,

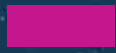
Arizona-based 4D Technology Corporation—to develop interferometers that could test large space mirrors. 4D created dynamic interferometry and enhanced the technology for optics, astronomy, aerospace, data storage, university research, manufacturing, and medical industries. The company has grown from 4 employees to more than 30.




146
Vision Systems Illuminate Industrial Processes

To ensure quality results from important manufacturing processes, Marshall Space Flight Center partnered with Control Vision Inc. of Sahuarita, Arizona, to create video sensor systems capable of imaging high-temperature, high-brightness processes like laser welding and plasma spray. The company's resulting commercial products help manufacturers maintain quality control and can be used to control processes such as additive manufacturing.

Spinoff Benefits: BY THE NUMBERS

 Total number gathered from companies featured in *Spinoff* 2000-2012

 Data gathered from companies featured in *Spinoff* 2012



In addition to the anecdotal evidence of their benefits, NASA spinoff technologies also yield quantitative evidence that demonstrates how NASA's investment in innovation produces tangible, positive outcomes for the Nation. NASA partnerships and the commercial products and services that emerge from these collaborations lead to the creation of new jobs, revenue that drives economic growth, cost-cutting capabilities that make industries more efficient, and the rescue of lives that would otherwise have been lost. For a deeper look at the benefits of NASA spinoffs, scan this code.

Lives SAVED

444,000

Techno-Sciences: 30,000
Page 68

Jobs CREATED

14,000

Diversified Industries: 2
Page 52
GreenField Solar: 30
Page 100
Rackspace: 50
Page 116
Unpeeled: 12
Page 36
NanoArk: 8
Page 126
VPT: 4
Page 122
4D Technology: 26
Page 144
4DSP: 5
Page 136
APlus-QMC: 100
Page 130
Eclipse International: 24
Page 66
Hyper Tech Research: 19
Page 46
Vecna Technologies: 20
Page 40

Revenue GENERATED

\$5 Billion

Rackspace: \$150 million
Page 116
Biospherical Instruments: \$2 million
Page 94
4DSP: Revenue increased by 60 percent
Page 136
APlus-QMC: \$250,000 annually
Page 130
CFDRC: \$2 million
Page 120
Hyper Tech Research: \$3 million
Page 46
Midwest Industrial Supply: Annual winter season revenue increases of \$300,000-\$600,000
Page 50
ISSI: \$200,000
Page 54

Costs REDUCED

\$6.2 Billion

Locus Energy: \$130,000 saved
Page 102
4D Technology: 1/10th the cost of other methods
Page 144
APlus-QMC: \$10 million saved
Page 130
Eclipse International: Electrical checks reduced from 8 hours to 45 minutes
Page 66
VoiceFlight Systems: Pilots enter waypoints 10 times faster, saving fuel
Page 56
4DSP: 20-fold improvement in processing speeds
Page 136
PURETi: 50 percent lower maintenance costs
Page 104

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 2012* 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



Inspire Healthy Beverages
page 36



Fortify Antioxidant Supplements
page 38



Pave the Way for Hospital Robots
page 40



Facilitate Remote Health Monitoring
page 42



Improve Speed, Accuracy of Eye Surgery
page 44



Enable Lower Cost MRI Systems
page 46

Transportation



Prevent Train Delays
page 50



Automate Vehicle Maintenance
page 52



Advance Rotorcraft Design Testing
page 54



Improve Flight Safety
page 56



Advance Heat Management Materials for Vehicles
page 58



Pinpoint Rotorcraft Troubles
page 60

Public Safety



Safely Identify Dangerous, Costly Leaks
page 64



Ensure Function, Safety of Aircraft Wiring
page 66



Save Tens of Thousands of Lives
page 68



Ensure Safer Medical Devices
page 72



Aid Emergency Decision Making
page 76

Consumer Goods



Encourage Exploration on Earth
page 80



Beautify Art
page 82



Add Comfort to Undergarments
page 84



Connect Sports Teams with Fans
page 86



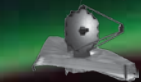
Deliver More Realistic Gaming
page 88



Authenticate Works of Art
page 90



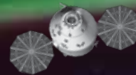
International Space Station



Space Telescopes and Deep Space Exploration



Satellites and Imaging Technology



Space Transportation



Astronaut Life Support



Aeronautics Research

Energy and Environment



Reveal Ocean Health, Climate Change
page 94



Enable Plants to Text Message Farmers
page 98



Cut the Cost of Solar Power
page 100



Inform Solar Power Analysis
page 102



Create Self-Cleaning Surfaces
page 104



Enhance Solar Power Systems
page 108



**Potentially Lower Facility
Maintenance Costs**
page 110

Information Technology



Expand Aircraft Design Options
page 114



Inspire Cloud Computing Platform
page 116



Strengthen Nanoelectronics
page 120



**Secure Electronics in Harsh
Environments**
page 122



Identify Faults Prior to Failure
page 124



Preserve Essential Historical Records
page 126

Industrial Productivity



**Reduce Operation Costs
for Industry**
page 130



Allow Affordable Space Research
page 132



**Deliver Real-Time Structural
Monitoring**
page 136



Rapidly Scan Large Structures
page 138



**Reveal Information for
3D Images**
page 140



**Protect Electronics from Heat
and Radiation**
page 142



**Sharpen Measurements for
Better Telescopes**
page 144



Illuminate Industrial Processes
page 146

NASA Partnerships Across the Nation

Health and Medicine

1. Water Treatment Technologies Inspire Healthy Beverages (MN)
2. Dietary Formulas Fortify Antioxidant Supplements (TX)
3. Rovers Pave the Way for Hospital Robots (MA)
4. Dry Electrodes Facilitate Remote Health Monitoring (VA)
5. Telescope Innovations Improve Speed, Accuracy of Eye Surgery (CA)
6. Superconductors Enable Lower Cost MRI Systems (OH)

Transportation

7. Anti-Icing Formulas Prevent Train Delays (OH)
8. Shuttle Repair Tools Automate Vehicle Maintenance (FL)
9. Pressure-Sensitive Paints Advance Rotorcraft Design Testing (OH)
10. Speech Recognition Interfaces Improve Flight Safety (NY)
11. Polymers Advance Heat Management Materials for Vehicles (NY)
12. Wireless Sensors Pinpoint Rotorcraft Troubles (AZ)

Public Safety

13. Ultrasonic Detectors Safely Identify Dangerous, Costly Leaks (NY)
14. Detectors Ensure Function, Safety of Aircraft Wiring (CA)
15. Emergency Systems Save Tens of Thousands of Lives (MD)
16. Oxygen Assessments Ensure Safer Medical Devices (NM)
17. Collaborative Platforms Aid Emergency Decision Making (MD)

Consumer Goods

18. Space-Inspired Trailers Encourage Exploration on Earth (TX)
19. Ultra-Thin Coatings Beautify Art (PA)
20. Spacesuit Materials Add Comfort to Undergarments (WI)
21. Gigapixel Images Connect Sports Teams with Fans (NY)
22. Satellite Maps Deliver More Realistic Gaming (CA)
23. Elemental Scanning Devices Authenticate Works of Art (WI)

Energy and Environment

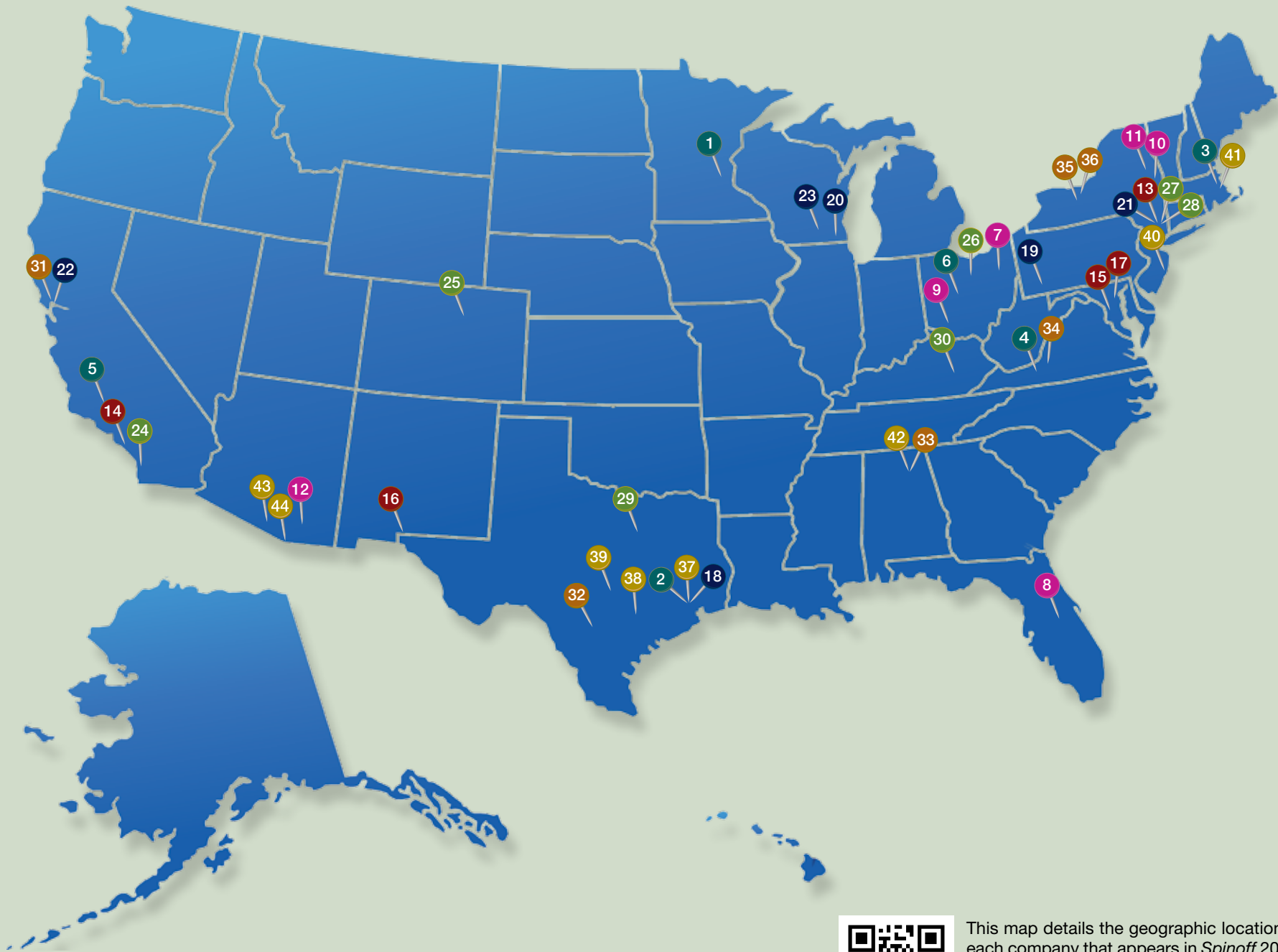
24. Microradiometers Reveal Ocean Health, Climate Change (CA)
25. Sensors Enable Plants to Text Message Farmers (CO)
26. Efficient Cells Cut the Cost of Solar Power (OH)
27. Shuttle Topography Data Inform Solar Power Analysis (NY)
28. Photocatalytic Solutions Create Self-Cleaning Surfaces (NY)
29. Concentrators Enhance Solar Power Systems (TX)
30. Innovative Coatings Potentially Lower Facility Maintenance Costs (KY)

Information Technology

31. Simulation Packages Expand Aircraft Design Options (CA)
32. Web Solutions Inspire Cloud Computing Software (TX)
33. Behavior Prediction Tools Strengthen Nanoelectronics (AL)
34. Power Converters Secure Electronics in Harsh Environments (VA)
35. Diagnostics Tools Identify Faults Prior to Failure (NY)
36. Archiving Innovations Preserve Essential Historical Records (NY)

Industrial Productivity

37. Meter Designs Reduce Operation Costs for Industry (TX)
38. Commercial Platforms Allow Affordable Space Research (TX)
39. Fiber Optics Deliver Real-Time Structural Monitoring (TX)
40. Camera Systems Rapidly Scan Large Structures (NJ)
41. Terahertz Lasers Reveal Information for 3D Images (MA)
42. Thin Films Protect Electronics from Heat and Radiation (AL)
43. Interferometers Sharpen Measurements for Better Telescopes (AZ)
44. Vision Systems Illuminate Industrial Processes (AZ)

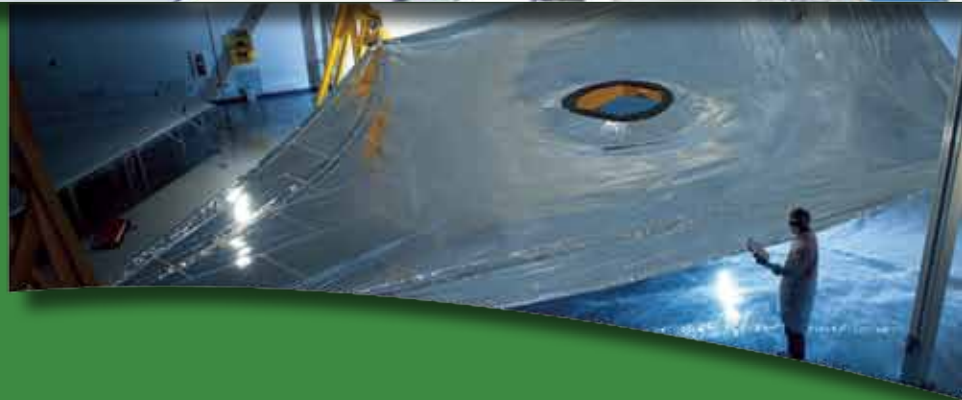


This map details the geographic location of each company that appears in *Spinoff* 2012. For a deeper look at how spinoffs have benefited your state and local economy, scan this code.

NASA Technologies Benefiting Society

Since its founding, NASA has been charged, not only with expanding humanity's reach into space and its knowledge of the universe, but also with finding ways for the technology it develops to benefit the Nation and world. NASA research and development has tangible, secondary benefits beyond supporting mission needs—creating jobs, generating revenue for businesses large and small, reducing costs, and saving lives. Through software innovations, fuel-saving capabilities for small aircraft, healthy beverages at your local grocery store, and more—NASA spinoffs are improving daily life in your hometown and beyond.







Health and Medicine

Through technology transfer partnerships, NASA innovations become a vital part of our Nation's healthcare industry. From robotic hospital assistants to technology for mapping eyes for vision correction, advances from NASA research boost fitness, improve medical devices, enhance disease treatments, and save lives. The spinoffs featured in this section:

- Inspire Healthy Beverages
- Fortify Antioxidant Supplements
- Pave the Way for Hospital Robots
- Facilitate Remote Health Monitoring
- Improve Speed, Accuracy of Eye Surgery
- Enable Lower Cost MRI Systems



Water Treatment Technologies Inspire Healthy Beverages

NASA Technology

If you wandered the halls of Johnson Space Center in the mid-1990s, you might have run across Mike Johnson lugging a large container of freshly collected urine down to the lab. There, Johnson assisted the scientists who were tasked with developing technology to convert the waste into drinking water. Johnson's role earned him a unique nickname that follows him to this day—"the Pee Man."

Though the idea of drinking reclaimed urine is unsettling for those of us with easy access to water on Earth, the research conducted by the Advanced Water Recovery Systems Development team has proven vital to space exploration. Thanks in part to their work, astronauts in low Earth orbit make the most of their resources, and those who will take part in future missions—like a trip to an asteroid or Mars—can count on having drinkable water for the journey.

The team in Houston specialized in using microorganisms to purify water. One breakthrough in the project involved the use of a unique technology: a trickling filter bioreactor. This cylinder-shaped unit is filled with porous spheres—providing a large amount of surface area for biofilm growth—and utilizes the wastewater itself as a growth medium for the bacteria.

Whereas fixed-plate cultures grow bacteria on a two-dimensional surface, the trickling filter bioreactor's media provides significantly more area for growth, and the reactor design



reduces limitations to the movement of fluids and gases. The resulting environment proves more conducive to the growth of the organisms, which can propagate in all directions and tend to form in healthier cultures.

In fact, Johnson says, the bioreactor proved too effective: "The results were so good, and the bacteria propagated so quickly, that it clogged the unit unless we cleaned it out much more frequently than we expected." The unanticipated growth rates meant that the scientists would have to recalibrate their system. It was at that time, however, that Johnson decided to change careers. He left NASA and attended chiropractic school, eventually opening up his own practice in Minnesota.

Technology Transfer

Though his days working in a science lab were behind him, the experience Johnson gained at NASA would soon come in handy. In addition to his work as a chiropractor, he also served as a healthcare practitioner by advising patients on nutrition. Given his background in wastewater regeneration, he was particularly sensitive to the issue of unhealthy drinks.

"I saw a lot of my clients consuming Coke, coffee, or other sugary drinks," he says. "But when I tried suggesting alternatives, I found there weren't many healthy beverages I could point to."

As Johnson pondered the situation, he thought back to his days of turning undrinkable waste into something healthy. "We used bacteria to remove the bad stuff from urine; so I thought, why not use probiotics to add healthy stuff to a drink?" (A probiotic is a microbe that protects its host and prevents disease.)

The experiment started in the back of his chiropractic office, where Johnson began growing probiotics in 55-gallon oak wine barrels. He used the bacteria to brew batches of kombucha—a live, cultured tea that has been fermented by bacteria and yeast—and filled empty beer bottles with the results. Johnson gave out samples to his patients, happy that he finally had a healthy drink to

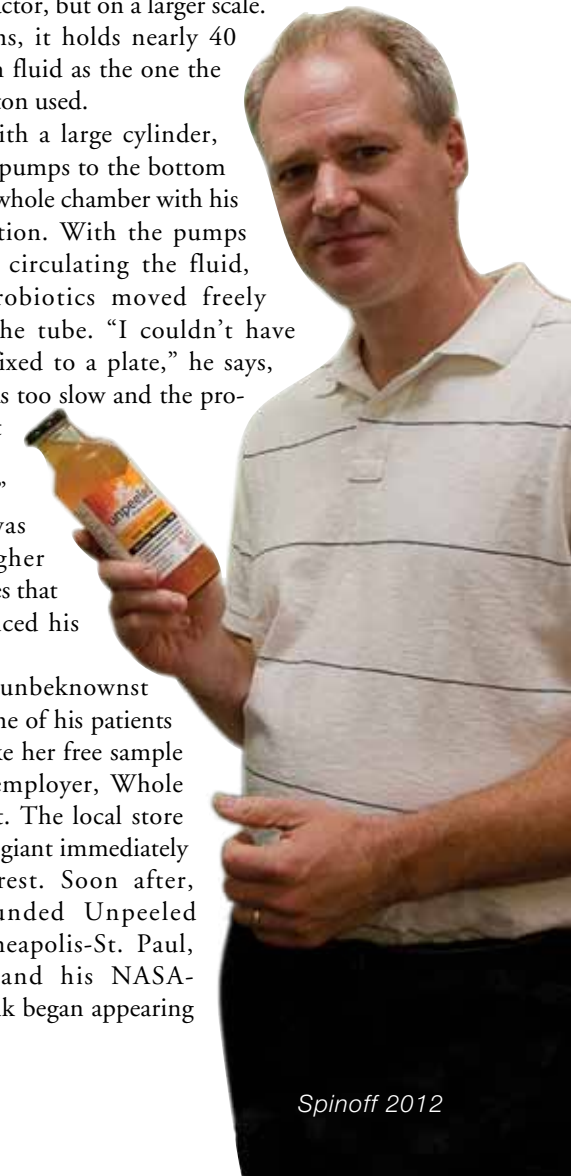
endorse. He says they were hooked right away: "People kept coming back—the next week, the next day—wanting more, because it had made them feel so much better."

In order to produce higher quality bacteria, and produce more of it, he looked to the trickling filter bioreactor from Johnson Space Center for inspiration. Johnson says he used the expertise he gained at NASA to custom build his own bioreactor, but on a larger scale. At 750 gallons, it holds nearly 40 times as much fluid as the one the team in Houston used.

Starting with a large cylinder, he connected pumps to the bottom and filled the whole chamber with his nutrient solution. With the pumps continuously circulating the fluid, Johnson's probiotics moved freely throughout the tube. "I couldn't have my bacteria fixed to a plate," he says, "because it was too slow and the probiotics didn't eat nutrients fast enough."

The result was stronger, higher quality cultures that further enhanced his drink.

One day, unbeknownst to Johnson, one of his patients decided to take her free sample back to her employer, Whole Foods Market. The local store of the grocery giant immediately showed interest. Soon after, Johnson founded Unpeeled Inc. in Minneapolis-St. Paul, Minnesota, and his NASA-enhanced drink began appearing





Johnson is on pace to sell more than 5 million bottles of his NASA-inspired drink in 2012.

on the shelves at Whole Foods, as well as other local specialty food stores.

Benefits

Unpeeled starts with a kombucha base, to which Johnson adds his own blend of four different probiotics. The bacteria and yeast naturally form a cellulose matrix, or a balanced growth configuration, which allows the organisms to inhabit the same medium without killing each other off.

The probiotics remain live and active to the time the consumer opens a bottle. Once consumed, the drink's bacteria propagate in the gastro-intestinal (GI) tract, aiding in digestion and reducing inflammation that causes muscle and joint pain. Unpeeled also helps balance the body's pH levels by alkalizing them. (The human body has a tendency to become overacidic under the influence of the typical modern diet.)

Johnson stresses that it is the quality of bacteria, not the quantity, that matters. Once the GI tract is seeded with good bacteria, they multiply on their own and crowd out pathogens. Each bottle of Unpeeled thus contains three servings' worth of probiotics, which he recommends be consumed throughout the day.

From Unpeeled's earliest batches, customers have responded favorably to its health benefits. "This beverage

is saving my life," one customer says. "It makes swelling go down [and] promotes good digestion. I don't know how I could do without it." Another of Johnson's customers—and longtime patient—has been faithfully drinking Unpeeled since before it had a name, and says the tea helps her manage her painful joints.

Unpeeled currently comes in six flavors, which begin with the same green tea kombucha and are differentiated using natural flavorings such as raw ginger, cranberry, mango, sea salt, and juices



from various organic fruits. In addition to enhancing flavor, these natural ingredients impart enzymes that bolster the drink's health benefits further. Johnson will soon release a second probiotic beverage line made from a coconut-water base, also to be available in a variety of flavors.

Business has been booming for Unpeeled. What began as a back-of-the-office beer-bottle operation now takes up a 10,000 square-foot warehouse. In it are four of Johnson's custom built bioreactors bubbling away with the next batch. Johnson has hired 12 employees to meet production demands and plans on hiring more help soon. After selling 500,000 units in 2010 and over 1 million in 2011, he is on pace to sell more than 5 million bottles of his NASA-inspired drink in 2012. ♦



Mike Johnson (left), says he could not have created the bioreactors he uses without the knowledge he gained at NASA. "There's no way I'd be able to do what I'm doing without that experience," he says. The result (above) is his line of probiotic beverages, Unpeeled.

Dietary Formulas Fortify Antioxidant Supplements

NASA Technology

The astronaut's life and work is so different from our own daily experiences that it's easy to forget that astronauts are people, too. Just like everyone else, astronauts have basic nutritional needs—such as five to nine servings of fruit and vegetables per day—in order to maintain optimal health. Here on Earth, it can be a challenge to incorporate the recommended amount of fruit and veggies into our diets—despite easy access to fresh produce. In space, it becomes even more difficult, as astronauts must take everything they need with them. And in the harsh conditions of space, many miles from medical assistance, proper nutrition takes on added importance.

As NASA makes plans to send astronauts on missions that could take months and even years, the Agency explores new ways to provide astronauts with a daily dose of nutrition equivalent to that provided by fresh produce. These foods are critically important because they provide the essential vitamins, minerals, pigments, and other micronutrients (substances required in small amounts for human health) that promote everything from healthy skin to a strong heart.

Technology Transfer

When NASA started looking for a potential partner to assist with a light-weight, low-volume micronutrient solution, it identified Houston-based AmeriSciences LP, which had already developed a number of similar supplements.

In 2004, the partners started examining the specific needs of an astronaut, not only for a balanced diet, but specifically for overall health while in space. One of the concerns the team focused on was oxidative stress. Primarily caused by radiation in the space environment, oxidative stress can damage cells and increase an astronaut's risk of cataracts, macular degeneration, skin cancer, and other diseases. Oxidative stress can be compounded

in space by breathing high concentrations of oxygen before spacewalks and by exposure to various spacecraft atmospheric contaminants, especially certain fuels.

“We started to look at how to overcome all of these challenges with a supplement,” says Carlos Montesinos, director of research and development and quality assurance at AmeriSciences.

In 2005, NASA's Johnson Space Center entered into a formal Space Act Agreement with AmeriSciences to develop a complete multivitamin regimen for general astronaut health, as well as other more specialized dietary supplements, such as omega-3 fatty acids and plant-derived antioxidant formulas to fight against oxidative stress. Once the team tailored the formulations for astronauts, NASA contacted the University of Pittsburgh's Department of Radiation Oncology, led by researcher Joel Greenberger, to test its ability to protect against radiation.

The university conducted an experiment that involved exposing four groups of mice to doses of radiation. Two groups were placed on a diet that included the AmeriSciences/NASA formulas. The other two groups were placed on a regular diet. After many months, results showed that the mice on the AmeriSciences/NASA formulas experienced longer life spans and fewer health problems than those on a regular diet.

At that point, Montesinos says, “Supplementation went from a dietary convenience to something that has a purpose.” The results of the study were published in the June 2011 issue of *Radiation Research* journal. Jeffrey Jones, a flight surgeon at NASA at the time and current professor at Baylor College of Medicine, describes the study as “groundbreaking.”

“There's no existing combination countermeasure like it,” he says.



NASA worked with AmeriSciences LP to develop a multivitamin that could help astronauts fight stress caused by radiation in space. Here, NASA astronaut Clayton Anderson takes a spacewalk in 2010.

In 2009, the AmeriSciences/NASA formulas were tested by astronauts aboard the space shuttle and International Space Station, and Montesinos and Jones are continuing to pursue opportunities for long-term testing in space while collaborating with other organizations to conduct human studies.

Benefits

In 2011, AmeriSciences started offering the benefits of its NASA partnership to consumers through a number of products. The products include multivitamins such as AS10 Life and MM6; fruit and vegetable-derived antioxidants such as AS10; and omega-3 fatty acids such as AmeriSciences Omega Max and EZ Omega+D. Many of the featured ingredients in each of the products are included as a direct result of AmeriSciences' research with



NASA. Hundreds of thousands of products have sold thanks to this joint initiative.

“In broad terms, AS10 Life is a comprehensive multi-vitamin that acts as an insurance policy against nutrient deficiency,” says Montesinos.

According to the manufacturer, the nutrient cocktails in these products provide vitamins, phytonutrients (chemical compounds that occur in plants), and an array of micronutrients for a comprehensive approach to nutrition, plus a blend of antioxidants for protection against environmental stressors like radiation.

Montesinos says certain populations are more likely to benefit from these products, but everybody could derive some benefit. “Undoubtedly, whole foods and a balanced diet are the optimal way to obtain nutrients. But given the complexities of modern society’s approach to food, most of us could benefit from having an extra dose of the compounds you would normally ingest if you ate spinach, broccoli, and strawberries. Aside from that, individuals who are at a higher risk for exposure to oxidative stressors could benefit as well.”

People at higher risk to oxidative stress include nuclear power plant workers, populations near nuclear sites, military forces working in radioactive zones, and civilian populations in the aftermath of a nuclear plant accident. In addition, people who fly frequently, industrial and construction workers, healthcare radiology workers, and sun-tanning salon workers are also at increased risk.

According to the manufacturer, these formulas provide a comprehensive approach to nutrition, plus a blend of antioxidants.

Already, Montesinos finds the supplements have improved—and potentially extended—the lives of thousands of consumers. As a result, these consumers have also reported a reduction in their other health maintenance costs.

Kimberly Samuels of Mission Viejo, California, appreciates the benefits of the products. “Since I have been using them, I have stopped using all my allergy and asthma medications that I have been on since I was 6 years old. I no longer have a need for prescriptions for me to be able to breathe and deal with the seasons and animals.”

The product line is available from small retailers and physician’s offices across the country, as well as in the United Kingdom, China, Japan, Brazil, Mexico, Canada, and Colombia.

According to Montesinos, a group of doctors recently performed an independent study on the effects of many of these products on skin. The subjects saw a reduction of UV damage as well as a reduction in wrinkles. “We are now hoping for a larger skin care study to see what potential benefit our products might have,” he says. “I am also interested in what kind of impact AS10 can have on the side effects of radiation therapy or chemotherapy.”

As studies and tests continue, Jones finds, “This is another instance where NASA-led research holds great promise for potential applications outside of space flight.” ❖



Rovers Pave the Way for Hospital Robots

NASA Technology

Before Curiosity came the Mars Exploration Rovers, Spirit and Opportunity. Before Spirit and Opportunity came Pathfinder and Sojourner. Before Pathfinder and Sojourner, the Mars Global Surveyor, and before the Mars Global Surveyor, the Viking landers. Over the years, a host of Mars missions and programs have built on one another, spurring technology advancements that have led to the impressive collection of Mars information and images that we have today.

The development of new technology has made Mars missions possible. Between and during actual missions and programs, NASA scientists and engineers also gain valuable knowledge and experience from research models, or prototypes, for Mars missions. One such prototype—Rocky 7—was built at the Jet Propulsion Laboratory (JPL) in the mid-1990s as a research test rover for navigation and sampling technology on Mars.

According to Richard Volpe, a robotics manager at JPL, the mechanical design of Rocky 7 allowed a system with fewer actuators, or motors. With fewer actuators needed for mobility, others could be used for manipulation: a short sampling manipulator (an arm), and a long instrument manipulator (a mast). Rocky 7's arm could dig and collect small rocks and soil, while the mast had stereo cameras and the capability to hold an additional instrument, usually a microscopic imager.

"The primary purpose of the mast was to provide images of the surrounding terrain from a high vantage point," says Volpe. "Using this capability in field tests in the Mojave Desert with Rocky 7, we demonstrated the operation style for a long distance rover—paving the way for Mars Exploration Rover operations later."

Following the desert field tests in 1996 and 1997, Rocky 7 was used for algorithm development and testing, including for autonomous rock grasping.

Technology Transfer

In the mid-1990s, JPL provided funding for the Vision and Touch Guided Manipulation group at the Massachusetts Institute of Technology's (MIT) Artificial Intelligence (AI) Lab to develop object acquisition capabilities for robotic missions with a mounted arm—like that on Rocky 7.

MIT utilized two platforms for developing control capabilities to acquire rock samples: a Whole-Arm Manipulator (WAM) and a mock-up of Rocky 7. At the time, Daniel Theobald was a graduate student working in the AI Lab, where he used the WAM to pick up rocks, present them to the camera, and then weigh and sort them into containers. "It was cutting edge work nearly 20 years ago," he says.

Theobald built the test system simulator for the mock-up Rocky 7 system and used it to test the arm's capabilities. "We were really focused on rock sample collection and opportunistic science," he says. "If a rover notices an interesting object, could we build a system where the robot is smart enough to say, 'Hey, this could be interesting, and I'm going by it, so I might as well grab a little bit of data? That's opportunistic science.'"

After developing the operating system for the Rocky 7 mock-up, Theobald wrote his graduate thesis on the system as well as research for autonomous robot behavior mediated by humans from a distance. He explains, "Rather than move the joystick and make the robot move forward, I might verbally dictate to the robot, 'Go to these coordinates,' and the robot figures out how to control the motors to get to those coordinates.

That's autonomy—having it control the motors itself rather than have me control them."

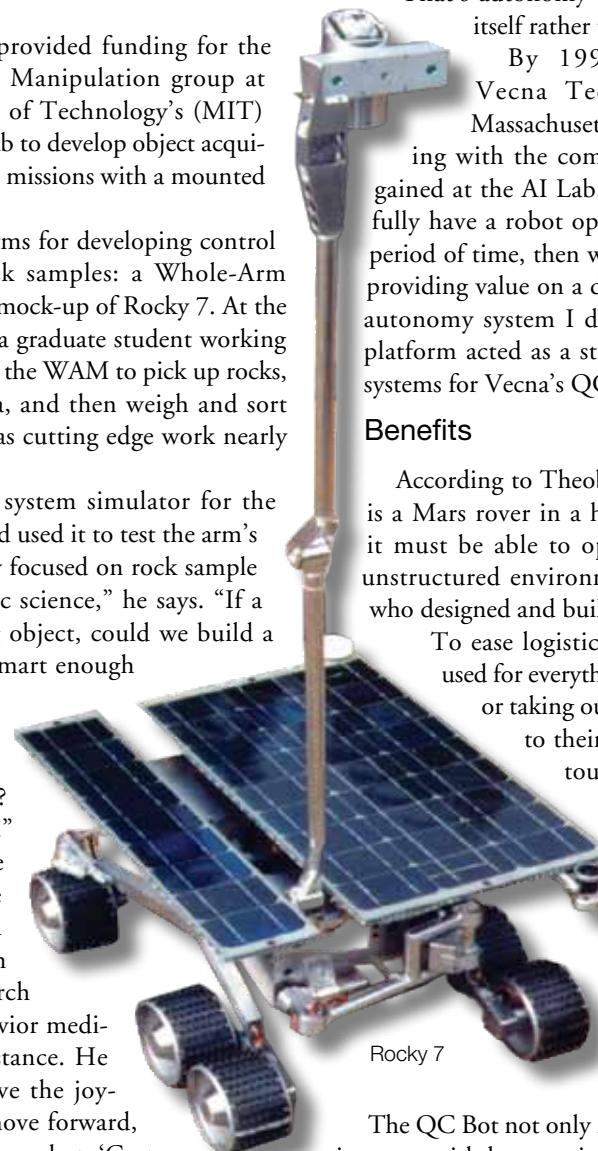
By 1999, MIT alumni founded Vecna Technologies, of Cambridge, Massachusetts, and Theobald started working with the company to apply the insights he gained at the AI Lab. "I thought, if we can successfully have a robot operate on Mars for an extended period of time, then we should have robots on Earth, providing value on a daily basis," he says. "The robot autonomy system I developed for the Rocky 7 test platform acted as a starting point for the autonomy systems for Vecna's QC Bot," he says.

Benefits

According to Theobald, conceptually, the QC Bot is a Mars rover in a hospital. "Like the Mars rover, it must be able to operate robustly in a complex, unstructured environment away from the engineers who designed and built it," Theobald says.

To ease logistics in hospitals, QC Bot can be used for everything from delivering medications or taking out the trash, to ushering patients to their appointments. A configurable touch screen allows hospital staff and patients to interact with the robot through intuitive menus. The touch screen can be used for completing bedside registration as well as capturing vital signs. To achieve each of these tasks, the robot can autonomously call elevators and find its way through corridors.

The QC Bot not only incorporates autonomy, but also interacts with humans in natural ways that follow social conventions. "We have put a lot of effort into the human-robot interaction aspect of the project to make sure that



Rocky 7



people enjoy interacting with the robot. That is one thing we didn't have to worry about on Mars," says Theobald.

The robot's location can be communicated to hospital workstations, smart phones, or mobile devices, and doctors and nurses can call QC Bot to transport items like laundry, packages, or meals. Users can also place items in the robot's locking drawers, indicate the recipient, and then verify identities through biometrics, ID cards, or barcodes. If QC Bot encounters an unfamiliar obstacle in a facility, it will find a way around it or find a new route.

Currently, QC Bot is being used at a number of hospitals in the United States and internationally. Theobald believes the technology has the potential to improve efficiency, reduce medical errors, and increase patient and staff satisfaction. So far, the NASA-derived technology has helped to create 20 new jobs at the company, and Theobald expects that number to expand.

Most recently, Vecna's QC Bot technology started spinning back into NASA. "We have a new NASA partnership through the SBIR program on using machine vision techniques to monitor astronaut performance and health based on human tracking work that we do on QC Bot," says Theobald. "We really enjoy working with NASA to push the boundaries of human understanding while at the same time using that work to provide concrete benefit to daily life here on earth."

And that is precisely how technology innovation happens. Before QC Bot came Rocky 7. What will QC Bot lead to? ♦

QC Bot® is a registered trademark of Vecna Technologies.



The QC Bot can do everything from delivering medications to ushering patients to their appointments. Conceptually, it's a Mars rover in a hospital, according to Daniel Theobald of Vecna Technologies. For a deeper look at the Mars Rovers program, scan this code.

Dry Electrodes Facilitate Remote Health Monitoring

NASA Technology

You wouldn't find a big bowl of spaghetti served on the International Space Station (ISS). In microgravity, it would be a complete mess. There is, however, something like spaghetti on the ISS: the wires that connect electrodes for an electrocardiogram (EKG). They can be just as much of a nuisance for the crew members.

During a visit to the ISS, an astronaut might experience chest pains or an irregular heartbeat—or might simply want a fitness check-up. Without a doctor's office or hospital nearby, astronauts perform EKGs themselves to monitor their cardiovascular health. The data is sent to Earth and monitored by a NASA flight surgeon.

The problem with using a conventional EKG machine in space is the electrodes that detect the heart's signals. First, there is the cumbersome "spaghetti" of wires connecting the electrodes to the EKG device.

"The 'spaghetti' flies here and there—it can get hooked on something and yanked off of an individual," says Todd Schlegel, a medical officer at NASA's Johnson Space Center.

The electrodes also must be wet to adhere to the skin. Over a period of time, the wires and moisture (or stickiness) make the electrodes uncomfortable for the person wearing them. Lastly, because they are not reusable, supplies of electrodes must be transported to and from space.

"We prefer something streamlined, with no wires flying around," Schlegel says. "We also want something that is reusable. A dry electrode system that is secured would be very useful."

Technology Transfer

One of the companies NASA partnered with to make Schlegel's concept a reality was NanoSonic Inc., based in Pembroke, Virginia. Founded in cooperation with Virginia Polytechnic Institute and

State University in 1998, NanoSonic produces a novel technology called Metal Rubber. Flexible like rubber but conductive like steel, the nanotechnology has been the subject of research and development efforts for more than a decade.

Rick Claus, NanoSonic's president and founder, says, "We found when you stretched Metal Rubber, the resistance changed, so it could be used as a sensor."

In 2005, NanoSonic was awarded Small Business Innovation Research (SBIR) funding from Johnson Space Center to employ Metal Rubber as a lightweight, comfortable sensor to potentially replace the electrodes and wiring currently used for astronaut health monitoring on the ISS.

Through the partnership, NanoSonic demonstrated the feasibility of using Metal Rubber sensors, as well as their performance. Testing to date has shown the health data gathered by the individual sensors is practically identical to standard sensors. The flexible electrodes have also been incorporated into a shirt, which potentially eliminates the burden of adhering electrodes to an astronaut's body.

"Without any glue or suction cups, the T-shirt tells you heart rate," says Claus. "We think it's an interesting step that we haven't seen other people take."

According to Schlegel, NanoSonic's dry electrode effectively receives signals the way a wet electrode would, thanks to the advanced materials. "The key innovation is the dry

electrode sensor," he says. "I think it's going to have usefulness in many different applications."

Benefits

In 2011, NanoSonic started marketing the dry electrode sensors as well as an EKGear Sensor Shirt based on the NASA-derived technology—to automatically measure heart rate and rhythm. According to Andrea Hill, the sensors group leader at NanoSonic, "We get inquiries from large and small companies weekly. There has been a lot of interest from around the world."

As a reusable, washable, form-fitting remote cardiac monitoring garment, EKGear uses no clips, clamps, external lead wires, or gels. "You don't have to treat the skin like you do with typical EKG leads. You just slip on the shirt and it's ready to go," Hill says.

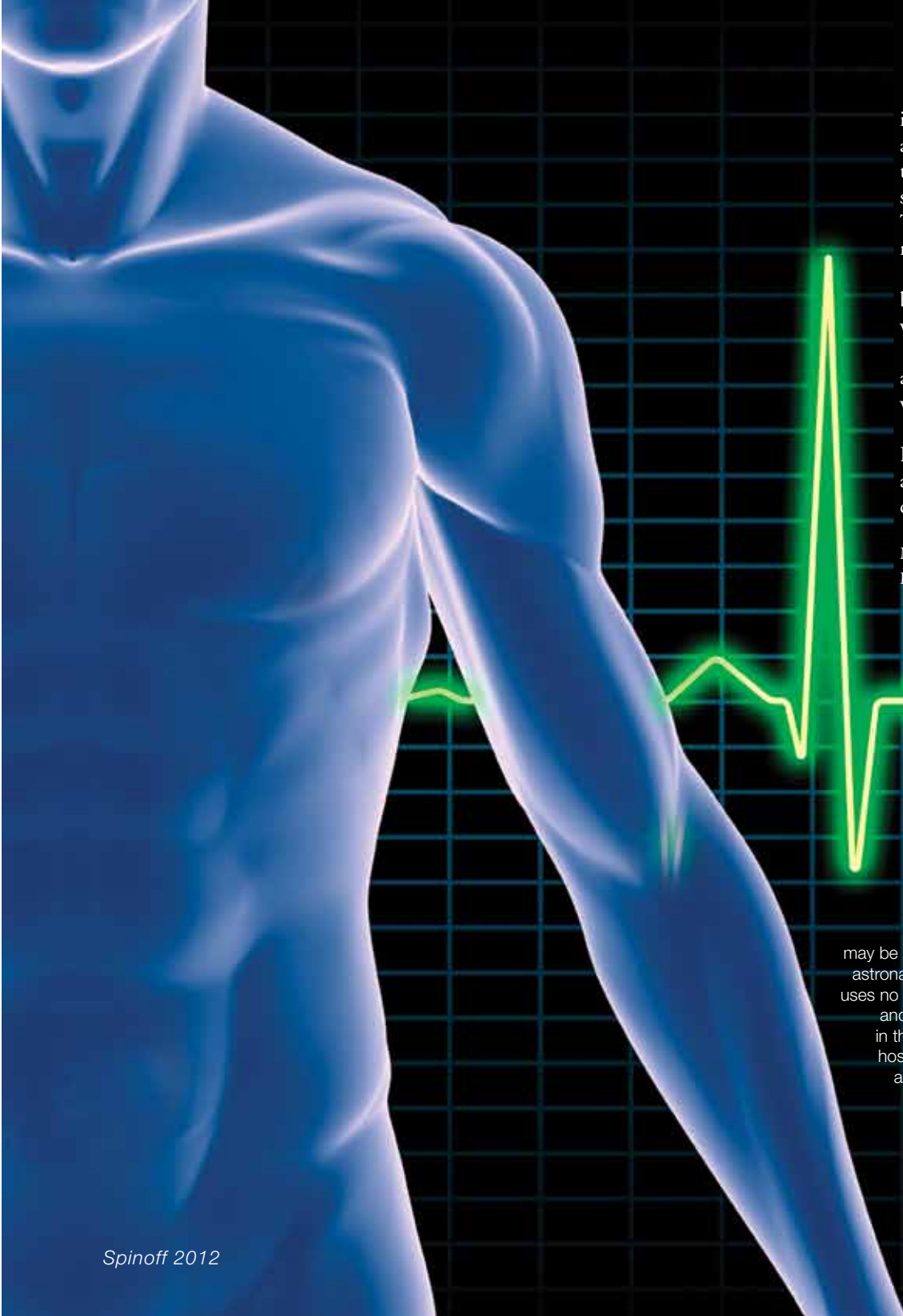
One difference between the original version of the technology and NanoSonic's version is that EKGear transmits information wirelessly to a display that is identical to a traditional heart rate and EKG display. "NASA did not want us to focus on any specific wireless system for them because it could interfere with their electronics. But with EKGear, the wearer can now go out for a jog and it will send a signal back to the display," says Hill.

The company has already sold a variety of its dry electrodes, a few of its EKGear shirts, and is currently in discussions with companies in the space, athletic apparel, and healthcare communities about using the technology in the future.

Especially convenient for remote health monitoring, there is great potential for the technology in the healthcare and sports and fitness industries, in emergency response situations, and in the military. In hospitals, where certain patients require around-the-clock monitoring, EKGear can provide an alternative to traditional wet and wired electrodes. Hospital garment manufacturers are interested in the technology, and NanoSonic has also spoken to the military about developing apparel for soldiers.



A shirt that monitors heart rate and EKG.



Besides EKG sensors, NanoSonic can incorporate additional electronics in the shirt, including temperature sensors, respiration sensors, and antennas for location information. “Beyond EKG measurements, being able to monitor a soldier and know where they are, how they are doing, what their stress level is, and what their heart rate is—would all be beneficial,” Hill says. The same applies to emergency responders like firemen, police, and disaster relief personnel.

Another area where comfortable, dry electrode sensors would be advantageous is scuba diving. The company recently started talking with a commercial manufacturer of dive suits to see if the sensors would be a good fit.

To add even more convenience to the technology, NanoSonic is also developing a wireless interconnect system and app that can be combined with EKGear and the wearer’s electronic device to capture, record, and track cardio and physiological data.

According to Schlegel, “The shirt is just one of many potential configurations.” He finds the electrodes could potentially be used for electromyograms to evaluate and record the electrical activity produced by skeletal muscles, and for electroencephalograms to study the electrical current within the brain. ❖

Metal Rubber™ is a trademark of NanoSonic Inc.
EKGear™ is a trademark of NanoSonic Inc.

The dry electrode (on right) may be used in the future to monitor astronauts’ heart health in space. It uses no clips, clamps, wires, or gels, and is being considered for use in the garments patients wear in hospitals, in apparel for athletes and soldiers, and in dive suits for scuba divers.



Telescope Innovations Improve Speed, Accuracy of Eye Surgery

NASA Technology

One of the main components of NASA's vision for the future of space exploration will actually have a keen eye for the past. The James Webb Space Telescope (JWST), scheduled to launch in 2018, will have spectacular sight—after it reaches orbit, one of its main goals is to observe the first galaxies that formed in the early universe.

“JWST offers new capabilities in the infrared well beyond what we can see from current telescopes, either

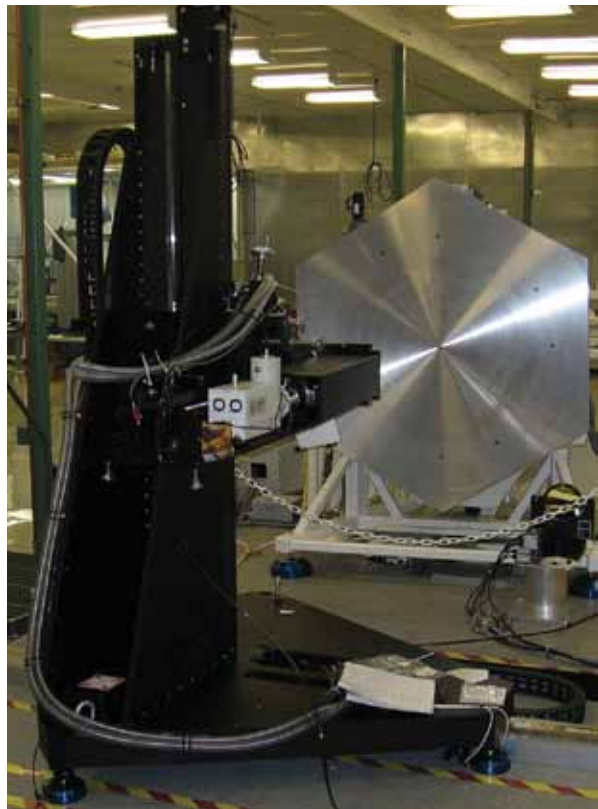


Image courtesy of Abbott Medical Optics Inc.

An advanced Scanning Shack Hartmann System measures the mirror segments of the James Webb Space Telescope (JWST) to create a detailed map for the next step in making the mirrors.

on the ground or in space. It will let us explore the early universe, extrasolar planets, and really, all branches of astrophysics,” says Lee Feinberg, optical telescope element manager for the JWST at Goddard Space Flight Center.

Building such a keen space telescope is an astronomic task. Because JWST will gaze over such incredible distances, it requires very large mirrors. In fact, the primary mirror will be more than two stories in diameter and consists of 18 separate segments. Each segment must be perfectly smooth, flat, and scratch-free in order to deliver a view 13 billion light years away.

Construction of the 18 mirror segments involved measuring, grinding, polishing, and testing—and more measuring, grinding, polishing, and testing—and more measuring, grinding, polishing, and testing (you get the idea). One of the most time consuming steps of the mirror development process—the grinding phase—can take years.

Technology Transfer

To polish the JWST's mirror segments, NASA's Goddard Space Flight Center contracted with Northrop Grumman Aerospace Systems and Ball Aerospace, which contracted with L3 Communications' Tinsley Facility in Richmond, California. A subcontractor to L3 at the time, WaveFront Sciences of Albuquerque, New Mexico, worked at the facility to assist with polishing by developing a system for metrology (measurement) testing of the large JWST mirrors after grinding. Called the infrared Scanning Shack Hartmann System, the technology enabled testing of the mirror's surface immediately after grinding and completely eliminated one of the polishing steps in the process.

“It was a key advantage,” says Dan Neal, cofounder of WaveFront Sciences. “They could take the mirror off grinding and in one day, get a test back with a detailed map on how to do the next step of the grinding.”

Neal explains how the new metrology testing stations measured just a small part of the mirror to create an image

of the entire surface. “We didn't have to build giant reference mirrors. Traditionally, the reference mirror has to be as big as the mirror you are going to test. It was very innovative,” he says.

For NASA, the system reduced the time it took to construct the high-quality primary mirror segments and also reduced the cost. “By measuring earlier, in the grinding phase, it allowed us to speed up the process and ensure the performance was what we wanted when we got to the final stages,” Feinberg says.

Now the innovation is enabling faster, more precise measurements of complex surfaces for researchers and doctors who measure a different kind of lens—the human eye.

“The testing systems developed for the JWST mirrors have allowed improvements in the machines for testing human eyes for LASIK surgery,” says Neal. “We were trying to solve one problem for JWST, and the tool we developed turned out to have many applications.”

Benefits

The work performed on the JWST spun off into one of WaveFront Science's products called the Complete Ophthalmic Analysis System, or COAS. By incorporating the algorithms developed for JWST, COAS performed 21 times faster.

Designed for diagnosing eye conditions and providing a detailed map of the eye, COAS supports research in cataracts, keratoconus (an eye condition that causes reduced vision), and eye movement. “There are a number of researchers around the United States and the world using the product for vision research,” says Neal.

In 2007, Advanced Medical Optics acquired WaveFront Sciences—and with it, the improved COAS technology. Two years later, Advanced Medical Optics was acquired by Abbott Laboratories and renamed Abbott Medical Optics. Today, Abbott Medical Optics is a leading company of vision correction technology based in Santa Ana, California. The company recently released a new product in Europe, based in part on COAS, called

“We were trying to solve one problem for JWST, and the tool we developed turned out to have many applications.”

—Dan Neal, Abbott Medical Optics

the iDesign Advanced WaveScan Studio. The technology is a main component of Abbott’s iLASIK laser vision correction solution.

A doctor uses the iDesign Advanced WaveScan Studio to measure a patient’s eye and then create a map of the LASIK treatment that is needed for correction. The map is transferred to a laser, which performs the custom treatment. “It’s a stand-alone piece of equipment, but works in conjunction with a laser. The software transfers directly to the laser,” says Neal, who is now a research fellow at Abbott Medical Optics.

According to the company, the technology is quick and accurate. It works within 3 seconds to obtain four different measurements, and provides accuracy in measuring distorted surfaces—for conditions like nearsightedness, farsightedness, astigmatism, and others. “The techniques for JWST needed to be able to measure a wide variation of shapes, and those are the same techniques we’ve used in designing instruments to measure the eye,” says Neal.

JWST also prepared Abbott Medical Optics for the large-format cameras that are now available in the industry, says Neal. “We are using them in our new products. When an eye doctor makes a measurement on his machine, he doesn’t want to wait 2 minutes for it to be complete. He wants to see it instantly. That’s taking advantage of those faster and better algorithms,” he says.

“Often, the government has the ability to fund big vision things and along the way, some of the technology pieces turn out to be important across the board in many different ways.” ❖

COAS™ is a trademark of WaveFront Sciences.



Image courtesy of Abbott Medical Optics Inc.

A new laser vision product released in Europe can map the human eye more quickly and accurately for LASIK vision correction, thanks to the innovations made while constructing the JWST mirrors.



Superconductors Enable Lower Cost MRI Systems

NASA Technology

The future looks bright, light, and green—especially where aircraft are concerned. The division of NASA's Fundamental Aeronautics Program called the Subsonic Fixed Wing Project is aiming to reach new heights by 2025–2035, improving the efficiency and environmental impact of air travel by developing new capabilities for cleaner, quieter, and more fuel efficient aircraft.

One of the many ways NASA plans to reach its aviation goals is by combining new aircraft configurations with an advanced turboelectric distributed propulsion

(TeDP) system. Jeff Trudell, an engineer at Glenn Research Center, says, "The TeDP system consists of gas turbines generating electricity to power a large number of distributed motor-driven fans embedded into the airframe." The combined effect increases the effective bypass ratio and reduces drag to meet future goals.

"While room temperature components may help reduce emissions and noise in a TeDP system, cryogenic superconducting electric motors and generators are essential to reduce fuel burn," says Trudell. Superconductors provide significantly higher current densities and smaller and lighter designs than room temperature equivalents.

Superconductors are also able to conduct direct current without resistance (loss of energy) below a critical temperature and applied field. Unfortunately, alternating current (AC) losses represent the major part of the heat load and depend on the frequency of the current and applied field. A refrigeration system is necessary to remove the losses and its weight increases with decreasing temperature.

In 2001, a material called magnesium diboride (MgB_2) was discovered to be superconducting. The challenge, however, has been learning to manufacture MgB_2 inexpensively and in long lengths to wind into large coils while meeting the application requirements.

Technology Transfer

For more than a decade, Hyper Tech Research, a Columbus, Ohio-based company, has been working on the development of MgB_2 superconducting wire. According to Mike Tomsic, president of Hyper Tech, "When MgB_2 came along, we were excited because the transition temperature was twice as high as any known intermetallic superconductor at the time. We saw the potential for many applications."

Early in the development process, the company received funding from Glenn Research Center's Small Business Innovation Research (SBIR) program to investigate MgB_2 for motors and generators for turboelectric aircraft propulsion systems. Hyper Tech also worked with Glenn on the process of making very fine superconducting filaments to reduce AC losses.

"Hyper Tech designed and fabricated a set of four MgB_2 rotor coil packs for a superconducting generator," says Trudell. "The advantages of using MgB_2 wire and coils developed by Hyper Tech include low cost and density, the ability to be easily configured in any critical current as a round wire, and the low AC loss potential."

While further development is required before MgB_2 can be used for NASA applications, Tomsic says the



These aircraft concepts are designed to burn less fuel and expel fewer emissions. For a deeper look at NASA's Fundamental Aeronautics Program, scan this code.

NASA projects have helped Hyper Tech to advance MgB₂ to a point where it can be used for commercial products.

“At the time we made the coils for NASA, they were probably the longest length MgB₂ wires and highest performing MgB₂ coils anyone had made in the world,” says Tomsic.

Benefits

Several years after its initial work with Glenn, Hyper Tech now builds superconducting coils and has patented a process for manufacturing MgB₂ superconducting wire in many different diameters and lengths. Through collaboration with various research organizations, Hyper Tech continues to increase the performance of MgB₂ wire. Tomsic says the company has obtained funding to do demonstrations and has sold wires and coils to companies for their own developmental products. “Instead of just making the wire, we are developing subsystem prototypes along with our customers,” he says.

Hyper Tech has received funding from the National Institutes of Health, the Department of Energy, the National Institute of Standards and Technology, and the State of Ohio, and has been cooperating with major companies to apply MgB₂ superconducting wire to magnetic resonance imaging (MRI) devices. These devices are used in medical facilities to make images of organs and structures inside the body. Most MRIs generate a strong magnetic field using superconductors, which allow for the highest-quality imaging.

By using MgB₂ superconducting wire for MRI background coils, the company hopes to help MRI producers drive down the cost of MRIs. “That’s the number one application for MgB₂ wire,” says Tomsic.

Tomsic explains that MRIs currently use niobium titanium superconductors that are cooled in a bath of liquid helium. The liquid helium helps prevent magnet quenches where the magnet increases in temperature due to local overheating and can cause damage. Some MRI machines experience the issue more often than others. “The problem is that liquid helium is in short supply,” says Tomsic. “By 2017–2018, it is predicted that the demand will exceed the supply. For many customers,



After Hyper Tech Research advanced superconducting wire for NASA, the company started applying the same wire to magnetic resonance imaging (MRI) devices to reduce the cost of MRI systems.

the cost of helium has tripled in the last five years, and is expected to keep increasing.”

The MRI industry is looking to convert to conduction cooled magnets, which would transfer heat from the superconductor coil to copper links to a refrigerator to remove the heat from the magnet, describes Tomsic. “This would eliminate the large helium bath,” he says. “We have programs with Siemens and General Electric working on developing replacement magnets for their existing MRI background magnets.”

Getting MgB₂ wire into MRIs will make MgB₂ wire more economical for other power applications like superconducting fault current limiters (SFCL). SFCLs use superconductors to limit electrical surges before they exceed a circuit breaker capacity. According to Tomsic, SFCLs can be advantageous when adding renewable energy like wind and solar to the grid, which can cause fault currents that exceed the breaker capacity. Many companies, including Hyper Tech, are working on the technology to develop and manufacture low cost SFCLs.

Presently, Hyper Tech is working on a British-government-funded program to make wires and coils for FCLs. “Hyper Tech and our collaborators have the potential to come up with a low cost fault current limiter. Full size distribution voltage SFCLs are scheduled to be on the grid in the next two years or less.”

In the last couple of years, there has been interest in lightweight generators for offshore wind power. “We have had great interest from Asia, Europe, and the US,” says Tomsic. “The potential MgB₂ wire market for offshore wind could be greater than the MRI wire market.”

Since 2003, the company has grown from 8 to 27 employees, with 16 employees involved with MgB₂ superconductor wire activity. The company has also increased its revenue from approximately \$1 million to \$5.4 million, with \$3 million from work on MgB₂ superconductor wires and coils.

Even though MgB₂ wire is not yet employed in aircraft or wind turbines, it promises a bright future with lighter, greener, low-cost technologies. ❖

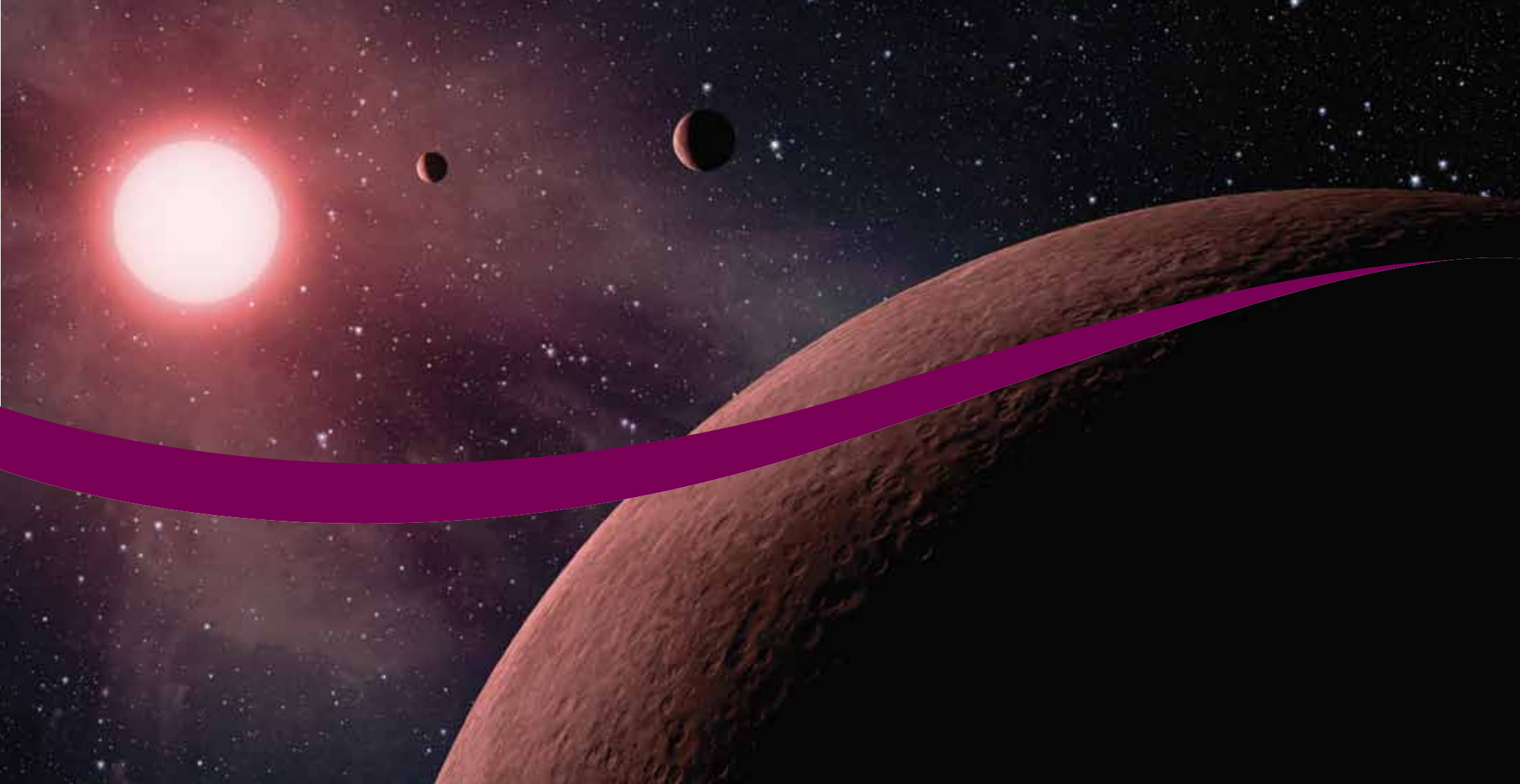




Transportation

From long trips to daily commutes, NASA technologies are often a part of how we travel. These innovations raise fuel efficiency, reduce environmental impact, and ensure the safety of vehicles in the sky, crossing the sea, or on the roads and rails. The spinoffs featured in this section:

- Prevent Train Delays
- Automate Vehicle Maintenance
- Advance Rotorcraft Design Testing
- Improve Flight Safety
- Advance Heat Management Materials for Vehicles
- Pinpoint Rotorcraft Troubles



Anti-Icing Formulas Prevent Train Delays

NASA Technology

In the winter of 2009, Washington, DC, workers faced the prospect of a difficult commute due to record-setting snowfalls. But thousands of the city's Metrorail riders found the public transportation system fully functional, thanks in part to a NASA technology invented years before.

Just like trains, an airplane must be snow- and ice-free to ensure safe travel. Traditionally, fluids containing a compound called ethylene glycol have been used to inhibit ice on planes. In 1992, however, the US Air Force banned its purchase of this ingredient due to toxicity concerns. According to the Centers for Disease Control, exposure to large amounts of ethylene glycol through air or water can damage the kidneys, nervous system, lungs, and heart. Urine samples from airport deicing workers have contained traces of the substance.

At the time of the Air Force's ban, Robert Lockyer was working at NASA's Ames Research Center in the Advanced Composites Model Development Branch, where he says "we decided to pick up the gauntlet and began researching existing fluid compositions and the processes used in deicing aircraft."

Along with Lockyer, in 1997 Ames researchers Leonard Haslim and John Zuk devised a nontoxic, biodegradable, and cost effective substitute for ethylene glycol. When applied to a dry surface before a snow or ice event, the solution prevented ice from forming a bond with the surface. This made it easy to wipe away any accumulation.

Technology Transfer

A couple of years after Ames patented its innovation, a lab manager at Canton, Ohio-based Midwest Industrial Supply Inc. read about the formula being used on military aircraft. Thinking that it would greatly enhance existing anti-icing technology, the manager approached Ames to license the technology for commercial use. By 1999,

Midwest began blending the NASA technology into an existing anti-icing agent, and also created a new product.

Benefits

Since 1975, Midwest has been a provider of Earth-conscious solutions in the quarry, mining, construction, iron/steel, and rail/mass transit industries. Over the last 5 years, the company has appeared several times on *Inc.* magazine's list of America's Fastest Growing Private Companies.

One of the company's original products, Ice Free Switch (IFS), remains successful today. IFS is a fluid that maintains railroad track switch operation in snow or ice. Railroad track switches transfer trains and equipment on and off of varying tracks. Shannon Noble, a sales manager at the company, says every track generally has at least two, and train yards usually have dozens of track switches. If snow or ice builds up on a component of a switch, a train has to stop until the buildup is cleared, causing delays and backlogs.

"It's very important that switches operate flawlessly, quickly, and easily because there's a lot of activity on them," says Noble. "Even a little ice can prevent a switch from properly throwing."

By incorporating NASA technology into IFS, Midwest improved the product in two important ways: The fluid is both easier to apply and more likely to remain on vertical surfaces. "Years ago, when you tried to get a formula to stay on the surface at very cold temperatures, it became too thick and hard to apply. If it doesn't stay in place, it gives little residual value," describes Noble.

IFS disrupts the freezing process of water molecules by placing "gaps" between the molecules. Any precipitation that falls will not turn into ice or build up on the surface of the treated area. Instead, most precipitation melts or becomes a soft-like slush. Due to this characteristic, IFS is known as an anti-icing agent rather than a deicing agent. "When dealing with winter operational issues, one approach is proactive, one is reactive," says Noble. "The

disadvantage with deicing is it requires 5 to 10 times more of a deicing chemical agent than anti-icing would initially require."

Customers across rail markets are using IFS, including large interstate railroads, regional railroads, short-line railroads, mass transit railroads, and industrial plant and factory railroads. The product has also been applied to the walls of train tunnels, on train crossing arms, on the door tracks of boxcars, and in other areas where metal freezes and operation becomes problematic.

After improving IFS, Midwest began focusing on a new anti-icing product designed for the third rail of mass transit train tracks. For certain train systems, the third rail



Railroads use Ice Free Switch, incorporating NASA technology, to stop water from becoming ice on train track switches. This helps to maintain train service during winter weather events.

is the source of electrical power. As Noble explains, “Ice can glaze on the third rail, and if it gets thick enough, the metal contact shoe will lift off the third rail and ride on top of the ice. When that happens, the power supply is disrupted, causing stalled trains.”

To prevent disruption, Midwest’s Zero Gravity Third Rail product, based on the licensed NASA technology, stops moisture from becoming ice on the third rail. The product is automatically applied by a system attached to a train car, with a sensor detecting the location of the third rail. A spray nozzle alternates to the side with the third rail while the train is moving and delivers solution based on the train speed, pressure setting, and nozzle selection. “Every 4th, 5th, or even 10th train can apply the product with assurance that the third rail isn’t going to experience a problem,” says Noble.

By preventing moisture from becoming ice, Zero Gravity Third Rail helps prevent interrupted passenger service. Today, the biggest customers are mass transit authorities in cities like Washington, DC, New York, and Toronto. In 2009, when Washington, DC, had record-setting snowfalls, up to 41 delivery systems were employed on the city’s Metrorail to keep the third rails from freezing. Airports and hospitals have also used the product on passenger trains with a third rail, and steel mills have used it on cranes and other electrical power rails.

Depending on the severity of a winter season, the two products provide Midwest with an increase in revenue between \$300,000 and \$600,000 a year. In addition, the products have helped to prevent seasonal layoffs during Midwest’s typically slower winter months. For the public, the NASA-derived innovations are helping provide reliable train service, as well as supporting a cleaner environment and improved health. When used as directed, they are noncorrosive, nonconductive, nonflammable, and biodegradable—providing safe anti-icing and deicing alternatives for commuters, workers, and the environment alike. ❖



Image courtesy of Gary Pancavage

Shuttle Repair Tools Automate Vehicle Maintenance

NASA Technology

Successfully building, flying, and maintaining the space shuttles was an immensely complex job that required a high level of detailed, precise engineering. After each shuttle landed, it entered a maintenance, repair, and overhaul (MRO) phase. Each system was thoroughly checked and tested, and worn or damaged parts replaced, before the shuttle was rolled out for its next mission.



Each space shuttle required a full maintenance, repair, and overhaul (MRO) phase before flying its next mission.

During the MRO period, workers needed to record exactly what needed replacing and why, as well as follow precise guidelines and procedures in making their repairs. That meant traceability, and with it lots of paperwork.

In 2007, the number of reports generated during electrical system repairs was getting out of hand—placing among the top three systems in terms of paperwork volume. Repair specialists at Kennedy Space Center were unhappy spending so much time at a desk and so little time actually working on the shuttle. “Engineers weren’t spending their time doing technical work,” says Joseph Schuh, an electrical engineer at Kennedy. “Instead, they were busy with repetitive, time-consuming processes that, while important in their own right, provided a low return on time invested.”

The strain of such inefficiency was bad enough that slow electrical repairs jeopardized rollout on several occasions. Knowing there had to be a way to streamline operations, Kennedy asked Martin Belson, a project manager with 30 years experience as an aerospace contractor, to co-lead a team in developing software that would reduce the effort required to document shuttle repairs. The result was System Maintenance Automated Repair Tasks (SMART) software.

SMART is a tool for aggregating and applying information on every aspect of repairs—from procedures and instructions to a vehicle’s troubleshooting history. Drawing on that data, SMART largely automates the processes of generating repair instructions and post-repair paperwork. In the case of the space shuttle, this meant that SMART had 30 years’ worth of operations that it could apply to ongoing maintenance work.

According to Schuh, “SMART standardized and streamlined many shuttle repair processes, saving time and money while increasing safety and the quality of repairs.” Maintenance technicians and engineers now had a tool that kept them in the field, and because SMART is capable of continually evolving, each time an engineer put it to use, it would enrich the Agency-wide knowledge

In a test conducted by NASA, SMART cut repair times by an average of 45 percent.

base. “If an engineer sees something in the work environment that they could improve—a repair process or a procedure—SMART can incorporate that data for use in future operations,” says Belson.

Technology Transfer

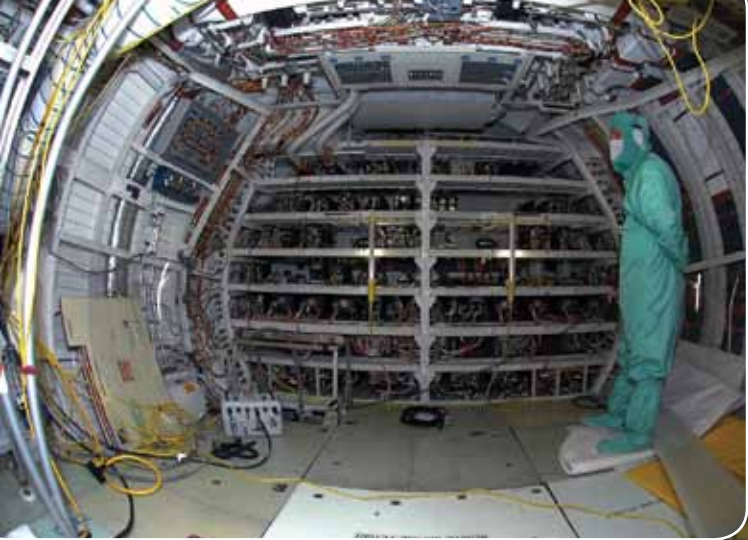
Knowing that the Space Shuttle Program would be ending in several years, Belson decided in 2007 to start planning for life after NASA. He spent his spare time building a business, eventually incorporated as Orlando, Florida-based Diversified Industries (DI) CS&I Inc., with the long-term goal of applying the expertise he gained at NASA to commercial products.

In 2010 Belson retired from NASA, and DI was accepted into the University of Central Florida’s Business Incubator Program. Belson then reached out to Kennedy’s Technology Transfer Office to discuss moving NASA’s SMART software into the private sector, which he says was met with great encouragement.

NASA filed a patent for SMART in 2007, and in 2011 it granted DI a license on the product. Now licensed, and armed with his intimate knowledge of the program, Belson adapted the software for general aviation, including commercial and military markets.

Benefits

SMART is primarily a discrepancy resolution and unplanned maintenance tool that automates many of the steps required to determine the correct action for a specific repair. The software draws on a preapproved library of repair procedures to guide technicians, providing them with a decision tree that lists a sequence of predefined actions, tools, parts, and materials appropriate for a given problem.



Above: Before SMART, repairs to the shuttle's electrical system were taking too much time and generating an enormous amount of paperwork—on several occasions jeopardizing the MRO schedule. The benefits offered by the software can make an immediate impact in commercial and military aviation markets. Right: The space shuttle during its MRO phase.



Belson says that a typical commercial airplane flies for 5–6 years before it enters its MRO phase. At that point, the entire craft is inspected in great detail, with many of its components being repaired or entirely replaced before the airplane is rolled out again. While roughly 60 percent of the routine maintenance can be anticipated well ahead of time, about 40 percent of problems aren't known until the systems and components are inspected and tested.

DI targets that unpredictable segment of repairs with SMART, emphasizing the improvements in work times that it can offer in both simple and complex environments. In a test conducted by NASA—requiring five certified shuttle technicians of varying skill levels and experience to make four different kinds of repairs, both with and without the help of SMART—the software cut repair disposition times by an average of 45 percent.

Belson's modifications to SMART allow it to fit within existing MRO infrastructures. Just as the soft-

ware incorporated 30 years of shuttle repairs for NASA, SMART can quickly adapt to the technical standards of various organizations and markets, such as commercial airlines, aerospace vehicles, industrial machinery, ships, and military ground vehicles, helicopters, and weaponry. Technicians in the field can even run SMART on mobile devices, making its benefits available in any situation.

While the time and paperwork savings may make engineers' lives easier and cut down on costs, Belson is also quick to point out that SMART offers real improvements to safety as well. Since the program can intelligently manage repairs by turning to a rich data set of accepted procedures, it ensures that technicians are applying the right tools for the job at hand, cutting down on mistakes due to inexperience or errors in judgment and decision making.

Belson's proactive approach to technology transfer is paying off for some of his former NASA colleagues.

Thanks to SMART's smooth transition from Agency solution to commercially available software, DI has started hiring engineers who used to work on the shuttle fleet and is putting their expertise in the software to use in the private sector.

Though the Space Shuttle Program has officially ended, entrepreneurs like Belson are demonstrating how the program continues to repay the American public for its investment. "We're excited to be able to take something that taxes paid for and use it to produce a quality product," he says. "This is an area where commercial airlines are in pain. We can offer them a solution that saves them money and introduces greater safety for the general public." ♦

Pressure-Sensitive Paints Advance Rotorcraft Design Testing

NASA Technology

The rotors of certain helicopters can spin at speeds as high as 500 revolutions per minute. As the blades slice through the air, they flex, moving into the wind and back out, experiencing pressure changes on the order of thousands of times a second and even higher.

All of this makes acquiring a true understanding of rotorcraft aerodynamics a difficult task. A traditional means of acquiring aerodynamic data is to conduct wind tunnel tests using a vehicle model outfitted with pressure taps and other sensors. These sensors add significant costs to wind tunnel testing while only providing measurements at discrete locations on the model's surface. In addition, standard sensor solutions do not work for pulling data from a rotor in motion.

"Typical static pressure instrumentation can't handle that," explains Neal Watkins, electronics engineer in Langley Research Center's Advanced Sensing and Optical Measurement Branch. "There are dynamic pressure taps, but your costs go up by a factor of five to ten if you use those. In addition, recovery of the pressure tap readings is accomplished through slip rings, which allow only a limited amount of sensors and can require significant maintenance throughout a typical rotor test."

One alternative to sensor-based wind tunnel testing is pressure sensitive paint (PSP). A coating of a specialized paint containing luminescent material is applied to the model. When exposed to an LED or laser light source, the material glows. The glowing material tends to be reactive to oxygen, explains Watkins, which causes the glow to diminish. The more oxygen that is present (or the more air present, since oxygen exists in a fixed proportion in air), the less the painted surface glows. Imaged with a camera, the areas experiencing greater air pressure show up darker than areas of less pressure.

"The paint allows for a global pressure map as opposed to specific points," says Watkins. With PSP, each pixel

recorded by the camera becomes an optical pressure tap. "Instead of having 100 or 200 pressure taps, you can have in theory several million—up to whatever the resolution of your camera is." Watkins explains that typical wind tunnel testing requires two models: one with very little instrumentation, and a pressure model with a significant amount of sensors applied. "If you can make all of your measurements on one model with PSP, you've decreased your model costs by at least a factor of two and preferably your testing costs by about that much," he says.

PSP technology has been around for almost 20 years, but a PSP solution for gathering instantaneous dynamic pressure data from surfaces moving at high speeds—such as rotor blades—was not available until a NASA partnership led to a game-changing innovation.

Technology Transfer

Innovative Scientific Solutions Inc. (ISSI) of Dayton, Ohio, is the world's primary commercial supplier of PSP technology. Their PSP products have been in use at Langley, Ames Research Center, and Glenn Research Center.

"We have worked closely with NASA and the Air Force Arnold Engineering Development Center over the years to develop PSP technology into a production tool that can be used in wind tunnels," says Jim Crafton, Senior Research Engineer for ISSI. Through the Small Business Innovation Research (SBIR) program, the company collaborated with Langley to develop a new kind of PSP data acquisition system that uses Fast PSP. Taking advantage of advances in laser and camera technology, ISSI's Fast PSP can collect at least 1,000 measurements in the same time that conventional PSP can collect 1, allowing it to capture pressure data from the highly dynamic surfaces, such as those of rotor blades and propellers.

"The opportunity to take our ideas and work with NASA to refine them has allowed us to move the technology ahead quickly," Crafton says. "Commercially, it is going to be a real success."

Benefits

ISSI has already translated its SBIR-developed Fast PSP into about \$200,000 in commercial sales.

"If you have a fixed-wing aircraft under fairly steady cruise conditions, then slower PSPs are just fine," says Grant McMillan, ISSI's head of business development. "But as soon as you have something slender and dynamic like a helicopter rotor that is twisting and turning and flapping, those pressure patterns are changing potentially thousands of times a second. That's when you need Fast PSP."

Fast PSP has garnered interest from customers working with helicopter rotors, propellers, wind turbines, and acoustic noise research. For Watkins, the benefits of the innovation are already apparent. Tests at the 14x22 wind tunnel and the Rotor Test Cell at Langley showed the Fast PSP was able to reveal the changes in pressure on a single blade as it rotated around a helicopter.

"We were able to see vortexes shedding off the blade," Watkins says. "Even with discrete pressure taps, you are not going to see a lot of this unless the taps are placed in the correct locations. It's answering a lot of questions." Watkins says the ability to capture this kind of data can influence future rotorcraft to improve performance and allow for radical departures from typical designs.

"It's a revolutionary evolution of the technology," says Crafton.

Both ISSI and NASA are working toward applying PSP technology to actual flight tests, which could unveil a whole new range of data for improving aviation.

"We ended up with two things—a measurement capability that enables NASA to do its work, and a commercial product we can sell worldwide," says McMillan. "It's a win-win from our perspective." ♦

“The opportunity to take our ideas and work with NASA to refine them has allowed us to move the technology ahead quickly.”

—Jim Crafton, ISSI Inc.



ISSI's Fast PSP, seen here in Langley Research Center wind tunnel tests on a helicopter model, enables the collection of pressure data from rotorcraft—data that is costly to acquire through traditional sensors and not attainable through standard pressure sensitive paint solutions. For a deeper look at NASA's work with pressure sensitive paints, scan this code.



Speech Recognition Interfaces Improve Flight Safety

NASA Technology

“Alpha, Golf, November, Echo, Zulu.”
“Sierra, Alpha, Golf, Echo, Sierra.”
“Lima, Hotel, Yankee.”

It looks like some strange word game, but the combinations of words above actually communicate the first three points of a flight plan from Albany, New York to Florence, South Carolina. Spoken by air traffic controllers and pilots, the aviation industry’s standard International Civil Aviation Organization phonetic alphabet uses words to represent letters. The first letter of each word in the series is combined to spell waypoints, or reference points, used in flight navigation. The first waypoint above is AGNEZ (alpha for A, golf for G, etc.). The second is SAGES, and the third is LHY.

For pilots of general aviation aircraft, the traditional method of entering the letters of each waypoint into a GPS device is a time-consuming process. For each of the 16 waypoints required for the complete flight plan from Albany to Florence, the pilot uses a knob to scroll

through each letter of the alphabet. It takes approximately 5 minutes of the pilot’s focused attention to complete this particular plan.

Entering such a long flight plan into a GPS can pose a safety hazard because it can take the pilot’s attention from other critical tasks like scanning gauges or avoiding other aircraft. For more than five decades, NASA has supported research and development in aviation safety, including through its Vehicle Systems Safety Technology (VSST) program, which works to advance safer and more capable flight decks (cockpits) in aircraft.

Randy Bailey, a lead aerospace engineer in the VSST program at Langley Research Center, says the technology in cockpits is directly related to flight safety. For example, “GPS navigation systems are wonderful as far as improving a pilot’s ability to navigate, but if you can find ways to reduce the draw of the pilot’s attention into the cockpit while using the GPS, it could potentially improve safety,” he says.

“If you can find ways to reduce the draw of the pilot’s attention into the cockpit while using the GPS, it could potentially improve safety.”

—Randy Bailey, Langley Research Center

Scott Merritt, an accomplished multi-engine pilot, agrees with Bailey. He was becoming frustrated using GPS while flying his private plane to favorite destinations, he says. “I was spending all my time twisting knobs instead of looking outside and flying the airplane. I thought, ‘There’s got to be a better way to do this.’”

Technology Transfer

Merritt began investigating the feasibility of using a speech recognition interface to speak waypoints into an airplane’s GPS, rather than twisting knobs to arrive at letters. After working with professors at Rensselaer Polytechnic Institute in Troy, New York, Merritt established the beginnings of a business and connected with NASA’s Aviation Safety Program.

By 2005, Merritt founded Pragmasoft Inc. (now VoiceFlight Systems LLC) in Troy, New York, and received a Small Business Innovative Research (SBIR) contract from Langley to demonstrate the effectiveness of using speech recognition technology to enter the waypoints of a flight plan into a GPS.

“It was basically for an interface for a Garmin GPS, which is a very popular system in general aviation,” says Bailey. “VoiceFlight’s approach seemed to have some advantages over what we had been doing at NASA, and it provided an interesting way to move the technology into the commercial market.”

The two main hurdles were to create a speech recognition system and to design that system to interact with the GPS. “We hammered those out through the SBIR,” says Merritt. Afterward, Langley performed flight tests of the technology on NASA aircraft.



With help from a NASA contract, VoiceFlight Systems LLC developed a speech recognition interface for Garmin GPS units (like the one shown here). The interface enables general aviation pilots to enter destination points through speech rather than by hand.

Benefits

In 2009, VoiceFlight's technology became the first Federal Aviation Administration (FAA)-certified speech recognition product for use in civilian aircraft. When Garmin upgraded its 430 and 530 GPS units with a Wide Area Augmentation System (WAAS) capability to improve position accuracy, VoiceFlight obtained a certification so the technology could be used with the 430W and 530W units (the W stands for WAAS). Merritt says the NASA SBIR was instrumental in attracting the investment capital that allowed the company to pursue certification and hire additional staff.

In 2011, VoiceFlight launched and started marketing its WAAS-enabled VSF101 product. Now available

for general aviation aircraft of less than 6,000 pounds, the devices are currently in use by pilots flying the Piper Arrow, Beechcraft Baron, and even the high-performance FJ-4 Fury.

Once installed, a pilot simply presses a button on the yoke (the aircraft's control column), and speaks a command to enter a waypoint, edit a flight plan, erase a plan, enter direct-to destinations, or enter Victor airways. (Victor airways expand to 5 or 10 waypoints, and are similar to using the name of one highway rather than using the names of all the cities along a route.)

Merritt finds the VSF101 makes it easier for a pilot to use GPS, whether in flight or on the ground. Pilots can enter waypoints up to 10 times faster than a pilot using

control knobs, and can keep their attention on the sky. Aside from safety, the technology saves time—and as a result could also save fuel. For example, Merritt estimates that if a pilot spends five minutes on the runway entering a flight plan after receiving clearance to depart, the aircraft would burn about a gallon of fuel. "That's a lot of fuel for a small aircraft. With VoiceFlight, the plan can be entered in 30 seconds," he says. In the future, Merritt aims to adapt the system for larger aircraft.

According to Bailey, VoiceFlight's technology is a prime example of research and technology development that can make a real difference in aviation safety. "Unless you can transition it out into a commercial product, then all that research and development will not affect safety. The important thing is that you need to be able to transition the technology—just like VoiceFlight has done." ❖

VoiceFlight® is a registered trademark of VoiceFlight Systems LLC.
Garmin® is a registered trademark of Garmin Ltd.



Polymers Advance Heat Management Materials for Vehicles

NASA Technology

For 6 years prior to the retirement of the Space Shuttle Program, the shuttles carried an onboard repair kit with a tool for emergency use: two tubes of NOAX, or “good goo,” as some people called it. NOAX flew on all 22 flights following the Columbia accident, and was designed to repair damage that occurred on the exterior of the shuttle.

Bill McMahon, a structural materials engineer at Marshall Space Flight Center says NASA needed a solution for the widest range of possible damage to the shuttle’s exterior thermal protection system. “NASA

looked at several options in early 2004 and decided on a sealant. Ultimately, NOAX performed the best and was selected,” he says.

To prove NOAX would work effectively required hundreds of samples manufactured at Marshall and Johnson—and a concerted effort from various NASA field centers. Johnson Space Center provided programmatic leadership, testing, tools, and crew training; Glenn Research Center provided materials analysis; Langley Research Center provided test support and led an effort to perform large patch repairs; Ames Research Center provided additional testing; and Marshall provided further testing and the site of NOAX manufacturing.

Although the sealant never had to be used in an emergency situation, it was tested by astronauts on samples of reinforced carbon-carbon (RCC) during two shuttle missions. (RCC is the thermal material on areas of the shuttle that experience the most heat, such as the nose cone and wing leading edges.) The material handled well on orbit, and tests showed the NOAX patch held up well on RCC.

Technology Transfer

While NASA funded the full-scale development of NOAX, the sealant was actually invented by Alliant Techsystems Inc. (ATK). Under NASA funding, ATK contracted with Starfire Systems Inc., a manufacturer of polymer-to-ceramic technology based in Schenectady, New York, to supply the unique polymer material that was incorporated into NOAX.

Called SMP-10, Starfire’s polymer was designed to convert into a ceramic at high temperatures. McMahon describes, “As it heated above 1,500 °F it would start to

convert over to ceramic. As a ceramic, NOAX could take much higher temperatures, allowing it to seal during the shuttle’s re-entry.”

According to Darren Welson, director of technology at Starfire, SMP-10 was formulated and processed for incorporation into NOAX, which laid the groundwork for Starfire to achieve a repeatable process for a reliable product. “Thanks to our experience working with ATK and NASA, we were able to demonstrate and test SMP-10 for aerospace, military, and commercial applications. The applications have grown and matured as a result of the ATK and NASA work,” he says.

Benefits

In looking for ways to make SMP-10 less expensive for commercial use, Starfire developed StarPCS for high temperature applications on Earth. Today, the company manufactures a family of StarPCS products for lightweight components that need to withstand extreme temperatures. “They share a common chemistry but are different based on the application,” says Welson.

The StarPCS family of products provides benefits for heat management in the military, aerospace, aviation, and automotive markets. According to the company, customers in general aviation are experimenting with StarPCS for various aircraft components.

Al Cornell, director of sales and business development at Starfire, says domestic and foreign auto manufacturers are testing StarPCS for passenger vehicles. “It can be run hotter and require less cooling than metallic counterparts. It also offers weight-saving and performance handling benefits,” he says.

StarPCS formulas are also being tested for heat shields in vehicles with extremely hot engines. According to the company, the material has already been qualified and is going forward for implementation for this application. “The thermal properties allow the material to be a very good insulator in race cars,” finds Cornell. “In this



The nose cone of the Space Shuttle experienced extreme heat during flight. NASA worked with industry to create a sealant to repair damage to such areas while in space.



particular case, the composite can protect the passenger from the hot engine components.”

Specifically, Cornell says StarPCS is being used in the test platforms for Formula 1 race cars. The teams are currently looking for a new exhaust management design to divert exhaust by routing it through body panels. It would use the aerodynamic suction to pull the gases out of the engine faster and allow a 1–3 percent increase in horsepower. The problem, says Cornell, is that manufacturers have not found a way to do it without burning the carbon fiber body of the vehicle. “It’s a technology race for all the teams to get the same technology in their cars to have the same performance,” he says. “StarPCS could potentially be used for such an application.”

Auto manufacturers outside of racing are also looking for alternative materials for heat management in turbo chargers. Cornell says manufacturers want to make exhaust pipes out of something other than metal so the pipe can withstand higher temperatures. “The higher the temperature bleed, the more efficient the turbo charger,” he says. “This is the same idea as the Formula 1 application to manage an incredible amount of heat.”

Even though NASA no longer uses the innovative solution for space shuttle repairs, the Agency is incorporating SMP-10 into some of the safety components for Orion, NASA’s next multi-purpose crew vehicle. ❖

StarPCS™ is a trademark of Starfire Systems Inc.

Formula 1™ is a trademark of Formula One World Championship Ltd.

Starfire Systems Inc. manufactured a unique polymer for the sealant for the Space Shuttle. A formula incorporating the polymer is now being used in test platforms for a new exhaust management design for Formula 1 race cars.

Wireless Sensors Pinpoint Rotorcraft Troubles

NASA Technology

Helicopters present many advantages over fixed-wing aircraft: they can take off from and land in tight spots, they can move in any direction with relative ease, and they can hover in one area for extended periods of time. But that maneuverability comes with costs.

For example, one persistent issue in helicopter maintenance and operation is that their components are subject to high amounts of wear compared to fixed-wing aircraft. In particular, the rotor drive system that makes flight possible undergoes heavy vibration during routine performance, slowly degrading components in a way that can cause failures if left unmonitored. The level of attention required to ensure flight safety makes helicopters very expensive to maintain.

As a part of NASA's Fundamental Aeronautics Program, the Subsonic Rotary Wing Project seeks to advance knowledge about and improve prediction capabilities for rotorcraft, with the aim of developing technology that will meet future civilian requirements like higher efficiency and lower noise flights. One of the program's goals is to improve technology to detect and assess the health of critical components in rotorcraft drive systems.

Technology Transfer

To improve its diagnostic technology, Glenn Research Center awarded multiple Small Business Innovation Research (SBIR) contracts to Tucson, Arizona-based Ridgetop Group Inc. Ridgetop has been providing technology and services in the predictive diagnostics field for many years, says Doug Goodman, CEO of the company.

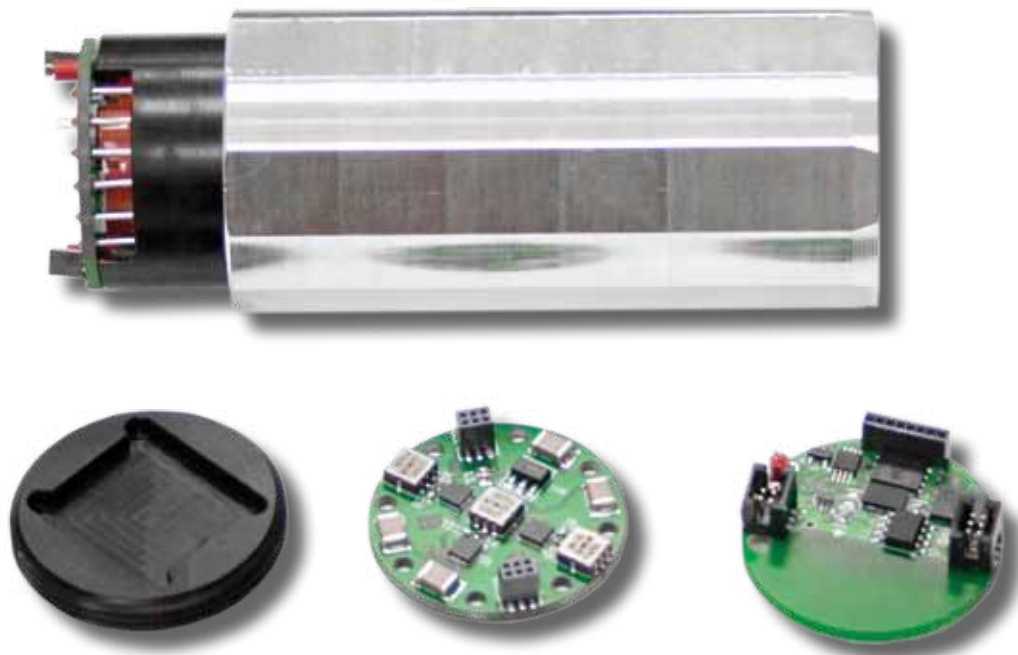
"What we've found over time is that there are often precursor signatures of failure that can be extracted from the system being observed. These signatures, when processed by algorithms, allow for an accurate prediction of how much useful life is remaining."

Having signatures derived from the performance of equipment not only improves diagnostic capabilities but can change the way rotorcraft are maintained. Goodman says such data supports "condition-based maintenance" strategies that focus maintenance on demonstrated need, not on an arbitrary number of scheduled flight hours between service intervals.

In the case of rotorcraft transmissions, what has traditionally caused problems in finding such precursor signals is the difficulty in getting high-resolution data from certain components in the transmission as it runs. Conventional sensors are placed on the transmission's external housing, where general mechanical noise interferes with data collection and keeps the sensor from acquiring a detailed look at components such as gear teeth buried deep in the gearbox.

Ridgetop proposed the use of wireless microelectromechanical systems (MEMS) sensors—that is, microelectronics—which can be deployed in rotorcraft transmissions themselves. "It is believed that fault detection capabilities will increase if sensors are mounted directly on the components of interest," says David Lewicki, who works in the Tribology and Mechanical Components Branch at Glenn and is collaborating with Ridgetop on its SBIR project. "Current rotorcraft transmission sensors have limited fault detection capabilities because of their location."

Through the SBIR program, Ridgetop demonstrated the feasibility of the concept, built the sensor itself, known as the MEMS accelerometer, and tested it on rotorcraft transmission test stands both in-house and at Glenn. Goodman says the NASA work enabled the company to get an unprecedented look at how those internal components wear. "Our sensors get right up close and



Ridgetop's wireless MEMS accelerometer can gather quality data from spots inaccessible to the sensors typically employed today.

personal with those gear teeth. The measurement is taken right where the action is, giving us the resolution that we need to detect faults.”

Benefits

Goodman says that the combination of the MEMS accelerometer’s small footprint and its sensitivity is what enables Ridgetop to acquire such high resolution data. Because the sensor is wireless, less weight and no additional space are needed to transfer and process the data being collected. “You always want solutions that add as little weight as possible for the functionality that is being added,” says Goodman.

Signature-related data collected by the sensors are sent wirelessly to a hub, where they are processed using an algorithm to create noise signatures, which can then be compared to a fault dictionary—or a resource of known problems and the vibrations associated with them—in order to diagnose any flaws in the transmission. “It allows a much improved ability to detect not only the precise cause of the degradation but where that degradation is occurring,” says Goodman.

Anomalous behavior of a rotorcraft’s gear train can thus be detected and interpreted very quickly. Goodman points out that in the field, this could allow the pilot to get the helicopter in for service as soon as possible, land the vehicle if a critical situation develops, or even take mitigating action against what’s been detected.

Having data on the precise area of concern also obviates much of the diagnostic work traditionally undertaken by mechanics. Currently, when a helicopter is brought in for service, repair crews can encounter trouble trying to reproduce a fault, or they might have only a general idea of where the issue is occurring. Goodman points out that with Ridgetop’s sensor data, helicopter maintenance crews will not need to rely so heavily on the service life estimates for components or spend as much time guessing which parts require attention. “When you land the vehicle and bring in a technician to repair it, you can pinpoint the damage, and you know exactly what needs to be replaced to get it back into the air again,” he says.

Ridgetop’s sensors are highly versatile and can be deployed in a wide variety of settings apart from rotorcraft. Some immediate applications the company hopes to take advantage of include drilling applications in the oil industry, automotive transmissions, and a wide variety of industrial equipment. Goodman envisions “a mesh network” of sensors monitoring all sorts of machines at large complexes. “There are a lot of opportunities to take advantage of this technology in many settings. We’re very excited about it.”

The company cites its work with NASA as a critical part of the MEMS accelerometer’s development. “The missing link, the piece that our NASA collaboration gave us,” says Goodman, “was getting improved, high fidelity signals that could be processed and translated into service actions for maintenance personnel. It’s all about being able to observe the low level signatures, and that’s what NASA’s design does.”

The sensors are now undergoing their final stages of validation testing at Glenn. Following that testing, Ridgetop plans on offering the product commercially in 2012. “In the discussions we’ve had with the platform makers—rotorcraft, oil and gas, and other industry engineers and experts—they estimate big savings,” says Goodman. “Published studies have shown the potential for up to 50 percent reductions in mean time to repair. There is a very strong return on investment with numbers like those.” ❖





Public Safety

For NASA missions, safety is a prime consideration for everyone from ground support to scientists in the lab to the crews on the International Space Station. While working to maximize the safety of its personnel, NASA develops technologies with protective benefits for everyone from pilots to medical workers to sailors on the open ocean. The spinoffs featured in this section:

- Safely Identify Dangerous, Costly Leaks
- Ensure Function, Safety of Aircraft Wiring
- Save Tens of Thousands of Lives
- Ensure Safer Medical Devices
- Aid Emergency Decision Making



Ultrasonic Detectors Safely Identify Dangerous, Costly Leaks

NASA Technology

In 1990, NASA grounded its space shuttle fleet. The reason: leaks detected in the hydrogen fuel systems of the Space Shuttles Atlantis and Columbia. Unless the sources of the leaks could be identified and fixed, the shuttles would not be safe to fly.



In order to scan unsafe or difficult-to-approach areas of the space shuttle for hydrogen leaks, NASA developed a long-range module to enhance a private industry partner's ultrasonic leak detection technology.

To help locate the existing leaks and check for others, Kennedy Space Center engineers used portable ultrasonic detectors to scan the fuel systems.

As a gas or liquid escapes from a leak, the resulting turbulence creates ultrasonic noise, explains Gary Mohr, president of Elmsford, New York-based UE Systems Inc., a long-time leader in ultrasonic detector technologies. "In lay terms, the leak is like a dog whistle, and the detector is like the dog ear." Because the ultrasound emissions from a leak are highly localized, they can be used not only to identify the presence of a leak but also to help pinpoint a leak's location. The NASA engineers employed UE's detectors to examine the shuttle fuel tanks and solid rocket boosters, but encountered difficulty with the devices' limited range—certain areas of the shuttle proved difficult or unsafe to scan up close.

To remedy the problem, the engineers created a long-range attachment for the detectors, similar to "a zoom lens on a camera," Mohr says. "If you are on the ground, and the leak is 50 feet away, the detector would now give you the same impression as if you were only 25 feet away." The enhancement also had the effect of reducing background noise, allowing for a clearer, more precise detection of a leak's location.

Technology Transfer

While the shuttle fleet was soon deemed flightworthy again, UE recognized the potential benefit of the NASA innovation for many ultrasound detection applications. The company licensed the long-range module from Kennedy (*Spinoff* 1998) and began offering it as a component for its Ultraprobe line of commercial ultrasound detectors.

"By the very nature of it, we probably would not have spent the money to develop this technology on our own," says Mohr. "It would have been hard to see the commercial value until it was already developed. NASA developed the technology to address its need, and we licensed it for the potential commercial success."

"NASA's expertise in research and development has allowed us to provide our customers with a value-added solution that has enhanced our technology."

—Gary Mohr, UE Systems Inc.

Benefits

The long-range module has since proven to be a valuable addition to UE's commercial offerings.

"We have maintained the original design since the beginning of the license. It works really well for our customers, and that's what we care about," Mohr says.

UE Systems' detectors play a key role in managing safety, cost, efficiency, and environmental impact across a broad range of industries. In addition to leak detection, the major applications for the technology include ball bearing and mechanical inspection, electrical inspection, and valve testing.

Detecting leaks in factory compressed air systems is perhaps the technology's most valuable use, says Mohr. "Intuitively, from an operating point of view, compressed air seems to be free. It's just air. But in reality, it is the single most expensive utility a plant will have." Almost every plant leaks at least 20 percent of its compressed air, if not 30 or 40, Mohr explains. This represents enormously expensive energy inefficiencies; for an automotive plant, these costs could be in the millions, says Mohr, while a big mining plant could incur losses in the several millions.

Using a UE ultrasound detector with the NASA-developed long-range module, factory inspectors can easily scan compressed air lines, which are typically run overhead, from below.

"It acts as a virtual ladder allowing customers to gather data safely and effectively from the ground," says Mohr.



Coupled with UE's proprietary software, the detector not only locates leaks but can calculate the impact each leak represents, helping companies save costs and reduce their carbon footprint. "If you go through a whole plant, you might determine you have 50 leaks costing you this much in compressed air, this much in electricity," says Mohr.

In the case of ball bearing and mechanical inspection, UE's detectors pick up the ultrasound produced by friction in mechanical components, allowing users to detect subtle changes that may indicate impending failure. In electrical applications, the detectors can scan substations, transformers, and switchgear for costly and potentially dangerous electrical discharge. While infrared cameras are often used to detect the discharge, these cameras do not detect coronas, a common indicator of an electrical "leak," and do not work if the user is out of the line of sight. With the addition of the NASA long-range module, inspectors can survey electrical equipment comprehensively and from a safe distance, identifying discharge through the high-frequency noise the emission produces.

The enhanced functionality and safety offered by UE Systems' NASA technology represents a boon for the company's worldwide customer base, Mohr notes.

"NASA's expertise in research and development has allowed us to provide our customers with a value-added solution that has enhanced our technology," he says. "It's been a great partnership with NASA, sharing with them our expertise and in turn getting to take advantage of theirs. It's definitely been a win-win." ❖

Ultraprobe® is a registered trademark of UE Systems Inc.



Using its licensed NASA technology, UE Systems' detectors allow users to scan for electrical leaks (left) and compressed air leaks (inset) safely and with ease.



Detectors Ensure Function, Safety of Aircraft Wiring

NASA Technology

Pedro Medelius waited patiently in his lab at Kennedy Space Center. He had just received word that a colleague was bringing over a cable from a Space Shuttle solid rocket booster to test Medelius' new invention. Medelius was calm until his colleague arrived—with about 30 other people.

“Talk about testing under pressure,” says Medelius. “There were people there from the Navy, the Air Force, and the Federal Aviation Administration.”

After the group's arrival, Medelius took a deep breath and connected his Standing Wave Reflectometer (SWR) to the cable. He wiggled the cable around, and the display showed a fault (a short or open circuit in wire) about an inch and a half inside the connector on the cable. His

colleague questioned the results, because he had already checked that area on the cable. Medelius used the SWR to check again but got the same result. “That is when we took the cable apart and looked inside,” Medelius says. “Lo and behold, that was exactly where the fault was.”

The impetus for Medelius' new wire inspection technology came about in 1999 when one of the space shuttles lost power due to a fault somewhere in its more than 200 miles of electrical wiring. “The backup circuit was activated and prevented a major dysfunction, but nevertheless, there was a problem with the wiring,” Medelius describes.

Even though technicians used a device called a multimeter to measure the electrical current to find which wire had a fault, it could not pinpoint exactly where on the wire the fault was located. For that, technicians had to visually inspect the wire.

“Sometimes they would have to remove the whole wire assembly and visually inspect every single wire. It was a very tedious operation because the wires are behind cabinets. They go all over the place in the shuttle,” says Medelius. “NASA needed an instrument capable of telling them exactly where the faults were occurring.”

To meet NASA's needs for a highly precise device to inspect electrical power bundles, wires, and connectors, Medelius devised the SWR. “It came down to what was affected when a wire is short circuited or opened,” he says. “We worked out a few equations based on physical principles.” The SWR proved very sensitive, and the technology was patented.

A NASA engineer tests wiring in the rear engine compartment of Space Shuttle Discovery. To pinpoint the location of faulty wires, a NASA contractor invented the Standing Wave Reflectometer.

Technology Transfer

Kennedy made the technology available for commercial licensing. Corona, California-based Eclipse International was immediately intrigued by the technology, due in part to the 1996 explosion and crash of TWA flight 800. Eclipse had worked with the White House-led Air Transport Safety and Rulemaking Committee on the investigation of the accident, which, according to the National Transportation Safety Board, was most likely caused by a short circuit in its wiring. Chris Teal, marketing director at the company, says, “We were trying to find a technology to test the wiring without being intrusive or destructive.”

After obtaining an exclusive license for the SWR, Eclipse refined the SWR for commercial use by incorporating an easy-to-use keypad and making the device more rugged. “The first version was hard plastic that shattered if you dropped it. We made it tough, so none of the connectors or casing would break if it fell,” says Teal.

Benefits

Originally featured in *Spinoff* 2005, Eclipse has had many years of success with the NASA technology, which is now in widespread use by the military and commercial airlines, among others. As a small business that started with just 6 employees, Eclipse now employs approximately 30 people.

Called ESP+, Eclipse's spinoff technology takes less than 5 seconds to locate a fault. “It's the fastest and easiest to use hand-held wire tester available today,” says Teal.

Available as a standalone piece of equipment or as part of Eclipse's Electrical Component Analysis System (ECAS), ESP+ provides step-by-step instructions to guide a user on the type and location of an electrical wiring fault.

“Mechanics who have never touched wiring can now fix it,” says Teal. “All they have to do is start the test, and in a matter of seconds, it will tell them where the fault is within



“It is comforting to know that what we did helped to make flight safer.”

—Pedro Medelius, Kennedy Space Center

18 inches. Electrical checks that used to take two folks 8 hours can now be done in 45 minutes with one person.”

According to the company, the US Army purchased 300 ESP+ devices to include in their helicopter battle damage and assessment repair kits. In addition, one of the military programs using ECAS reported a savings of \$2.19 million on development costs.

ESP+ is currently employed throughout the United States and abroad to check the health of wiring in commercial and military aircraft, submarines, sea vessels, and even presidential helicopters. A sampling of commercial customers includes Sikorsky, Boeing, Raytheon, Qantas Airlines, United Airlines, Continental Airlines, American Airlines, and FedEx. Military customers include the United States Navy, the United States Marine Corps, Australian Defense, the South Korean Army, the Spanish Navy, and Portuguese Air Forces.

In the future, Eclypse plans to promote its technology for routine maintenance of system wiring. “Our core technology and philosophy is to handle the electrical from the date it is put in service to the date of its retirement,” says Teal. The company also aims to attract the interest of networking and mainframe distribution entities and similar complex electrical industries to help ensure normal operations for their electrical wiring.

Today, Medelius says he appreciates seeing how NASA technology helps not only NASA, but everybody—even himself. “I fly a lot, and it is comforting to know that what we did helped to make flight safer. It’s a good feeling, not only as an engineering accomplishment, but from a personal standpoint.” ❖

Eclypse International licensed NASA technology and then commercialized the ESP+ to identify the location of a fault down the path of wiring on aircraft, submarines, sea vessels, and helicopters. Here, a HH-60G Air Force Special Operations Command intercommunications subsystem is tested.



Emergency Systems Save Tens of Thousands of Lives

NASA Technology

Shortly before midnight on September 21st, 2010, the small fishing boat *Ebby Luz* started taking on water. In immediate danger and 8 miles from the shore, its crew activated an emergency beacon that began transmitting their distress signal, identity, and location. Within minutes, the Coast Guard was notified and launched a helicopter to the coordinates received from the alert. Even though the vessel had already sunk by the time help arrived, and despite it being pitch dark, the rescuers were able to locate and save both crewmembers from the water.

These two sailors were among the 295 people in the United States saved through the NASA-developed Search and Rescue Satellite Aided Tracking (SARSAT) system in 2010. Since SARSAT was introduced in 1982, nearly 7,000 have been saved in the United States alone. Worldwide—the international effort is known as Cospas-Sarsat—over 30,000 people have been rescued as a result of these emergency beacons and the satellite/ground-station system they rely on.

SARSAT had its beginnings in a tragic 1972 plane crash in Alaska that resulted in the deaths of two US congressmen. The plane's disappearance sparked a 39 day search over 300,000 square miles, but to this day the spot of the crash remains undiscovered.

At the time, emergency communications for crashed or stranded airplanes were limited to beacons that transmitted a signal at 121.5 MHz, which is in the middle of an aircraft's radio band. Pilots worldwide left their plane's radio tuned to that frequency when not in use, in the hopes that distress signals might be picked up by someone flying overhead.

Though better than nothing, there were critical problems with this system, explains David Affens, manager of the Search and Rescue Mission Office located at Goddard Space Flight Center. "Even though there are many airplanes flying at any given time, the territory they

actually cover is sparse. And even when a pilot did pick up a signal, those early beacons gave no intelligence—no location or identification. It was just a simple tone that indicated trouble," he says.

Following the Alaskan plane crash, Congress directed that an effort be made to find a better technology for locating the sources of distress calls—an effort that NASA led. In the latter half of the 1970s, NASA and several other international organizations experimented with the use of satellites to detect and locate emergency beacons.

Satellite tracking of distress signals offered several advantages over the original "monitoring the radio" system. Most importantly, relatively few satellites could provide near-global coverage, ensuring that many more distress calls were heard. And because of the motion of the orbiting satellite, the signal frequency changes as the satellite passes the location of the beacon (this is known as the Doppler effect), meaning that even a simple tone could now be processed to provide location data for rescuers. "You can do some interesting Doppler calculations with the signal that gets captured," says Affens. "The measurements we make from the change in frequency as a function of the satellite's position give us a pretty good idea of the signal's location."

Following testing, the United States, Canada, France, and the Soviet Union signed an agreement in 1979 to develop what would become Cospas-Sarsat, an internationally recognized configuration of beacons, satellites, and ground stations—as well as the technology behind each of these components—to receive and process distress signals.

SARSAT, the part of the system operated in the United States by the National Oceanic and Atmospheric Administration (NOAA), began official operations in 1982. Within days, a downed aircraft was detected and its passengers rescued using the system, which Affens says was a confirmation of SARSAT's viability and importance. Following a set of international agreements—including commitments to run the system for many years, as well as



A 406 MHz personal locator beacon can be registered with search and rescue authorities. Registered beacons send more information to rescuers, helping them find those in distress more quickly.

to make its benefits available to all states on a nondiscriminatory basis—Cospas-Sarsat was declared operational in 1985.

Technology Transfer

The first generation of the technology used satellites in low Earth orbits (LEO) to detect signals transmitted at the same 121.5 MHz frequency used by airplanes, which were repeated by the spacecraft to designated ground stations for processing. For the satellite component of the system, NASA could utilize spacecraft that had other primary missions. But in order to establish the beacon

and ground station components, NASA enlisted the help of commercial entities, including Techno-Sciences Inc. (TSi), of Beltsville, Maryland, which won multiple contracts with Goddard to create the first operational ground stations.

This first system provided near global coverage for emergency beacons, but it still had limitations. Because the LEO satellites in use move at high speeds relative to the distress beacon on the surface, a stranded person has at most a 15-minute window to be heard by a passing satellite. Additionally, the orbits of present satellites equipped to handle distress signals are spaced apart such that someone in distress might only encounter one or two satellites over the course of several hours—potentially creating long delays before the transmission is picked up.

The system has been augmented over the years to include geostationary satellites—or satellites whose orbit matches the rotation of the Earth, making them appear stationary from the ground—and an improved beacon signal, both developed at NASA. While these satellites cannot transmit Doppler data, they can alert rescuers that a beacon has been activated. They also have the capability to receive signals transmitted at 406 MHz, a frequency that allows the beacon to send digitally encoded information, such as a GPS location and personal identification, giving rescuers greater awareness of the situation.

Despite the aid of geostationary satellites, however, the potential delays in signal reception remained. To resolve this weakness, NASA spearheaded an effort to create what became the Distress Alerting Satellite System (DASS). DASS enhances the existing system by incorporating search and rescue instruments on global positioning system (GPS) satellites. Currently, there are more than two dozen satellites in the GPS constellation in mid-Earth orbit (MEO), and they are distributed such that every point on the Earth is visible to at least four satellites at any given time.

DASS is designed to reduce the time from beacon activation to rescue by acquiring as much data as possible.

Whenever a distress signal is relayed by multiple MEO satellites to a ground station, time and frequency measurements are made and combined to calculate the beacon's location. "With just one burst of the beacon, you get two different data sets from each of at least four satellites," explains Affens. "Each one alone is sufficient to give you an accurate location. And with each additional burst you get even more data to refine the location further."

The high quantity of data received means that rescuers have the luxury of being picky about the quality of the data they rely on. With so much information available, the system can simply throw out any bad data, improving the precision of calculations.

As each generation of SARSAT has been developed by NASA, commercial partners like TSi have contributed hardware and technology to support development and ongoing operations. TSi designed and installed the DASS prototype ground station for the Search and Rescue Laboratory at Goddard, and the company was selected by NOAA in 2009 to build the first DASS ground station capable of becoming operational in the United States, which will be installed in Hawaii.

Gilmer Blankenship, chairman of TSi and a professor at the University of Maryland College Park, says that these partnerships help put TSi in position to compete in the global market for search and rescue components.



Thanks to Cospas-Sarsat, not only can rescuers be dispatched within minutes of receiving a signal, but they are deployed knowing exactly where they need to go. "We are taking the 'search' out of 'search and rescue,'" says Dave Affens of Goddard Space Flight Center.



“I’ve **met** some of **the 30,000 people**
who have **been saved** by this **system** . . .

Without **NASA**, they wouldn’t **be here**
with **us today.**”

—Gilmer Blankenship, Techno-Sciences Inc.



The Coast Guard runs a water rescue training exercise off the coast of New Jersey. “People often take for granted the risks that rescuers take on,” says Affens. “Anything we can do to minimize the area they have to cover, and the time they have to search, is better for them.” For a deeper look into NASA’s Search and Rescue Mission Office, scan this code.

“We’ve now built stations in the United States, India, Spain, Norway, and about 15 other countries for a wide range of organizations. For us, this was a direct spinoff of NASA technology that turned into a commercial business, which we still participate in today,” he says.

Benefits

The long reach and overall effectiveness of the Cospas-Sarsat system was demonstrated in 2010 through the high profile rescue of Abby Sunderland. Sunderland, 16 years old at the time, was attempting to become the youngest person ever to sail solo around the world. When her boat was severely damaged in a storm in the middle of the Indian Ocean, Sunderland found herself stranded in one of the most remote parts of the globe: she was 2,000 miles from the nearest land and in a region where few other vessels pass by.

Before leaving, Sunderland had been given a personal beacon by one of NASA’s commercial partners, which was now her only chance to call for help. Less than 10 minutes after she activated the device, the signal was received, Sunderland’s identity and location were processed, her parents were contacted, and authorities began making arrangements for her rescue. A French fishing vessel, more than 400 miles away at the time, was directed to Sunderland’s precise location and picked her up. “I don’t think it could have been done any faster,” she says.

Because she was an adventurer looking to break a world record, Sunderland’s rescue brought a lot of attention to Cospas-Sarsat. Many other adventurers, whether pilots, sailors, or those climbing mountains or hiking in remote terrain, have likewise been rescued from a recreational trip gone awry. Nevertheless, most rescues—on average more than six people per day—involve fishermen, pilots, and others in remote areas who are putting their lives at risk in order to make a living.

“Sunderland is a great example of why you need this system, but the vast majority of those using it are people conducting their everyday business,” says Affens. “We get reports of these rescues weekly, and they are great stories.”

Today, 41 countries participate in the operation and management of Cospas-Sarsat, ready to respond to any one of the over 1 million beacons registered and in



Image courtesy of GizaraArts.com

Abby Sunderland attempted a solo circumnavigation of the world in 2010, hoping to become the youngest person ever to have done so. When her boat was disabled in the south Indian Ocean and her satellite phone was not working, a personal locator beacon became her only chance to receive help.

use worldwide. Between more ground stations—many of which to be built by TSi—and satellites that will be linked, the system will continue to provide a great deal of redundancy, which is a good thing for those receiving and interpreting distress signals.

Blankenship is happy that TSi has had the opportunity to be part of the ongoing project. “This is an example of something NASA does that, while important, is very low

visibility compared to other missions. It might not make the front page, but on the other hand I’ve met some of the 30,000 people who have been saved by this system. And I can tell you that, for them, it’s a very big deal.

“Without NASA, they wouldn’t be here with us today.” ❖



Oxygen Assessments Ensure Safer Medical Devices

NASA Technology

Alongside the tragedies that are part of the history of human spaceflight, bittersweet lessons have been learned. These lessons have not only taught us about the extreme requirements of space travel; they have taught us how to live more safely on Earth.

When the first Apollo mission to carry humans to the Moon ended in a fire that took the lives of three astronauts, NASA undertook a thorough investigation. The final accident report identified a lack of understanding concerning the dangers posed by the use of pure oxygen inside a spacecraft.

Fire requires three things: fuel, oxygen, and a source of ignition. While it may sound like a simple formula, starting a fire can become quite complicated because the fuel, sources of ignition, and amounts of oxygen vary dramatically from place to place. Consider the fact that some materials are not flammable in air at all, which has approximately 21 percent oxygen, but become flammable in a slightly higher oxygen environment composed of just 23 percent oxygen.

Joel Stoltzfus, an engineer at Johnson Space Center's White Sands Test Facility (WSTF), knows just how hazardous an oxygen-rich environment can be. "The general problem is that, as oxygen concentration and pressure increase, the fire hazard increases. As you increase the pressure, more oxygen is available, and things burn better," he explains.

Since before the Apollo program, NASA has studied the flammability and ignitability of materials. The Agency has tested everything from materials designed for use inside oxygen-rich environments like spacecraft to the materials used on the tanks that stored liquid oxygen for the space shuttle main engines. Over the past five decades, NASA has become a go-to source for expertise about materials, flammability, and oxygen-rich or high-pressure oxygen environments.

Stoltzfus describes how, in the early 1980s, WSTF developed a process to determine the oxygen fire hazard associated with a component or system. "We ended up capturing the thinking in a way that could be explained and taught," he says. "We wanted to help share information on what materials should be used in systems with oxygen to control the hazard."

Called the oxygen compatibility assessment (OCA), the procedure evaluates the fire hazard in oxygen-enriched environments and has been adopted by NASA, the American Society for Testing and Materials (ASTM),

and the International Organization for Standardization. ASTM incorporates the procedure as part of its recommended practices to ensure oxygen safety. As of 2012, WSTF had conducted over 400 OCAs for the International Space Station, space shuttles, ground support equipment, and rocket engine components and test systems.

Over the years, WSTF has created manuals and training courses to teach oxygen compatibility standards. The facility also partners with other organizations to develop training materials and to perform hazard and failure



Johnson Space Center's White Sands Test Facility in Las Cruces, New Mexico, is a center of technical excellence in high-pressure oxygen systems/materials and rocket propellant safety. Among other services, the facility provides failure analyses of materials and systems, system evaluation tests, and safety training courses.

analyses. Alongside the OCA, WSTF devised a unique test method to determine which metals and alloys are flammable, and at what conditions. Now patented by WSTF, the method is being used to answer questions about the burning behavior of metal alloys. “This test method enables you to know which materials support burning and which ones do not,” says Stoltzfus.

While WSTF’s test methods, analyses, and training are of extreme benefit to the aerospace community, the valuable information they contain also applies to other fields. Today, WSTF specializes in the study of oxygen compatibility in space, aircraft, medical, and industrial applications. “We investigate the effects of increased oxygen concentration on the ignition and burning of materials and components used in these applications,” says Stoltzfus.

Technology Transfer

Throughout the 80s, one of Stoltzfus’ colleagues at WSTF was Barry Newton. Together, Newton and Stoltzfus gained years of experience testing materials and components in high-pressure oxygen and performing failure analyses on components and systems.

In 1988, Newton testified for an oxygen safety legal case while at NASA and enjoyed the forensic challenge. Because of his positive experience, he soon went to work for Wendell Hull and Associates (WHA), an engineering firm in Las Cruces, New Mexico, started and owned by his father in law.

“At that time, the company did not do any oxygen testing, but it began doing oxygen fire forensic origin and cause evaluations due to my background and training received at WSTF,” says Newton, now vice president of research and development at WHA. “The WSTF capability and technology was the starting point for virtually all of the firm’s oxygen testing technology. There has been a huge impact on our business from what we learned at WSTF, and what we continue to do in collaboration with WSTF.”



An external tank holding liquid hydrogen and liquid oxygen for the now-retired space shuttle arrives at the Vehicle Assembly Building at Kennedy Space Center. To ensure safety, NASA studied and tested the materials used on the tank for ignitability and flammability.

Today, WHA specializes in fire and explosion investigations, oxygen and hydrogen testing and safety training, and accident reconstruction and forensic engineering. Besides Newton, the firm employs four engineers and one technician who also started their work on oxygen system safety at WSTF.

In addition to having expertise acquired at WSTF, Newton appreciates the partnership the firm has through a Space Act Agreement with NASA. “We bring a number of clients to WSTF to use their special test capabilities

every year that otherwise wouldn’t know where to have it done,” says Newton. “It also allows for a pipeline of activity, including testing, to flow from WSTF to private industry and vice versa.”

Benefits

As a provider of forensic analysis of oxygen-related fire investigations, WHA also provides training around the world—from Canada to Australia and Nigeria—largely focused on oxygen distribution, oxygen component





design, and medical oxygen supply and treatment. “We help them to understand the relationship between materials and flammability,” says Newton. “We educate people on the hazards and provide the tools to fire-harden their devices.”

In total, WHA trains an estimated 500–750 students per year at its own facility, at customer locations, and by e-Training—ranging from training on oxygen pipeline and distribution to oxygen use at chemical processing plants to medical component and device manufacturing.

According to Newton, “Oxygen is being used to a greater degree now than ever before. Fires are occurring in almost every industry that uses oxygen.”

One area where oxygen fires occur is the medical industry. According to Newton, “From what we are seeing, the health and medical industry gets hit by the largest number of fires. Statistics indicate there are over 600 oxygen-related fires in medical treatment facilities and hospitals each year. Many more are occurring in home healthcare settings.”

As an example, back in 1999, the Food and Drug Administration and the National Institute of Occupational Safety and Health released a public health advisory about explosions and fires in aluminum oxygen regulators. These regulators convert compressed oxygen to a safe pressure for patients to inhale in an emergency

situation, in a home healthcare setting, in hospitals, and in industrial settings.

“The reason they started having fires is the manufacturers started making them out of aluminum, which is very flammable in oxygen,” says Stoltzfus. “If you have high pressure oxygen in a container at a high oxygen concentration, and the material construction of that container is flammable, the fire hazard is pretty significant.”

WHA, along with WSTF and several other organizations, performed tests on the regulators and then devised a new ASTM International standard for devices that deliver oxygen. The standard specifies that the devices must demonstrate resistance to burn out when they are exposed to an intentional, internal ignition source. Since the standard’s inception, no devices that met the standard have experienced any component burnout fires.

In home healthcare, Newton says there have been a large number of oxygen fires from high-pressure cylinder breathing systems, low-pressure-concentrator breathing systems, and liquid oxygen systems. Such equipment supplies oxygen to people with breathing problems while at home, shopping, or traveling.

In medical facilities where patients receive 100 percent oxygen, Newton says fires have resulted from the breathing tubes when a heat-producing laser is used during surgery.

Additionally, oxygen hoods and hyperbaric chambers, which produce a 100-percent oxygen environment for patients to receive oxygen therapy to promote healing,

have also experienced accidents—but with less frequency. “We are currently working with the hyperbaric industry on specific standards and test methods for qualifying materials and devices that go into hyperbaric chambers at healthcare facilities offering hyperbaric treatment,” says Newton.

A new area that WHA is working on is to help qualify medical devices called valve integrated pressure regulators (VIPRs) for use in the United States. WHA is being consulted to ensure that the devices, which integrate the valve and medical regulator on medical oxygen regulators, are safe. “There have been quite a few fires in VIPRs in Europe,” says Newton. “We’re currently testing different types for the United States and Europe and are working with WSTF, ASTM International, and the FDA to revise the test standard for VIPRs.”

WHA is working daily with industries on a variety of new technologies. “Pressures and concentrations are increasing,” says Newton. “If you can get more oxygen in same bottle, it lasts longer. Companies come to us to learn how to prevent fires.”

For Newton, this just shows how “NASA is important to us all.”

“We work hand in hand all the time,” he says, “and there’s been a huge movement of technology from NASA into industry.” ♦



Oxygen regulators convert pressurized oxygen to a safe level for patients to inhale. When the regulators started experiencing fires and explosions, Wendell Hull and Associates worked with NASA and others to devise a new safety standard for the devices.

“There’s been a huge movement of technology from NASA into industry.”

—Barry Newton, Wendell Hull and Associates



The medical industry, including emergency response personnel, benefit from NASA's expertise on materials, flammability, and oxygen-rich environments. For a deeper look at NASA's materials and components testing for oxygen systems, scan this code.

Collaborative Platforms Aid Emergency Decision Making

NASA Technology

Terra. Aqua. Cloudsat. Landsat. NASA runs and partners in many missions dedicated to monitoring the Earth, and the tools used in these missions continuously return data on everything from shifts in temperature to cloud formation to pollution levels over highways. The data are of great scientific value, but they also provide information that can play a critical role in decision making during times of crisis. Real-time developments in weather, wind, ocean currents, and numerous other conditions can have a significant impact on the way disasters—both natural and human-caused—unfold.



Governor Martin O'Malley is pictured here in Maryland's State Emergency Operations Center, where the state government made use of StormCenter's collaboration tools to keep decision makers informed.

"NASA has long recognized the need to make its data from real-time sources compatible and accessible for the purposes of decision making," says Michael Goodman, who was Disasters Program manager at NASA Headquarters from 2009–2012. "There are practical applications of NASA Earth science data, and we'd like to accelerate the use of those applications."

One of the main obstacles standing in the way of eminently practical data is the fact that the data from different missions are collected, formatted, and stored in different ways. Combining data sets in a way that makes them useful for decision makers has proven to be a difficult task. And while the need for a collaborative platform is widely recognized, very few have successfully made it work.

Dave Jones, founder and CEO of StormCenter Communications Inc., which consults with decision makers to prepare for emergencies, says that "when I talk to public authorities, they say, 'If I had a nickel for every time someone told me they had a common operating platform, I'd be rich.' But one thing we've seen over the years is that no one has been able to give end users the ability to ingest NASA data sets and merge them with their own."

Technology Transfer

To make its large body of real-time data more accessible for authorities, NASA issued a Research Opportunities in Space and Earth Sciences (ROSES) solicitation in 2008, looking for solutions to support preparation for disasters such as wildfires, earthquakes, landslides, and coastal hazards. ROSES solicitations are published annually by the Science Mission Directorate at NASA and are open for anyone—inside or outside NASA and the Federal Government—to consider and pursue.

At the time the solicitation was issued, Baltimore-based StormCenter had been working on its own real-time collaboration technologies, and it decided to write a proposal. "At that time we had been working with and

learning a lot from the Federal Emergency Management Agency and the National Weather Service—seeing how they communicate and share data. Our goal was to connect the agencies together with collaboration technologies that would give them access to NASA data," says Jones.

During the 4-year partnership, which will end in 2013, NASA has provided real-time environmental data and StormCenter has provided the technology to incorporate that data in a single platform and enable authorities to work together using that platform during emergencies. Goodman says that StormCenter proved a good fit for NASA's solicitation. "Scientists can improve models and provide better forecasts," he says, "but just as important is having the ability to distribute and communicate NASA's satellite observations and findings to the public, and that is where StormCenter fit in so well. The company has strong connections with the agencies that interface with the public on a daily basis."

StormCenter's technology has had multiple real-world tests. During Hurricane Irene, which threatened the Atlantic coast in 2011, StormCenter used its collaboration tools in Maryland's State Emergency Operations Center to brief Governor O'Malley on many occasions. During and following the storm, the governor received praise in the national press for his situational awareness.

In recognition of its innovation and growth, StormCenter was selected as Maryland's 2012 Incubator Company of the Year, an award sponsored by the Maryland Department of Business and Economic Development and judged by regional industry leaders and early-stage investors.

The company has also worked with the Gulf of Mexico Alliance—a partnership of the states along the southern coast—to develop its capabilities for emergency management and decision making. That led to extensive work done with the Texas Division of Emergency Management in disaster preparation, including regular collaboration sessions and data sharing during the record-setting 2011 Texas wildfires.

Benefits

The primary tool StormCenter offers is the Envirocast Vision Collaboration Module (EVCN), which serves as the platform for merging NASA data with anything else public authorities need. Says Jones, “Without our technology, people coordinating decision making in an emergency are essentially on a teleconference. With us, they are getting the full picture at the same time. Emergency managers have their own data sets for various sensors, traffic patterns, electrical outages and the like, and with EVCN they also gain access to all of the real-time NASA data we collect.”


EVCN uses a Google Earth interface, which has a small learning curve due to its familiarity, allowing end users to navigate the system efficiently even on short notice. The system allows people to participate from anywhere; for example, a high-ranking official can receive briefings and even lead the geospatial collaboration session while traveling by plane, which Jones says gives them total situational awareness “as soon as the wheels hit the ground.”

Increased awareness has the potential to avoid significant costs and damages, bolster response efficiency and effectiveness, and ultimately save lives. Jones cites as an example the 2010 eruption of Eyjafjallajökull, a volcano in Iceland, which caused the cancellation of more than 100,000 flights across Europe over an 8-day period. “The estimate is that it cost the European economy about \$6–7 billion dollars,” he says. “They had to make their cancellations based on model projections, and they didn’t have access to data that would have let them see where the ash actually was. Our estimates are that if they had NASA data in hand, they’d have saved \$2–4 billion, because they could have opened up air space in areas where the data showed there was no danger from ash.”

StormCenter has attracted attention from a number of state and federal organizations. The National Oceanic and Atmospheric Administration (NOAA) has included StormCenter in its preparations to launch the GOES R-Series of satellites—essentially the next generation of

weather satellites—to ensure that the data its spacecraft collect are can easily be incorporated with EVCN’s collaboration technology. The National Weather Service (NWS) awarded StormCenter a contract to launch EVCN at its operational proving ground in Kansas City, with plans to possibly roll out the technology throughout the entire NWS.

For Jones, the company’s partnership with NASA is crucial to improving emergency management at the state and federal level. “In a crisis, moving from knowledge to action requires multimillion dollar decisions,” he says. “We’re working with NOAA and NASA to make sure that the data public authorities receive are from trusted sources.” ❖



The 2011 Texas Wildfires, as seen from onboard the International Space Station. Smoke from the fires can be seen at the center and right side of the image, where it is spreading across hundreds of miles of land. NASA spacecraft are often in a unique position to capture data that is useful to public authorities responding to natural disasters and emergencies.





Consumer Goods

NASA aerospace innovations are found just about everywhere—even in your home and the products you use every day. These technologies enhance the experience of sports fans, yield more comfortable clothing, and bring space-inspired improvements to the campground. The spinoffs featured in this section:

- Encourage Exploration on Earth
- Beautify Art
- Add Comfort to Undergarments
- Connect Sports Teams with Fans
- Deliver More Realistic Gaming
- Authenticate Works of Art



Space-Inspired Trailers Encourage Exploration on Earth

NASA Technology

An inch can make a world of difference. Which is why Garrett Finney moved the office coffee-maker into the full-size, cardboard mockup of the new trailer he was designing. The need for caffeine—and the threat of hot coffee accidentally dumped on a coworker—provided motivation and means for assessing the feasibility of a confined living space.

“We all had to go inside and bump into each other and figure out when 20 inches is much different from 21 inches in terms of the size of a table or passage,” Finney says.

Finney has what he calls a “nonstandard expertise in people in small spaces.” He developed it while part of a NASA team designing living quarters for the International Space Station (ISS).

Though its crew of six—plus one Robonaut—has space larger than a five-bedroom house to live and work in, the ISS is also packed with electronics, life-support systems, racks of experiments, and more. Then consider

that all of these components must be built to strict performance specifications for operation in a harsh space environment.

“It’s very difficult to write human beings into those performance specs,” says Finney.

Then add in further complications such as micro-gravity; long-duration stays far from family and friends; the lack of any nearby maintenance assistance; and crewmembers with diverse backgrounds, cultures, and concepts of personal space. Accommodating all of these considerations while offering the greatest possible ease and comfort for the crew becomes a significant challenge.

Technology Transfer

In order to help address the problems arising from long-term living in space, NASA’s Johnson Space Center established the Habitability Design Center. In 1999, Finney, an award-winning architect in New York City, joined the center to collaborate with engineers on the design of a Habitation Module, planned as the main living quarters for the ISS crew.

“My interest in going there intellectually was to be working on the first permanent settlement, or home, in space. There’s science fiction, and then there’s that exciting place where dreams become reality, and I thought of the space station as that,” Finney says.

Whereas everything on the ISS must in a technical sense be operable and repairable by any crewmember regardless of that person’s size or strength, Finney explains, “That has nothing to

do with irritation and emotion and function over time and comfort.” Finney formed a connection between the astronauts and the engineers, applying his architectural expertise not with an eye toward aesthetics, but instead “trying to remove irritation from astronauts’ lives.” This included finding space-friendly solutions to considerations that would be minor to those not orbiting hundreds of miles above Earth—such as a place, Finney says, “to accommodate a laptop and a book and a picture of your family, and yet not have it be wrong if you didn’t have a family photo. I wanted to let the crew use the space as they wanted. Physically, but also culturally, demographically.”

While Finney contributed a number of innovative approaches to living in space, including a table that substituted toeholds for chairs, funding for the Habitation Module was ultimately cancelled. (The partially built structure was later appropriated as a testbed for ground-based life support research.) Finney’s NASA experience, however, would prove a significant influence on his vision for “a piece of equipment people just happen to live in,” a new means for exploring Earth informed by the exploration of space.

Combining his NASA expertise with his love of the outdoors, Finney turned to an industry where space is also at a premium: recreational vehicles. In 2009, he launched Cricket, based in Houston, and set about designing the first Cricket trailer. Beginning with the coffee-machine-equipped cardboard model—testing ideas in full-scale cardboard form was a holdover from Finney’s time at NASA—the company soon arrived at a highly versatile, user-friendly trailer that it believes can revolutionize the camping experience and how people interact with the natural environment.

Benefits

“The RV industry in general makes houses on wheels,” Finney says. “We think many people want to—and should—leave their house at home.”



The International Space Station and everything onboard is built to strict performance specifications. How to make such an environment as comfortable as possible for the diverse international crew—especially given the unique conditions of low Earth orbit—posed a significant challenge to NASA architects and engineers.

The Cricket trailer hits a midway point between camping and home living. Suitable for a full hookup campsite or going completely off-grid, the trailer can accommodate two adults and two children for sleeping and can be customized with a range of features including a shower, refrigerator, toilet, an array of storage options, and more. As in space where every surface—floor, walls, ceiling—can be functional, Finney designed the Cricket for maximum utility by virtually any user. The children's berths, for example, are suspended from the ceiling and serve as storage when not in use.

Designing for the ISS, Finney explains, meant accommodating crewmembers of different nationalities, each with different ideas of what personal space means, how close people should be when talking, how one acts when in a bad mood. "For Cricket, the question was how to design a trailer whose space evolved from the inside out

and be able to claim with a straight face that it is perfect for a 75-year-old and a 25-year-old, a fly fisherman and a duck hunter and a family camper—even though it's the same trailer."

In a NASA-like way, Finney says, the company devised a shorter performance specification for the trailer. It designed the trailer to be light enough (1,300–1,400 pounds) to be towed by a 4-cylinder car and crafted an aerodynamic shape that is easy to see around and fits into most garages. And as is required of ISS equipment, the Cricket's components are readily accessible and fixable. In that sense, "It's more like a mountain bike than a house on wheels," Finney says.

The Cricket trailer has attracted significant coverage from media outlets such as *Dwell* magazine and the Travel Channel. Finney hopes Cricket will prove the ideal tool

for helping people connect with the natural world and revitalize interest in and sustainable use of the Nation's park system.

"To be better stewards of our national parks, we need to go see them and fall in love with them again. We need to be inspired to be light on the land and part of the big ecosystem instead of pretending the parks are just postcards for looking at."

When he talks about the Cricket trailer's design, Finney says, he's actually talking about what he learned at NASA.

"I'm tremendously glad I went to work at NASA and got a whole new set of eyes, a way to view the world and all the systems that interact in it." ❖



Informed by the "nonstandard expertise in people in small spaces" that founder Garrett Finney acquired at NASA, Cricket's trailers are designed as the ideal tools for exploring and reconnecting with our home planet. The Cricket trailer, Finney says, is "part of what a 21st century campground should be, and how it can be educational and sustainable."

Ultra-Thin Coatings Beautify Art

NASA Technology

The craftsmen in the Roman Empire who constructed the Lycurgus Cup 17 centuries ago probably didn't think their artifact would survive for nearly 2,000 years as a prized possession. And they certainly couldn't have known that the technology they used to make it would eventually become an important part of space exploration.

Carved from one solid mass, the cup is one of the few complete glass objects from that period, and the only one made from dichroic glass. Meaning "two-colored" in Greek, dichroic glass was originally created by adding trace amounts of gold to a large volume of glass melt. The resulting medium partially reflects the light passing through it, causing an observer to see different colors depending on the direction of the light source.

The Lycurgus Cup, for example, is famous for appearing green in daylight and red when lit at night—symbolic of the ripening grapes used to fill it with wine.

NASA revitalized the production of dichroic glass in the 1950s and 1960s as a means of protecting its astronauts. Ordinary clear substances cannot protect human vision from the harsh rays of unfiltered sunlight, and everything from the human body to spacecraft sensors and computers are at risk if left unprotected from the radiation that permeates space. The microscopic amounts of metal present in dichroic glass make it an effective barrier against such harmful radiation.

While the ancient manufacturing technique called for adding metals to

glass melt, NASA developed a process in which metals are vaporized by electron beams in a vacuum chamber and then applied directly to surfaces in an ultra-thin film. The vapor condenses in the form of crystal structures, and the process is repeated for up to several dozen coatings. The resulting material, still only about 30 millionths of an inch thick, is sufficient to reflect radiation even while the glass—or polycarbonate, as in the case of space suit helmets—remains transparent to the human eye.

Technology Transfer

The NASA method of applying metal in ultra-thin layers has since become a widespread technique, used in

everything from special lighting fixtures to contemporary art. Jan Lewczenko, owner of JL Crystal Artistry LLC, based in Mount Pleasant, Pennsylvania, first heard of dichroic glass through a crystal vendor based in nearby Pittsburgh and has used it in his own work ever since.

For 40 years, Lewczenko has practiced as a master cutter—a designation he originally achieved while living in his native

Poland. Following a dramatic escape from the communist regime to the United States in 1981, he worked in the crystal art industry while establishing a new life. Years later, he finally achieved his dream of independence by opening his own art studio, where NASA technology benefits his art to this day.

Benefits

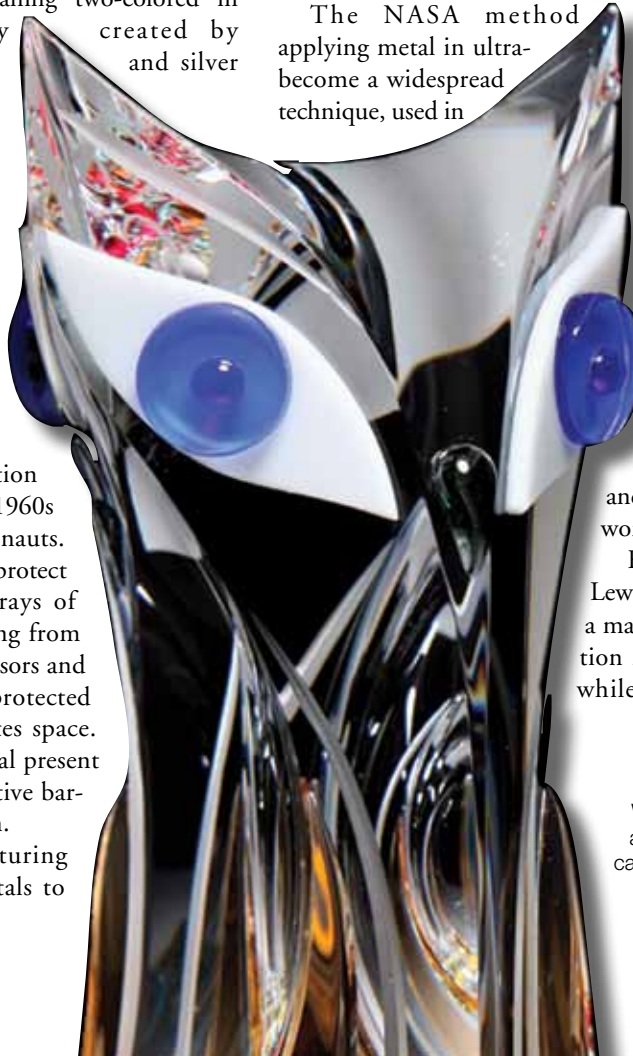
Lewczenko believes that the key to incorporating dichroic glass into artwork is using just enough of it to create something special. "Dichroic glass can overwhelm a piece of art if you aren't careful, so I use it to create accents. It adds surprise to a piece. A main color shows from one angle, and when the glass is laminated on a piece of art, it creates a very different color."

Lewczenko uses the material's special properties to great effect. For example, in one piece, titled *Magnolia*, the center of the flower is made of dichroic glass, shining deep red while at the same time subtly radiating a rich blue at the base of the petals. Lewczenko often works the dichroic glass into his art between the sculpture and its crystal base. "If you light it from underneath or behind, the effect is just magical," he says.

Today Lewczenko undertakes custom art of all kinds. His creations are in high demand, and have been commissioned by such dignitaries as popes John Paul II and Benedict XVI, as well as every President of the United States since George H.W. Bush. His works can also be found in the corporate collections of Tiffany, PepsiCo, Audi, Mercedes-Benz, and Porsche, among others.

Even some of the clear crystal he uses has a NASA connection: the glass he prefers to work with—according to Lewczenko, the purest in the world—is formulated specifically for NASA and the military, who use it in optical applications. A small amount is made available each year for artists, which Lewczenko acquires whenever possible. ❖

When used at the base of a sculpture, dichroic glass can create color throughout the piece.





“When I need surprising reflections or colors, I use **dichroic** glass. It’s **amazing stuff.**”

—Jan Lewczenko,
JL Crystal Artistry



This creation, Magnolia, features dichroic glass laminated into the center of the flower. Although red is the primary color infused by the glass, one can also see blue reflections in the crystal, thanks to the glass’ ability to show different colors from different angles.

Spacesuit Materials Add Comfort to Undergarments

NASA Technology

“Life’s too short to wear average underwear,” says Mo Moorman, the director of public relations at Jockey International. By “average underwear,” Moorman means underwear without NASA technology in it.

More than two decades ago, NASA started looking for a new way to keep astronauts comfortable—not in their underwear, but in their space gloves. During a spacewalk, temperatures can range between 250 °F and -250 °F. One of the technologies NASA looked at to help maintain a “just right” temperature was phase change materials (PCMs). At a designated high temperature, PCMs absorb and hold heat to produce a cooling effect. At a designated low temperature, PCMs release their stored heat to produce a warming effect in an area.

To incorporate PCMs in spacesuit fabrics, NASA’s Johnson Space Center collaborated with a private company called Triangle Research and Development Corporation (TRDC) through a Small Business Innovation Research (SBIR) contract. Previous to its NASA partnership, TRDC had gained valuable insight in working on microencapsulated PCMs—PCMs contained in tiny capsules—with the US Air Force.

In testing, TRDC found the materials to be a simpler solution than NASA had previously used to maintain comfortable temperatures in spacesuits. When the environment became too warm or too cool, the PCMs automatically

responded. The material showed promise—not only for space, but on Earth as well.

Technology Transfer

In the 1990s, a private company obtained exclusive rights to incorporate the NASA-proven technology into fabrics for use on Earth. Today, Boulder, Colorado-based Outlast Technologies Inc. calls the PCMs “Thermocules” and compares them to ice cubes in a drink. As an ice cube melts, it absorbs heat and cools the drink. Thermocules do the same thing but are permanently enclosed.

After licensing the technology from TRDC, Outlast incorporated it into everything from bedding to industrial fabrics, and in 2005 the company’s Thermocules were inducted into the Space Technology Hall of Fame.

Jockey International, headquartered in Kenosha, Wisconsin, learned about Outlast’s technology and was intrigued. The apparel company soon started working with Outlast to print the Thermocules directly onto its high-quality fabric for undergarments.

“This is something no one else in the US market is

offering,” says Jockey’s Moorman. “If there’s anywhere you want to be most comfortable, we think it’s your underwear!”

Benefits

By March 2011, Jockey released a full line of men’s and women’s Jockey staycool undergarments—incorporating the NASA spinoff technology—to regulate temperature and reduce sweating. “Jockey’s mantra has always been to ‘satisfy the human need for comfort,’ and with Jockey staycool, we deliver on that promise, and then some,” says Moorman.

Available in underwear tops and bottoms, including thermal underwear, Moorman says Jockey staycool is “going gangbusters.” “Jockey staycool is Jockey’s fastest-selling collection in modern history, and though the technology involved may sound a bit like science fiction, the benefits are very real.”

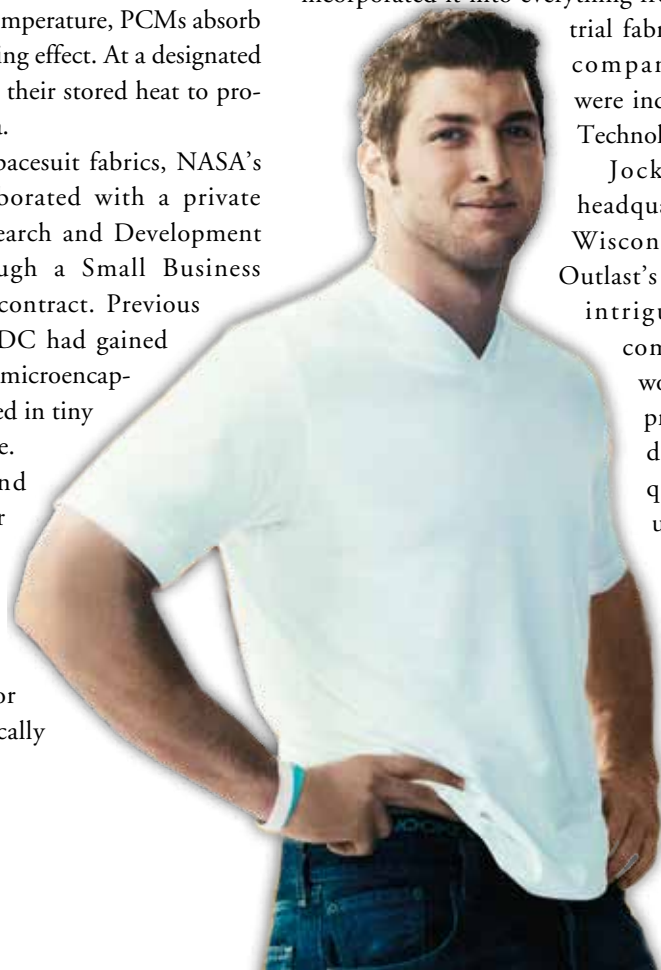
Although Jockey staycool is described as feeling no different to the touch than other quality cotton underwear, Moorman says the wearer should feel a difference when it comes to enhanced comfort. According to the company, the products can regulate the temperature between a wearer’s skin and clothing by as much as 3 degrees. This helps to reduce overheating and prevent chills.

Everyday consumers to pro athletes are experiencing the benefits of the staycool technology. Professional football player Tim Tebow, a Jockey spokesman, wears Jockey’s NASA spinoff products on and off the field.

“If it’s good enough for astronauts,” he says, “it’s good enough for me.” ♦

Professional football player Tim Tebow sports an undershirt made with NASA spinoff technology.

Thermocules™ is a trademark of Outlast Technologies Inc. Jockey® is a registered trademark of Jockey International, Inc. Outlast® is a registered trademark of Outlast.





“Though the **technology** involved may **sound a bit** like **science fiction,** the **benefits** are **very real.**”

—Mo Moorman,
Jockey International



NASA astronaut Richard Arnold takes a spacewalk in 2009. Because of the extreme temperatures in space, NASA investigated phase change materials (PCMs) for spacesuit fabrics. Today, PCMs are used in a line of Jockey undergarments.

Gigapixel Images Connect Sports Teams with Fans

NASA Technology

NASA's twin Mars rovers, Spirit and Opportunity, remain one of the Agency's greatest achievements in exploration. On Earth, these robots are best known for their stunning pictures of the Martian landscape—images that, in addition to providing invaluable scientific data, have also given ordinary people an unprecedented look at the Red Planet.

While the rovers each took a mere 1 megapixel camera for the journey, the pictures they have become famous for measure up to 96 megapixels in size. This was made possible by a NASA-built automated tripod, which with the help of photo processing software seamlessly integrates a series of smaller shots into one large image.

Today, using the same technology, baseball fans are enjoying their own version of highly detailed panoramic pictures—and are sharing the benefits through social media.

Technology Transfer

Through multiple commercial partnerships, NASA and Carnegie Mellon University first brought the supersized digital picture technology to the market as the GigaPan robotic platform (*Spinoff* 2008). Soon after it had spun off into consumer applications, the technology's potential caught the eye of Major League Baseball Advanced Media (MLBAM) LP, based in New York City.

MLBAM runs the official website for Major League Baseball (MLB) and coordinates the interactive media efforts of the league and its 30 teams. In 2009, MLBAM was already taking large-scale, flat images of stadiums at game time. "These photos were interesting," says Andrew Patterson, director of New Media at MLBAM, "but we were really looking for a way to make them more personal and interactive."

The opportunity came when MLBAM was approached by David Bergman, a professional photographer experienced with the GigaPan system. Bergman received a high

degree of recognition for a GigaPan photo he took during President Obama's inauguration in 2009. "I always try to make unique images using technology," he says. "When I got the assignment, I knew I had to produce something that could live up to the magnitude of the event." The resulting photo—a 1,474 megapixel shot that details thousands of crowd members, including every living former president—received over 15 million views online and was profiled by every major news outlet.

Following consultation with Bergman, MLBAM worked with GigaPan engineers to customize the system for capturing large scale in-game shots, photos that the MLB hoped would become a new platform for engaging and energizing its fan base. The resulting technology is now licensed to MLBAM, who offers its benefits to individual teams and supports its use in stadiums nationwide—with Bergman taking many of the photos.

Benefits

Photos taken during games are displayed as navigable images on MLB.com's TagOramic website. While nearly the entire stadium can be viewed at a glance, thanks to the image's high resolution users can zoom in to see individuals in the crowd with remarkable detail.

Nicole Blaszczyk, marketing coordinator for the Detroit Tigers, says the technology came at a good time for her organization. "We have had a photo booth in the park; however, because it's been there for so long, it wasn't piquing fan interest as much." Rather than enticing fans into an individual shot, the GigaPan camera captures nearly everyone in its series of candid photos, typically spanning a period of time under 20 minutes. Once the images are stitched together, users can explore almost the entire stadium, zooming in to high levels of detail.

Social media has intensified the reach of this technology: Fans can log in using their Facebook accounts and tag themselves and their friends in the image, with the option to post it on their personal news feed for friends and family to see. The photos stored online have

"We were looking for a way to make the photos personal and interactive. People love to be able to say 'I was there' when a memorable event unfolds."

—Andrew Patterson, MLBAM

accumulated thousands of tags. "People love to be able to say 'I was there' when a memorable event unfolds," says Patterson. "Tagging has been an increasingly popular feature on the site."

Just as fans use the images to publicly associate with their team, teams are using the opportunity to better serve their fans. The Detroit Tigers, for instance, place the pictures on their website and social media pages to generate additional web traffic. Users who browse the gameday photos are exposed to special offers run by the team for tickets, merchandise, and special events.

TagOramic GigaPan photos have proven so popular that more teams are taking them—and more often. Patterson says MLBAM bears the licensing costs on behalf of every team in the league. "The technology is available for anyone who wants it," he says, "and many teams are taking advantage of it."

The fans are clamoring for more, too. "Every time we posted a new photo on Facebook, people would comment saying they had just been at a game the day before or after, asking if we would post photos from those days, too," says Blaszczyk. "We decided to take a photo for every game of the America League Championship series while the Tigers were in their postseason stretch. And we plan on using it again next year, starting with opening day." ❖

Gigapan™ is a trademark of Carnegie Melon University.

TagOramic™ is a trademark of Major League Baseball.



This Gigapan image was taken at a Detroit Tigers game during the American League Championship Series in October 2011. The 1,777-megapixel photo is comprised of 300 individual shots taken over 18 minutes that were subsequently stitched together. Users who view the image online can zoom in to high levels of detail, shown here to the right and left. For a deeper look at how the system has been used on Mars, and to explore panoramas taken by Spirit and Opportunity, scan this code.

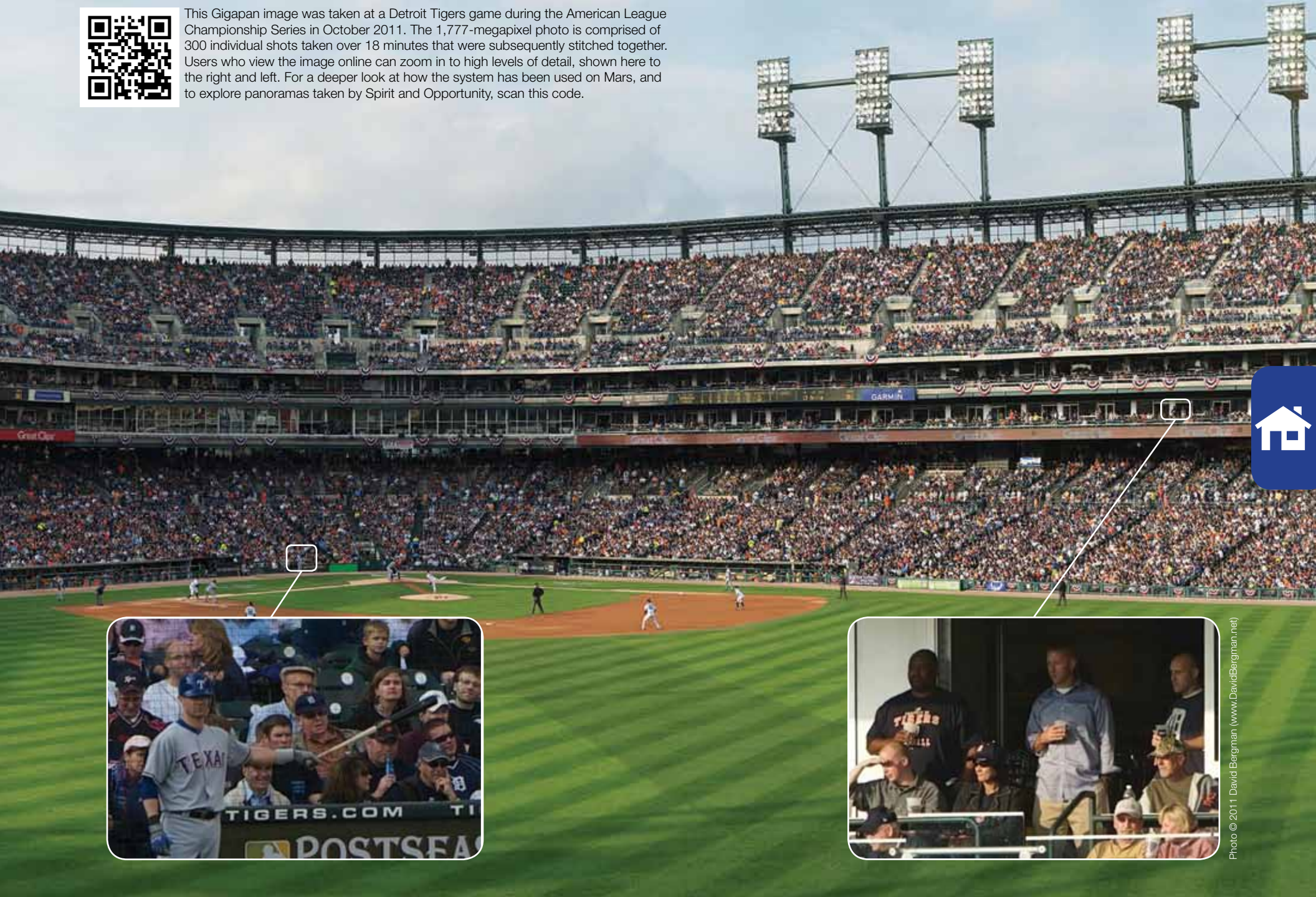


Photo © 2011 David Bergman (www.DavidBergman.net)

Satellite Maps Deliver More Realistic Gaming

NASA Technology

In June 2009, NASA launched Terra, the flagship of NASA's Earth Observing System, which studies a sweeping set of the planet's characteristics. Included in the satellite is the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). ASTER is a cooperative effort between NASA and Japan's Ministry of Economy Trade and Industry, with the collaboration of scientific and industry organizations in both countries. The instrument provides the next generation in remote sensing imaging capabilities when compared to the older Landsat Thematic Mapper and Japan's JERS-1 OPS scanner.

One of the goals of the collaboration has been to make ASTER data publicly available, says Michael Abrams, a science team leader at the Jet Propulsion Laboratory. "The ASTER Global Digital Elevation Map is the most complete global topographic data set freely available to the public. In the two and a half years since we released it, we have distributed millions of 1 by 1 degree tiles to users all over the world."

Technology Transfer

One prominent user of ASTER's data is Redwood City, California-based Electronic Arts (EA) Inc. The company is one of the largest video game companies in the world, generating nearly \$4 billion in revenue a year.

In 2009 the company started production on Super Snowcross (SSX), the latest in its series of snowboarding games. Todd Batty, producer and creative director of SSX, says that "one of the development team's first tasks was to establish the physical environment of the game's virtual world, which meant building mountains and tracks. The series has always been big, crazy, and over the top, and we wanted to deliver a massive amount of content by creating entire landscapes."

Rendering a full mountain from scratch is a time-consuming process that can require an army of programmers,

artists, and level designers. To streamline the process, the team figured out how to generate mountain terrains algorithmically using an in-house software tool called Mountain Man.

While the mountains created by this process were close to what the team wanted, Batty says they still lacked some essential qualities. "As we researched the mountains of Earth and compared them to the ones we were building, ours just didn't have the same character, interesting features, or, obviously, the great history that the famous mountains of the world have."

One day a technical lead on the project called Batty into his office, where he had been experimenting with mountain-building. The programmer said he had "found something really cool online"—ASTER's data—which he had downloaded and converted into a format Mountain Man could use. He asked Batty to name any mountain on Earth, and within 30 seconds the two were looking at and manipulating a 3D replication of it.

While the data wasn't fine-grained enough to replace EA's existing tools outright, it proved the perfect complement to Mountain Man. "That had been the weakest link in the chain," says Batty. "When we found that we could start with what was essentially a real mountain, and then let Mountain Man and our artists build on top of that, it proved to be the last piece of the puzzle."

Benefits

The millions of people who have played SSX since its release in early 2012 are experiencing first-hand the benefits that the ASTER data infused into EA's product. No previous title in the series included real mountains, but the 2012 game features 28 real-world mountains—each with multiple paths of descent—from nine different ranges. And thanks to the completeness of ASTER's data, the background scenery throughout SSX also features accurate renderings of neighboring mountains and terrain.

While the overall look and feel of the mountains is realistic, EA added all of the flair, obstacles, and power-ups one typically finds in an action game, as well as iconic landmarks such as the Great Wall of China to add interest. Says Batty, "Players experience the best of both worlds: everything has an air of authenticity because the base of the data is straight from satellites, but they also get larger than life gameplay."

The team's use of the data has caught people's attention. "We've had a lot of interest around the company in how we acquired the ASTER data, manipulated it, and combined it with our tools," Batty notes. "And I know for sure that, if we end up doing another game in the series, we will use the data again, because this was an awesome experience for us." ♦

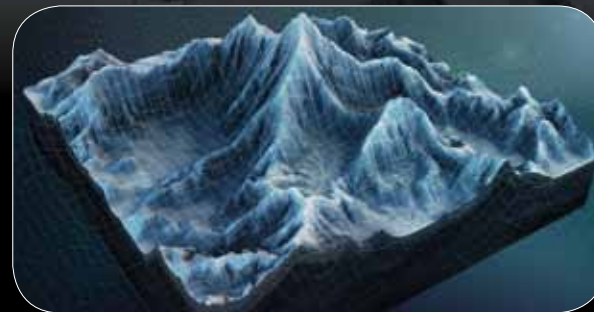
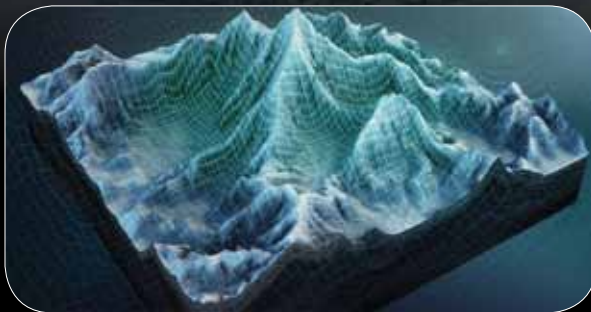


Designers were able to incorporate ASTER data directly into their in-house software tools (above) and render it into usable terrain for the game (bottom right, inset images). Full-featured courses were built on top of the data, including landmarks like an abandoned nuclear power plant in Siberia (right).



“The data we got
from **NASA** became
a **launch point** for the **game.**”

—Todd Batty, Electronic Arts



Elemental Scanning Devices Authenticate Works of Art

NASA Technology

What do you think the paper or computer screen you are looking at is made of? Are the shoes you are wearing really made of leather? Is the table nearby made of wood? How can you be sure?

For most people, these questions may sound like useless speculation, because they are largely inconsequential to daily life. But knowing the precise chemical makeup of spacecraft components is a crucial part of quality control and can help ensure a successful mission. And learning that the paint on a canvass was produced using modern materials



The Tracer is the first handheld X-ray fluorescence (XRF) scanner that can detect aluminum alloys, which are used frequently in flight hardware.

could be what prevents a museum from spending \$10 million on a forgery.

The truth is that we perform a kind of molecular analysis every time we use our eyes. As light reflects off objects, the photons captured by our eyes get interpreted as colors. Of the millions of colors human beings are capable of seeing, all fall within gradations between 1–3 electron volts (eV). Photons close to 1 eV we see as red, photons close to 3 eV we see as violet, and everything in between correlates with the rainbow.

X-ray fluorescence (XRF) analysis is one way of getting past the limitations of human vision. As Bruce Kaiser, a scientist and pioneer in XRF technology, explains, “An XRF scanner is essentially an expensive flashlight, except that instead of using 1–3 eV, it uses 1,000–40,000 eV.” The difference in range is due to a specialized fluorescent tube. Ordinary fluorescent tubes produce light by agitating a gas with electrons; the tube in an XRF scanner, by contrast, houses a solid piece of rhodium, which is agitated using highly accelerated electrons.

With XRF-created light shining on an object, all one needs is a device to interpret the X-ray photons that are coming back—information that conveys the elemental structure of the object being viewed. “It works just like your vision, except that instead of seeing colors you can look at the atomic structure and detect elements. Every atom emits a unique color pattern; we just don’t have names for them because our eyes cannot see them,” says Kaiser.

The lighter an element is—that is, the lower its number on the periodic table—the lower its eV range will be, meaning that returning X-rays will be weaker. Conventional XRF scanners typically have no trouble reading elements heavier than calcium, but some materials important to NASA, like aluminum and silicon, fall below that threshold and are difficult to

detect. “Aluminum is really popular with the aerospace industry, but its photon is only 1,470 volts,” says Kaiser. “That won’t even go through a quarter-inch of air; the air stops it.”

In 2001, scientists at Marshall Space Flight Center began searching for ways to enable easy, accurate, and consistent XRF scanning of aluminum alloys using a portable device. Doing so would improve quality control on a wide range of flight hardware, effectively giving field technicians an entire materials lab’s worth of tools in a single, hand-held instrument.

Technology Transfer

To develop XRF capabilities for sensing lighter elements, Marshall partnered with KeyMaster Inc., later acquired by Madison, Wisconsin-based Bruker AXS Inc. Under a Space Act Agreement, Kaiser—at the time chief technology officer of Keymaster—worked with Fred Schramm of Marshall’s Technology Transfer Office to develop a system for detecting lighter elements.

Because the primary hurdle facing light-element detection was the air between the scanner and its object, NASA and KeyMaster created a vacuum chamber that could be incorporated into the instrument. During development, NASA provided the materials for a prototype and personnel to evaluate the device; KeyMaster contributed its technical expertise and hosted the project in its facilities.

The resulting XRF scanner could easily detect lighter elements such as aluminum and silicon; in fact, it could detect any gas, liquid, powder, or solid heavier than neon. KeyMaster and NASA filed joint patents on the vacuum system as well as on some of the other applications of their research.

Following the patents, the company licensed the technology and made it commercially available. Says Kaiser, “The partnership was a very fruitful relationship and essential to the development of the vacuum technology for the XRF system. NASA’s participation added credibility when our small company began

marketing this new product.” Bruker AXS now sells the technology as the Tracer III-SD and Tracer III-V.

Benefits

The NASA-improved XRF scanners have been particularly well received in museums, where they are used to authenticate artifacts and works of art and assist those who conserve them. Tracer’s ability to detect the elemental composition of an object with a simple, nondestructive scan makes it ideal for analyzing precious, rare, or delicate items. Kaiser estimates that more than 600 museums and universities worldwide now use the device, including such institutions as the National Archives, the Field Museum of Natural History, the Louvre, the National Gallery, and the British Museum.

One reason the device is so popular is that experts in art history or archeology can easily be taught how to use it. “It doesn’t take a chemist to operate it,” says Kaiser. “I can teach anyone how to point the scanner, look at the color pattern, and figure out what they’ve got.”

As a practical example of the technology’s impact, Kaiser cites art authentication: “I can make something look yellow, but there are a hundred different ways to make something look yellow. Van Gogh only used one. If a museum is eyeing a newly discovered painting, it might be beautiful, it might have the right style and details, but if the elements in the pigments don’t match what Van Gogh used, then you know it’s not his. And yet the museum was about to spend \$2 million on it.”

In addition to authenticating objects, the scanner also assists conservators as they preserve or restore items. For example, a person getting ready to restore a painting can use the scanner to ensure that he or she is using the same pigments found in the painting so that the new paint matches it exactly. At other times, museums will purposefully select the wrong pigment so that the new paint can easily be identified and removed when the work is restored at a later date.

The expanded capabilities of XRF scanners have proven valuable for many other applications outside of museums. Tracer scanners have previously been profiled for their impact in the carpet cleaning industry (*Spinoff* 2006), and they are also used to test the composition of consumer products like food and medication to ensure they are free of contaminants.

We might not spend much time wondering about the elemental composition of the things we use and consume each day, but for those who need to find out, this successful NASA-commercial partnership has provided a valuable tool for the job. ❖



Bruker AXS’s XRF scanners quickly and easily identify the elements of an object down to parts-per-million—sufficient to analyze NASA spacecraft components or authenticate works of art.





Energy and Environment

While NASA explores the universe, it also focuses on understanding Earth. Whether contributing to the reduction of air pollution, a greater comprehension of ocean ecosystems, or the advancement of solar power systems, NASA technologies play a major role in preserving our planet's health for future generations. The spinoffs featured in this section:

- Reveal Ocean Health, Climate Change
- Enable Plants to Text Message Farmers
- Cut the Cost of Solar Power
- Inform Solar Power Analysis
- Create Self-Cleaning Surfaces
- Enhance Solar Power Systems
- Potentially Lower Facility Maintenance Costs



Microradiometers Reveal Ocean Health, Climate Change

NASA Technology

When NASA researcher Stanford Hooker is in the field, he pays close attention to color. For Hooker, being in the field means being at sea. On one such research trip to the frigid waters of the Arctic, with a Coast Guard icebreaker looming nearby and the snow-cruled ice shelf a few feet away, Hooker leaned over the edge of his small boat and lowered a tethered device into the bright turquoise water—a new product devised by a NASA partner and enabled by a promising technology for oceanographers and atmospheric scientists alike.

Color is a function of light. Pure water is clear, but the variation in color observed during a visit to the beach or a flight along a coastline depends on the water's depth and the constituents in it—how far down the light penetrates and how it is absorbed and scattered by dissolved and suspended material. Hooker cares about ocean color because of what it can reveal about the health of the ocean, and in turn, the health of our planet.

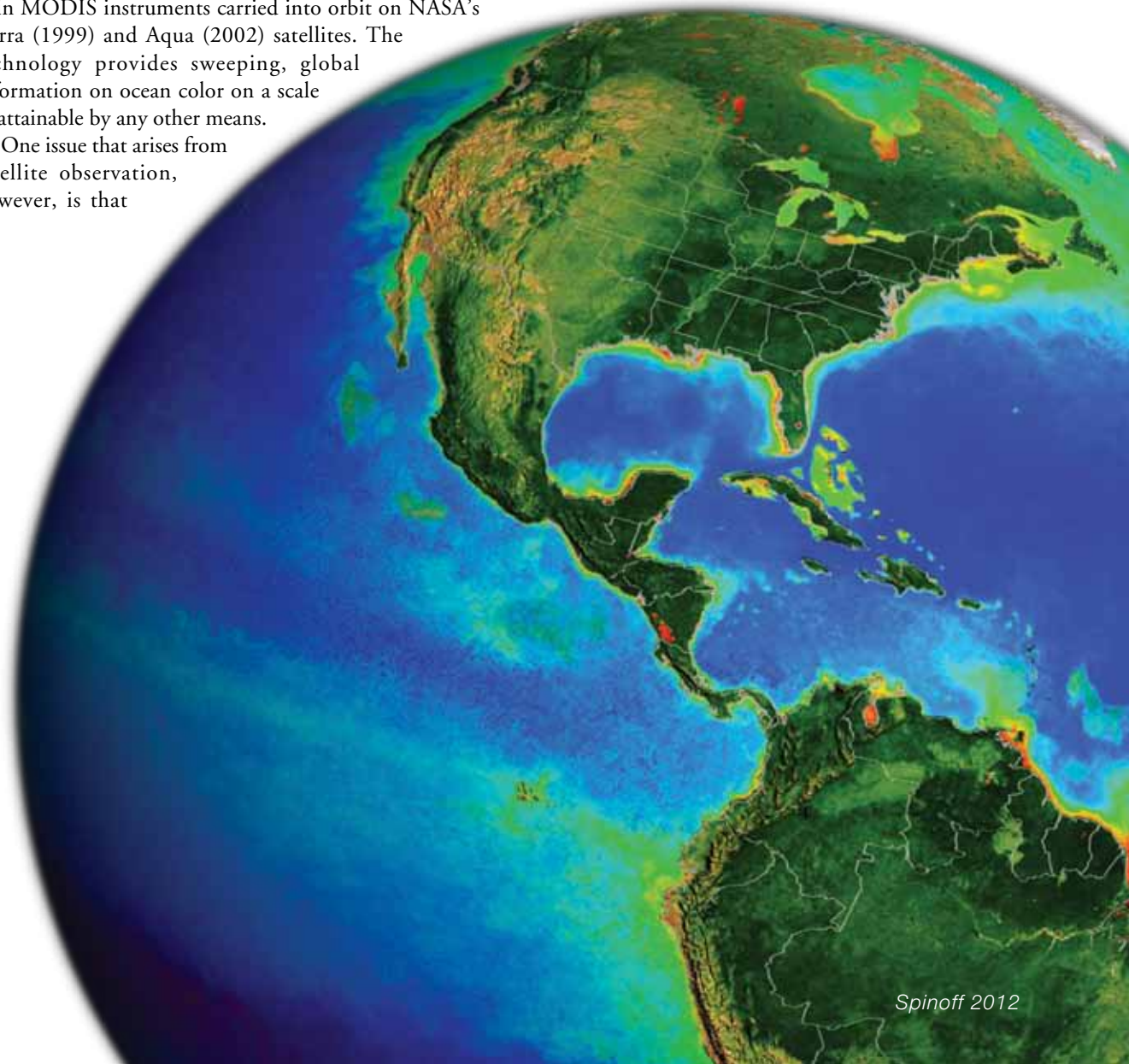
“The main thing we are interested in is the productivity of the water,” Hooker says. The seawater contains phytoplankton—microscopic plants—which are the food base for the ocean's ecosystems. Changes in the water's properties, whether due to natural seasonal effects or human influence, can lead to problems for delicate ecosystems such as coral reefs. Ocean color can inform researchers about the quantities and distribution of phytoplankton and other materials, providing clues as to how the world ocean is changing.

NASA's Coastal Zone Color Scanner, launched in 1978, was the first ocean color instrument flown on a spacecraft. Since then, the Agency's ocean color research capabilities have become increasingly sophisticated with the launch of the SeaWiFS instrument in 1997 and the twin MODIS instruments carried into orbit on NASA's Terra (1999) and Aqua (2002) satellites. The technology provides sweeping, global information on ocean color on a scale unattainable by any other means.

One issue that arises from satellite observation, however, is that

the instruments must be continuously calibrated over time to maintain the quality of the data they gather from orbit. To validate and calibrate the satellites, researchers must also gather data at sea level.

The SeaWiFS instrument has been collecting ocean data since 1997. By monitoring the color of reflected light via satellite, scientists can determine how successfully plant life is photosynthesizing. This image represents nearly a decade's worth of data taken by the SeaWiFS instrument, showing the abundance of life in the sea.



“We are eagerly working to
adapt this **technology** to make
measurements that **have not** been
made before.”

—Rocky Booth, Biospherical Instruments Inc.



Biospherical Instruments' C-OPS technology measures light in Arctic waters during NASA researcher Stanford Hooker's scientific expedition. For a deeper look at NASA's ocean color research, scan this code.



Joining Hooker on his Arctic mission, Clark University researcher Karen Frey used a C-OPS system designed for lowering into boreholes in the ice. One of the key benefits of the spinoff technology is its versatility, allowing for the creation of customized arrays for a variety of research needs.

Technology Transfer

Biospherical Instruments Inc., based in San Diego, has engaged with NASA in multiple Small Business Innovation Research (SBIR) partnerships over the company's lifetime, including the development of an instrument for studying the energy intake and photosynthetic rates of phytoplankton (*Spinoff* 1991).

In the early 2000s, Biospherical began working with Hooker and Goddard Space Flight Center through the SBIR program to focus on a device with the potential to improve the calibration and validation of ocean color satellites, as well as to advance other environmental research.

"We were trying to develop instrumentation that can be deployed rapidly and at the lowest cost possible to collect high-quality data and increase the baseline understanding of what these marine ecosystems look like so that, as these ecosystems evolve, we have something to compare them back to," Hooker says. The core technology that emerged from the partnership was dubbed the "microradiometer." A narrow tube shorter in length than

a standard pencil, each microradiometer contains light and temperature sensors and was designed with lower cost, smaller size, and increased adaptability in mind. The devices can be clustered into customized arrays to meet a range of data-gathering needs.

"This innovation has proven to be a very versatile architecture that allows us to take instrument sensor assemblies configured in a variety of ways. You just plug them together, turn the system on, and you have a functioning data acquisition network," says Biospherical CEO Rocky Booth.

Benefits

The microradiometer is now at the heart of a number of environmental sensor products commercialized by Biospherical. The device Hooker used to measure light in the Arctic waters was the company's Compact-Optical Profiling System, or C-OPS. A radiometer system on a platform with adjustable buoyancy, C-OPS descends through the water, making highly accurate measurements

on the way. The system is ideal for satellite calibration and validation activities and for conducting research both in shallow waters close to land and in deep waters far out at sea.

"The ocean color community is concerned with working close to the shore so that our near coastal waters can be better understood," explains Booth. "These instruments are particularly well-suited for making measurements in near-coastal waters."

C-OPS can be customized to specific research requirements. Also on Hooker's Arctic mission was Clark University researcher Karen Frey, who used a C-OPS configuration called ICE-Pro to gather measurements from boreholes drilled deep into the Arctic ice. Also employing the core microradiometer technology is Biospherical's Advanced Multi-purpose USB Radiometer, or AMOUR. A high-speed radiometer that can be plugged into a computer's USB port like a mouse, AMOUR provides a uniquely versatile tool for field research.

And through a 2008 joint project with NASA, Biospherical created the only commercially available

satellite vicarious calibration and algorithm validation system. Called the Optical Sensors for Planetary Radiant Energy (OSPRey) system, it employs microradiometers and other instruments on multiple platforms to gather a comprehensive array of oceanic and atmospheric information to compare to satellite data.

The adaptability of the company's spinoff technology benefits both scientists and taxpayers, says Hooker.

"We are able to apply this technology to multiple disciplines," he says. "If you can serve two scientific communities with one instrument, you have savings."

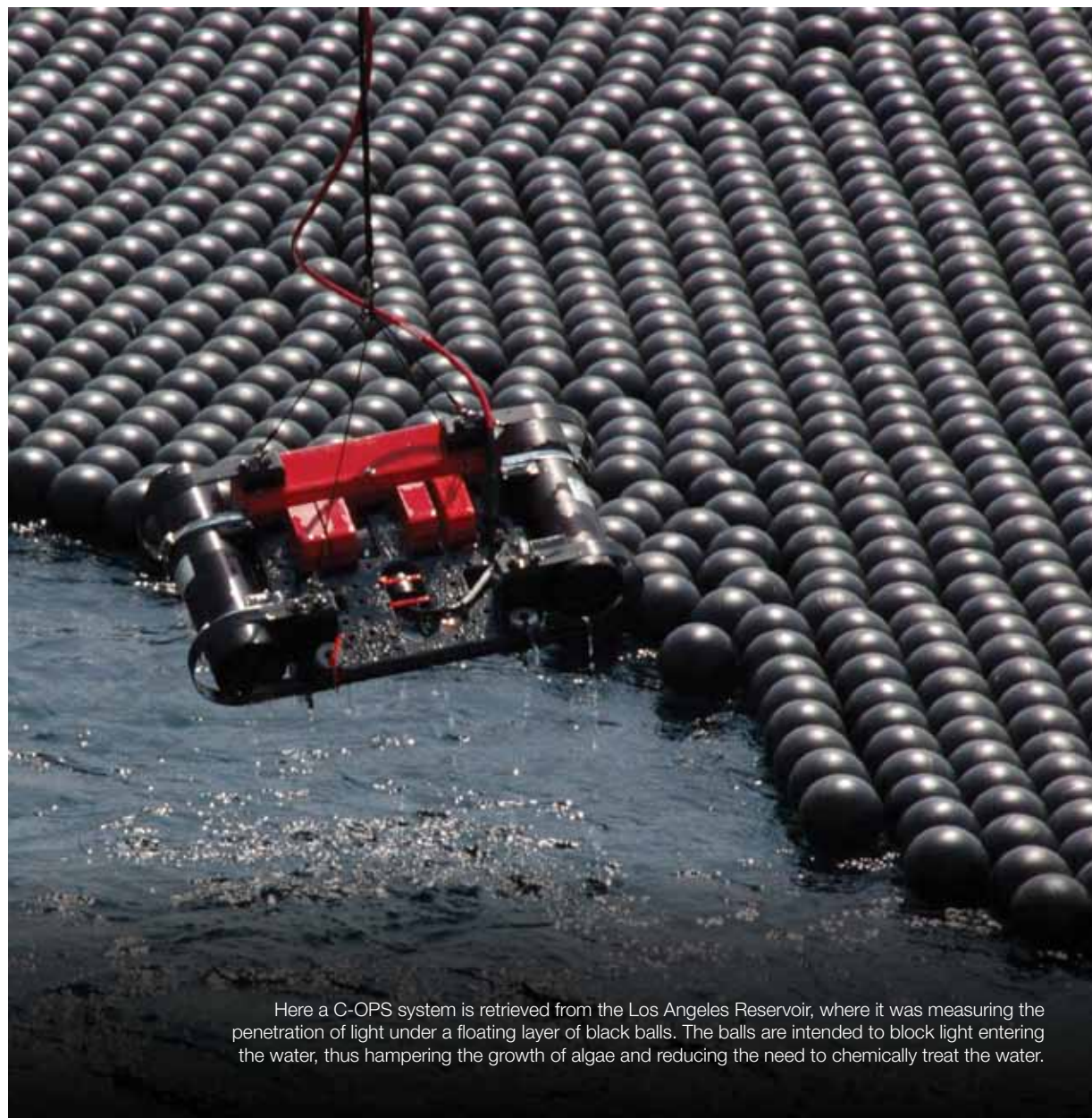
An additional benefit of the microradiometer is the fact that it is machine made. "We were able to solve a big part of the quality problem compared to prior technologies, which were all hand assembled," Hooker says. He sees the availability of technologies like Biospherical's microradiometer as providing the means to create a baseline understanding of the rich diversity of ocean ecosystems around the world, many of which are unique.

Biospherical has had substantial commercial success with its spinoff innovations, with significant export sales to researchers in countries ranging from Poland to Canada and China. The company has received more than \$2 million in contracts as a result of its NASA work.

"Almost every SBIR program we have had has been very successful in returning many times more dollars in sales than went into the development," Booth says.

Most recently, Biospherical adapted its microradiometers to fly in aircraft, conducting atmospheric research in partnership with NASA's Ames Research Center and demonstrating that the limits of its NASA-derived technology have yet to be reached.

"As we hear about global climate change, we know that many of the unanswered questions have to do with properties of the atmosphere," says Booth. "We are eagerly working to adapt this technology to make measurements that have not been made before." ❖



Here a C-OPS system is retrieved from the Los Angeles Reservoir, where it was measuring the penetration of light under a floating layer of black balls. The balls are intended to block light entering the water, thus hampering the growth of algae and reducing the need to chemically treat the water.



Sensors Enable Plants to Text Message Farmers

NASA Technology

Long-term human spaceflight means long-term menu planning. Since every pound of cargo comes with a steep price tag, NASA has long researched technologies and techniques to allow astronauts to grow their own food, both on the journey and in some cases at their destination. Sustainable food technologies designed for space have resulted in spinoffs that improve the nutrition, safety, and durability of food on Earth.

There are of course tradeoffs involved in making astronauts part-time farmers. Any time spent tending plants is time that can't be spent elsewhere: collecting data, exploring, performing routine maintenance, or sleeping. And as scarce as time is for astronauts, resources are even more limited. It is highly practical, therefore, to ensure that farming in space is as automated and precise as possible.



Technology Transfer

In the early 2000s, a NASA cooperative agreement for developing hardware for biological experiments in space was made available to Hans Seelig, at the time a PhD student at the University of Colorado Boulder and an employee of BioServe Space Technologies, a nonprofit, NASA-sponsored research partnership center located at the university and at the time connected to the Space Product Development Office at Marshall Space Flight Center. As part of his research, Seelig studied the relationship between plant leaf rigidity and its water content, and whether such data could be directly measured using sensors. “No device was available that could measure leaf thickness continually, so I built a prototype sensor that measured thickness by way of electrical pulses,” he says.

Seelig hypothesized that sensor-based watering could eliminate a significant amount of guesswork in farming and free up time and resources that could be applied elsewhere. “Astronauts are not supposed to spend their days weeding, watering, and the like, so we wanted to investigate technologies that would make a closed ecological life support system more efficient.”

Following the cooperative agreement, Seelig looked to secure additional funding to move the technology forward. For help, he turned to Richard Stoner, an entrepreneur, inventor, and plant researcher who had partnered with

By measuring electrical pulses, AgriHouse's sensors can determine several characteristics important to plant health. The sensors can remain attached through wind and rain while leaving the plant unharmed.

BioServe in the past. Stoner's previous NASA-related projects included an organic biopesticide suitable for space and aeroponic technology to grow plants without the use of soil (*Spinoff* 2006, 2008). The partnership between BioServe and Stoner's company, Berthoud, Colorado-based AgriHouse Brands Ltd. resulted in an experiment to see whether the sensor could be used successfully to trigger automated irrigation. With the sensors, they grew healthy plants while reducing water use between 25 and 45 percent compared to traditional methods.

The next step in product development was to perform a field test on a large scale, which AgriHouse conducted in collaboration with the United States Department of Agriculture. Stoner says the test, though not terribly practical, proved effective: “We had to run thousands of feet of cable down the road and to each of the leaf sensors. It was a huge effort, but for the first time in human history, you had plants in a field telling the farmer how much water they had and when they needed more.”

Looking at the data, Stoner and his colleagues determined that the plants—irrigated using traditional methods—had actually received more water than was necessary. Stoner explains that in the West, farmers typically water their crops at certain set times throughout the growing season. “In our test, we set four watering dates, but what we discovered by looking at the data is that some rain that fell before one of those dates made the irrigation unnecessary. The plants simply didn't need to be watered—though we couldn't have known that without the sensors in place.”

Benefits

With the technology demonstrated, AgriHouse soon after commercialized the product and now sells several models of the sensor. Currently, its primary market is researchers and scientists. “This is a new, emerging science, and it's still in its infancy,” says Stoner. “We've got a long way to go, but one day farmers will be able to pick

up a pack of these devices like candy from a convenience store.”

AgriHouse’s line of patented leaf sensors are thin clips, smaller than a postage stamp, that easily attach to the plant, adhering to the leaf structure without damaging the leaf or falling off in the presence of natural movements, wind, or inclement weather. The sensors transmit data (either through a wire or using radio waves) on leaf turgidity, which indicates plant water levels as well as the plant’s general health.

Right now the data is all transmitted to a user’s computer, and the system can send text messages calling attention to particular crops that need water. Stoner envisions text message alerts becoming a common tool among farmers in the future, which could be combined with precision irrigation systems to eliminate a large amount of guesswork.

Because the sensors’ primary commercial benefit is in preventing overwatering, Stoner says they would be especially useful in the West, where water is sometimes scarce

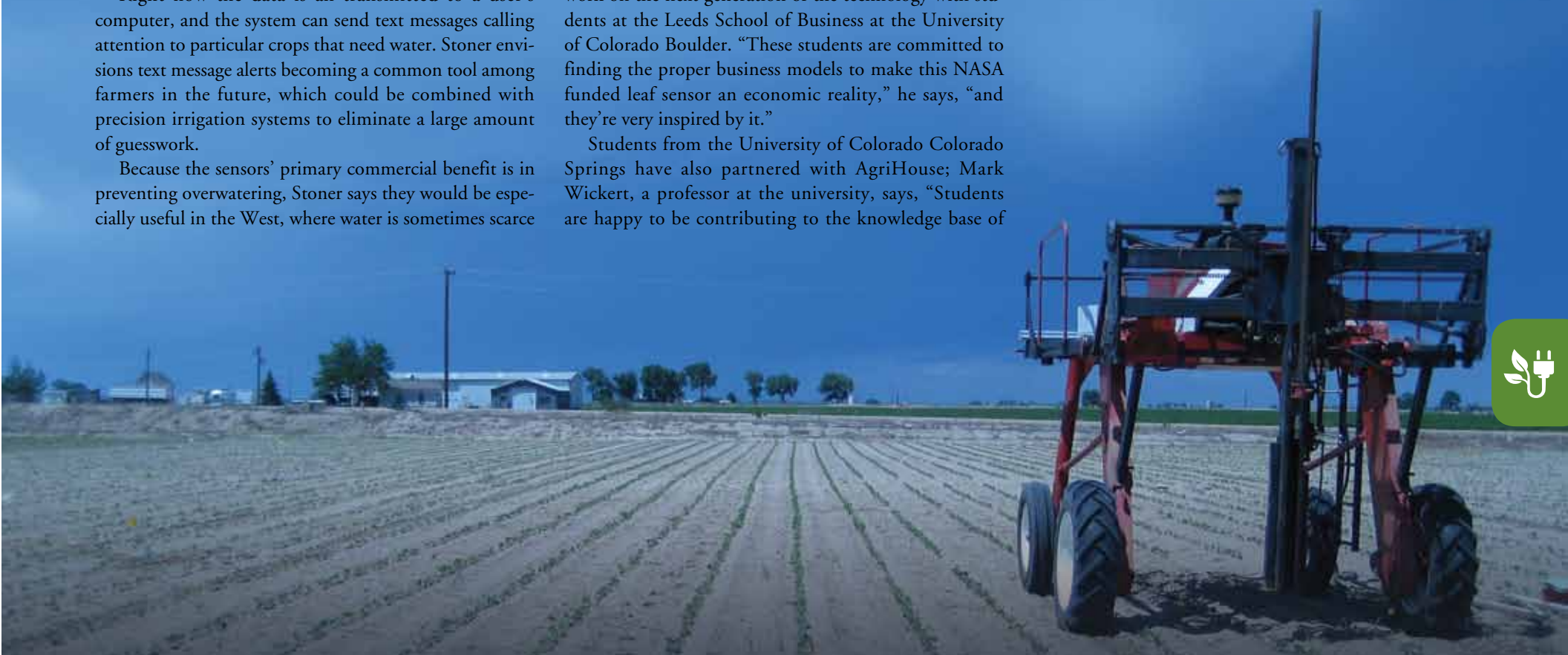
and farmers rely on underground aquifers to meet their needs. “This technology has the potential to reduce water spending in agricultural applications substantially,” says Seelig, now a professor in Germany. “The importance of this becomes clear when one considers the relative scarcity of irrigation water in many places in the United States and worldwide. Imagine the reduction in consumption that would be possible if our greenhouse results were extrapolated to the rest of the world.”

The spinoff has also given Stoner an opportunity to work on the next generation of the technology with students at the Leeds School of Business at the University of Colorado Boulder. “These students are committed to finding the proper business models to make this NASA funded leaf sensor an economic reality,” he says, “and they’re very inspired by it.”

Students from the University of Colorado Colorado Springs have also partnered with AgriHouse; Mark Wickert, a professor at the university, says, “Students are happy to be contributing to the knowledge base of

what NASA originally funded. They fully understand the implications of the leaf sensor technology in addressing the world’s food and fresh water problems.”

Whether or not AgriHouse’s sensors ever make it to low Earth orbit and beyond, this NASA-derived technology is likely to be employed on Earth to conserve resources, save money, and put farmers in closer contact with the crops they grow. ❖



In a partnership with the United States Department of Agriculture, AgriHouse conducted the first large-scale test of its leaf sensors on the field shown here. To Richard Stoner’s surprise, the plants were actually overwatered during the test—information that only came to light thanks to the sensors. The technology could have an impact in the West, where water use is closely monitored.

Efficient Cells Cut the Cost of Solar Power

NASA Technology

If you visit Glenn Research Center, you might encounter a photovoltaic (PV) array that looks unlike anything you've ever seen. In fact, what one would normally identify as the panel is actually a series of curved mirrors called solar concentrators, engineered to reflect sunlight rather than absorb it.

These concentrators gather, intensify, and focus sun beams upward, aiming at a fixture containing specialized silicon concentrated PV chips—the actual solar cells. If you stay by the array for a while, you'll notice that the solar concentrators follow the path of the sun throughout the day, changing position to best capture and utilize the sunlight.

The specialized chips that make the technology possible are the brainchild of Bernard Sater, an engineer who had worked at Glenn since the early 1960s before retiring to pursue his unique ideas for harnessing solar power.

Sater contributed to multiple PV projects in the latter part of his career at the Center, including research and development on the International Space Station's solar arrays. In his spare time, he enjoyed tinkering with new approaches to solar power—experiments that resulted in the system installed at Glenn today.

Sater's basic idea had two components. First, he wanted to create a silicon cell that was smaller, more efficient, and much lower cost than those available at the time. To ensure that the potential of such a chip could be realized, he also planned on pairing it with a system that could concentrate sunlight and focus it directly on the cell.

When he retired from Glenn in 1994 to focus on researching and developing the technology full time, Sater found that NASA was interested in the concept and ready to provide funding, facilities, and expertise in order to assist in its development.

Technology Transfer

Sater's first set of Space Act Agreements with Glenn resulted in the development of what is today the PhotoVolt cell: a silicon chip many times smaller than those employed in conventional solar technology—each array of miniature cells is about the size of a thumb nail. At the time, no standards existed to test high intensity solar cells, so Sater worked with NASA scientists to develop test methods in Glenn's world-class facilities.

All the while, Sater's progress was supported by his son, Neil. Although Neil was employed at Intel at the time, he worked with his father in his spare time to develop the technology. With PhotoVolt in place, Neil and Bernard became convinced that it was time to move toward commercialization. Says Neil, "What we decided in 2007, when I decided to go full time, is that we needed to develop the whole solution. We had this chip, so next we needed a concentrator that the chips could go in."

The two formed Oberlin, Ohio-based GreenField Solar Inc. and began assembling a team and raising money—all while continuing to develop the technology under ongoing Space Act Agreements with Glenn. Their solar concentrator concept soon became the StarGen system, which features parabolically shaped mirrors designed for use with the PhotoVolt cell.

The partnership between Greenfield Solar and Glenn has reaped rewards for both parties. NASA has received access to the unique chip, which has played a role in multiple space missions, and GreenField Solar has refined its solar concentrator system. "The facilities and expertise at Glenn have been essential to solving numerous technical issues," says Neil.

In 2008, Glenn purchased and installed two StarGen solar concentrators for research and testing, as well as

GreenField Solar's StarGen system uses a tracking system to follow the path of the sun, which the parabolic mirrors concentrate into a small area. The system is approximately 20 percent more efficient than conventional solar panels.





PhotoVolt cells can generate grid-scale solar power at a lower cost per kilowatt-hour than most existing PV systems.

to demonstrate the cutting-edge solar technology at the Cleveland facility. Roshanak Hakimzadeh, deputy chief technologist at Glenn, points to GreenField Solar as an example of how beneficial the Agency's partnerships can be for everyone involved. "GreenField Solar's founders were able to work closely with experts in the field at Glenn, which contributed to the success of the company. This technology represents a successful partnership between NASA and the commercial sector."

Benefits

Whereas conventional solar cells lay flat and passively collect sunlight, the StarGen solar concentrators ensure that the PhotoVolt cells receive as much intensified light as possible, all day. Between the sunlight being intensified by mirrors—hundreds of times stronger than normal—and the efficiency of the PhotoVolt cell, Neil says that the StarGen system is able to provide about 200 times more power than conventional panels for a given amount of silicon.

Bernard says it's the smaller size of the PhotoVolt cell that reduces costs and gives GreenField Solar its competitive edge. "The majority of the market is large panels of

silicon. The problem is that silicon is relatively expensive, especially compared to glass. So we take all of that silicon and shrink it down to just a little chip, and then we concentrate the light so that we produce more power using much less silicon."

The intensity of the system produces an excess of thermal energy, which Neil says can be put to creative secondary uses. At Glenn, for example, NASA originally planned on using that energy to heat a nearby conference room. And currently on another site, a greenhouse stationed next to the panels is being kept warm with the superfluous heat.

Solar power may be a renewable, clean, zero-emission energy source, but it still occupies only a small portion of the total market for energy. Neil sees GreenField Solar's technology as having the potential to change that in the long run by making solar power less expensive even than fossil fuels and nuclear power. "Our mission is to move solar into mainstream deployment. When you drive around, you rarely see solar panels—in fact, you really notice them when you see them, because they're so rare. We want to make them ubiquitous."

After spending many years developing the technology, in large part through its partnership with NASA, GreenField Solar is now making its system commercially available in 2012. The company is also focusing globally, with strong connections in Asia. While the technology itself was developed by the company, Neil emphasizes that NASA's support was essential to their success in bringing it to the point of commercialization.

"Right now we have 30 employees, and it'll be a lot higher in the future," he says. "Essentially, these jobs exist because of NASA's investment in this technology. We wouldn't have been able to raise the funds we've raised or position ourselves the way we have without NASA's support." ❖

PhotoVolt™ is a registered trademark of GreenField Solar.
StarGen™ is a registered trademark of GreenField Solar.



GreenField Solar's concentrators produce an excess of thermal heat that can be used for secondary purposes, such as heating nearby buildings or even greenhouses.



Shuttle Topography Data Inform Solar Power Analysis

NASA Technology

The next time you flip on a light switch, there's a chance that you could be benefitting from data originally acquired during the Space Shuttle Program. An effort spearheaded by Jet Propulsion Laboratory (JPL) and the National Geospatial-Intelligence Agency (NGA) in 2000 put together the first near-global elevation map of the Earth ever assembled, which has found use in everything from 3D terrain maps to models that inform solar power production.

For the project, called the Shuttle Radar Topography Mission (SRTM), engineers at JPL designed a 60-meter mast that was fitted onto Shuttle Endeavour. Once deployed in space, an antenna attached to the end of the mast worked in combination with another antenna on the shuttle to simultaneously collect data from two perspectives. Just as having two eyes makes depth perception possible, the SRTM data sets could be combined to form an accurate picture of the Earth's surface elevations—the first high-detail, near-global elevation map ever assembled.

What made SRTM unique was not just its surface mapping capabilities but the completeness of the data it acquired. Over the course of 11 days, the shuttle orbited the Earth nearly 180 times, covering everything between the 60° north and 54° south latitudes, or roughly 80 percent of the world's total landmass. Of that targeted land area, 95 percent was mapped at least twice, and 24 percent was mapped at least four times.

Following several years of processing, NASA released the data to the public in partnership with NGA. Robert Crippen, a member of the SRTM science team, says that the data have proven useful in a variety of fields. "Satellites have produced vast amounts of remote sensing data, which over the years have been mostly two-dimensional. But the Earth's surface is three-dimensional. Detailed topographic data give us the means to visualize and analyze remote sensing data in their natural three-dimensional structure, facilitating a greater understanding of the features and processes taking place on Earth."

Technology Transfer

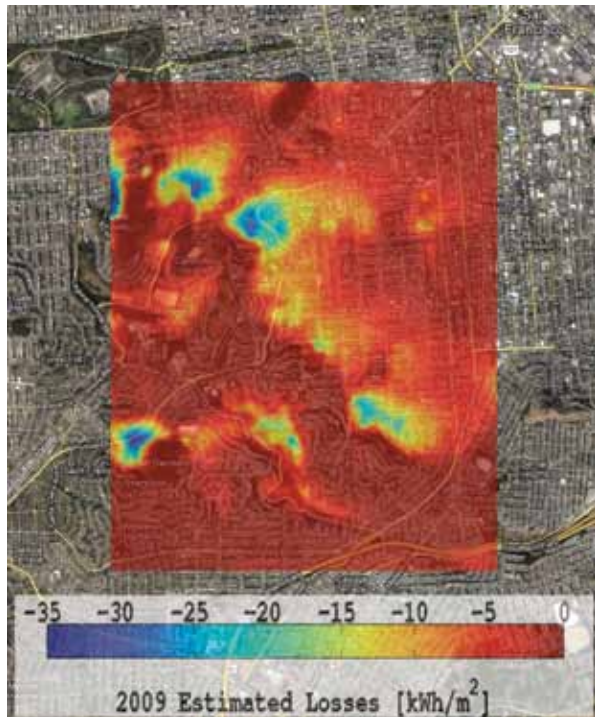
Seeing the potential for elevation data to play a role in solar power modeling and planning, the California Public Utilities Commission asked Jan Kleissl, a professor of environmental engineering at the University of California San Diego, to use the SRTM data to build models showing how much shade an area on the ground receives given its horizon—that is, to what degree nearby terrain (such as a large hill) blocks out the sun during the day.

By identifying places prone to long periods either with or without direct sunlight, Kleissl's data can assist people who are planning to build solar installations. "What we did was take the data and postprocess it, analyzing the elevations to simulate what the horizon would be for any place on the map," says Kleissl. Horizon modeling proved a resource-consuming task, he says. "It's a different metric than elevation, because you have to relate a given point to all of its surroundings."



But with the modeling done, multiple parties expressed interest in the resulting product. “We weren’t the first ones to do this analysis,” says Kleissl, “but we were the first ones to do it on a large spatial area. We’ve covered the whole of Southern California and parts of the Bay Area. All of that is now a publicly available data set that we provide to anyone who is interested.”

Among the companies who acquired Kleissl’s data was New York City-based Locus Energy LLC. Locus Energy provides technology for analyzing and monitoring distributed solar installations; it offers historical, real-time, and forecasting information that helps power providers plan for and predict solar power production. The company



SRTM data helped construct shading models that can be overlaid on a Google Maps interface.

In nearly 180 orbits over 11 days, Shuttle Endeavour imaged more than 80 percent of the world’s landmass.

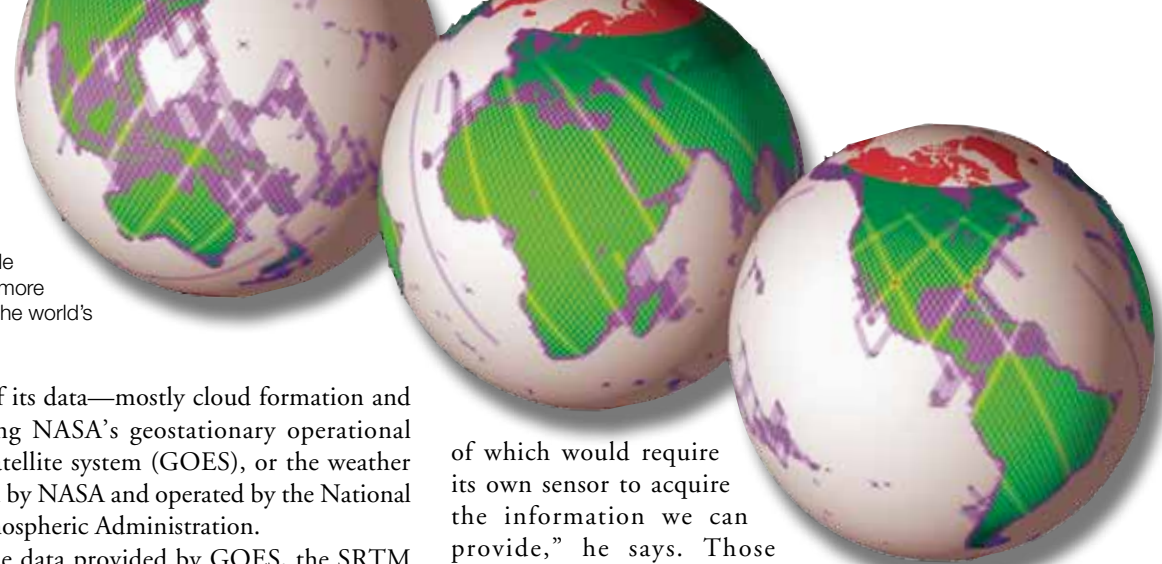
draws the bulk of its data—mostly cloud formation and movement—using NASA’s geostationary operational environmental satellite system (GOES), or the weather satellites designed by NASA and operated by the National Oceanic and Atmospheric Administration.

Along with the data provided by GOES, the SRTM data that has been processed by Kleissl helps Locus Energy accurately determine how much solar energy is reaching a given location. Says Shawn Kerrigan, CTO of Locus Energy, “We combine these two data sets to model how much solar irradiance is hitting a particular location. The understanding that we’re developing with the help of NASA data, integrated with some of the knowledge and expertise we have, gives us some interesting insights into how much power is produced at distributed solar installations.”

Benefits

Locus Energy’s NASA-derived services have been incorporated into its Virtual Irradiance project—a software package that can estimate solar irradiance without the need for a physical sensor. “We deal with a lot of small- to mid-sized solar installations in distributed solar space,” says Kerrigan. “In order to understand how well their equipment is performing, these companies would otherwise have to install a sensor at each site. But it’s often prohibitively expensive to do so.”

As Kerrigan likes to say, Locus Energy “replaces expensive hardware with smarter software,” potentially bringing down the cost of solar energy as a whole. The savings offered merely by replacing those sensors with software is significant: Kerrigan says that a typical sensor might cost about \$1,000 on average. “Our fleet consists of more than 130,000 monitored nodes, each



of which would require its own sensor to acquire the information we can provide,” he says. Those savings only reflect the initial cost of purchasing sensors; companies stand to save even more in ongoing operation and maintenance costs.

According to the company, each set of data—historical, real-time, and forecasting—has a different value proposition. The historical data provides a basis for “solar prospecting,” or the process of determining which location would be most effective for deploying a solar system. Virtual Irradiance’s forecasting models use current cloud formation to develop a forward-looking picture of what cloud cover will be like to develop an accurate estimate of solar resource availability for the near future.

Kerrigan credits NASA’s SRTM and GOES data as an essential piece of what Locus Energy offers. “It’s fundamental to the modeling we’re doing. Without it, we literally would not be able to do our forecasting work,” he says. “And the same thing applies to the real-time and historical data we do. Without NASA data, we would have to rely on other weather models that are less effective. NASA’s technology is at the core of our technology.” ❖

Virtual Irradiance™ is a trademark of Locus Energy LLC.



Photocatalytic Solutions Create Self-Cleaning Surfaces

NASA Technology

Hazy smog over cities and smoke pouring from the stacks of factories and power plants are visible reminders of the threat posed by air pollution to the environment and personal health. But air quality is often an unseen influence on our lives. Even on clear days, the air can be rife with particulate matter and other irritants that can trigger everything from minor allergies to life-threatening asthma attacks and other respiratory ailments. Indoors—where we spend as much as 90 percent of our time—pollutant levels can be 2–50 times higher than outdoors. The World Health Organization estimates that urban outdoor air pollution causes 1.3 million deaths worldwide per year, while in developing countries, indoor air pollution causes an estimated 2 million premature deaths.

Fortunately, there may be an equally invisible solution for reducing the damage air pollution causes—not only to people, but to buildings and infrastructure as well.

NASA has explored the beneficial applications of a process called photocatalysis for use both in space and on Earth. Photocatalysis is essentially the opposite of



NASA has explored photocatalytic technologies as a means for keeping space environments such as the International Space Station clean.

photosynthesis, the process used by plants to create energy. In photocatalysis, light energizes a mineral, triggering chemical reactions that result in the breakdown of organic matter at the molecular level, producing primarily carbon dioxide and water as byproducts.

NASA has studied the benefits of photocatalysis for purifying water during space missions, and plant growth chambers featuring photocatalytic scrubbers have flown on multiple NASA missions, using the photocatalytic process to preserve the space-grown crops by eliminating the rot-inducing chemical ethylene. (The scrubber technology resulted in a unique air purifier, featured in *Spinoff* 2009, now preserving produce and sanitizing operating rooms on Earth.)

Lauren Underwood, a senior research scientist at Stennis Space Center, began studying photocatalytic materials as part of a NASA partnership with the US Department of Homeland Security, which was investigating the materials for multiple applications, including protecting infrastructures against terrorism threats. From NASA's perspective, Underwood explains, "We don't want to introduce anything into space that could be potentially harmful. This is a future promising application of these materials—to keep surfaces not only clean, but potentially germ free."

Intrigued by the technology's potential, Underwood saw a way for photocatalytic materials to provide benefits for NASA on Earth, as well.

"At Stennis, we have a lot of buildings and facilities that are primarily white, and there are maintenance costs associated with keeping these buildings clean," Underwood says. She began testing photocatalytic materials as a valid solution for reducing these maintenance costs—with an eye not only for potential NASA benefits, but for the greater public as well.

Technology Transfer

Among the technologies selected for Underwood's research were those developed by New York City's

PURETi Inc., a company that had created a new approach to titanium dioxide-based photocatalysis. (Titanium dioxide, a common compound found in everything from paint to suntan lotion to food coloring, acts as a photocatalyst when exposed to ultraviolet light.) Common methods of incorporating titanium dioxide involve melting or mixing the compound into building materials, or applying it with solvent-based carriers like paint. With these methods, however, the nanoparticles of titanium dioxide clump together, reducing their exposed surface area and thus their exposure to light. Much of the compound ends up buried in the building material, providing no benefit.

PURETi (pronounced "purity") devised a liquid-based method of growing nanocrystals of highly photoactive titanium dioxide, which are suspended in a highly adhesive and durable water-based solution. To study the effectiveness of the technology, Underwood applied PURETi's solution to building surfaces at Stennis and monitored any changes through standard photography as well as remote sensing technology that measured the surfaces' spectral reflectance—how much they reflect light.

"Not only did the photographs show that the coated surfaces maintained the clean, white state seen when they were initially painted, from an analytical perspective, it was also demonstrated that the surfaces that were photocatalytically coated maintained higher reflectance values, when compared to the uncoated surfaces," Underwood says, implying that there is less dirt build up on the photocatalytically treated surfaces. "I was very pleased with the outcome. It's exciting that there is a nontoxic mechanism to keep buildings clean and at the same time reduce maintenance costs, energy costs, and the use of harsh chemicals."

Through its participation in Underwood's research, PURETi became a NASA Dual Use Technology partner, a cost-sharing collaboration aimed at the development of products that meet both NASA and commercial needs.

Benefits

PURETi now offers a range of nontoxic, environmentally sound commercial photocatalytic formulations designed to transform nearly any surface—from buildings to textiles to glass—into a self-cleaning air purifier. One spray application of the photocatalytic solution breaks down organic pollutants, keeps surfaces clear of grime and mold, and purifies surrounding air for at least 3 years.

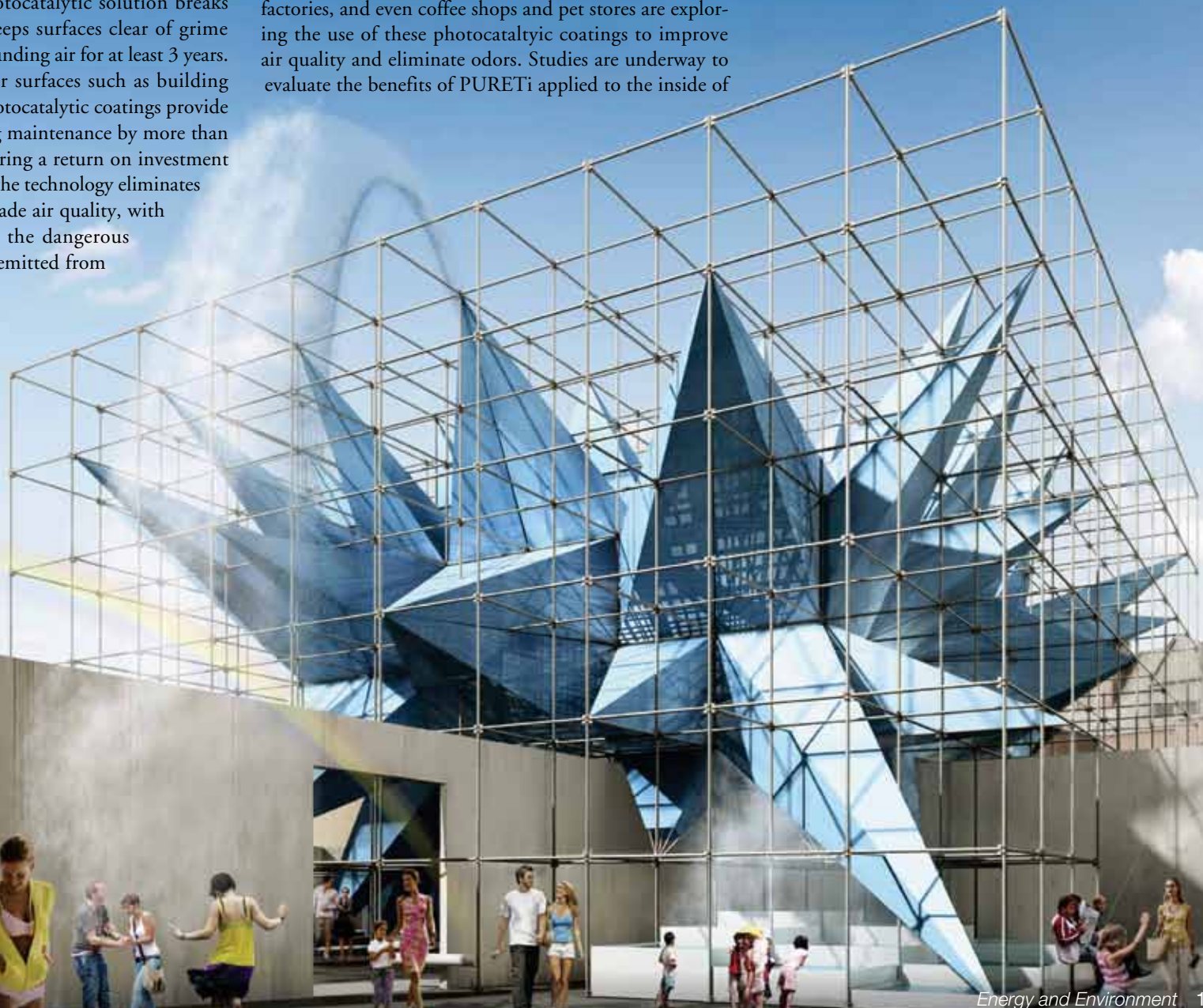
When applied to outdoor surfaces such as building facades, these proprietary photocatalytic coatings provide extensive savings by reducing maintenance by more than 50 percent and typically offering a return on investment in less than 2 years. Indoors, the technology eliminates odors and creates hospital-grade air quality, with an 85 percent reduction in the dangerous volatile organic compounds emitted from

some paints, new furniture and carpets, and photocopy machines and other office equipment.

PURETi's innovation is now being applied by manufacturers of textiles, porcelain tiles, and home furnishings, with expectations to expand into the glass, precast concrete, and roofing membrane industries. Schools, hotels, factories, and even coffee shops and pet stores are exploring the use of these photocatalytic coatings to improve air quality and eliminate odors. Studies are underway to evaluate the benefits of PURETi applied to the inside of

animal barns; previous research indicates that livestock breathing cleaner air grow faster with less food and require less need for antibiotics and steroids. Roads coated with PURETi act as effective depolluters, according to university studies.

This sculpture—called *Wendy* and coated with PURETi's technology—became the world's most unusual air purifier during the summer of 2012.





PURETi's photocatalytic solutions keep building surfaces (left, with the treated segment on the left), solar panels (above, with treated cells in the foreground), and windows (right, with treated windows toward the middle) free of grime—reducing maintenance costs, increasing efficiency, and providing all of these surfaces with air purifying capabilities.

A number of projects are also testing the ability of PURETi's solutions to keep solar panels clean for longer, improving their efficiency. The company even collaborated with an architectural firm to transform the firm's massive modern art sculpture—called Wendy and on display at the Museum of Modern Art's Queens, New York, campus in 2012—into perhaps the world's most unusual air purifier.

"The applications are virtually endless," says Glen Finkel, PURETi's president. "There is no surface that light can reach that PURETi can't enhance."

While photocatalysis is well known in Japan and Europe, PURETi's mission, Finkel says, is to gain traction for its unique version of the technology as a real answer to air quality issues in the United States. With the help of its NASA collaboration, PURETi is seeing ongoing returns on its efforts. The company's technology has won mul-

multiple awards, including the *Popular Science* Green Tech 2011 Innovative Product of the Year and the Material of the Year Award from Material ConneXions. One of the company's customers, the Asthma and Allergy Prevention Company, recently received Class II Medical Device approval from the Federal Drug Administration for its protocol—centered on PURETi's technology—that creates hospital-grade pure air environments in homes to prevent respiratory problems for cystic fibrosis patients. And a Yale University team is set to study PURETi as a means for enhancing infection control in rural health clinics in developing countries.

"We all love innovation," Finkel says. "But you can only have innovation if someone has the guts to go first. We will forever be indebted to NASA for taking us seriously, for engaging with us as a Dual Use Technology partner. We have this technology that sounds too good to

be true. Our challenge is to raise awareness in a credible way, and the involvement with NASA lends support to our credibility."

At Stennis, Underwood is continuing to explore the full potential of PURETi's technology, with an additional study set to begin using the new INFINITY at NASA Stennis Space Center as a testbed. Partnerships like the one between NASA and PURETi are a key driver of innovation, says Underwood, who says she is always looking for ways to help NASA give back to the taxpaying public.

"You can't do everything by yourself," she says. "It's a combination of expertise and skill sets that helps bring things to fruition." ❖

INFINITY® is a registered trademark of the nonprofit 501(c)(3) Board of Directors, INFINITY Science Center Inc.

“We all love innovation, but you can only have innovation if someone has the guts to go first.”

—Glen Finkel, PURETi Inc.



Stennis Space Center's new INFINITY Science Center not only inspires learning in the science, technology, engineering, and math disciplines, but will serve as the site of ongoing research on PURETi's photocatalytic technologies. For a deeper look at INFINITY, scan this code.

Concentrators Enhance Solar Power Systems

NASA Technology

“Right now, solar electric propulsion is being looked at very seriously,” says Michael Piszczor, chief of the photovoltaic and power technologies branch at Glen Research Center. The reason, he explains, originates with a unique NASA mission from the late 1990s.



Deep Space 1 was a spacecraft designed to test a dozen different space technologies, including a solar array that focused sunlight on a smaller solar cell to generate electric power.

In 1998, the Deep Space 1 spacecraft launched from Kennedy Space Center to test a dozen different space technologies—including SCARLET, or the Solar Concentrator Array with Refractive Linear Element Technology. As a solar array that focused sunlight on a smaller solar cell to generate electric power, SCARLET not only powered Deep Space 1’s instruments but also powered its ion engine, which propelled the spacecraft throughout its journey.

Deep Space 1 was the first spacecraft powered by a refractive concentrator design like SCARLET, and also utilized multi-junction solar cells, or cells made of multiple layers of different materials. For the duration of its 38-month mission, SCARLET performed flawlessly, even as Deep Space 1 flew by Comet Borrelly and Asteroid Braille.

“Everyone remembers the ion engine on Deep Space 1, but they tend to forget that the SCARLET array powered it,” says Piszczor. “Not only did both technologies work as designed, but the synergy between the two, solar power and propulsion together, is really the important aspect of this technology demonstration mission. It was the first successful use of solar electric propulsion for primary propulsion.”

More than a decade later, NASA is keenly interested in using solar electric propulsion (SEP) for future space missions. A key issue is cost, and SEP has the potential to substantially reduce cost compared to conventional chemical propulsion technology.

“SEP allows you to use spacecraft that are smaller, lighter, and less costly,” says Piszczor. “Even though it might take longer to get somewhere using SEP, if you are willing to trade time for cost and smaller vehicles, it’s a good trade.”

Potentially, SEP could be used on future science missions in orbit around the Earth or Moon, to planets or asteroids, on deep space science missions, and even on exploration missions. In fact, electric propulsion is already being used on Earth-orbiting satellites for positioning.

Technology Transfer

Developed through a partnership between NASA’s Glenn Research Center and Fort Worth, Texas-based ENTECH Inc. (now Entech Solar), SCARLET originated from Small Business Innovation Research (SBIR) contracts that started in 1985. The partners’ purpose was to adapt Entech’s existing terrestrial solar concentrator technology, already demonstrated on Earth, for space applications. The Ballistic Missile Defense Organization was also a supporter and contributor to the work.

“At that time, concentrators were being looked at for space, but most were reflective systems that used mirrors to reflect light and focus it on a small point,” says Piszczor. “Entech’s design uses a unique refractive concept.”

The concentrating lens of Entech’s design had a curved outer surface with Fresnel patterns, or grooves, on the inside. It makes the most use of available sunlight and focuses the light onto multi-junction solar cells. According to Piszczor, a main advantage of Entech’s technology is its optical performance and shape error tolerance. This translates to a concentrator design that has high optical efficiency, can be readily manufactured, and is less sensitive to thermal and structural distortions.

“The overall design hits a sweet spot,” says Piszczor. “It’s both high performance and easily manufactured.”

After SCARLET, Entech and NASA continued to work through the SBIR program, along with the Department of Defense, to develop a lightweight version of the same technology called the Stretched Lens Array (SLA). The SLA replaces the top glass surface used in the SCARLET lens design with a stretched thin film lens to concentrate sunlight onto photovoltaic cells below the lens. Compared to the SCARLET design, the SLA technology minimized mass and cost even further.

Entech’s CEO, David Gelbaum, says multi-junction cells are extremely efficient under Entech’s color-mixing, arched Fresnel lenses, thanks to how they concentrate

more light on the cells and how they distribute the full-spectrum of sunlight onto the cells. The bigger advantages of the technology, however, are the cost, weight, and robustness. “By using only one-eighth as much solar cell area per Watt of array power, we save cost and weight and make it possible to better insulate and shield the smaller solar cells,” he says.

Entech has now taken its knowledge from working with Glenn over the last 25 years and incorporated it into a new ultra-light solar concentrator for terrestrial applications. In 2012, the technology won an R&D 100 Award, recognizing it as one of the top 100 technologically significant new products of 2012 by *R&D Magazine*.

Benefits

Entech’s new product, SolarVolt, is a concentrating photovoltaic solar module that incorporates a significant amount of technology from the SLA. “While the SLA was primarily optimized to save mass because launching into space is so expensive, SolarVolt is optimized to save cost because the terrestrial market is so cost-competitive,” says Gelbaum.

For space, the company uses multi-junction solar cells with lenses made of space-qualified silicone rubber. For terrestrial applications, Entech uses low-cost silicon cells under acrylic plastic lenses. Because the space version does not need to resist wind and hail, there is no lens cover; SolarVolt uses a tempered glass window to protect the lenses and cells.

On Earth, SolarVolt can be used to generate electricity for applications from a fraction of a megawatt to multimewatt systems. Commercial applications include utility-scale power plants, distributed energy for smart grid systems, communications systems, industrial building power systems, and government and military power systems.

The technology is most productive in areas with high, continuous direct normal irradiation, or DNI, which comes directly from the sun. High DNI areas in

the United States include southern California, Arizona, Nevada, New Mexico, west Texas, and Colorado. As Gelbaum describes, “SolarVolt is primarily aimed at large utility-scale solar power plant applications in the sunny desert regions.”

In 2011, SolarVolt received international certification designating it has met concentrating PV module testing and construction evaluation requirements to verify its performance and reliability in hail, extreme temperatures, and wet and dry conditions.

Even as the SLA spins off for terrestrial use, NASA continues to improve it for use in space. Glenn is now partnering with Deployable Space Systems, Inc. to fuse Entech’s SLA concentrator with a lightweight, deployable structural platform called SOLAROSA, or the Stretched Optical Lens Architecture on Roll-Out Solar Array. Ad Astra Rocket Co. is interested in using SOLAROSA to support



Entech’s SolarVolt product, incorporating NASA technology, can be used to generate electricity for utility-scale power plants, communication systems, and government and military power systems. It is most productive in sunny desert regions like Nevada.

its Variable Specific Impulse Magnetoplasma Rocket engine, an advanced plasma propulsion system.

Thanks to such public-private partnerships, the future is bright where solar electric power is concerned—both on the ground and in space. “Collaborating with NASA has not only helped us to improve and refine our space and ground solar power technologies, but has helped Entech gain credibility for its technology,” says Gelbaum. “NASA is a terrific partner for small businesses like us.” ❖

SolarVolt™ is a trademark of Entech Solar.



Innovative Coatings Potentially Lower Facility Maintenance Costs

NASA Technology

NASA's Stennis Space Center is located on 13,500 acres in Hancock County, Mississippi, surrounded by another 125,000 acres that act as a buffer for the deafening roar of rocket engines. It has witnessed the flame and smoke spout from the Saturn V rockets that would carry astronauts to the Moon for the first time, and the space shuttle main engines that would carry them into space more often than any other. More recently, it has hosted the testing of the J-2X engine belonging to the upper stage of NASA's Space Launch System—technology that will power manned spaceflight during a new era of exploration beyond Earth's orbit.

Stennis has played a vital role in NASA's greatest missions and continues to be one of the Agency's key contributors to aerospace innovation. Over the years, the Center has become a hotbed of collaboration between Government and industry, with organizations such as the Mississippi Enterprise for Technology on site, as well as over 30 companies and Government agencies, driving research and development in space, environmental studies, national defense, and more. The Center is also an Agency and national leader in remote sensing—gathering information without physical contact, as from a satellite.

Often, NASA's unique facilities and the world-class expertise of its scientists provide benefits outside of the Agency, helping innovators in industry and academia in ways only the Space Program can. In the case of Stennis, the Center that is NASA's testbed for rocket engine technology is now also—thanks to an enterprising researcher and a private industry partnership—a testbed for a product that seems “too good to be true.”

Technology Transfer

NASA and Stennis senior research scientist Lauren Underwood, working in partnership with the US Department of Homeland Security (DHS), investigated an intriguing class of materials called photocatalytic

compounds. When light strikes these compounds, it triggers chemical reactions that break down organic matter—including air pollution, soot, and even potentially dangerous microbes—breaking down these organics into primarily carbon dioxide and water.

While the DHS was studying the materials for national security applications, such as preserving infrastructure against terrorist threats, Underwood saw remarkable potential for NASA applications in space and on the ground. At Stennis, a number of buildings and facilities would benefit from a photocatalytic coating that would eliminate the buildup of grime, reducing the Center's maintenance costs. In space, the material's antimicrobial qualities could prove useful for preserving clean, germ-free environments onboard spacecrafts, as well as the

International Space Station. But first, Underwood wanted to comprehensively evaluate and validate the technology's capabilities.

“There is a lot of exciting information that is available and laboratory work that has been conducted on photocatalytic coatings, but not a lot of real-life application research,” she says. “We are working to help validate that these materials are performing the way they are described to perform. It is almost as if they seem too good to be true. If they are so simple and safe, how can they work?”

Underwood led a NASA-funded study of commercial photocatalytic solutions, employing tests ranging from a photographic time series of coated and uncoated surfaces to reflectance measurements utilizing Stennis' technical expertise in remote sensing.



Stennis Space Center is the premier rocket engine test facility in the Nation. All three of the Center's test complexes—the E Test Complex (foreground), the three A Test Complex stands (middle) and the B Test Complex (back) are visible in this aerial photo.



Nanocept's versatile spinoff technology can break down noxious gasses released by new carpeting in homes, destroy microbes responsible for hospital-acquired infections, and help keep buildings free of grime.

One of the solutions tested came from Lexington, Kentucky-based Nanocept Inc. A young company eager to bring a technology popular in Japan to a level of equal recognition in the United States, Nanocept leapt at the chance to partner with NASA.

"NASA's strengths are in R&D and technology trends. Since we had a good relationship with manufacturers and developers from Japan, we had the knowledge that Stennis was looking for about the commercial technology, its availability, and which products are best suited for which type of application," says Balaji Vatsavaya, Nanocept's president. "Every time we've been to Stennis, it has been a success. It has been a very good partnership."

Underwood was impressed with the results from the photocatalytic coatings provided by Nanocept, noting that they performed at a "superior" level. Surface feature evaluations using scanning electron microscopy to assess coating surface coverage and topology characteristics demonstrated that upon application, the test surfaces remained smooth and largely free of cracking which enables the coatings to perform effectively by maximizing the photocatalytic surface area exposed to light. Additionally, once applied to building surfaces outside, over time, the coatings maintained the initial cleanliness of the test surfaces.

Nanocept's participation in the Stennis study resulted in the company becoming a NASA Dual Use Technology

partner, and the company is now working to build on the validation the collaboration has provided.

"We don't have access to the kinds of test equipment, facilities, and engineering skills that an agency like NASA has," says Vatsavaya. "It gives the credibility the technology needs. From an international point of view, me testing it in my lab just isn't the same as NASA testing it."

Benefits

Nanocept's commercially available, water-based coatings contain titanium dioxide, a powerful photocatalytic element that, when exposed to light, can decompose almost all organic pollutants, destroy many microbes, and eliminate noxious compounds such as ammonia. These capabilities allow the technology to provide a range of benefits in a safe, environmentally friendly way.

First, the coatings are self-cleaning, explains Vatsavaya. They have super-hydrophilic qualities that, during a rain or with a simple spray of water creates a sheeting action, which causes the water not to bead, enabling the easy washing away of any grime and preventing buildup. Even 5–7 years after an application of the material, surfaces remain cleaner than uncoated surfaces. "On bigger buildings, this means a huge reduction in maintenance costs," Vatsavaya says.

In hospitals, Nanocept's products provide an additional benefit: combating bacteria. Studies have shown

tens of thousands of deaths occur each year as a result of hospital-acquired infections. Vatsavaya notes that the coatings decompose 99.99 percent of microbes such as *E. coli* and MRSA, as well as the poisonous endotoxins some of these bacteria can release—thus reducing the chance of life-threatening infections contracted in operating rooms and other hospital areas.

In new buildings, these solutions can break down the volatile organic compounds (VOCs), such as formaldehyde, that can be emitted from building materials, new carpets, and paints. These VOCs have been shown to have damaging health effects when present in high enough quantities. "As long as there is enough light for it to react, these photocatalytic coatings can decompose those toxic compounds," says Vatsavaya. The reduction of air pollution such as car exhaust and even cigarette smoke are other applications in which the materials can provide significant benefit, he explains.

This technology is currently attracting attention and is engaged in further testing both in the United States and internationally. Vatsavaya says more still needs to be learned before the full potential of his company's products can be unlocked, and he feels Nanocept's NASA partnership holds the key.

"In every area we've worked with NASA, the results have been promising," he says. ❖

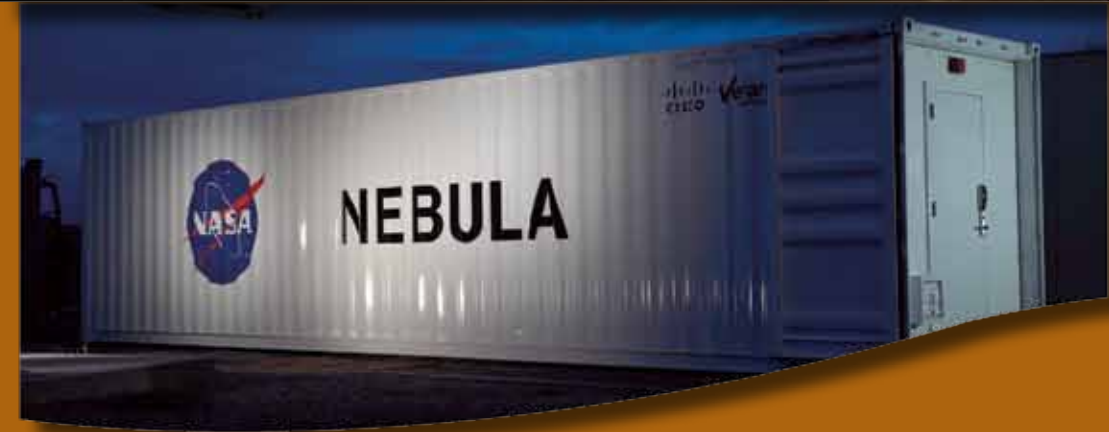




Information Technology

Complex computer technologies are at the core of many NASA missions. On Earth, these technologies transfer to the public to provide benefits ranging from cloud computing innovations to methods for preserving the contents of ancient texts. The spinoffs in this section:

- Expand Aircraft Design Options
- Inspire Cloud Computing Platforms
- Strengthen Nanoelectronics
- Secure Electronics in Harsh Environments
- Identify Faults Prior to Failure
- Preserve Essential Historical Records



Simulation Packages Expand Aircraft Design Options

NASA Technology

When engineers explore designs for safer, more fuel efficient, or faster aircraft, they encounter a common problem: they never know exactly what will happen until the vehicle gets off the ground.

“You will never get the complete answer until you build the airplane and fly it,” says Colin Johnson of Desktop Aeronautics. “There are multiple levels of simulation you can do to approximate the vehicle’s performance, however.”

When designing a new air vehicle, computational fluid dynamics, or CFD, comes in very handy for engineers. CFD can predict the flow of fluids and gasses around an object—such as over an aircraft’s wing—by running complex calculations of the fluid physics. This information is helpful in assessing the aircraft’s aerodynamic performance and handling characteristics.

In 2001, after several years of development, NASA released a new approach to CFD called Cart3D. The tool provides designers with an automated, highly accurate computer simulation suite to streamline the conceptual analysis of aerospace vehicles. Specifically, it allows users to perform automated CFD analysis on complex vehicle designs. In 2002, the innovation won NASA’s Software of the Year award.

Michael Aftosmis, one of the developers of Cart3D and a fluid mechanics engineer at Ames Research Center, says the main purpose of the program was to remove the mesh generation bottleneck from CFD. A major benefit of Cart3D is that the mesh, or the grid for analyzing designs, is produced automatically. Traditionally, the mesh has been generated by hand, and requires months or years to produce for complex vehicle configurations. Cart3D’s automated volume mesh generation enables even the most complex geometries to be modeled hundreds of times faster, usually within seconds. “It allows a

novice user to get the same quality results as an expert,” says Aftosmis.

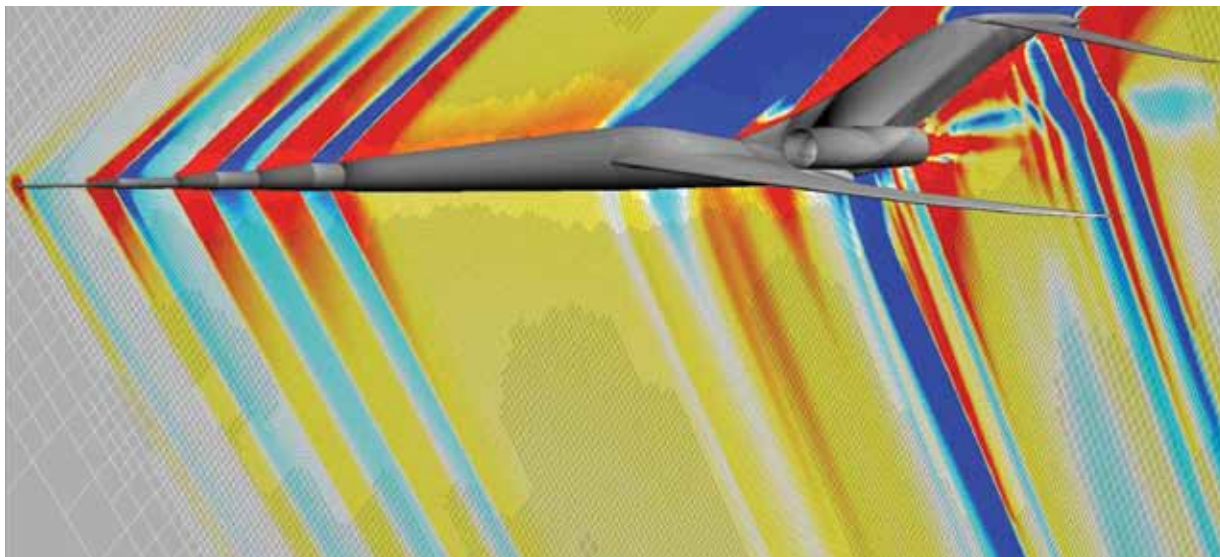
Now, a decade later, NASA continues to enhance Cart3D to meet users’ needs for speed, power, and flexibility. Cart3D provides the best of both worlds—the payoff of using a complex, high-fidelity simulation with the ease of use and speed of a much simpler, lower-fidelity simulation method. Aftosmis explains how instead of simulating just one case, Cart3D’s ease of use and automation allows a user to efficiently simulate many cases to understand how a vehicle behaves for a range of conditions. “Cart3D is the first tool that was able to do that successfully,” he says.

At NASA, Aftosmis estimates that 300–400 engineers use the package. “We use it for space vehicle design, supersonic aircraft design, and subsonic aircraft design.”

Technology Transfer

To enable more use of Cart3D for private and commercial aviation entities, the Small Business Innovation Research (SBIR) program at Langley Research Center provided funds to Desktop Aeronautics, based in Palo Alto, California, to build a plug-in to Cart3D that increases the code’s accuracy under particular flow conditions. Aftosmis says Desktop Aeronautics delivered valuable results and made Cart3D more applicable for general use. “Now they are bringing the product to market. This is something we never would have had the time to do at NASA. That’s the way the SBIR process is supposed to work.”

In 2010, Desktop Aeronautics acquired a license from Ames to sell Cart3D. The company further enhanced the software by making it cross-platform, incorporated a graphical user interface, and added specialized features to enable extra computation for the analysis of airplanes with engines and exhaust.



Here, NASA’s Cart3D models the computational fluid dynamics of a supersonic jet design. Cart3D saves time by automatically producing the mesh, or grid, for analyzing vehicle designs.

“I think it’s going to be game-changing for CFD,” says Aftosmis. “Cart3D is the only commercial simulation tool that can guarantee the accuracy of every solution the user does.”

Benefits

Today, Desktop Aeronautics employs Cart3D in its consulting services and licenses the spinoff product to clients for in-house use. The company provides commercial licenses and academic licenses for research and development projects.

The software package allows users to perform automated CFD analysis on complex designs and, according

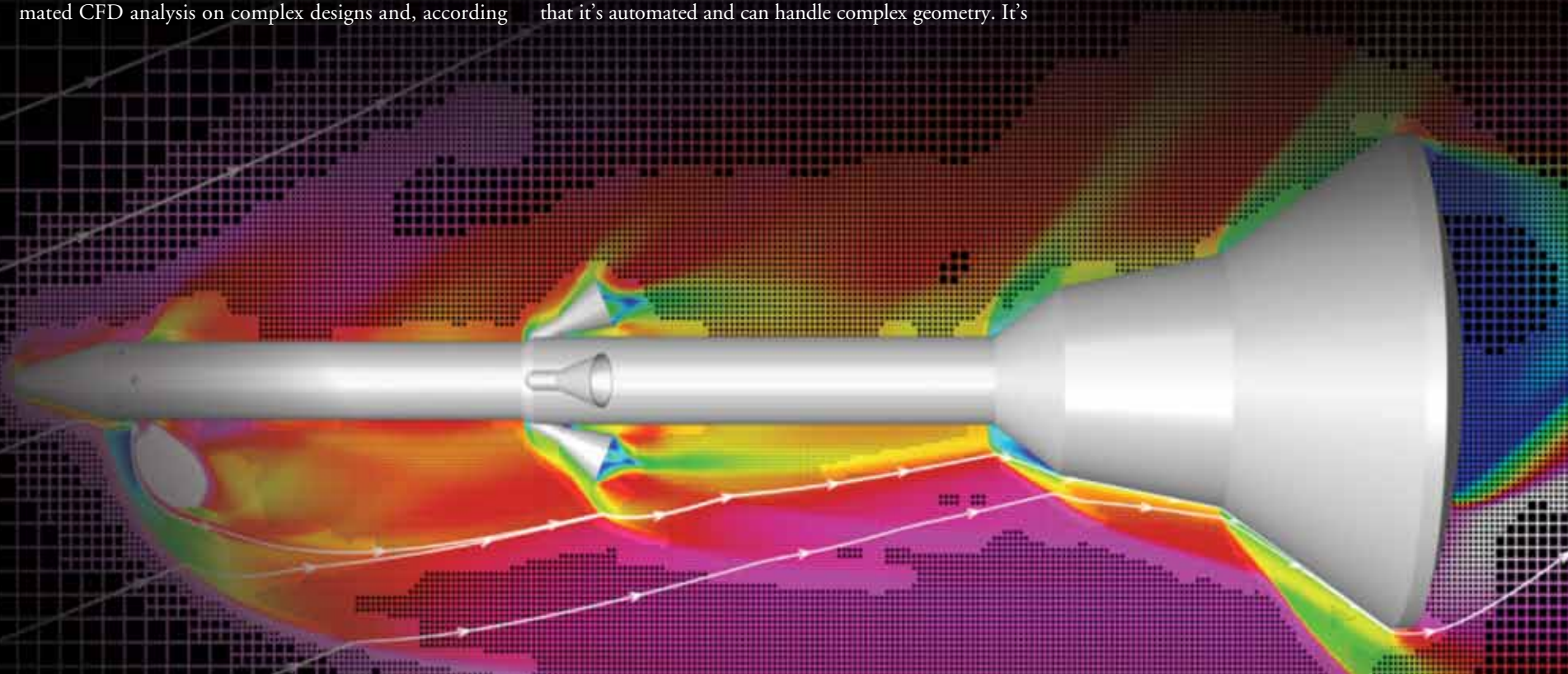
to the company, enables geometry acquisition and mesh generation to be performed within a few minutes on most desktop computers.

Simulations generated by Cart3D are assisting organizations in the design of subsonic aircraft, space planes, spacecraft, and high speed commercial jets. Customers are able to simulate the efficiency of designs through performance metrics such as lift-to-drag ratio.

“It will assemble a spectrum of solutions for many different cases, and from that spectrum, the cases that perform best give insight into how to improve one’s design,” says Johnson. “Cart3D’s preeminent benefit is that it’s automated and can handle complex geometry. It’s

blazing fast. You push a button, and it takes care of the volume meshing and flow measurement.”

Without building an aircraft, engineers can never be completely certain which design concept will perform best in flight. However, they now have a tool to make the most informed prediction possible. ❖



Cart3D streamlines the conceptual analysis of complex aerospace vehicles like the Orion multipurpose crew vehicle’s launch abort system shown here. For a deeper look at Cart3D, scan this code.



Web Solutions Inspire Cloud Computing Software

NASA Technology

In 2008, a NASA effort to standardize its websites inspired a breakthrough in cloud computing technology. The innovation has spurred the growth of an entire industry in open source cloud services that has already attracted millions in investment and is currently generating hundreds of millions in revenue.

William Eshagh was part of the project in the early days, when it was known as NASA.net. “The feeling was that there was a proliferation of NASA websites and approaches to building them. Everything looked different, and it was all managed differently—it was a fragmented landscape.”

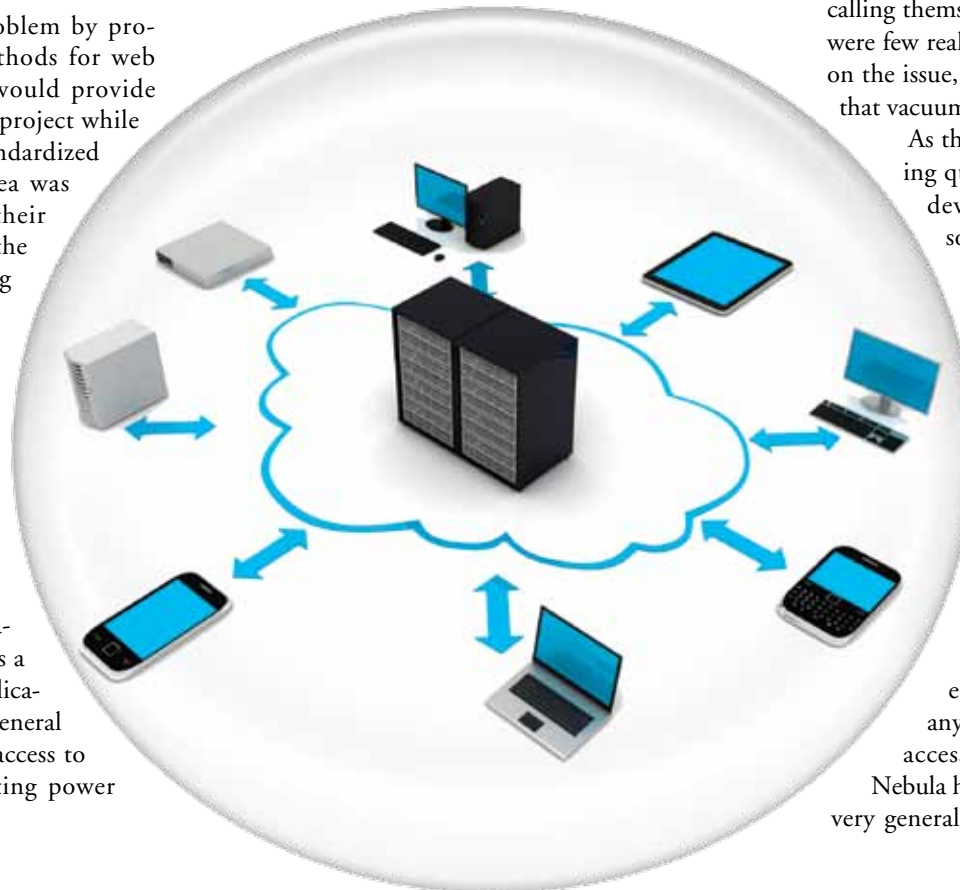
NASA.net aimed to resolve this problem by providing a standard set of tools and methods for web developers. The developers, in turn, would provide design, code, and functionality for their project while adopting and incorporating NASA’s standardized approach. Says Eshagh, “The basic idea was that the web developer would write their code and upload it to the website, and the website would take care of everything else.”

Even though the project was relatively narrow in its focus, the developers soon realized that they would need bigger, more foundational tools to accomplish the job. “We were trying to create a ‘platform layer,’ which is the concept of giving your code over to the service. But in order to build that, we actually needed to go a step deeper,” says Eshagh.

That next step was to create an “infrastructure service.” Whereas NASA.net was a platform for dealing with one type of application, an infrastructure service is a more general tool with a simpler purpose: to provide access to computing power. While such computing power

could be used to run a service like NASA.net, it could also be used for other applications.

Put another way, what the team came to realize was that they needed to create a cloud computing service. Cloud computing is the delivery of software, processing power, and storage over the Internet. Whether these resources are as ordinary as a library of music files or as complex as a network of supercomputers, cloud computing enables an end user to control them remotely and simply. “The idea is to be able to log on to the service and say ‘I want 10 computers,’ and within a minute, I can start using those computers for any purpose whatsoever,” says Eshagh.



As the scope of the project expanded, NASA.net came to be known as Nebula. Much more than setting standards for Agency web developers, Nebula was intended to provide NASA developers, researchers, and scientists with a wide range of services for accessing and managing the large quantities of data the Agency accumulates every day. This was an enormous undertaking that only a high-powered cloud computing platform could provide.

Raymond O’Brien, former program manager of Nebula, says the project was in some ways ahead of its time. “Back in 2008 and 2009, people were still trying to figure out what ‘cloud’ meant. While lots of people were calling themselves ‘cloud enabled’ or ‘cloud ready,’ there were few real commercial offerings. With so little clarity on the issue, there was an opportunity for us to help fill that vacuum.”

As the team built Nebula, one of the most pressing questions they faced was that of open source development, or the practice of building software in full view of the public over the Internet.

On the one hand, proprietary code might have helped the project overcome early hurdles, as commercial software can offer off-the-shelf solutions that speed up development by solving common problems. Proprietary software is sometimes so useful and convenient that the Nebula team wasn’t even sure that they could create the product without relying on closed source solutions at some point.

On the other hand, open source development would facilitate a collaborative environment without borders—literally anyone with the know-how and interest could access the code and improve on it. Because Nebula had evolved into a project that was addressing very general, widespread needs—not just NASA-wide,

“It quickly became **apparent** that we were onto **something big.**”

—Raymond O’Brien, Ames Research Center



During its early stages, the Nebula project was housed in a trailer on the campus of Ames Research Center, though its team members were in many locations. “They weren’t physically present all the time, but they worked around the clock,” says Raymond O’Brien. “It didn’t matter where people were located, because we could do awesome work as a team.” For a deeper look at OpenStack, scan this code.

Image courtesy of Dominic Harr/NASA





Image courtesy of Dominic Hart/NASA

A NASA engineer makes adjustments to hardware in the trailer. Nebula's cloud controller—or the software that manages how hardware resources are distributed—proved to be the key breakthrough in the project.

but potentially worldwide—the possibility of avoiding restrictive licensing agreements by going open source was very attractive.

O'Brien says that broad appeal was an important part of Nebula's identity. "From the beginning, we wanted this project to involve a very large community—private enterprises, academic institutions, research labs—that would take Nebula and bring it to the next level. It was a dream, a vision. It was that way from the start."

Despite uncertainties, the development team decided to make Nebula purely open source. Eshagh says the real test for that philosophy came when those constraints were stretched to their limits. "Eventually, we determined that existing open source tools did not fully address Nebula's requirements," he says. "But instead of turning to proprietary tools, we decided to write our own."

The problem was with a component of the software called the cloud controller, or the tool that can turn a single server or pool of servers into many virtual servers, which can then be provisioned remotely using software. In effect, the controller gives an end user access in principle to as much or as little computing power and storage as is needed. Existing tools were either written in the wrong programming language or under the wrong software license.

Within a matter of days, the Nebula team had built a new cloud controller from scratch, in Python (their preferred programming language for the controller), and under an open source license. When the team announced this breakthrough on its blog, they immediately began attracting attention from some of the biggest players in the industry. "We believed we were addressing a general problem that would have broad interest," says Eshagh. "As it turns out, that prediction couldn't have been more accurate."

Technology Transfer

Rackspace Inc., of San Antonio, Texas, was one of the companies most interested in the technology. Rackspace

"In the future, you can imagine almost all computing being done in the cloud, much of which could be powered by OpenStack."

—Jim Curry, Rackspace

runs the second largest public cloud in the world and was at the time offering computing and storage services using software they had created in-house. Jim Curry, general manager of Rackspace Cloud Builders, says they faced hurdles similar to those NASA faced in building a private cloud. "We tried to use available technology," he says, "but it couldn't scale up to meet our needs."

The engineers at Rackspace wrote their own code for a number of years, but Curry says they didn't see it as a sustainable activity. "We're a hosting company—people come to us when they want to run standard server environments with a high level of hosting support that we can offer them. Writing proprietary code for unique technologies is not something we wanted to be doing long-term."

The developers at Rackspace were fans of open source development and had been looking into open source solutions right at the time the Nebula team announced its new cloud controller. "Just weeks before we were going to announce our own open source project, we saw that what NASA had released looked very similar to what we were trying to do." Curry reached out to the Nebula team, and within a week the two development teams met and agreed that it made sense to collaborate on the project going forward.

Each of the teams brought something to the table, says Curry. "The nice thing about it was that we were more advanced than NASA in some areas and vice versa, and we each complemented the other very well. For example, NASA was further along with their cloud controller, whereas we were further along on the storage side of things."

The next step was for each organization to make its code open source so the two teams could launch the



Image courtesy of Ariel Zambelich of Wired

Jesse Andrews, Jim Curry, and Lew Moorman, all of Rackspace, helped make collaboration with NASA possible. Andrews was a NASA contractor while Nebula was in development.

project as an independent, open entity. Jim Curry says the team at Rackspace was stunned by the speed at which NASA moved through the process. “Within a period of 30–45 days, NASA completed the process of getting the agreements to have this stuff done. From my perspective, they moved as fast as any company I’ve ever worked with, and it was really impressive to watch.”

The OpenStack project, the successor to Nebula with development from Rackspace, was announced in July 2010. As open source software, OpenStack has attracted a very broad community: nearly 2,500 independent developers and 150 companies are a part of it—including such giants as AT&T, HP, Cisco, Dell, and Intel. Semi-annual developers’ conferences, where members of the development community meet to exchange ideas and explore new directions for the software, now attract over 1,000 participants from about two dozen different countries.

Benefits

Because OpenStack is free, companies who use it to deploy servers do not need to pay licensing fees—fees that

can easily total thousands of dollars per server per year. With the number of companies that have already adopted OpenStack, the software has potentially saved millions of dollars in server costs.

“Before OpenStack,” says Curry, “your only option was to pay someone money to solve the problem that OpenStack is addressing today. For people who want it as a solution, who like the idea of consuming open source, they now have an alternative to proprietary options.”

Not only is OpenStack saving money; it is also generating jobs and revenue at a remarkable pace. Curry says that dozens of Rackspace’s 80 cloud engineering jobs are directly attributable to OpenStack, and that the technology has created hundreds of jobs throughout the industry. “Right now, trying to find someone with OpenStack experience, especially in San Francisco, is nearly impossible, because demand is so high.”

The technology is currently generating hundreds of millions in revenue: Rackspace’s public cloud alone—which largely relies on OpenStack—currently takes in \$150 million a year. Curry, Eshagh, and O’Brien all

predict that the software will be its own billion-dollar industry within a few years.

Because OpenStack is open source, and is modified and improved by the people who use it, it is more likely to remain a cutting-edge solution for cloud computing needs. Says Eshagh, “We are starting to see the heavyweights in the industry adding services on top of OpenStack—which they can do because they have a common framework to build from. That means we’ll see even more services and products being created.”

In 2012, Rackspace took steps to secure OpenStack’s future as a free and open source project: the company began the process of spinning off the platform into its own nonprofit organization. By separating itself from any one commercial interest, Curry says, the project will be better positioned to continue doing what its founders hoped it would.

O’Brien maintains that OpenStack’s potential is far from being realized. “It’s hard to characterize in advance. If you had asked an expert about Linux years ago, who could have predicted that it would be in nearly everything, as it is today? It’s in phones and mobile devices. It’s in 75 percent of deployed servers. It’s even used to support space missions. OpenStack has a chance to hit something similar to that in cloud computing.”

Curry agrees: “In the future, you can envision almost all computing being done in the cloud, much of which could be powered by OpenStack. I think that NASA will need to receive significant credit for that in the history books. What we’ve been able to do is unbelievable—especially when you remember that it all started in a NASA lab.” ❖

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Behavior Prediction Tools Strengthen Nanoelectronics

NASA Technology

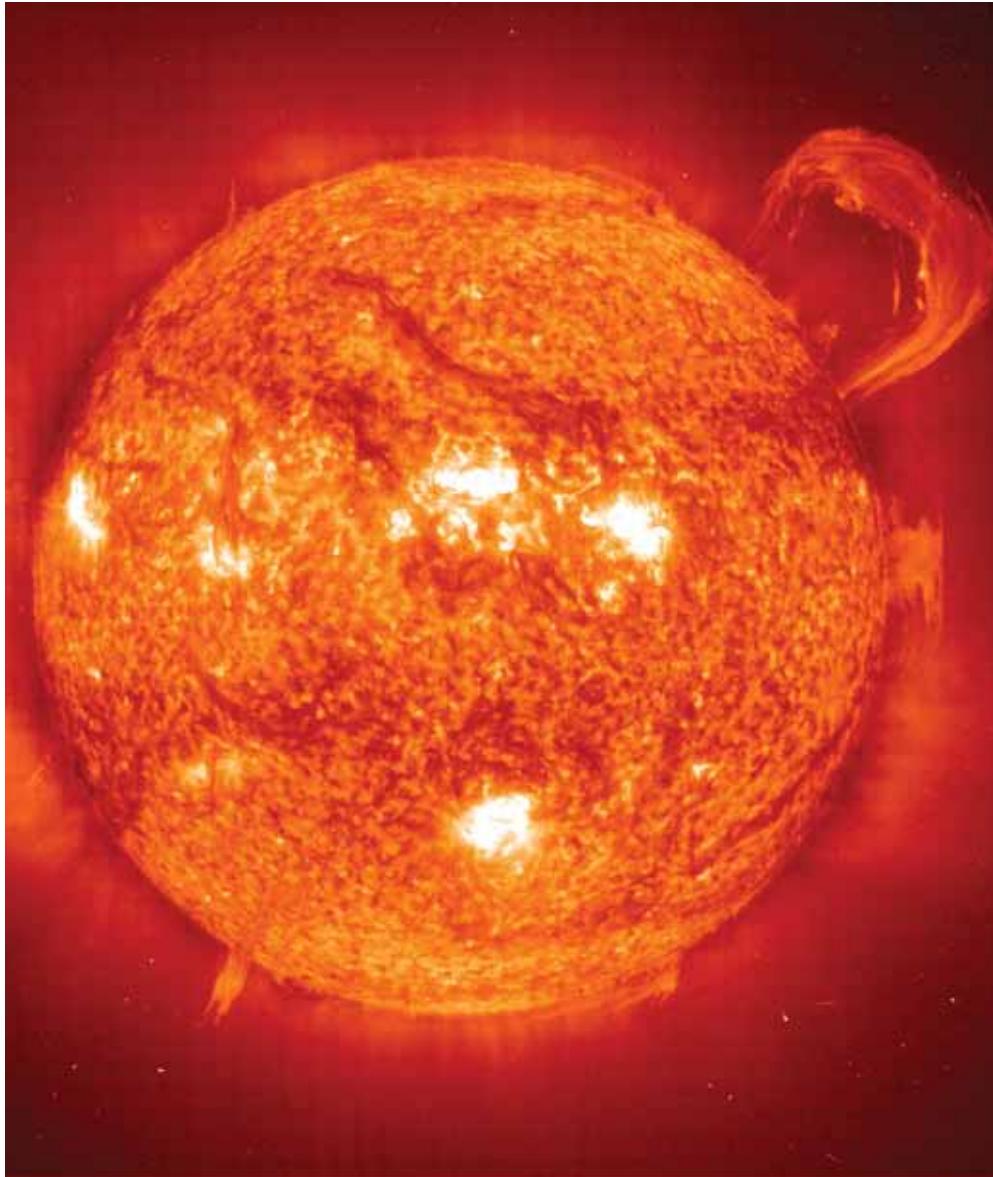
Several years ago, NASA started making plans to send robots to explore the deep, dark craters on the Moon. As part of these plans, NASA needed modeling tools to help engineer unique electronics to withstand extremely cold temperatures.

According to Jonathan Pellish, a flight systems test engineer at Goddard Space Flight Center, “An instrument sitting in a shadowed crater on one of the Moon’s poles would hover around 43 K”—that is, 43 kelvin, equivalent to -382 °F. Such frigid temperatures are one of the main factors that make the extreme space environments encountered on the Moon and elsewhere so extreme.

Radiation is another main concern.

“Radiation is always present in the space environment,” says Pellish. “Small to moderate solar energetic particle events happen regularly and extreme events happen less than a handful of times throughout the 7 active years of the 11-year solar cycle.” Radiation can corrupt data, propagate to other systems, require component power cycling, and cause a host of other harmful effects.

In order to explore places like the Moon, Jupiter, Saturn, Venus, and Mars, NASA must use electronic communication devices like transmitters and receivers and data collection devices like infrared cameras that can resist the effects of extreme temperature



Activity on the Sun increases radiation in space, which can negatively affect the electronics on a spacecraft. To help reduce the risk of failure during a mission, NASA worked on software with CFD Research Corporation to predict the behavior of nanoelectronics in the extreme conditions of space.

and radiation; otherwise, the electronics would not be reliable for the duration of the mission.

Technology Transfer

Since 1987, NASA has partnered with Huntsville, Alabama-based CFD Research Corporation (CFDRC), a company that specializes in engineering simulations and innovative designs and prototypes for aerospace and other industries. A few years ago, CFDRC received funding from Marshall Space Flight Center’s Small Business Innovation Research (SBIR) program to refine an existing software tool to predict the behavior of electronics in the cold, radiation-filled environment of space.

During the first phase of its work, in collaboration with Georgia Tech, CFDRC enhanced and demonstrated a technology called NanoTCAD for predicting the response of silicon-germanium (SiGe) semiconductor technology to radiation. During its second phase, the company demonstrated and validated NanoTCAD for temperature ranges from -382–266 °F.

Marek Turowski, the director of the nanoelectronic and plasma technology group at CFDRC explains how, as electronic parts become smaller, the effects of radiation and temperature become more severe. “When radiation particles bombard a microchip, it is like hail hitting a car,” he says.

Even though hail may not damage a large truck, the same hail could cause

significant damage to a truck the size of a toy. Likewise, as electronic devices decrease in size, radiation particles can damage them more easily.

Being able to predict the behavior of nanoelectronics in the extreme space environment reduces the risk of failure during a critical NASA mission. Using NanoTCAD, designers can better evaluate performance and response of electronics early in the design stage, thereby reducing the costs and testing time involved. As Turowski explains it, “The purpose of NanoTCAD tools and models is to predict the behavior of electronics in space before they actually go to space. The prediction happens on the computer screen and accurately takes temperature and radiation into account.”

Pellish says NanoTCAD has already been used to evaluate key technologies for the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2), scheduled for launch in 2016. ICESat-2 will look at polar ice, sea-level change, vegetation canopy height, and climate. “The NanoTCAD research on SiGe semiconductor technology processes provided a portion of the necessary insight into this technology so that it can be used in space,” he says.

Benefits

NanoTCAD software is now available from CFDRC as a nanotechnology computer aided design (CAD) tool to predict the effects of extreme thermal and radiation environments on electronic systems. It is also used by CFDRC in its modeling and simulation services provided to the aerospace industry. The “nano” part of the product’s name means the software can address nano-size devices while “TCAD” stands for “technology computer aided design.”

“It solves basic physics equations,” says Turowski. “It looks at how electrons flow, how fields inside the devices behave, and how the varying temperature affects their behavior.”

Today, CFDRC’s NanoTCAD customers include electronic chip designers at Georgia Tech and Vanderbilt

University. The electronics, chips, circuits, and devices that the universities are modeling with NanoTCAD are often for NASA missions. The European Space Agency and the Japanese Aerospace Exploration Agency are also potential customers of CFDRC’s NASA-improved technology.

The tool is also being employed for Department of Defense applications for space communication and surveillance systems for satellites. Entities like the Air Force and Navy design electronics that can suffer the same problems as NASA spacecraft. CFDRC also uses NanoTCAD to provide modeling, simulations, and radiation-hardening design services to national nuclear laboratories and commercial satellite designers.

According to CFDRC, the technology has led to approximately \$2 million in revenue for the company, created new jobs, and led to partnerships with other defense and industrial customers.

“NASA has given us the opportunity to develop valuable technology,” says Turowski. “Now the technology is

The electronics that go to the Moon must be able to withstand extremely cold temperatures.

being adapted and enhanced for every new generation of electronics.”

Whether it is for the Moon, on-orbit, or other applications, CFDRC’s work with NASA is helping to make future space missions possible. ❖



Power Converters Secure Electronics in Harsh Environments

NASA Technology

“Space weather” is a term more frequently used as solar storms and flares are closely monitored and analyzed for the impact they might have on Earth. Blasts of radiation, if strong enough, can make their presence felt by temporarily shutting down power grids or interrupting communication channels. While such events on the Earth’s surface are rare, thanks to the planet’s many layers of protection, the threat posed by radiation to satellites and spacecraft is always on the minds of the engineers who design them.

In fact, many ordinary challenges have to be reexamined when considered in an extreme environment. One prime example is power conversion. A basic problem in electrical engineering is that individual components of a complex device, such as a mobile phone or computer, require different amounts of power to function properly. These issues are solved by using a power converter, which takes voltage from a power source and routes the correct amount of power wherever it is needed.

In space, however, power systems are especially at risk to radiation damage from the Sun and extra-solar-system sources. These high energy particles wreak havoc on electrical components over time, slowly degrading their performance until eventually they fail—and in some cases even a single particle can cause serious damage. This problem has become more acute over time, as spacecraft components and electronics have become smaller and more precise, essentially making them more vulnerable as the radiation particles have become by comparison larger.

According to Sabbir Hossain, an electrical engineer in the Energy Systems Division at Johnson Space Center, power converters “have for many years been inconsistent in quality and performance, and have sometimes failed catastrophically in flight hardware. The complexity and cost of these parts can have a severe impact on a mission’s schedule and budget.” NASA thus decided to form a



Mercury MESSENGER (left) is scheduled to end its mission after more than 8 years of operation, and New Horizons (right) will fly by Pluto in 2015, nearly 10 years after launch. Both spacecraft utilize radiation-hardened converters designed by VPT. To learn more about these missions, scan this code.

partnership with industry experts to meet the challenges posed by radiation in space.

Technology Transfer

In 2004, Johnson awarded the first of multiple Small Business Innovation Research (SBIR) contracts to Blacksburg, Virginia-based VPT Inc. to create a line of hybrid DC-DC power converters for aerospace applications. “The idea of the project was to develop standard, off the shelf converters that could be used to put together full power system solutions for NASA programs,” says Leonard Leslie, manager of space programs at VPT.

VPT has long manufactured DC-DC converters, so the primary challenge in this project was to make a line of converters that met the radiation quality requirements of space applications. That meant selecting the right

VPT’s expanded offerings are creating high-paying jobs and have generated millions of dollars in revenue for the company.

components—picking among materials that are known to be robust—and putting those components through a large amount of testing. Leslie says the company also reengineered circuit design techniques to increase the converters’ resistance to radiation.

“VPT developed an innovative concept whereby complex NASA power systems can be configured using a small number of qualified converters,” says Hossain. “This significantly improved mission scheduling, as the most difficult part of the design—the power stage—became readily available in a standard package.”

The resulting converters, hardened against radiation, have been employed on multiple important NASA missions, including the Mercury MESSENGER probe, the New Horizons mission to Pluto, and the Lunar Reconnaissance Orbiter.

As part of the work carried out under its Phase I and II SBIR contracts, VPT's converters achieved a major industry certification from the Defense Logistics Agency (DLA), an organization that oversees military specifications. The Radiation Hardness Assurance Requirements certification from DLA, Leslie says, "was a major accomplishment that resulted from our partnership with NASA. The inclusion of testing for enhanced low dose rate component sensitivity (ELDRS) as part of the RHA plan has been adopted as an industry standard."

Benefits

VPT's certified, standardized line of converters have found immediate applications in aerospace markets and with the military. "We have gotten a lot of benefits out of that NASA effort," says Leslie. "We've been doing custom space work for a long time, but this was a stepping stone to get into standard product offerings in the space

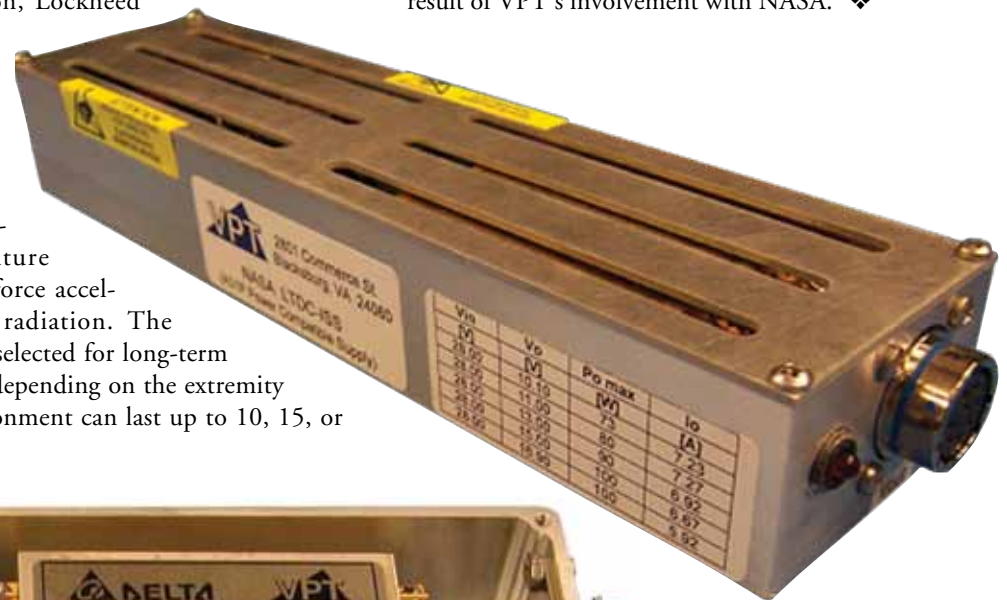
industry. It gave us a chance to develop several lines of standard products for aerospace applications."

The expertise and certifications gained by the company through its work with NASA have positioned it well to supply aerospace and military organizations with power solutions. VPT's converters are currently deployed in commercial and military aerospace vehicles, ground vehicles, ships and submarines, and weapons systems. In addition to NASA, VPT counts among its clients Boeing, Honeywell, Raytheon, Lockheed Martin, and the US Air Force.

The company's converters can withstand extreme conditions and environments, including rapid temperature changes, extreme g-force acceleration, and space radiation. The converters are often selected for long-term space missions, and depending on the extremity of the mission environment can last up to 10, 15, or

even 20 years—a long period of time for electronics to function in space.

VPT's expanded offerings are creating high-paying jobs and have generated millions of dollars in revenue for the company. In response to the increased sales, VPT created a new division to handle space product development, which meant adding four high-tech jobs—three engineers and one technician. All of these benefits to the company, its employees, and its customers are, Leslie says, "a direct result of VPT's involvement with NASA." ❖



A VPT laptop power supply, developed during the company's SBIR work with NASA, is pictured here close to its actual size.



Diagnostics Tools Identify Faults Prior to Failure

NASA Technology

The Drilling Automation for Mars Exploration (DAME) project was designed to unearth the secrets of Mars—literally. The project's engineers designed a light, low-power drill to penetrate into the Martian surface and return clues about the Red Planet's geological makeup and ancient life that may have once thrived there.

The development of new, innovative technologies such as the DAME drill comes with an unavoidable



The DAME drill during summer field tests on Devon Island, NASA's Mars analog site. The devices at center are laser vibrometers that measure the movements and vibrations of the drill when in use.

complication: the consequent introduction of new and unknown ways those technologies can develop faults and failures. To anticipate these problems, NASA engineers use specialized software that monitor system performance during virtual and actual testing, identifying and diagnosing abnormalities.

For DAME, one of the diagnostic technologies used to evaluate the drill's performance was the Hybrid Diagnostic Engine (HyDE), developed at Ames Research Center by a team led by Sriram Narasimhan, a researcher in the Prognostics Center for Excellence (PCoE). HyDE observes sensor signals from the system being tested and compares those measurements with the anticipated behavior previously established from a model of that system, explains Kai Goebel, head of the PCoE at Ames.

"If the two disagree, then HyDE tries to determine whether that represents a malfunction or not," he says. "It tries to find the root cause of a particular abnormal condition." In DAME's case, HyDE successfully identified approximately 85 percent of the faults the drill developed during testing.

For space vehicles and habitats, it is very important to be cognizant of the health of the systems, Goebel says, to ensure the safety of operations. Because the same holds true on Earth, one company has partnered with NASA to advance the HyDE technology for terrestrial applications from automobiles to geothermal systems for the greenest Federal building in the Nation.

Technology Transfer

Impact Technologies LLC, based in Rochester, New York, has partnered with NASA on many prognostics and health management projects, including fault diagnosis in jet engines and automated contingency management tools that allow vehicles to alter their performance to accommodate faults and avoid complete failure.

"The common thread for all of our developments is trying to figure out when machines are going to break,

and then what you can do if they do break," says Jeff Hoffman, project manager at Impact.

Collaborating with Ames through the Small Business Innovation Research (SBIR) program, Impact extended HyDE's capabilities and then commercialized the tool.

Benefits

Impact incorporated HyDE into its ReasonProX software suite. The software integrates HyDE with the MATLAB/Simulink environment, a popular commercial setup for modeling and simulation. This allows users to identify potential faults and craft solutions during the design phase, saving time and money in the development of systems for controlling and monitoring everything from printers to automobiles, power generators, and robots.

"We built tools around HyDE that allow people to model physical systems like a car in MATLAB, send information to the diagnostic engine, and get results back in the same environment you use to run your model. You can figure out how your car might break, all on your workstation using our software," says Mark Mosher, also a project manager at Impact.

Hoffman says that the company is finding applications for ReasonProX in the wind turbine market and will be incorporating the software into a helicopter diagnostics platform. In the meantime, NASA's partnership with Impact has also resulted in benefits for the Agency: Impact's spinoff technology is now part of the NASA Sustainability Base at Ames, which incorporates a host of aerospace innovations into a unique "smart" office building that can adapt its energy use depending on weather, season, and work patterns. Impact's software modeled and now monitors the base's geothermal heating and cooling system.

Benefits for both sides is typical of partnerships between NASA and private industry, says Goebel. "We find that these kinds of collaborations are an inspiration that drives technology development." ♦

ReasonProX™ is a trademark of Impact Technologies LLC.

“We find that these kinds
of **collaborations** are
an **inspiration** that drives
technology development.”

—Kai Goebel, Ames Research Center



NASA's Sustainability Base at Ames Research Center is expected to be the greenest building in the Federal Government. The building features a number of “smart system” technologies designed to make it adaptable to changes in sunlight, temperature, and usage. Among the technologies employed in the building is Impact Technologies' spinoff software, which monitors the base's geothermal climate control system. For a deeper look at the Sustainability Base, scan this code.



Archiving Innovations Preserve Essential Historical Records

NASA Technology

The Moon hosts perhaps the most fascinating museum that no one ever visits. From reflectometers to space boots, the lunar module's descent stage, and the famous first footprints left behind by Neil Armstrong, the Apollo 11 mission alone left over 100 artifacts on the Moon's surface.

Among the items at rest in the lunar regolith is an aluminum capsule containing a small silicon disc about the size of a half-dollar coin. The disc displays messages of goodwill from 73 countries and four US presidents, all inscribed in letters a quarter of the width of a human hair, visible only under a microscope.

In order to compile the commemorative messages into a format that would not significantly add to Apollo 11's payload, while also being able to endure the wild temperature extremes of the Moon's surface, NASA partnered with Worcester, Massachusetts-based Sprague Electric Company. The company, which had already worked with the Agency to produce multiple components for the Apollo 11 mission, applied semiconductor manufacturing techniques to etch the messages on silicon, sizing them down until each individual message was smaller than the head of a pin.

Sprague patented the technique in 1971, but it would be decades later when a pair of innovators would build upon the NASA-derived technology to create a spinoff that is now preserving vital records on Earth in the same way that the world's support of Apollo 11 is preserved on the Moon.

Technology Transfer

In 2006, P.R. Mukund, professor of electrical engineering at Rochester Institute of Technology, and PhD student Ajay Pasupuleti took on a task working with a material not typical to their field—palm leaves. The pair joined a project to preserve the content of the Sarvamoola Grantha, an ancient work of Hindu spiritual scholarship



The famous Apollo 11 mission left behind over 100 artifacts on the Moon, including a small silicon disc inscribed with messages of goodwill from 73 countries (below).



transcribed on stacks of palm leaves that, after some 700 years, were in severe danger of being lost to decay. Working with a team experienced in the preservation of ancient documents such as the Archimedes Palimpsest and the Dead Sea Scrolls, Mukund and Pasupuleti captured and preserved the text of the Sarvamoola Grantha using infrared imagery, winning international acclaim in the process.

“After we did that, we thought about creating a technology that would combine the best of ancient preservation technology with the most recent,” says Mukund. There are pros and cons on both ends of the spectrum, he explains. Stone tablets preserve information for thousands of years—but are not exactly easy to share or copy. Electronic images are ideal for sharing and are easy to copy, manipulate, and archive, but rapid changes in digital formats and storage media threaten to make certain formats of archived information obsolete. Physical storage media such as DVDs and even flash memory can also experience “bit rot,” in which data can be lost or corrupted.

“This is not exactly the way you want to save things that are meant to be preserved for 500 or 1,000 years,” Mukund says.

Mukund and Pasupuleti hit upon a solution within their field of expertise. Silicon, used extensively in the semiconductor industry, is highly durable and resistant to water, humidity, and temperatures up to 572 °F. Research into using silicon and semiconductor production techniques to create enduring copies of documents and records turned up the patent from NASA’s Apollo 11 mission. Since the patent had expired and entered the public domain, Mukund and Pasupuleti were able to use it as a building block for their own patented archiving technology. The pair formed NanoArk Corporation of Fairport, New York, to bring the innovation to market.

“People always ask, when we spend taxpayer dollars on the Space Program: Other than going to space, what does the technology do?” Mukund says. “Here is a classic story

where it took more than 40 years before somebody actually thought of commercializing it.”

Benefits

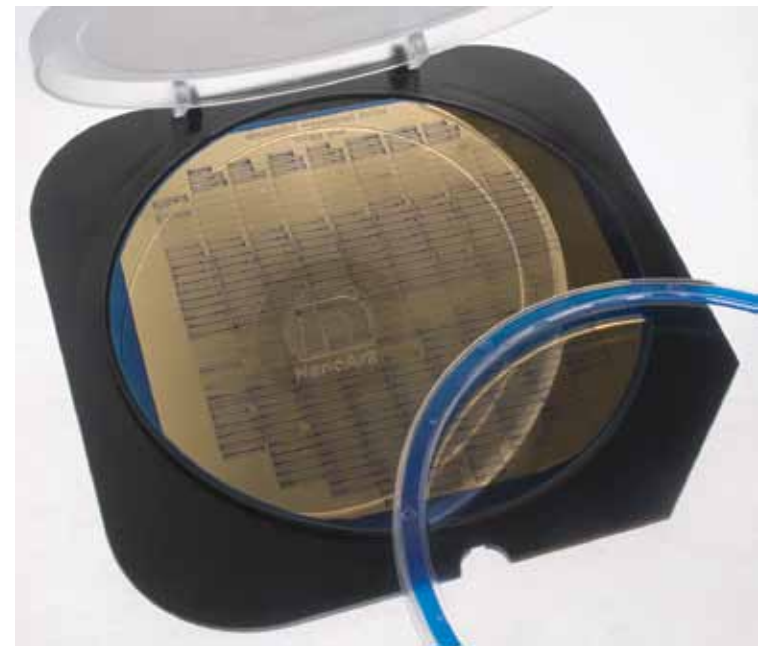
NanoArk’s Waferfiche technology employs a photolithographic process to inscribe minute copies of documents onto thin silicon discs, each of which can fit about 2,000 letter-sized images. The Waferfiche’s inherent material properties render it resistant to fire over a limited duration and, more importantly, practically impervious to water damage. NanoArk notes that the biggest threat to any kind of archived information is moisture.

“Last year, in New York state alone, 65 local governments lost records due to water damage,” says Pasupuleti, now NanoArk’s vice president of technology. “Our technology is water resistant. You can leave it in water for months, take it out, and just wipe it down with a cloth.”

NanoArk claims its Waferfiche technology will preserve essential records for 500 years. While the currently prevalent archiving technology, microfilm, offers the same longevity, it can only do so in temperature and humidity controlled environments. Waferfiche requires no such care, resulting in increasing cost savings over time and minimal environmental impact. If the customer needs to retrieve any archived information from a Waferfiche, the minimal technology required is a magnifying glass.

“There is nothing out there that can beat this technology in terms of long-term preservation of important records and documents,” says Mukund, NanoArk’s president and CEO.

Since introducing the technology commercially in 2008, NanoArk has grown from 2 employees to 10, expe-



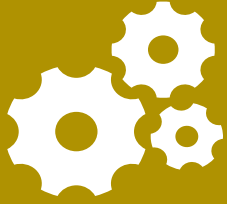
NanoArk’s Waferfiche technology can preserve important documents for hundreds of years without any need for controlled storage environments. Resistant to fire and water damage, the spinoff provides peace of mind for archivists and government officials.

rienced a five-fold increase in revenue between 2010 and 2011, and recently opened an office in Hyderabad, India. It counts multiple town, county, and state governments among its customers, as well as universities, and has plans to market the technology as a franchise. One of the keys to the innovation’s future success, says Mukund, is its NASA connection.

“When people find out that this technology is what NASA used as a time capsule on the Moon,” he says, “surely that is a good enough credential as far as the viability of the technology for long-term preservation.” ❖

Waferfiche™ is a trademark of NanoArk Corporation.

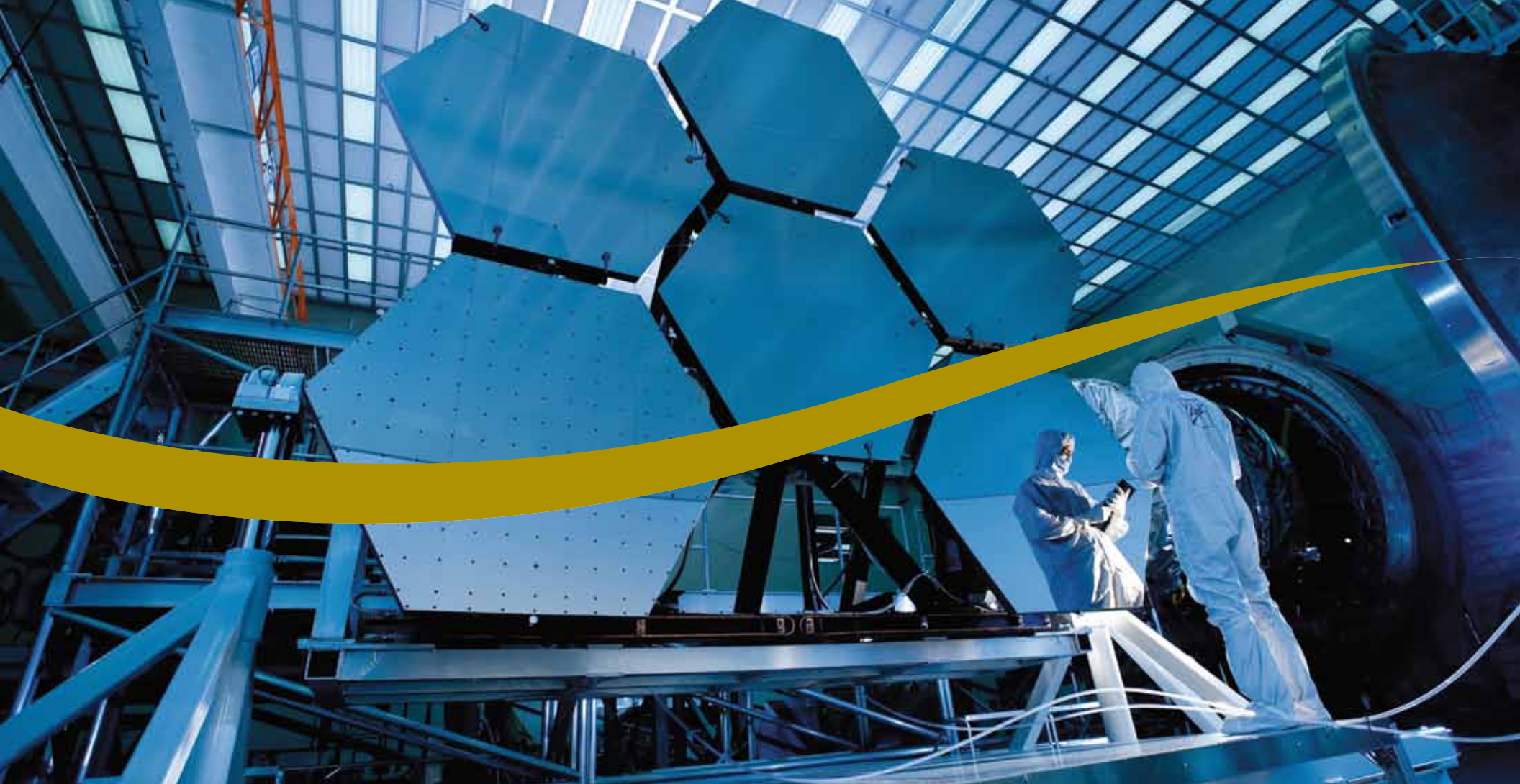




Industrial Productivity

To build unprecedented spacecraft and structures, NASA explores new materials and means of manufacturing—leading to technologies that lower industry costs, enhance electronics, and open up space-based research to students and scientists around the world. The spinoffs in this section:

- Reduce Operation Costs for Industry
- Allow Affordable Space Research
- Deliver Real-Time Structural Monitoring
- Rapidly Scan Large Structures
- Reveal Information for 3D Images
- Protect Electronics from Heat and Radiation
- Sharpen Measurements for Better Telescopes
- Illuminate Industrial Processes



Meter Designs Reduce Operation Costs for Industry

NASA Technology

The space shuttle engines changed drastically from the drawing board to the launch pad. The engine—and each of its intricate parts—required extensive testing and modification before launch. Even in the final moments before use, NASA continuously monitored and measured their performance to ensure fail proof operation.

Years ago, during routine ground testing of a shuttle engine at Stennis Space Center, the measuring device for liquid oxygen (LOX) failed and resulted in a fire that burned the test stand beyond repair. Anthony Kelley, an engineer at Marshall Space Flight Center, says the event prompted NASA to consider alternative approaches for measuring LOX fuel. “We started thinking about safe ways to accurately measure LOX flow without inducing serious failure,” he says.

Although it might sound like a small detail, measuring the flow rate (the amount of fluid that flows in a certain time) is very important in liquid rocket engines, as it provides the basis for evaluating the engine’s performance and reliability.

Technology Transfer

At the time, there were no meters that met NASA’s stringent requirements for rocket engine LOX flow. The flow meter needed to perform with high accuracy in extreme temperatures and pressures and in various states—while ensuring no catastrophic failures.

To address the challenge, NASA’s Marshall Space Flight Center collaborated with a company called Quality Monitoring and Control (QMC) of Humble, Texas, through a 2001 Space Act Agreement. Together, the team brainstormed concepts and came up with a unique mathematical formula that was employed to make the



NASA worked with APlus-QMC LLC to develop a new meter for the shuttle engines (shown here being prepped for the next generation heavy lift rocket).

new technology. Called a balanced flow meter (BFM), the invention was successfully applied in two of NASA’s rocket engine programs.

“The meters have operated accurately during highly dynamic flow conditions, which most metering technologies cannot do,” says Kelley. “The ability to meter and control propellants to very high levels of precision was proven.”

When NASA’s technology transfer office saw the potential of the BFM for applications outside of NASA, it funded a test program to evaluate its performance. “In most applications, the BFM produces typical flow measurement accuracies around 0.2 percent in very harsh environments and with no moving parts,” says Kelley.

To commercialize the technology, QMC founded A+ FlowTek (now APlus-QMC LLC), also of Humble, Texas. A+ FlowTek licensed the BFM from NASA, and by 2004, the company made its first commercial sale. In 2007, the technology was designated the Marshall Space Flight Center Invention of the Year. In 2010, it won the

Approximately 5,000 versions of the balanced flow meter have been manufactured—resulting in 100 new jobs and approximately \$250,000 in annual sales.

prestigious Federal Laboratory Consortium National Excellence in Technology Transfer award across all Federal agencies.

Benefits

BFMs are now used at chemical plants, refineries, power plants, pharmaceutical plants, and pulp and paper plants to determine the flow rate in piping, channel, and conduit systems. Aside from routine measurements, the technology also takes measurements for environmental standards reporting, facility certification, and for safety and process control systems. Sold around the world from the United States to China, Europe, and Australia, industry leaders such as Dresser-Rand, ABB, DuPont, and Rosemont are now using the NASA-derived BFM.

According to Paul Van Buskirk, the owner of APlus-QMC, approximately 5,000 different versions of the BFM have been manufactured since the company was founded—resulting in the creation of 100 new jobs and approximately \$250,000 in annual sales.

APlus-QMC designs the devices using software that performs all the calculations necessary to manufacture custom meters for particular conditions, temperatures, pressures, and flows. Traditionally, flow meters have a single hole. The NASA-derived BFMs use a multi-hole design with a particular number and size of holes. They can be made of any material—stainless steel, titanium, or special alloys—and can be anywhere in size from half an inch to 10 feet in diameter.

Compared to the single hole design, BFMs provide a 10-fold increase in accuracy and a 15 to 1 reduction

in audible noise. In some cases, says Van Buskirk, the company's technology proves desirable because the Occupational Safety and Health Administration requires less noise in certain environments.

Another advantage of the technology is reduced energy use. "The payback compared to a single hole meter is a matter of weeks for energy efficiency," says Van Buskirk.

BFMs also provide overall cost savings thanks to simpler installed-piping requirements, lower manufacturing costs, lower operating costs, and a longer lifespan. According to the company, the technology has saved an estimated \$10 million for industrial facilities.

"It can save millions per year compared to standard plates," says Van Buskirk. "Accurate measurements are critical to plant operational efficiency, and the difference between an accurate and an inaccurate flow reading can mean a significant cost savings."

Over the next 5 years, Van Buskirk aims to multiply the number of BFMs being manufactured. "We're looking at contracts with companies like Shell and Exxon as exclusive flow-meter providers. We are also looking to open up the markets in two-phase flow for liquid and gas," he says.

While many of the benefits of BFMs concern industrial productivity, there is an important application that has improved consumer safety. Through a Space Act Agreement between NASA and a commercial pool

company, a BFM was used to test swimming pool safety systems. Tests showed the existing meter was not properly configured, and resulted in major changes in pool safety system test results on a National level.

"NASA technology transfer to benefit Americans was specified in our original charter and I believe it is one of the more important things NASA does. The efforts often create new capabilities, leading to benefits like more American jobs, greater energy efficiency, and improved industrial processes," says Kelley. "In this case, the improved pool safety information will provide consumer benefits in safety for many years to come." ❖



The NASA-derived flow meter uses a multi-hole design that consumes less energy than traditional meters. The technology has saved an estimated \$10 million for industrial facilities.



Commercial Platforms Allow Affordable Space Research

NASA Technology

At an altitude of about 240 miles, its orbital path carries it over 90 percent of the Earth's population. It circles the Earth in continuous free fall; its crew of six and one Robonaut pass the days—experiencing 16 sunrises and 16 sunsets every 24 hours—in microgravity, an environment in which everything from bodily functions to the physical behavior of materials changes

drastically from what is common on the ground. Outside its shielded confines, temperatures cycle from one extreme to the other, radiation is rampant, and atomic oxygen corrodes everything it touches.

A unique feat of engineering, the International Space Station (ISS) also represents the most remarkable platform for scientific research ever devised.

In 2005, anticipating the space station's potential for NASA and non-NASA scientists alike, the NASA

Authorization Act designated the US segment of the ISS as a national laboratory, instructing the Agency to “increase the utilization of the ISS by other Federal entities and the private sector.” With the ISS set to maintain operations through at least 2020, the station offers an unprecedented long-term access to space conditions, enabling research not previously possible.

“There will be new drug discoveries, new pharmaceuticals, a better understanding of how we affect the planet and how we can maintain it,” says Marybeth Edeen, the ISS National Laboratory manager, based at Johnson Space Center. The ISS, she says, represents a major example of the government's role in making such advancements possible. “The government is key in that researchers cannot afford to build the kind of infrastructure that the government can provide. But we then have to make that infrastructure available at a reasonable cost.”

Enter Jeff Manber, who saw in the ISS National Lab an extraordinary opportunity to advance science, education, and business in ways never before seen.

Technology Transfer

A veteran commercial space businessman who previously headed MirCorp, which leased the Mir space station for two years, Manber co-founded NanoRacks LLC of Houston, Texas, and approached NASA with an idea for a partnership that would transform the way space-based research is conducted.

“We said, ‘We want to put our own research platforms on the ISS and market them to customers, and we'll pay for it,’” Manber says. He and his co-founders, all industry veterans, envisioned a partnership in which NanoRacks would provide the research hardware and the customers, and NASA would act as a kind of landlord and regulator, providing the necessary comprehensive safety checks and access to the ISS and its crew. The key, says Manber, was that NanoRacks would fund the entire effort as a commercial venture, incurring no additional costs to NASA or the Nation's taxpayers. NASA and NanoRacks



The NanoRacks Platform-1, seen in the inset image during installation on the International Space Station (ISS), can host up to 16 NanoLabs, which simply attach to plugs along the right and left sides of the platform. The “plug and play,” standardized system reduces the cost and increases the efficiency of space research.



soon formalized the partnership through a Space Act Agreement.

To realize its vision, NanoRacks had to devise a research platform that could be utilized by a broad range of researchers, for a broad range of experiment concepts. Considering the many challenges—the conditions of the space environment; the limited, carefully managed resources onboard the ISS (including crewmember time); the breadth of research topics for which the National Lab could be used; and the significant costs of launching, maintaining, and sometimes returning research payloads—this was no simple task.

The ISS already featured standardized lockers and drawers intended to remove custom research hardware from the equation, allowing scientists to focus on their experiments instead. NanoRacks built on that concept, finding a solution in the increasingly popular CubeSat model and creating a plug-and-play research platform both standardized in size and versatile in function. CubeSats are nanosatellites of a specific, small size that

have been employed largely by universities as an affordable means of space research. NanoRacks used the cubesat form factor to create NanoLabs, four-inch cubes with a USB port for drawing power from the ISS and transmitting near real-time data gathered from the contained experiment. Individual experiments can operate within a single NanoLab, or multiple NanoLabs can be used in varying configurations for larger research setups.

“All the ISS crewmember has to do is attach the NanoLab to our platform using the USB, and immediately power from the station flows into the experiment, and the data can transmit from the station down to the customer,” says Manber.



Within 6 months of the Space Act Agreement, NanoRacks launched two research platforms—with space for a total of 32 NanoLabs—that became operational on the ISS in August 2010.

Benefits

NanoRacks has since flown the experiments of 15 customers, with over 60 total payloads currently under contract. Its customers range from high schools to universities to pharmaceutical research organizations around the globe.

“Researchers have believed, since the dawn of the space age, that removal of gravity will allow us to better understand complex processes and maybe even develop new materials. We’ve never had the opportunity we have today to test that belief,” says Manber. Because of the small size and standardized format of the NanoLab cubes,



The CubeSat form factor of the NanoLab (left) allows it to be configured in various combinations—2 by 4 or 3 by 1, for example—on the NanoRacks platform. This allows for the accommodation of a variety of experiments. Above is the plant incubation chamber inside the Valley Christian School’s 2010–2011 NanoRacks experiment—the first commercial high school experiment in the ISS National Lab.

NanoRacks’ customers can design experiments for that platform instead of having to devise their own hardware, which can be a costly and time-consuming venture. With the ability to fly to the ISS on any of the station’s resupply vehicles, including those of commercial providers such as SpaceX, NanoRacks is averaging under a year from contract signing to launch. The typical active research time is 30 days. All of this represents a game-changing development, a vast improvement over the days of expensive, custom-built research payloads that would have to wait years for an opportunity to fly on the Space Shuttle and years after to test again.

“NanoRacks has put the barrier to spaceflight research low enough to give people a chance to fail,” says Edeen. “That sounds bad, but in reality what we’re saying is that





STS-134 astronauts Greg Chamitoff (left) and Mark Kelly prep NanoRacks hardware hosting experiments from multiple customers. Working with NASA and other partners, NanoRacks continues to expand the capabilities of and access to the US National Lab for the benefit of students and researchers around the globe. For a deeper look at the US National Lab on the ISS, scan this code.

it is cheap enough where you can try something, and if it doesn't work, you can try something else."

By 2013, NanoRacks expects to have three research platforms on the ISS, in addition to a plate reader (used to perform sample analyses), two already operational microscopes, and a centrifuge developed by Astrium Space Transportation. The Astrium collaboration is one example of how the NanoRacks approach to ISS research is spawning new partnerships and technologies.

"We have other companies designing circuit boards for us, designing their own NanoLabs, so you see a whole ecosystem developing," says Manber.

Plant growth, pharmaceutical crystals, and nanomaterials are among the research subjects targeted by NanoRacks' customers. But the benefits of these experiments are not limited to their scientific outcomes; in keeping with NASA's own educational mission, inspiring the next generation of scientists and engineers has become a key component of NanoRacks' efforts, as well.

"We have now flown experiments for over 27 school districts in two missions, and we're about to fly 11 more," says Manber. Through a partnership with the National Center for Earth and Space Science Education, NanoRacks has developed a national science, technology,

engineering, and mathematics space program for middle and high school students.

"Around the world, the best and brightest students know they are being given the most extraordinary opportunity they can imagine: a chance to perform experiments on the US National Lab in outer space," says Manber. "That will pay dividends for America in the decades to come."


The NASA-NanoRacks partnership is mature and healthy, Manber says, but far from exhausting its potential. The company is developing a platform for the outside of the ISS, allowing researchers to pursue investigations in sensor developments, advanced satellite communications, and biological studies. NanoRacks and Astrium are self-funding the External Platform Program, expected to deploy in early 2014, with NASA contributing hardware and services.

"This program opens the door to allow commercial users to fully utilize not only the US National Laboratory in a pressurized environment, but also outside," says Edeen. "It's another example how companies are investing their own money to take advantage of this unique national resource."

NASA is also soliciting proposals from industry partners to advance technologies based on the NanoLab model. Beyond the ISS, Virgin Galactic selected NanoRacks to design and fabricate research hardware and a payload rack for suborbital flights.

"We will go wherever humans are going in space in the next few decades," Manber says.

"We need to demonstrate that American leadership and American ingenuity is alive and well in outer space. With NASA and companies working together, we are getting value that is not always possible the traditional way. It's a harbinger for a great future for the Space Program." ❖

A photograph of the International Space Station (ISS) in orbit above Earth. The station's complex structure, including multiple large solar panel arrays and various modules, is clearly visible against the blue and white background of the planet. The perspective is from a high angle, looking down at the station as it orbits.

“Around the world, the best and brightest students are being given the most extraordinary opportunity: a chance to perform experiments on the US National Lab in outer space.”

—Jeff Manber, NanoRacks LLC



Fiber Optics Deliver Real-Time Structural Monitoring

NASA Technology

If the wings of a plane could talk about what they feel during flight, what would they say? Engineers at Dryden Flight Research Center are beginning to find out.

Having access to real-time information about wing shape, stress, temperature, pressure, and strength could enable adjustments to aircraft wings to maximize aircraft performance—and affect everything from safety to efficiency. To develop the capability to alter the shape

of wings during flight, researchers at Dryden Flight Research Center need to know what is happening when it is happening.

Traditionally, large, heavy instrumentation is used for taking measurements about shape and forces applied on wings during flight, but this instrumentation is bulky, slow, and limited. After the sensors acquire the data, they have to send it to a computer for processing. After that, it is translated and then analyzed.

In the 1990s, Dryden started looking for smaller, lighter alternatives to use as sensors on aircraft wings

to deliver real-time data. One of the options was fiber optics, or flexible, transparent glass cores about the size of a human hair. Fiber optics are not only less bulky than traditional sensors; they are easier to apply and capable of delivering far more data more quickly.

For several years, the Dryden research team worked on the development of a fiber optic sensor, a supporting avionics system, and algorithms to make the sensor work on an aircraft wing. Allen Parker, a research engineer at Dryden, developed a unique mathematical algorithm that enabled high-speed calculations of the fiber optic sensor measurements, which led to the utilization of this technology for aerospace applications.

To validate the system, the team employed a long fiber optic strand on the wings of an unmanned science and technology development aircraft called Ikhana (Predator-B). Every half of an inch along the fiber, a sensor fed data on the wing structure back to a computer. According to Parker, “Ikhana represented one of the first comprehensive flight validations of fiber optic sensor technology.”

The fiber optic system met several of the research team’s goals: it was small, easy to install, and it did not affect aerodynamic lift. Parker says, however, that “around 2007, I realized that we needed a different platform to execute the algorithm more efficiently to get where we wanted to go.”

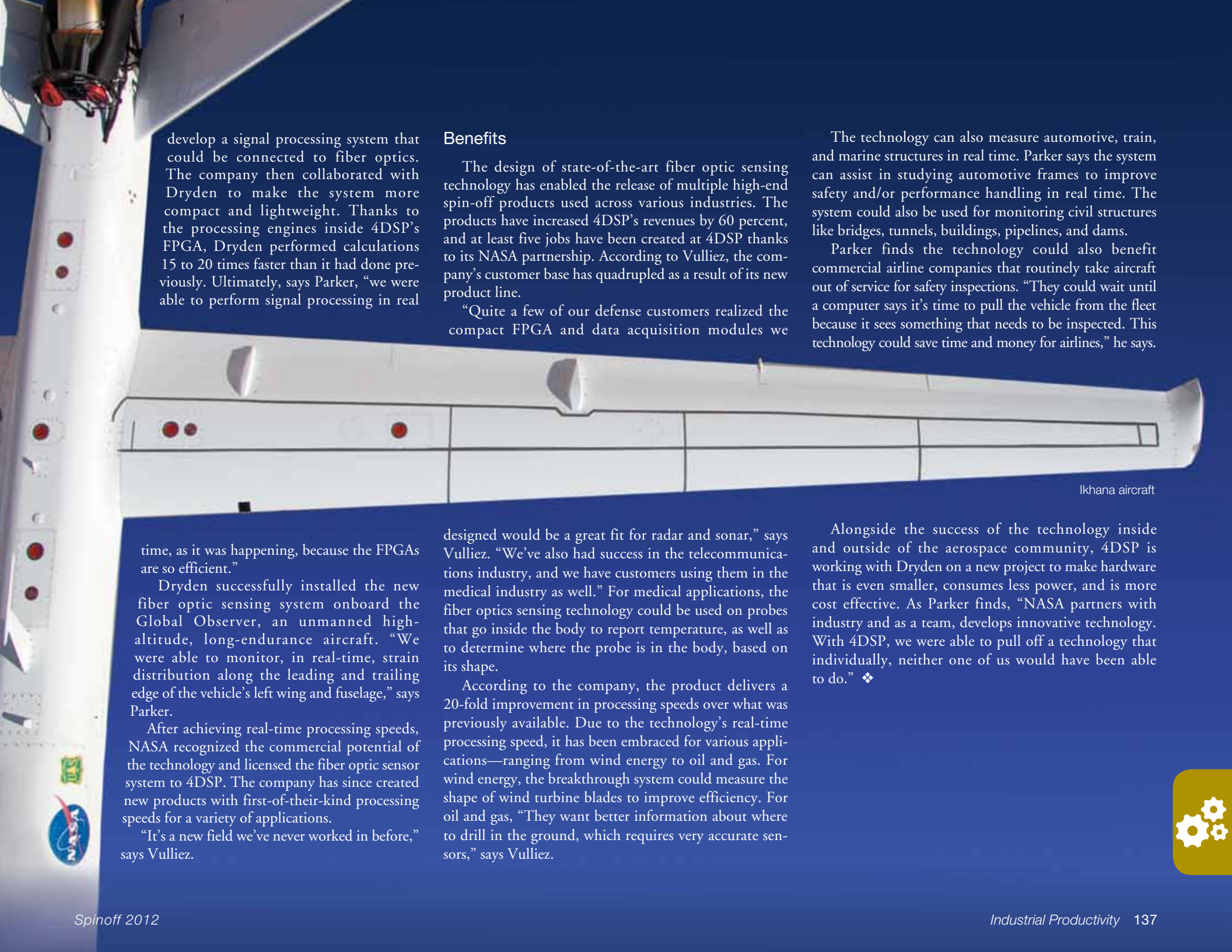
Technology Transfer

Parker started looking for an industry partner to assist with data processing for the fiber optic system and turned to Austin-based 4DSP LLC. After searching the Internet, “I found their field programmable gate array (FPGA) processing board, which had all the necessary components that I thought we were going to need, minus the algorithm side of the product.”

Parker approached 4DSP about combining the NASA algorithm with the company’s FPGA, and his request was met with enthusiasm. Pierrick Vulliez, president of 4DSP, says his company soon started working to



4DSP’s real time fiber optics sensing system incorporates NASA technology to rapidly process data for a host of monitoring and sensing applications such as monitoring wind turbine blades, civil structures like bridges and dams, and aging aircraft.



develop a signal processing system that could be connected to fiber optics. The company then collaborated with Dryden to make the system more compact and lightweight. Thanks to the processing engines inside 4DSP's FPGA, Dryden performed calculations 15 to 20 times faster than it had done previously. Ultimately, says Parker, "we were able to perform signal processing in real

Benefits

The design of state-of-the-art fiber optic sensing technology has enabled the release of multiple high-end spin-off products used across various industries. The products have increased 4DSP's revenues by 60 percent, and at least five jobs have been created at 4DSP thanks to its NASA partnership. According to Vulliez, the company's customer base has quadrupled as a result of its new product line.

"Quite a few of our defense customers realized the compact FPGA and data acquisition modules we

The technology can also measure automotive, train, and marine structures in real time. Parker says the system can assist in studying automotive frames to improve safety and/or performance handling in real time. The system could also be used for monitoring civil structures like bridges, tunnels, buildings, pipelines, and dams.

Parker finds the technology could also benefit commercial airline companies that routinely take aircraft out of service for safety inspections. "They could wait until a computer says it's time to pull the vehicle from the fleet because it sees something that needs to be inspected. This technology could save time and money for airlines," he says.

time, as it was happening, because the FPGAs are so efficient."

Dryden successfully installed the new fiber optic sensing system onboard the Global Observer, an unmanned high-altitude, long-endurance aircraft. "We were able to monitor, in real-time, strain distribution along the leading and trailing edge of the vehicle's left wing and fuselage," says Parker.

After achieving real-time processing speeds, NASA recognized the commercial potential of the technology and licensed the fiber optic sensor system to 4DSP. The company has since created new products with first-of-their-kind processing speeds for a variety of applications.

"It's a new field we've never worked in before," says Vulliez.

designed would be a great fit for radar and sonar," says Vulliez. "We've also had success in the telecommunications industry, and we have customers using them in the medical industry as well." For medical applications, the fiber optics sensing technology could be used on probes that go inside the body to report temperature, as well as to determine where the probe is in the body, based on its shape.

According to the company, the product delivers a 20-fold improvement in processing speeds over what was previously available. Due to the technology's real-time processing speed, it has been embraced for various applications—ranging from wind energy to oil and gas. For wind energy, the breakthrough system could measure the shape of wind turbine blades to improve efficiency. For oil and gas, "They want better information about where to drill in the ground, which requires very accurate sensors," says Vulliez.

Alongside the success of the technology inside and outside of the aerospace community, 4DSP is working with Dryden on a new project to make hardware that is even smaller, consumes less power, and is more cost effective. As Parker finds, "NASA partners with industry and as a team, develops innovative technology. With 4DSP, we were able to pull off a technology that individually, neither one of us would have been able to do." ♦

Ikhana aircraft



Camera Systems Rapidly Scan Large Structures

NASA Technology

Aging aircraft are an increasing concern at the national level. Commercial and government vehicles are being flown past their originally intended service life in order to save money, and fewer aircraft are being built to replace older vehicles. The Department of Defense, for example, is replacing its fleet at well below the rate required to maintain the present average age of its aircraft.

The answer, however, isn't merely to build more aircraft. NASA's Aircraft Aging and Durability (AAD) Project is taking a proactive approach to extending the life of aircraft even before age is a concern. Rather than focusing on old vehicles, the project targets young aircraft and develops technologies and materials to mitigate the effects of aging as early—and for as long—as possible.

Working with innovative materials means lots of testing, and, in the case of large structures like an

aircraft wing, it means developing methods to scan components without taking them apart. Nondestructive testing (NDT) is the field of performing such analyses on materials without altering them permanently. While there are many ways to perform NDT, NASA has developed special methods for using thermography, or infrared imaging, to obtain the best results from scanning composite aircraft structures.

Thermography works by detecting infrared radiation emitted by objects—essentially, it measures how hot something is. While thermographic cameras can only see the surface of objects, the rate at which different parts of a surface emit heat can vary based on what lies beneath. For example, thermographic imaging can easily show water leaks behind normal-looking walls, because the water keeps an area of wall cooler than its surroundings. Similarly, defects throughout the material composing an aircraft wing can be exposed by measuring the heat given off along its surface.

Thermography can be passive or active. Passive thermography simply measures surface temperatures as they are. Active thermography involves applying or removing heat from a system or material and then observing how its temperatures change over time following the intervention.

Active thermography works best to reveal any hidden flaws on large structures, but it is difficult to capture high quality data quickly. The camera must be positioned to detect one part of the wing at a high resolution. Heat

Infrared thermography reveals differences in temperature that can indicate flaws or damage in a material—in this case the white spots along this wall.

The LST system, developed by NASA, makes rapid active thermography a reality.

is applied, the subsequent temperature shifts are recorded, and then the camera is moved to repeat the whole process until a full picture can be stitched together.

To make this process more efficient, NASA developed line scanning thermography (LST). In LST, a moving device applies heat to the material's surface in a thin line, while an infrared camera above moves in tandem with the heat source, capturing each part of the surface before, during, and after the application of heat. Elliott Cramer, head of the Nondestructive Evaluation Sciences Branch at Langley Research Center, says LST enabled the AAD project to rapidly inspect aircraft components and structures. The data from the scans could be processed using a NASA-created algorithm to determine disbonding of composite materials and any thickness changes caused by corrosion.

In the 1990s, NASA filed a patent on the system, with an emphasis on the algorithm for generating data from the measurements taken by the LST camera. "The technology has since been used by NASA for large-area inspections of both metallic and composite structures," says Cramer.

Technology Transfer

After Cramer presented the technology at a technical conference in 1996, NASA was approached by ThermTech Services Inc., a company that specialized in inspecting boiler waterwall tubing at power stations. ThermTech licensed the technology in 1999 and developed equipment for applying the method to industrial applications, a commercial product featured in *Spinoff* 2003.

Before too long, the company's work caught the eye of MISTRAS Group Inc., located in Princeton Junction, New Jersey. For 34 years, MISTRAS has specialized in nondestructive testing, both in performing such tests and

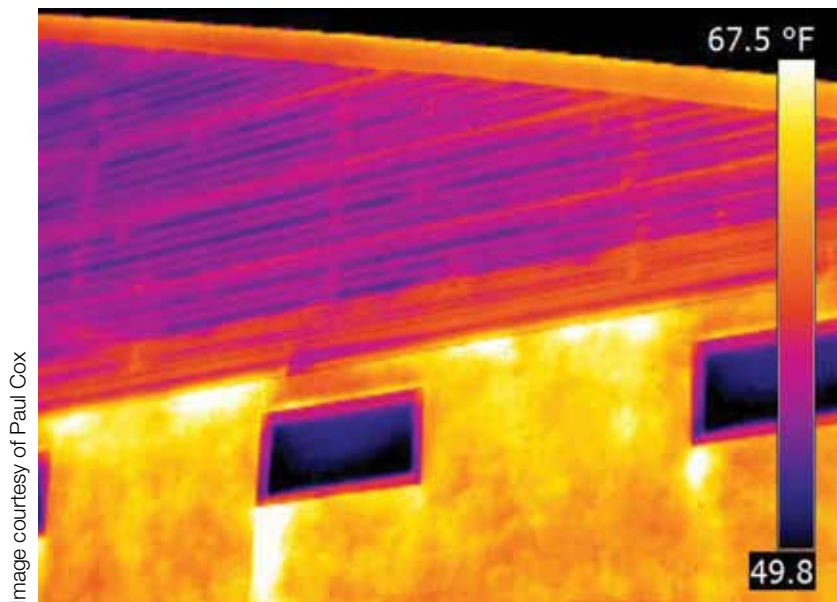
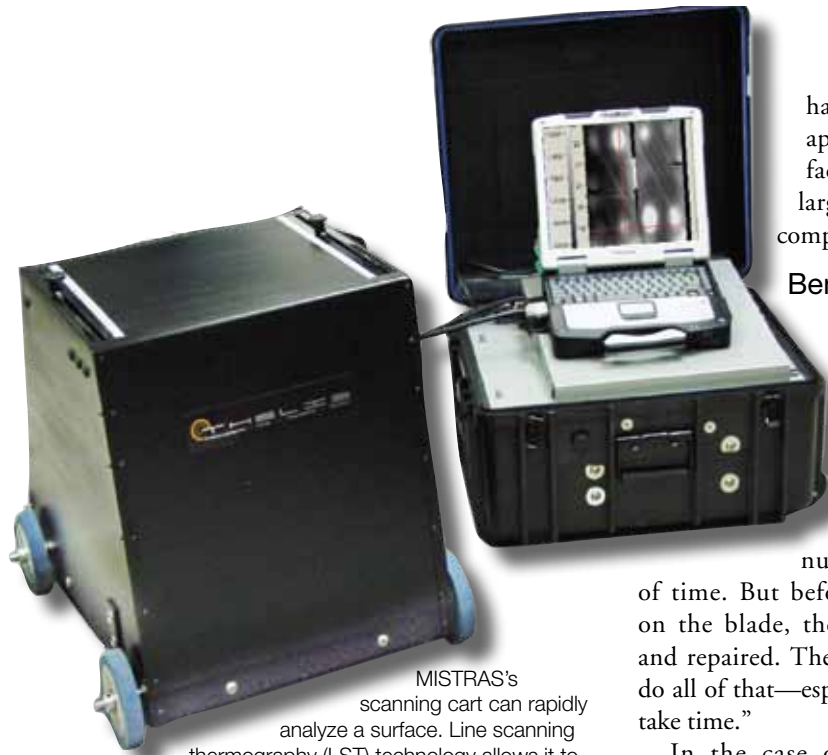


Image courtesy of Paul Cox



MISTRAS's scanning cart can rapidly analyze a surface. Line scanning thermography (LST) technology allows it to take infrared measurements much faster than more traditional methods.

in developing techniques to conduct them. The company established itself largely with acoustic emission and ultrasonic tests—using acoustic waves to probe the integrity of equipment—and in manufacturing the electronics associated with data acquisition and motion controlled scans.

Recently, MISTRAS decided to expand into thermography in order to broaden its capabilities. As Obdulia Ley, a senior research scientist at MISTRAS, explains, “Sometimes defects in a structure—for example, a composite—are easily and quickly detected after heat is deposited and allowed to diffuse within the structure. In some materials and structures, variations and defects can be easier to detect using thermal imaging rather than acoustic measurements.”

MISTRAS acquired ThermTech and has since applied LST in a variety of applications in power stations, manufacturing plants, and even in scanning large sections of ships constructed from composite materials.

Benefits

Ley says that LST has given MISTRAS the ability to handle large jobs that come with demanding time schedules. “A company might manufacture wind turbine blades,” she says, “and they have to provide a certain number of them in a short amount of time. But before they put the final coat of paint on the blade, the composite must be cured, tested, and repaired. There is a very small window of time to do all of that—especially if you find a flaw, since repairs take time.”

In the case of boilers in power stations, any unplanned downtime can quickly become expensive, as the electricity that the plant fails to generate while components are offline must be purchased instead. LST allows MISTRAS to scan large structures within planned downtime, minimizing the cost for power stations while still giving them an accurate picture of the health of their components. Typically, power stations set aside one week out of the year for testing and repairs, says Ley. “When we’ve done boiler inspections, they have to be done in 18–36 hours, and we’re talking about a 3–4 story building that requires scans all over.”

Using LST on aircraft, MISTRAS is also able to get a sense of how close an older vehicle is to structural failures. Says Ley, “We help our clients understand how the composites are aging and when they are not fit for service anymore. Doing these inspections allows them to avoid the high prices associated with catastrophic failures.”

Ley points out that NASA-developed technology plays a crucial role in making that assessment. “You might have an airplane that is 50 years old, and you still want to use it. In that case it’s critical to be sure that it can still perform. The LST system is fundamental to that effort.” ❖



One of MISTRAS's portable scanners that utilizes NASA's LST system.



Terahertz Lasers Reveal Information for 3D Images

NASA Technology

After taking off her shoes and jacket, she places them in a bin. She then takes her laptop out of its case and places it in a separate bin. As the items move through the x-ray machine, the woman waits for a sign from security personnel to pass through the metal detector. Today, she was lucky; she did not encounter any delays. The man behind her, however, was asked to step

inside a large circular tube, raise his hands above his head, and have his whole body scanned.

If you have ever witnessed a full-body scan at the airport, you may have witnessed terahertz imaging. Terahertz wavelengths are located between microwave and infrared on the electromagnetic spectrum. When exposed to these wavelengths, certain materials such as clothing, thin metal, sheet rock, and insulation become transparent.

At airports, terahertz radiation can illuminate guns, knives, or explosives hidden underneath a passenger's clothing. At NASA's Kennedy Space Center, terahertz wavelengths have assisted in the inspection of materials like insulating foam on the external tanks of the now-retired space shuttle.

"The foam we used on the external tank was a little denser than Styrofoam, but not much," says Robert Youngquist, a physicist at Kennedy. The problem, he explains, was that "we lost a space shuttle by having a chunk of foam fall off from the external fuel tank and hit the orbiter."

To uncover any potential defects in the foam covering—such as voids or air pockets—that could keep the material from staying in place, NASA employed terahertz imaging to see through the foam. For many years, the technique ensured the integrity of the material on the external tanks.

Technology Transfer

In 2009, NASA's Kennedy started looking for new capabilities to examine foam materials and other thermal coatings being considered for use on future space vehicles. "We had systems that provided 2D information, but we wanted to invest in technology to provide 3D imaging," says Youngquist. "Going from 2D to 3D is a huge step in making a determination of whether something is severely or deeply damaged." For NASA, 3D terahertz imaging can provide more complete information such as size, location, and depth of defects in thermal materials.

To gather ideas on potential technologies to create 3D images of the materials that might be used on future spacecraft, Kennedy solicited proposals from academia and industry through the Small Business Technology Transfer (STTR) program. One of the responses that garnered NASA's interest was from Boston-based LongWave Photonics LLC and the Massachusetts Institute of Technology (MIT).

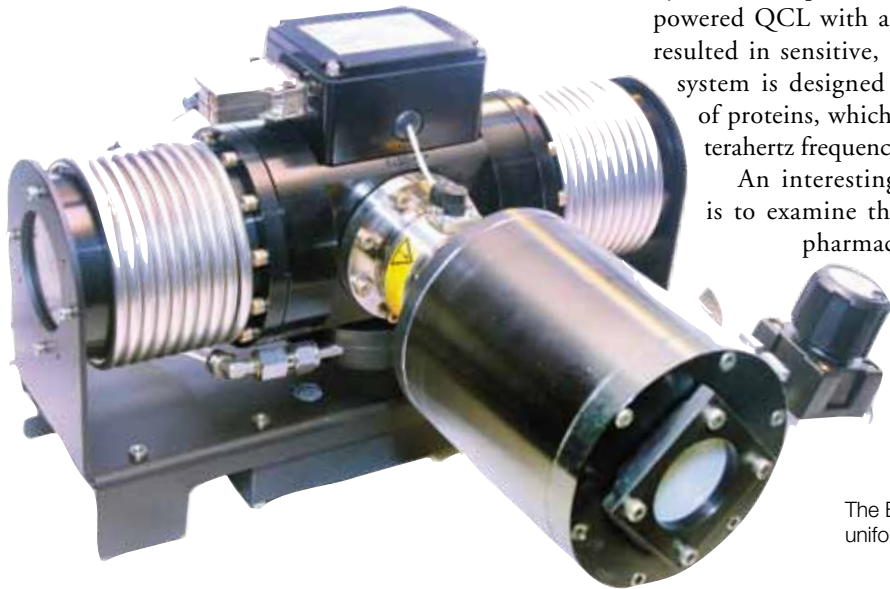


Image courtesy of Lockheed Martin

NASA worked with LongWave Photonics LLC to advance terahertz imaging technology for examining the materials on future spacecraft like the Multi-Purpose Crew Vehicle. Here, the vehicle is shown at Lockheed Martin's Vertical Testing Facility.

Alan Lee, president of LongWave Photonics, launched the company soon after graduating from MIT. At MIT, Lee had gained experience working with terahertz technology, and he felt there were opportunities to commercialize a unique terahertz device. Called the quantum cascade laser (QCL), the technology is a high-power source of terahertz radiation. "The basic idea is that you use a QCL to illuminate a sample and cause the reflected light to interfere with itself," says Lee. "An algorithm is applied to the interference signal to measure the distances between reflections, which results in a signal similar to an ultrasound scanner."

According to Lee, the QCL was first developed to produce infrared frequencies at Bell Labs in 1994. By 2002, it was demonstrated at terahertz frequencies; a capability was later developed to adjust the terahertz frequency. Through the NASA partnership, LongWave Photonics was afforded the time and resources to advance the QCL to a point where it could be sold for research purposes. "The STTR funding has allowed us to develop a research system, the Easy QCL, to access niche markets that will



The Easy QCL could help to improve the uniformity of coatings on drug capsules.

help to grow the business while we explore larger markets," says Lee.

According to Youngquist, the technology has been shown to be very powerful, and was proven to generate 3D scanning for NASA's potential needs.

Benefits

In 2011, LongWave Photonics started selling the Easy QCL commercially as a turnkey terahertz source for academic, industrial, and government researchers. It has already been demonstrated for use in imaging, spectroscopy (looking at the energy emitted from an object), and tomography (imaging a section inside a solid object).

Over the last year, LongWave Photonics has sold several Easy QCLs, and one system is currently being used as an illumination source for an experimental biological microscope at the University of Tokyo. The Easy QCL emits light that is detected by a terahertz-specific uncooled camera, the IRV-T0831 fabricated by NEC Corporation. This combination of a high powered QCL with an uncooled terahertz imager has resulted in sensitive, real-time imaging. Lee says the system is designed to determine the binding state of proteins, which often have observable features at terahertz frequencies.

An interesting future application, notes Lee, is to examine the coatings on controlled-release pharmaceutical tablets. "As it turns out, many of the polymer coatings are terahertz-transparent and, therefore, a 3D non-destructive



system has the potential to improve the tolerances of these coatings," he says. The main benefit of 3D terahertz imaging is that it provides information on the subsurface defects in a sample without damaging or otherwise modifying it, Lee explains. Defects in the tablet coatings can affect the performance and reliability of the drugs, but Easy QCL's imaging capabilities could optimize the manufacturing and improve the uniformity of the coatings.

As the STTR work continues between Kennedy, LongWave Photonics, and MIT, Lee looks forward to producing a new compact, multi-frequency QCL system. Youngquist, meanwhile, looks forward to seeing how LongWave's QCL hardware might be used in NASA's future.

"We don't know all our plans for the future, but there will probably be applications looking for voids and defects in insulative materials," says Youngquist. "Lockheed is currently working on a crew capsule at Kennedy, so if we get something promising, we will coordinate with them." ❖



Thin Films Protect Electronics from Heat and Radiation

NASA Technology

Back in 1972, Anne St. Clair worked side by side with Langley Research Center colleague Vernon Bell as part of NASA's research and development efforts to create robust materials for space applications. Bell synthesized new building blocks for high performance polyimides while St. Clair adapted them to make thin films—very thin materials.

As a unique substance known for its heat- and chemical-resistant properties, present-day polyimides are in everything from laptops to kitchen toasters. For NASA, polyimides are useful in space because they can withstand extreme temperatures and radiation.

After working with almost 100 different polyimide structures, St. Clair noticed that a few of the resulting films were nearly colorless. This characteristic was only mildly interesting to Bell, but St. Clair thought it could be extremely beneficial for NASA. In space, color causes heat absorption, which can destroy structures and electronics.

St. Clair decided to explore her suspicion about the value of color-free polyimides. She collaborated with Langley colleague Wayne Slep and Marshall Space Flight Center to characterize the substances. The results confirmed her suspicion, finding that the color-free polyimides were more stable in simulated space environments.

SRS Technologies (now a part of ManTech International Corporation) worked with St. Clair and Marshall Space Flight Center to create demonstration pieces for space applications utilizing the thin film. They were successfully proven, and St. Clair's polyimides became known as Langley Research Center Colorless Polyimide 1 and 2 (LaRC-CP1 and LaRC-CP2).

Technology Transfer

In the late 1990s, SRS exclusively licensed the polyimides from Langley. According to Garrett Poe, program director at ManTech International Corporation, the

company soon learned how to make CP1 and CP2 more effectively. "We've made several manufacturing improvements with regard to batch size, batch yield, reproducibility, and molecular weight," he says.

In 2007, ManTech International acquired SRS Technologies, which became ManTech SRS Technologies



NASA researchers discovered unique heat-resistant substances that were nearly colorless when made into thin films. Proven to be stable in space environments, a private company licensed the NASA technology.

Incorporated. A couple of years later, ManTech separated the group and renamed it NeXolve Corporation, which is based in Huntsville, Alabama.

NeXolve vice president, Jim Moore, explains that the company was working on solar thermal applications at the time when it licensed the technology, and needed a thin film capable of surviving the extreme conditions of space. "The polyimide structure was intended to be folded into a small package, deployed in space to create a large mirror, and then reflect the sun's energy down to the absorber so it could be used as propellant," he says. "Using CP1, we could have a mirror that was made out of polyimides."

Benefits

Today, NeXolve is a leading provider of polyimide thin film products not only to NASA, but to commercial customers including Boeing, Lockheed Martin, and Northrop Grumman.

One of NeXolve's larger NASA projects is the James Webb Space Telescope. The company is providing the five-layer sunshields that will expand to nearly the size of a tennis court when in space.

"We've worked with NASA on solar thermal propulsion, inflatable concentrators, and solar sails," says Garrett. "Most polymer materials start decomposing above 200 or 250 °C. We test our materials to 300 °C. If it withstands that, we have confidence it can withstand temperatures it will see on orbit," says Poe.

NeXolve is also working with government and commercial entities that are developing applications that require lightweight, thin film optics for telescopes. "We use LaRC-CP1 to make transmissive membrane optics or reflective membrane optics," says Poe. "We combine it with another technology we have to manufacture membrane mirrors. We can make the same surface as a glass mirror, but using a thin plastic film that is very light."

The company also produces a CP1-coated copper foil for use as in thermal control. "In spacecraft insulation, it's a multilayer insulation material," describes Poe. "The

blanket is comprised of several layers of films, some of which may be made with CP1 with aluminum coating, for example.”

Over the years, NeXolve has demonstrated CP1 to have stable physical and electrical properties over a range of temperatures and environments. Because it has significantly lower moisture uptake than traditional polyimides, the substance is useful on flexible printed circuit boards for electronics. “The more electronics there are in an area, the more things heat and expand and contract. The more they expand and contract, the more they are subject to moisture expansion, so if you have a material that doesn’t absorb much moisture, like ours, it is beneficial,” says Poe.

The company also supplies its spinoff technology to a leading provider of test solutions for coating electronic test hardware, and is in discussions with a supplier of disk drive components. “We have worked to develop materials to incorporate into suspension assemblies for hard disk drives,” says Moore.

After 40 years of innovation, this one NASA technology not only provides benefits on Earth but continues to influence the future of space exploration. The company recently proposed to use LaRC-CP1 as part of a special kind of photovoltaic technology which could enable lightweight cells for space-based solar power. ❖



NeXolve Corporation is using NASA-derived thin films to construct the five-layer sunshields—one of which is shown here on a test fixture—for the James Webb Space Telescope. The company also provides spinoff products for coating electronic test hardware and for incorporating into hard disk drives.

Image courtesy of Northrop Grumman Aerospace Systems



Interferometers Sharpen Measurements for Better Telescopes

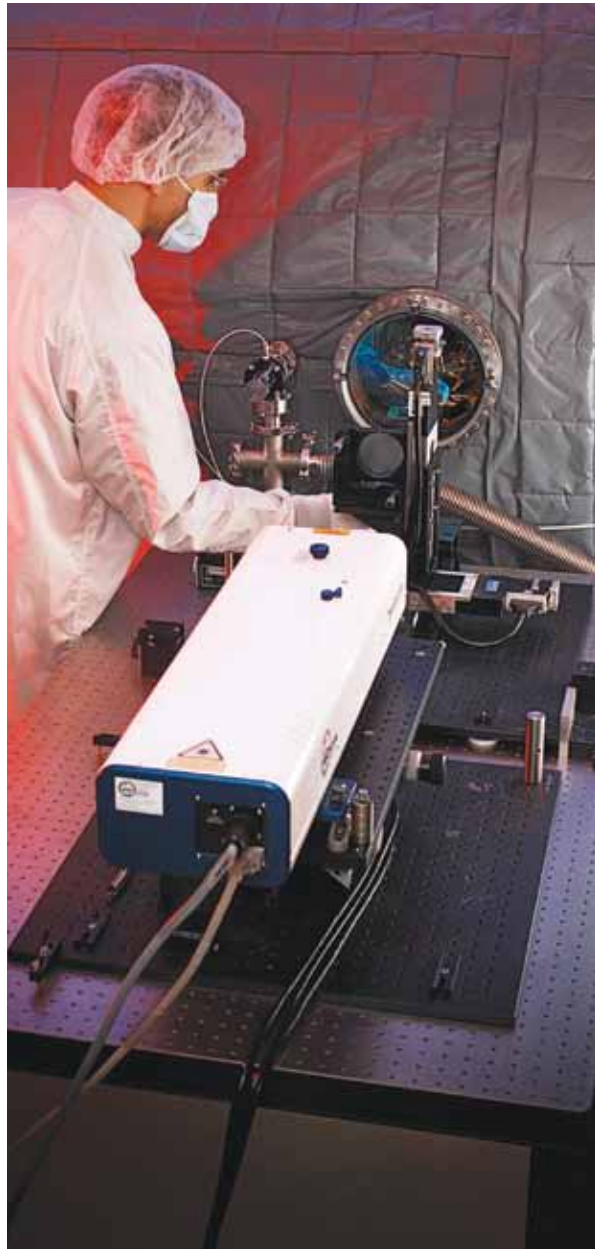


Image courtesy of Bell Aerospace

NASA Technology

Over the last decade, there have been a number of innovations that have made possible the largest and most powerful telescope of its time: the James Webb Space Telescope (JWST). Scheduled to launch in 2018, JWST will provide insight into what the oldest, most distant galaxies look like.

When engineers build a first-of-its-kind instrument like the JWST, they often must make new tools to construct the new technology. Throughout the decades of planning, development, and construction of the JWST, NASA has worked with numerous partners to spur innovations that have enabled the telescope's creation. Though the JWST's launch date is still several years away, a number of these innovations are spinning off to provide benefits here on Earth.

One of these spinoffs has emerged from the extensive testing the JWST must undergo to ensure it will function in the extreme environment of space. In order to test the JWST instruments in conditions that closely resemble those in space, NASA uses a cryogenic vacuum chamber. By dropping the temperatures down to -400°F and employing powerful pumps to remove air from the chamber, engineers can test whether the JWST instruments will function once the spacecraft leaves Earth.

Traditionally, a phase-shifting interferometer is used to measure optics like the JWST's mirrors to verify their precise shape—down to tens of nanometers—during manufacturing. However, the large size of the mirrors, coupled with vibration induced by the cryo-pumps, prohibits the use of traditional phase-shifting interferometers to measure the mirrors within the chamber environment. Because the JWST will be located in deep space, far from any possible manned service mission, it was essential to find a robust solution to guarantee the performance of the mirrors.

4D Technology Corporation developed the PhaseCam to test NASA's telescope mirrors. Here, it measures an optic inside an environmental chamber.

Technology Transfer

In 2000, NASA started contract work with a company called 4D Vision Technology—later acquired by Tucson, Arizona-based 4D Technology Corporation—to develop interferometers that could test large space mirrors and structures more accurately in the chamber environment.

In response to NASA's need, the company integrated a special phase sensor they had developed with an optical system to create a new technology called dynamic interferometry that could take measurements much more quickly than traditional interferometers. The dynamic interferometer was insensitive to vibration and could average out the effects of environmental noise to provide more accurate data.

"The acquisition time is thousands of times faster than that of a traditional phase-shifting interferometer, and fast enough to render the instrument insensitive to the effects of vibration and other environmental noise," says Mike Zecchino, marketing communications manager at 4D.

The first interferometer incorporating the technology was called PhaseCam, installed for testing NASA's large telescope mirrors. "It verified the surface shape of telescope mirror segments and aided the polishing process to ensure that the segments would retain that required shape in the cold vacuum of space," Zecchino says.

By 2005, NASA selected 4D as the primary metrology vendor for the JWST, and in 2006 the company earned a prestigious R&D 100 Award from the editors of *R&D Magazine* as one of the 100 most technologically significant new products created that year.

Ritva Keski-Kuha, an optical physics engineer at Goddard Space Flight Center, says 4D's interferometers are critically important to "prove out" JWST telescope technology. In total, 4D has provided nine powerful instruments to NASA and its partners.

"The technology provides accurate measurements for space hardware at a few nanometers accuracy. Prior to

“this, nothing existed that could do what 4D’s technology does.” Keski-Kuha says.

Benefits

Today, 4D is thriving as a result of its NASA innovations. Zecchino says the partnership has led to the development of products that have sold in the hundreds in more than a dozen different countries. In addition, 4D has grown from a 4-person startup to over 30 employees, thanks in large part to programs that started with NASA.

“4D’s main technology—dynamic interferometry—and most of 4D’s product lines, trace their lineage to the JWST project or to projects that directly developed technology for JWST,” says Zecchino.

Alongside its NASA work, the company has refined and enhanced its dynamic interferometers for general use in the optics, astronomy, aerospace, data storage, university research, manufacturing, and medical industries.

The technology is now being used in laboratories, clean rooms, environmental chambers, and production environments where vibration is an intrinsic and detrimental facet of the manufacturing process. One of 4D’s interferometers was even recently delivered to a facility where vibration from a proposed adjacent streetcar line was predicted to cause disturbance of the facility and restrict the ability to take accurate measurements of optics under test. While several options were considered to lessen the effects, an interferometer from 4D mitigated the vibration at approximately 1/10th the cost of other proposed methods.

4D believes that NASA-derived dynamic interferometry has been a significant contributor to the development of the current generation of ground and space based telescopes, and that it has also helped ensure the performance of satellite optics. Customers who used to spend time waiting for low vibration conditions so they could mea-

sure large optics can now measure at virtually any time. The technology also reduces the total time required to test optics—often from days to hours, with data delivery in seconds.

Ultimately, such developments will not only benefit industry, but everyone on Earth—as soon as JWST sends back its first bits of data from space. ❖



Here, the primary mirror segments for the James Webb Space Telescope (JWST) are prepped to begin final cryogenic testing. The technology developed for testing the JWST mirrors has been refined for the optics, astronomy, data storage, university research, manufacturing, and medical industries.



Vision Systems Illuminate Industrial Processes

NASA Technology

When NASA designs a spacecraft to undertake a new mission, innovation does not stop after the design phase. In many cases, these spacecraft are firsts of their kind, requiring not only remarkable imagination and expertise in their conception but new technologies and methods for their manufacture.

In the realm of manufacturing, NASA has from necessity worked on the cutting-edge, seeking new techniques and materials for creating unprecedented structures, as well as capabilities for reducing the cost and increasing the efficiency of existing manufacturing technologies. From friction stir welding enhancements (*Spinoff* 2009) to thermoset composites (*Spinoff* 2011), NASA's innovations in manufacturing have often transferred to the public in ways that enable the expansion of the Nation's industrial productivity.

NASA has long pursued ways of improving upon and ensuring quality results from manufacturing processes ranging from arc welding to thermal coating applications. But many of these processes generate blinding light (hence the need for special eyewear during welding) that obscures the process while it is happening, making it difficult to monitor and evaluate.

In the 1980s, NASA partnered with a company to develop technology to address this issue. Today, that collaboration has spawned multiple commercial products that not only support effective manufacturing for private industry but also may support NASA in the use of an exciting, rapidly growing field of manufacturing ideal for long-duration space missions.

Technology Transfer

The company was Control Vision Inc., then based in Idaho Falls, Idaho. Through the Small Business Innovation Research (SBIR) program, Control Vision partnered with Marshall Space Flight Center to create video sensor systems capable of imaging industrial pro-

cesses in which high temperatures and brightness impede in-process visualization. These systems used specialized illumination to overcome process light, explains Dan Crawford, president of Control Vision.

"The basic technology uses intense, pulsed illumination to overwhelm whatever specific process light there is," he says. The system's sensors, tuned to a wavelength within the brighter light source, filter out the light generated by the welding arc or furnace, producing clear images of the process as it is happening. At Marshall, Control Vision's systems were installed and tested on low pressure plasma spray processes to image the particles inside the plasma spray plume.

After a change of ownership, Control Vision is now based in Sahuarita, Arizona, and offers three products that have their origins in the company's NASA work.

Benefits

One of the products, the LaserStrobe system, uses 10-nanosecond laser pulses and high speed shuttering to create high quality images of conventional and laser welding, plasma spray, and processes such as fiberglass spinning that operate at high speeds. In contrast, the company's two PyroCam products use a pulsed xenon strobe as their light source. PyroCamLP is ideal for laser processing and PyroCamMV for imaging ceramics, glass, molten metals, and continuous casting processes.

Building off of the LaserStrobe technology, the company created its SprayCam system, created as a low cost means of imaging thermal spray coating processes. SprayCam can image the powder particles in flight within a plasma stream, allowing users to monitor important qualitative characteristics, such as particle distribution, as the coating is being applied.

While quality control has been the traditional application for Control Vision's spinoff innovations, Crawford says, "Process control is an area where we are really pushing these technologies." Using machine vision software, the company's systems can monitor a process and make

constant adjustments to ensure consistent, high quality results.

It is in this way that Control Vision's technologies can contribute significantly to a rapidly developing field of manufacturing: additive manufacturing—also known as 3D printing—a quickly growing \$1.7 billion industry. In this case, a three-dimensional object is created by a device that "prints" successive layers of a feedstock material such as a metal or plastic, building up the object one layer at a time. NASA is exploring additive manufacturing methods, such as electron beam freeform fabrication, as a means for creating spare parts or tools in space, allowing astronauts to create what they need instead of having to carry along a supply of extras. NASA's Innovative Advanced Concepts program has even funded research into using additive manufacturing to create entire buildings on the Moon. Control Vision has been in talks with NASA about using its SBIR-derived technology to provide process control for additive manufacturing.

"In an additive manufacturing process, we measure the melt pool diameter and perform closed loop control on, for instance, the power of the electron beam so we can maintain a constant melt pool shape in spite of a changing, dynamic process," explains Crawford.

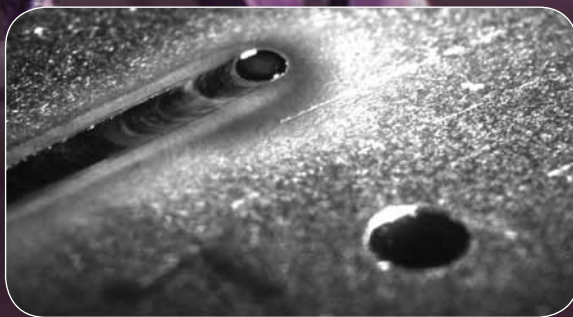
In the meantime, Crawford says Control Vision's products are finding many applications in the aerospace and defense sectors, and the company has numerous projects underway with the Department of Defense. The company's successes, Crawford says, go back to the SBIR program.

"The SBIR program continues to be very beneficial for us as we take this technology into new areas and do things we weren't able to do in the past." ♦

LaserStrobe™, PyroCam™, and SprayCam™ are trademarks of Control Vision Inc.

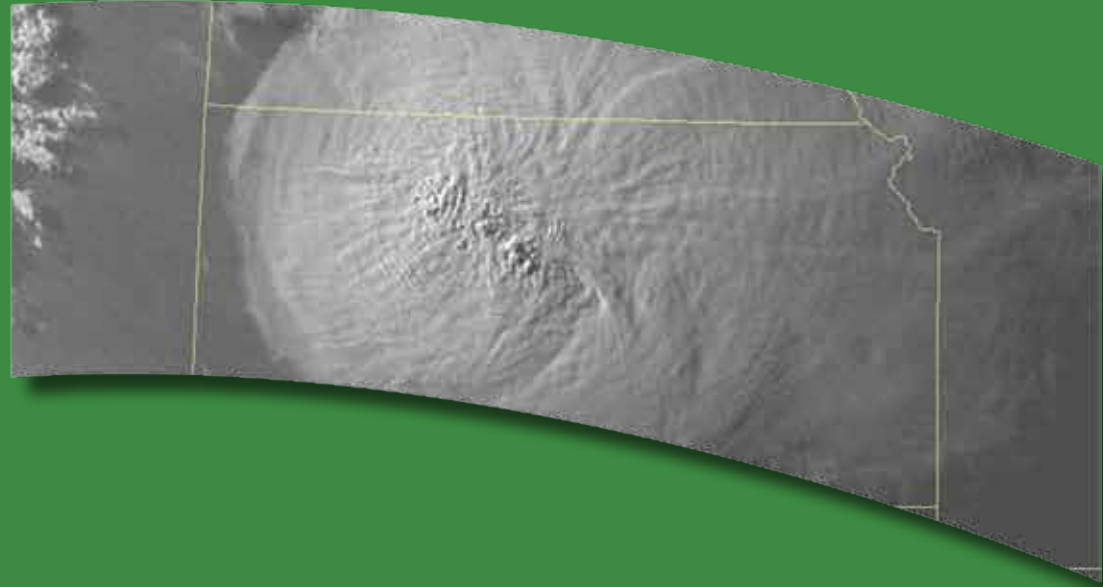


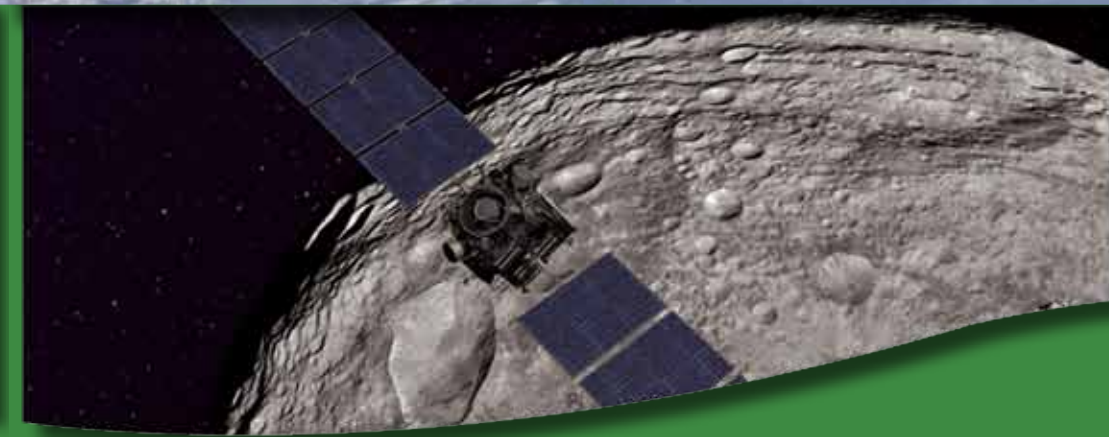
Control Vision's spinoff technology reveals the details of high-energy, high-brightness industrial processes, including (inset, from left to right) thermal spray, laser welding, and additive manufacturing.



Aeronautics and Space Activities

Every day, NASA leads a nationwide effort to foster innovation in technology, engineering, and scientific research. NASA's research operations provide the foundation for unprecedented accomplishments in space exploration, aviation, Earth science, astrobiology, and much more. Headed by three mission directorates and spreading across the Agency's 10 field centers, NASA's research and development moves the ideas of the Nation's best and brightest minds from possibility to reality—and sets the stage for future spinoffs, as well.





Aeronautics and Space Activities

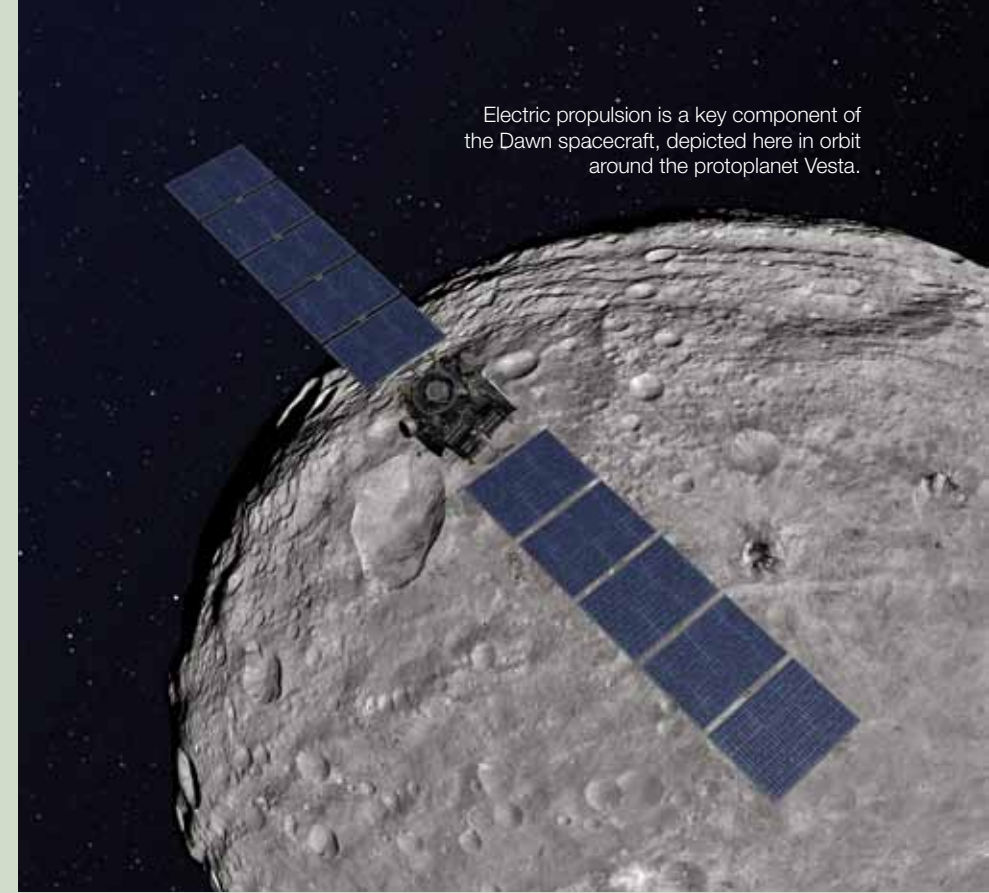
Aircraft, Heal Thyselves

One day, aircraft components may be able to repair their own damage from fatigue cracking and low-velocity impacts. Called “self-healing,” researchers within NASA’s Aviation Safety Program have already successfully demonstrated some early concepts in metals and composites—the two basic building blocks of all airplanes.

Typical structural repairs can often leave materials prone to further damage because the material is ground away and holes are drilled to secure patches. In contrast, self-healing materials offer a non-intrusive means of automatically detecting and repairing damaged components.

NASA lab demonstrations showed a lessening of fatigue crack spreading in metals, as well as the effects of impacts on composite materials. For metals, a heat-activated self-healing material placed into cracks successfully reduced the crack tip driving force of aluminum and titanium alloys. It also dramatically held back crack propagation. For composites, a unique material demonstrated a healing effect when the material was heated under pressure.

These materials offer promise for repairs before damage is ever detected. Such self-healing could significantly improve aircraft safety and prevent the need for costly maintenance.



Electric propulsion is a key component of the Dawn spacecraft, depicted here in orbit around the protoplanet Vesta.

Innovative Engines

Electric propulsion is a spacecraft rocket propulsion system that provides fuel-efficient propulsion capabilities for satellite maneuvers. Rather than depending on conventional rocket propellants, these devices harness electrical power generated by solar arrays or from nuclear power sources.

There are several different types of electric propulsion systems, but recent focus has been the development of electrostatic ion and hall thrusters. The Dawn spacecraft is currently orbiting around the asteroid Vesta and will eventually orbit the protoplanet Ceres. This mission was enabled by solar electric propulsion investments in ion propulsion systems.

NASA investments in electric propulsion thrusters, power processing units, and flow control devices are leading to improvements in the efficiency, life, and throttling capabilities of these propulsion systems for deep space missions. And the commercial interest in communications satellites helps provide an industrial base to keep the cost of these systems down for NASA’s interplanetary missions.



Naruse River

Higashi-
matsushima

Flood Water

Matsushima Airport

Ishinomaki Bay

The camera on ISERV (inset) could provide an unprecedented live view of disasters as they develop. It will take photos from the same perspective as this photo analysis (background) taken during the 2011 Japanese earthquake and tsunami.

A Space-Eye View of Disasters

Of all the spacecraft and satellites in orbit, few can match the International Space Station (ISS) for its view of the Earth below. Scientists would like to put that spectacular view to good use—by having the ISS photograph disasters, both natural and manmade, in real time.

Thanks to a collaboration between the NASA/USAID program known as SERVIR within NASA’s Applied Sciences Program, and NASA’s International Space Station (ISS) program, the station will be outfitted with a new instrument—part of a system called ISERV—and equipped with a prototype automated camera that could image areas threatened by floods, landslides, forest fires, or other disasters.

“Let’s assume an earthen dam gives way in Bhutan,” says Burgess Howell, a science lead for SERVIR. “With an instrument like Pathfinder, we could show disaster officials where the bridge is out, for example, or the hospital is gone, the road washed out, or the power substation inundated. We could also estimate the number and location of structures destroyed and the amount of agricultural land affected. All of this information is critical to focus and speed rescue efforts.”

Pathfinder is capable of taking a series of high-resolution photographs of the area at 7 frames per second for 6 to 8 seconds, totaling 40–60 images per pass. The camera’s nominal resolution is 2.8 meters—about the size of a cow—although scientists may be able to sense the presence of smaller targets down to the size of a person.

“In ideal conditions, the party requesting the data could receive them within 3 hours,” says Howell. “But in some cases, because of the station’s varying orbit, it might be 3 days before a viewing opportunity arises. Even then the data could be used to analyze environmental changes the disaster causes, and this is vital information.”



The Orion team loads a test version of the spacecraft into a C-17 in preparation for a parachute drop test in Arizona. The main objective of the July 2012 drop was to see how the system would respond if one of the parachutes inflated too quickly.

Orion Arrives

More than 450 guests at NASA's Kennedy Space Center in Florida welcomed the arrival of the Agency's first space-bound Orion spacecraft in July of 2012, marking a major milestone in the construction of the vehicle that will carry astronauts farther into space than ever before.

"Orion's arrival at Kennedy is an important step in meeting the president's goal to send humans to an asteroid by 2025 and to Mars in the 2030s," NASA Deputy Administrator Lori Garver said. "As NASA acquires services for delivery of cargo and crew to the ISS and other low-Earth destinations from private companies, NASA can concentrate its efforts on building America's next generation space exploration system to reach destinations for discovery in deep space. Delivery of the first space-bound Orion, coupled with recent successes in commercial spaceflight, is proof this national strategy is working."

Orion will be the most advanced spacecraft ever designed. It will provide emergency abort capability, sustain astronauts during space travel, and provide safe re-entry from deep space. The space-bound Orion will launch on Exploration Flight Test-1, an uncrewed mission planned for 2014. The spacecraft will travel 3,600 miles above the Earth's surface, 15 times farther than the ISS' orbital position. This is farther than any spacecraft designed to carry humans has gone in more than 40 years.

"Work is under way on America's next great spacecraft that will surpass the boundaries within which humanity has been held," said William Gerstenmaier, associate administrator for the Human Exploration Operations Mission Directorate at NASA Headquarters in Washington. "In a facility that once processed cargo for space shuttles and various components for the ISS, hundreds of people at Kennedy are coupling advanced hardware assembly systems with a new human-rated spacecraft designed for deep space travel. It is a fitting testament to the American work force at Kennedy that has enabled the exploration of space for 50 years is again working on hardware that will extend human presence throughout the solar system."

Flying to the Future

NASA's Fundamental Aeronautics Program (FAP) is conducting research for more efficient, quieter, greener, and faster aircraft—meaning less noise, shorter flights, and cleaner air for the American public.

Because of its potential to reduce aircraft emissions, one area getting concentrated effort is alternative fuels. FAP's Subsonic Fixed Wing Project recently sponsored a test of synthetic Hydrotreated Renewable Jet fuel that provided information on emissions at various locations in the engine exhaust plume. The results confirmed that biofuels in jet engines are cleaner-burning and release fewer pollutants when compared to conventional jet fuel.

Another area of interest is reduced aircraft drag, which could help improve fuel efficiency due to less energy being needed to move a vehicle through the air. Researchers from FAP's Subsonic Rotary Wing Project tested the use of active flow control to reduce the drag and download forces from a rotor on an aircraft model in a subsonic wind tunnel at Langley Research Center. Researchers were able to achieve less drag by utilizing controlled airflow through slots that had been strategically placed in the model's fuselage.

Another area of research involves commercially viable airliners that can fly over land at supersonic speeds. The Supersonics Project invested in the development of computational tools to enable designs that achieve low sonic boom noise while maintaining high efficiency. These tools allow designers to manipulate all aspects of the configuration's geometry to fully explore solutions. Wind tunnel tests of the designs created using these approaches have verified their effectiveness.

NASA is **conducting research** that will result in **less** noise, **shorter** flights, and **cleaner air** for the **American public.**



This computer-generated image shows a possible future "flying wing" aircraft, very efficiently and quietly in flight over populated areas. This kind of design, produced by Northrop Grumman, would most likely carry cargo at first and then also carry passengers. For a deeper look at NASA's down to Earth future aircraft concepts, scan this code.

Early Warning

On January 22 and 23, 2012, more than 37 tornadoes struck the southern United States. Ten of them tore across the Lower Mississippi Valley into Alabama. Worst hit were St. Clair and Jefferson County, Alabama, where 2 people were killed, about 100 others injured, and at least \$30 million in damage was done.

“Even with our advances in science and communications, we can still be surprised by the deadliest storms,” says National Oceanic and Atmospheric Administration (NOAA) scientist Steve Goodman. “But NOAA is working with NASA and university researchers to give more lead time in tornado warnings.”

Southern tornadoes are especially insidious and challenging to track. The hilly, forested terrain in southern states makes an approaching twister harder to spot than in the flat Midwest. In the South, you might not see the

first evidence of an approaching tornado until it’s almost in your back yard.

To reduce the surprise, NOAA and NASA are developing the Geostationary Operational Environmental Satellite-R, or GOES-R series, with the first expected to launch in late 2015. These next-generation weather satellites bristle with state-of-the-art instruments for improved scouting of these killer storms, even at night.

Tornadoes are, by their very nature, difficult to pin down, but the Advanced Baseline Imager (ABI) on GOES-R will improve meteorologists’ ability to assess conditions that spawn twisters. Compared to current GOES imagers, the ABI provides twice the spatial resolution, three times as many channels of information, and more than five times the update rate.

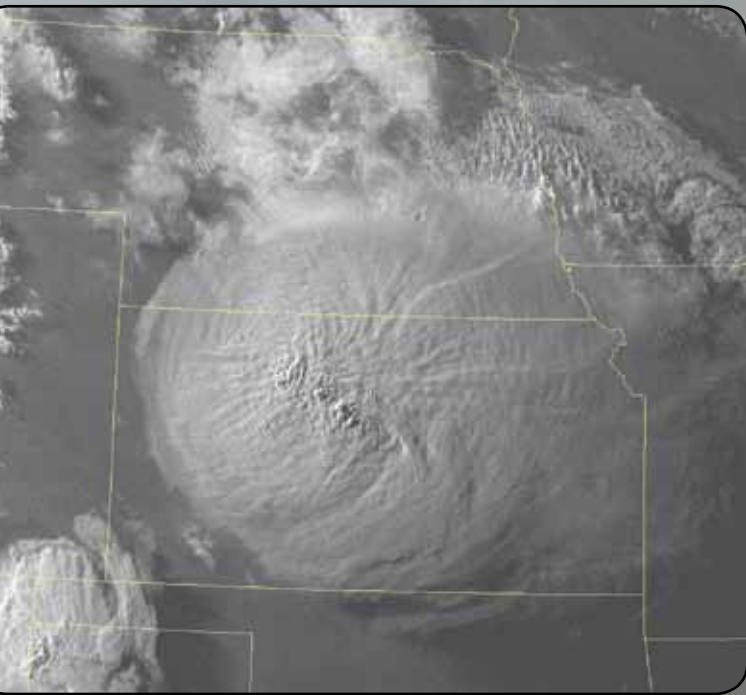
“ABI will give us a much clearer picture of the clouds—where and how tall they are, how much and what kind of moisture they hold, and how they are

moving and intensifying,” says NOAA research meteorologist Tim Schmit.

Most importantly, ABI can better detect the super-cold “overshooting tops” that mean severe weather is imminent. “Overshooting tops portend huge energy inside the cloud—it takes tremendous energy and upward velocity to poke through the lid of the tropopause,” explains Schmit.

“During episodes of severe weather, ABI can show conditions every 30 to 60 seconds. The system in use now only shows them every 7.5 minutes. And in normal mode, ABI will send readings over the continental United States every 5 minutes, as opposed to every 15–30 minutes.”

With GOES-R, those in danger will have upwards of 20 minutes’ warning to get to a safe haven—a 7 minute improvement over current technology.



A satellite image of a supercell thunderstorm over Kansas.

Image courtesy of the National Weather Service.



New Information for Safer Flights

NASA's Aviation Safety Program is developing new algorithms to quickly comb through the large number of files stored from millions of commercial airline flights to identify anomalies, or data points that are significantly different from comparable flights. NASA is developing the algorithms through partnerships with the airlines, the Commercial Aviation Safety Team, the Federal Aviation Administration, and the French aerospace research agency ONERA.

The algorithms are being designed to find anomalies that can impact flight safety. Such anomalies could include everything from a pilot configuring the airplane for landing at an inappropriate time, to excessive maneuvering close to the ground, to unexpected readings from an airplane. If an algorithm detects a statistically significant anomaly, a human analyst can then review the event to determine if it is operationally significant. If the analyst confirms a problem, an airline could consider multiple mitigation paths to prevent it from recurring or to minimize its safety impact.

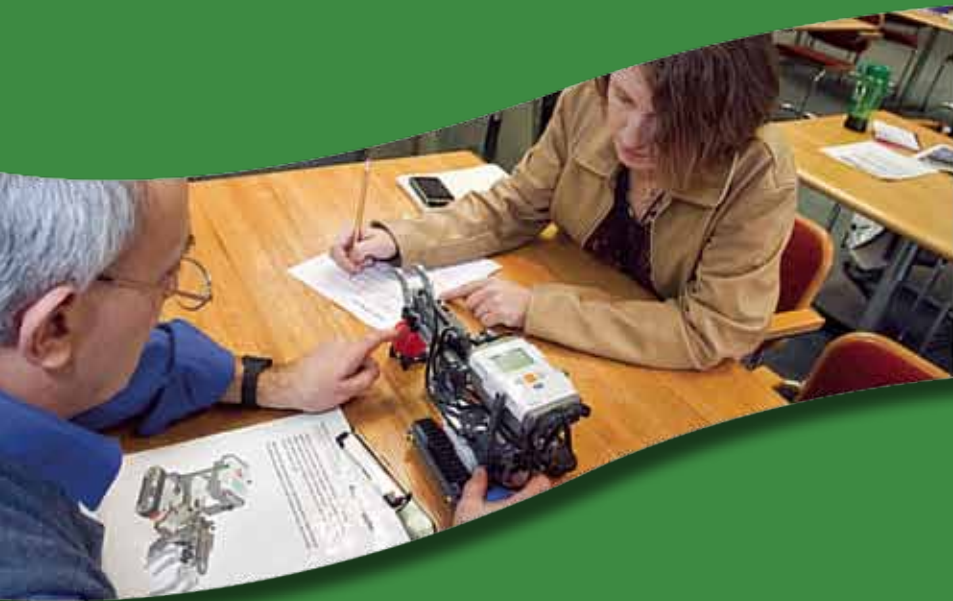
In 2011, the algorithm development incorporated an approach of concurrently considering three different data types: discrete, continuous, and text records. Discrete variables represent pilot-controlled inputs such as flap position and warnings such as low oil pressure. Continuous variables represent measurements such as altitude, airspeed, and vertical speed. The text reports typically discuss problems that occurred during the flight.

The capability to efficiently search for anomalies across increasingly large datasets will allow analysts to conduct more targeted safety studies, which are currently limited by the time needed to discover and review example occurrences of suspected problems. As an ultimate goal, analysts will be able to mine the extensive data fields to uncover new areas of potential safety issues that the aviation safety community had not previously considered.

Going forward, NASA plans to test the algorithms on larger datasets. In 2012, NASA will conduct a test on a large 10 terabyte file to determine whether a certain algorithm can still detect statistically and operationally significant anomalies. ♦

Education News

NASA's commitment to investing in the Nation's future extends beyond the development of new technologies and capabilities for the next big space mission. To ensure the United States stays at the forefront of global innovation, NASA also drives efforts to inspire and educate the next generation of inventors and problem solvers. Through programs that promote science, technology, engineering, and math to students of all ages, NASA's Office of Education takes the lead in making sure our Nation's greatest resource—the young minds of today—have all the tools they need to become the innovators of tomorrow.





Education News

50 Years of STEM

In March 2011, NASA's longest running education program, the Aerospace Education Services Project (AESP), celebrated 50 years of providing NASA science, technology, engineering, and mathematics (STEM) education activities and professional development workshops across 50 states and US territories.

The celebration engaged more than 1,100 STEM educators and took place during the 2011 National Science Teachers Association annual conference, "Celebrating the Joy of Science: Imagine and Create." AESP presenters and speakers led 26 professional development workshops and presentations highlighting NASA's unique education activities and resources.

Getting Their Wings

NASA selected 25 graduate and undergraduate students from across the country to receive aeronautics scholarships through the Agency's Aeronautics Scholarships Program, which aids students enrolled in fields related to aeronautics and aviation studies. This year's recipients were enrolled at universities in Colorado, Florida, Illinois, Indiana, Massachusetts, Michigan, New Jersey, New York, Ohio, Pennsylvania, Virginia, and Texas.

Students were offered the opportunity to intern with NASA researchers and directly contribute to NASA projects, such as managing air traffic more efficiently; reducing aircraft noise, fuel consumption, and emissions; and improving aircraft safety.

Tracie Hall, an elementary school teacher, and Garrison Hall, a middle school teacher, work together to program a robot during a NASA science, technology, engineering, and math (STEM) Educators Workshop.



Grants Boost STEM Programs

To strengthen particular STEM programs serving large numbers of minority and underrepresented students, NASA awarded grants to four different universities and partner institutions totaling approximately \$600,000. The grants were provided through NASA's Curriculum Improvement Partnership Award for the Integration of Research project and reflect NASA's commitment to achieving a broad-based, competitive aerospace research and technology development capability among the nation's historically black colleges and universities, tribal colleges and universities, and Hispanic and other minority-serving institutions.

Langley One of "10 Best Internships"

Langley Research Center celebrated the 25th anniversary of its longest running research internship program, the Langley Aerospace Research Summer Student (LARSS) program, in August 2011. Launched in 1986 with 20 students, today LARSS engages more than 4,500 prestigious high school, undergraduate, and graduate students from 48 states and US territories.

NASA's chief technologist at the time, Bobby Braun—himself a 1986 LARSS participant—said, "LARSS provided my first glimpse of NASA, first practical knowledge of engineering, and an introduction to other aerospace professionals, many of whom I am happy to still call colleagues today."

The program has set a precedent for research internships, mentoring, and development programs at other NASA Centers, and was ranked among the "10 Best Internships for 2011" by Vault Career Intelligence.

The Girl Scouts Visit NASA

NASA marked the 100th anniversary of the Girl Scouts of America by hosting an event in June 2012 at NASA Headquarters in Washington, DC. The Agency shares a common goal with the Girl Scouts to encourage and educate young girls about STEM in exciting new ways. At the Girl Scouts Rock@NASA program, attendees learned about NASA's missions and careers, and interacted with displays about NASA and STEM.



Girl Scouts react to water bubbling in a vacuum chamber during the Girl Scouts Rock@NASA event. The event celebrated the 100th anniversary of the Girl Scouts of America at NASA Headquarters in Washington, DC.

Invest in Teachers, Invest in the Future

The NASA Explorer Schools (NES) program gives educators of grades 4–12 access to NASA’s people, missions, research, and facilities. Each year, NES recognizes exemplary educators by providing the opportunity to work with NASA scientists and engineers during summer STEM research experiences.

In 2011, NES selected 63 teachers to participate in five different Summer STEM Research Workshops. During these multi-day events, teachers learned new research techniques and made connections to the STEM subjects they teach. In addition to hands-on research experiences, teachers toured a variety of operational facilities and met NASA employees who are directly involved with the Agency’s missions and research.



A team from the 19th annual Great Moonbuggy Race maneuvers a lightweight, human-powered moonbuggy through a half-mile course simulating the cratered lunar surface. Winning teams have the fastest vehicle assembly and race times.

Moonbuggy Race to the Future

More than 70 student teams from 22 states, Puerto Rico, Canada, Germany, India, and Russia competed in the 18th Annual NASA Great Moonbuggy Race that took place in April at the US Space and Rocket Center in Huntsville, Alabama. The event aimed to inspire and engage America’s next generation of scientists, engineers, and explorers.

Teams were challenged to design, build, and race lightweight rovers— a.k.a. moonbuggies—capable of traversing a grueling course that simulates the harsh lunar surface. Vehicles were required to be exclusively propelled by two students—one female and one male. Over 40,000 people watched the race live online.



Summer of STEM

In June, Langley Research Center launched its 2012 Summer of Innovation with two special events in Columbia, South Carolina. NASA Administrator (and Columbia native) Charlie Bolden was there to spark students' excitement about STEM.

Bolden returned to his alma mater, W.A. Perry Middle School, for the celebration, and addressed a group of more than 100 students. He encouraged them to work hard and reach for their dreams, and then joined the students in hands-on activities based on real NASA programs and missions. Bolden also visited the nearby Columbia Challenger Center to join another group of students and teachers to celebrate the start of summer with STEM learning activities.

The Summer of Innovation program is NASA's response to a national need for improvements in STEM education. It is designed to enhance the skills and engagement of students in STEM disciplines and build a robust pipeline of talent to carry out the Agency's future missions.

NASA Administrator Charles Bolden joined students for hands-on activities at the Columbia Challenger Center as part of the 2012 Summer of Innovation kickoff.



The 2011 NASA Ames STEM Symposium showcased activities from NASA's Harriett G. Jenkins Predoctoral Fellowship Project, the NASA Science and Technology Institute, and the NASA Astrobiology Institute.

Renewing the Spirit

The 2011 NASA Ames science, technology, engineering, and mathematics Symposium, "Renewing the Spirit of Innovation and Discovery," took place in July in San Jose, California. The annual symposium provides undergraduate, graduate, and faculty fellows with opportunities to network, conduct formal research presentations, participate in professional development training, and collaborate on research ideas.

The theme reflected NASA's efforts to create a vigorous path of innovation and technological development, and to lead an array of challenging and inspired missions designed to advance the next generation of human spaceflight system development. The event highlighted participants and activities from the NASA Harriett G. Jenkins Predoctoral Fellowship Project, the NASA Science and Technology Institute, and the NASA Astrobiology Institute.

MUST Stimulate Success in STEM

The Motivating Undergraduates in Science and Technology (MUST) program, funded by NASA, is a joint partnership between the Hispanic College Fund, the United Negro College Fund Special Programs, and the Society for Hispanic Professional Engineers. It awards scholarships and internships to undergraduates pursuing degrees in STEM fields.

The program reports that over 70 percent of MUST program graduates from the 2011–2012 academic year have enrolled in master and doctoral degree programs for the fall of 2012—with the majority in mechanical, aerospace, or computer engineering. Some of the students have received notable awards, including the Marshall Scholarship, the GEM Fellowship, and the NASA Space Technology Research Fellowship.

Since 2009, over 80 percent of alumni have reported that their experiences gave them a competitive edge when applying for jobs. Retention rates among MUST scholars have increased sharply since the first symposium—from 77 percent in 2008 to 94 percent in 2011.

MUST scholars have also gained powerful professional development training during the NASA MUST Orientation and Leadership Symposium, which brought together 115 students from across the nation to prepare them to enter the global workforce.



Ricky Fernandez is a NASA Motivating Undergraduates in Science and Technology (MUST) program participant. MUST provides scholarships and internships to undergraduates pursuing degrees in STEM fields.



The Reduced Gravity Student Flight Opportunities Project provides a unique academic experience for undergraduate students to propose, design, fabricate, fly and evaluate a reduced-gravity experiment of their choice.

A Fresh Approach

Throughout the year, NASA's Office of Education has led a variety of efforts to enhance STEM offerings. Together, the Agency's Offices, Mission Directorates, and Centers are collaborating to implement a single approach to STEM education that provides unique NASA experiences to learners, educators, and institutions, as well as streamlines access to NASA Web sites, people, resources, and facilities.

NASA is also playing an active role in national and state STEM policy discussions. The Office of Education's Infrastructure Division is implementing the principles of transparency, participation, and collaboration throughout all of its activities.



Student Ambassadors Across 34 States

NASA recently inducted 100 high-performing interns into the 2012 NASA Student Ambassador Virtual Community. The selection is part of the Agency's effort to engage undergraduate and graduate students in science, technology, engineering, and mathematics research, and education outreach to K–12 learners. The fourth cohort of student ambassadors includes interns from 73 universities across 34 states.

Members of the student ambassador community interact with NASA personnel, share information, make vital professional connections, collaborate with peers, represent NASA in a variety of venues, and help inspire and engage future interns.

It's Cool to Work for NASA

The Office of Education hosted its second annual Education Stakeholders' Summit in Chantilly, Virginia in November/December 2011. The theme was, "An Innovative Solution for the STEM Workforce of Tomorrow," and a major focus of the conference was the One Stop Shopping Initiative, designed to build a robust NASA infrastructure for attracting students and facilitating their entry into the NASA workforce through internships, fellowship, and scholarship opportunities.

John Berry, director of the Office of Personnel Management, delivered the keynote speech on "Why It's Cool to Work for the Federal Government." His address was followed by a series of presentations, including "Why It's Cool to Work in NASA Education" by Leland Melvin, NASA's Associate Administrator for Education.



Tweetup with will.i.am

During the prelaunch activities for the Mars Science Laboratory (MSL) Curiosity rover at Kennedy Space Center in Florida, NASA's Associate Administrator for Education, Leland Melvin, joined entertainer will.i.am for a Tweetup. The event marked the beginning of NASA's collaborative effort with will.i.am to inspire the next generation to pursue science, technology, engineering, mathematics, and robotics studies.



What's All the Buzz About?

NASA Deputy Administrator Lori Garver addressed an audience at the Smithsonian National Air and Space Museum in March 2012—with Buzz Lightyear of "Toy Story." Launched aboard Space Shuttle Discovery and returned 15 months later, the action figure is the longest serving toy in space and has become part of the museum's popular culture collection.

Buzz supported NASA's STEM education program by creating a series of fun educational online outreach programs. Following his return, Disney joined with NASA to create an online game and mission patch competition for school kids across America. This partnership was created to give children a unique insight into life on the ISS, how to get there and back home again, and the unique challenges of microgravity. ❖

“NASA has a **critical** need for new **people** to **enter the pipeline** of **STEM studies** and **become** the **exploration leaders** of **tomorrow.**”

—Lori Garver, NASA Deputy Administrator



Partnership News

Improved response to natural disasters, early detection of debilitating diseases, apps for enhancing everything from renewable energy to scientific research—the outcomes of NASA’s innovative partnerships are as diverse as they are beneficial. Through varied collaborations with the best of business, industry, Government, and academia, NASA not only advances its own missions but arrives at solutions to significant problems, strengthening the economy and encouraging growth in the process.





Open Innovation

NASA's founding legislation in 1958 instructed NASA to "provide for the widest practicable and appropriate dissemination of information." Now, the Agency is expanding transparency, participation, and collaboration and creating a new level of openness and accountability. Whether it's focusing on embedding open government into its operations, using social networks to allow students to interact directly with astronauts, or creating a cloud computing platform to give unprecedented access to scientific data, the Agency has embraced open government.

In 2011 NASA launched <http://open.nasa.gov/>, a collaborative platform for the open government community to share success stories and projects they are working on. The content on the site is written by NASA employees and contractors across the agency and highlights the ways that transparency, participation, and collaboration are being embraced by NASA policy, technology, and culture.

Open.NASA aims to increase Agency transparency and accountability by enabling citizen participation in NASA's mission, improving internal NASA collaboration and innovation, encouraging partnerships that create economic opportunity, and institutionalize open government philosophies and practices at NASA. Among the group's achievements in 2011–2012 are the International Space Apps Challenge and the launches of code.NASA and data.NASA.

More than 2,000 people from around the world—including all seven continents and astronauts on the International Space Station—joined together in April 2012 to create solutions of global importance related to spaceflight. The first International Space Apps Challenge was a 2 day technology "codeathon" event during which citizens from around the world worked together to solve current challenges relevant to both space exploration and social need.

The event celebrated software development in its most positive context—using minimal resources and maximum brainpower to create outside-the-box solutions in response to interesting problems. Volunteers joined one of more than two dozen organized groups for the weekend event, and the teams competed and collaborated with each other to design solutions for one or more of a predetermined set of global challenges.

To solve many of the challenges, teams used data and content made openly available by NASA. In total, more than 100 solutions were created to meet 61 unique challenges. Participants will be free to develop mobile apps, software and hardware, data visualization, and platform solutions.

"Open Government is more than simply releasing data. It is a fundamental shift in the way government interacts with citizens," said Chris Vein, deputy US chief technology officer for Government Innovation at the White House Office of Science and Technology Policy. "This apps challenge is an opportunity for governments to involve citizens in solving some of the most challenging problems facing our Nation and the world, and the White House is excited that NASA is at the forefront of this worldwide effort."

Thirty-six teams from around the world were nominated for global recognition and invited to create video presentations of their solutions. Global contest winners included:

- Most Inspiring Award to Planet Hopper (Oxford, United Kingdom). An app that visualizes Kepler data to allow children and teachers to explore all the exoplanets that we know about.
- Most Disruptive Award to Growing Fruits: Pineapple Project (Santo Domingo, Dominican Republic; San Francisco, US; Santiago, Chile; and Virtual Participation). An app that provides the optimal crop for your community by filtering a tropical crop database by location's rainfall, latitude, elevation and pH.

- Most Innovative Award to Strange Desk (Oxford, United Kingdom). An app that allows users to socially share and analyze the occurrence of strange events with others.
- People's Choice Award to Bit Harvester (Nairobi, Kenya). An SMS-based remote data acquisition and control system for remote renewable energy installations.

On January 4, 2012, NASA's Open Government Initiative launched <http://code.nasa.gov/>, the latest member of the open NASA web family. Through this website, NASA will continue, unify, and expand its open source activities.

NASA was an early adopter of open source and has been using and releasing code for years in order to address project and mission needs, accelerate software development, and maximize public awareness and impact of research. However, there was never a central repository for the code; someone looking for software needed to visit desperate field center-specific websites, many of which did not offer version control.

Code.NASA will provide a home for the current state of open source at the Agency. This includes guidance on how to engage the open source process, points of contact, and a directory of existing projects. By providing information about the process of open sourcing Agency code, the hope is to lower the barriers to building open technology in partnership with the public.

Future plans include providing a robust forum for ongoing discussion of open source concepts, policies, and projects at the Agency, as well as improving the tools and mechanisms development projects generally need to be successful.

So far more than 30 Agency projects are listed on the site. To be listed, the software must not only be released under an open source license but also have its code available on a public repository. Included among the hosted



International Space Apps Challenge participants discuss the solutions to challenges at the iHub in Nairobi, Kenya in April 2012.

Image courtesy of Sean Herron

projects is Apache OODT, data management software profiled in *Spinoff* 2011.

Ultimately, the goal of code.NASA is to create a highly visible community hub that will imbue open concepts into the formulation stages of new hardware and software projects, and help existing projects transition to open modes of development and operation. "We believe that tomorrow's space and science systems will be built in the open, and that code.nasa.gov will play a big part in getting us there," says William Eshagh, a member of NASA's Open Government team. "Will your code someday escape our solar system or land on an alien planet? We're working to make it happen, and with your help, it will."

The Open Data project at <http://data.nasa.gov/> is part of the NASA Open Government Initiative and is intended to improve public access to NASA data. This data catalog is a continually-growing listing of publicly available NASA datasets.

In pursuit of its exploration mission, NASA has generated, collected, and compiled vast amounts of digitized data that has helped us better understand Earth, other planets in our solar system, and the depths of space through the eyes of satellites, telescopes, robots,

and through the cameras of astronauts. With each passing decade, advances in technology made images clearer, the information coming back from space richer, and the world smaller.

NASA has a long history of placing large amounts of data online for members of the public to use. Since NASA's inception, the agency has publicly archived all of its data received from spacecraft projects, including over 4 terabytes of new Earth Science data each day, and continues to make a large amount of this raw data open for public exploration.

NASA's commitment to open data expands the audience for the vast body of knowledge captured in nearly 100 years of US aeronautics and space data. Developers, technologists, entrepreneurs, citizen scientists, and many others can contribute directly to the exploration of space and Earth by helping to create new ways of looking at what NASA does every day.

The website features data from NASA's research and scientific efforts in a number of areas, including aeronautics, Earth science, space science, life science, climate science, engineering, and mission operations.

Angry Birds—in Space

For nearly 3 years, millions of gamers have used physics in the battle between birds and pigs in the video game Angry Birds. In cooperation with NASA, Finland-based Rovio Entertainment, creator of the Angry Birds franchise, announced its newest game, Angry Birds Space, in March 2012.

NASA and Rovio are working together to teach people about physics and space exploration through the internationally successful puzzle game. Game developers incorporated concepts of human space exploration into the new game: From the weightlessness of space to the gravity wells of nearby planets, players use physics as they explore the various levels of the game set both on planets and in microgravity.

“This collaboration began with a simple Twitter exchange about birds and pigs in space, and it has grown into a tremendous outreach and education opportunity,” said David Weaver, associate administrator for communications at NASA Headquarters in Washington. “Games are fun and entertaining, but they also can be inspirational and informative. This ongoing collaboration with Rovio and Angry Birds is an exciting way to get people engaged with NASA’s missions

of exploration and discovery, and get students energized about future careers in science and technology.”

“NASA has been the perfect partner for our Angry Birds Space program, and we can’t wait to work with them on creating more compelling educational experiences,” said Peter Vesterbacka, chief marketing

officer of Rovio Entertainment. NASA participated with Rovio on Angry Birds Space under a Space Act Agreement. Within four months of the game’s launch it had been downloaded over 100 million times.

NASA astronaut and ISS crew member Don Petit transformed the Angry Birds game into a lesson on microgravity and trajectories.



Image courtesy of Rovio Entertainment Ltd.



Adopting Innovators

NASA Chief Technologist Mason Peck joined Agency and Ohio officials in naming nine small and medium-sized Ohio manufacturers that will receive NASA assistance to solve technical problems with new or existing products. Through partnership between NASA, the City of Cleveland, Cuyahoga County, and the Manufacturing Advocacy and Growth Network, the companies will gain expertise from NASA personnel and low interest rate loans from the city and county to help support their innovations.

“NASA is proud to be a part of a venture that promises to be a successful partnership between the Space Program and local companies in the City of Cleveland and in Cuyahoga County,” said Peck. “This project demonstrates NASA’s ability to provide on-the-ground technical assistance and planning resources tailored to the business needs of communities to ensure America’s manufacturers continue to compete in the new, innovation-driven economy.”

NASA is committed to providing 400 hours of technical assistance from its science and engineering work force to offer potential solutions to the selected companies. This initiative is part of the White House’s Office of Science and Technology Policy “Strong Cities, Strong Communities” effort with this partnership developed as a local “Adopt a City” program.

A Prime Concept

For the second year in a row, NASA partnered with Hasbro Inc. to run a contest encouraging students to produce short, creative videos about their favorite technology from NASA's *Spinoff* publication.

The contest featured the popular Transformers brand and its leader Optimus Prime, who like NASA technology "transform"—the Transformers to protect Earth against evil, and NASA spinoffs to provide tangible benefits for the world. Student submissions were split into three age categories, with high-school level submissions being accepted in addition to those from third through fifth grades and sixth through eighth grades.

NASA recognized the winning videos from this year's contest during a special awards ceremony at Kennedy Space Center. Peter Cullen, the voice of Optimus Prime,

was on hand to deliver an inspirational message to the students. "You are the adventurers. You are the Galileos, the Newtons," he said. "Hold on to your dreams—the future is built on dreams. You are the future, and I am proud of you all."

"The level of skill, effort and comprehension demonstrated by last year's contestants was truly amazing," said Nona Cheeks, head of the Goddard Space Flight Center's Innovative Partnerships Office, which administers the contest for the Agency. "This year we opened the contest up to include high school students, and the videos sent in by that group took the contest to a whole new level."

Submissions to the contest consisted of three-minute videos on a spinoff of each student's choosing. Participants strove to demonstrate an understanding of the NASA technology used for mission needs, as well as its commercial application and public benefit. The

videos were posted on YouTube, and members of the public voted for their favorites. A panel of NASA judges reviewed the top five videos in each age category and selected a winner for each group.

The winning students received cash awards or scholarship money, and they along with the associated NASA innovators and their commercial partners received an Optimus Prime Spinoff Award trophy at the awards ceremony in April 2012.

Transformers™ and Optimus Prime™ are trademarks of Hasbro and are used with permission.

How Does a Nevada Lake Bed Help Us Understand Mars?

Scientists from NASA's Ames Research Center joined a multi-institute team of researchers to investigate carbon dioxide and methane gas emissions from a dry lake bed and neighboring environment in Railroad Valley, Nevada.

The Railroad Valley Vicarious Calibration Campaign, a collaboration between NASA's Jet Propulsion Laboratory (JPL) and the Japan Aerospace Exploration Agency (JAXA) is an international, multi-year effort to calibrate space-based observations of carbon dioxide and methane collected by the Japanese Greenhouse Gases Observing Satellite (GOSAT), using ground and airborne data.

During the campaign, the Ames team conducted a series of flights with an unmanned aircraft system (UAS), a modified Alpha Jet and a NASA ER-2 Earth resources aircraft. The UAS, known as the Sensor Integrated Environmental Remote Research Aircraft (SIERRA), carried sensors to measure greenhouse gasses and winds. Onboard SIERRA was a gas analyzer developed by Santa Clara, California-based Picarro Inc. The Picarro analyzer showed extensive pockets of methane seeping into the air throughout the area. Not only was this important data for



Held at Kennedy Space Center, the NASA Optimus Prime Spinoff Award Ceremony honored students who created informational and inspirational videos about NASA spinoff technologies.

the campaign, it attracted the attention of California utility Pacific Gas and Electric, which purchased 100 of the Picarro analyzers to be used in the field for monitoring methane leaks.

“Although there is a general understanding of the natural and anthropogenic sources and sinks of carbon dioxide and methane, their fluctuations must be better quantified to better forecast and mitigate global climate change,” said Ames space science researcher Brad Bebout.

This work is also important to NASA’s goals in astrobiology. Methane has been reported on Mars, and pinpointing sources and determining whether or not the methane is biogenic—created by living things—will be important there. According to Bebout, “We can use Railroad Valley and other Mars analogue sites to help interpret methane data to be returned from upcoming Mars missions.”



NASA’s SIERRA aircraft carried aloft sensors to measure greenhouse gasses and winds as part of a collaborative study that promises to provide important data for climate change and astrobiology research.

Preserving the Past

Thanks to a NASA-developed archiving system, the Vatican Library is scanning, preserving, and making accessible many of its rare and valuable manuscripts. Work is underway to digitize 80,000 of the library’s documents, many of which are so delicate that, to avoid any damage, they can only be partially opened. The resulting files will be stored in the Flexible Image Transport System (FITS) format.

FITS evolved out of the recognition that a standard format was needed for transferring astronomical data from one installation to another. The original form, or Basic FITS, was designed for the transfer of images using 9-track half-inch magnetic tape. As the technology improved, FITS came to be understood as a logical format and was adapted for use on any medium, continually expanding to accommodate more complex data formats.

Among those manuscripts selected by the Vatican Library for digitization is the Bodmer Papyri, which contains the earliest known fragment from the New Testament Gospels. The prefect of the library says that the Vatican has wanted to begin this project for years but that funding and technology were challenges that needed to be overcome. With the FITS format, the technology is now in place, and multiple universities have offered to partner with the Vatican to help cover the costs of the effort.



A section of the Bodmer Papyri



The Future Workplace

NASA's 50,000-square-foot, lunar-shaped Sustainability Base opened in April 2012 at Ames Research Center. Unlike any other government building ever constructed, the new facility's performance includes repurposed NASA aerospace technologies. Highly intelligent, even intuitive, the building is designed to optimize its performance automatically, in real time, and in response to internal and external changes.

Sustainability Base—awarded LEED platinum certification as well as multiple prestigious national recognitions—is simultaneously a workplace, a showcase for NASA technologies, and a living prototype for buildings of the future. The base, for example, features a Bloom Energy (*Spinoff*2010) Box that uses fuel cell technology in a clean, electrical-chemical process to produce electricity. The facility also has a water recovery system derived from one originally designed for the International Space Station, which will help the facility consume an expected 90 percent less potable water than conventionally constructed buildings of equivalent size. The building is embedded with advanced intelligent control technology—derived from software originally developed for NASA's Aviation Safety Program—that allows it to adapt climate control systems depending on the weather. The base was created through collaboration between NASA, architectural firm AECOM, design architect William McDonough and Partners, with some of the integrated, repurposed technologies also originating with NASA partnerships.

"We are thrilled to be applying NASA aerospace technologies to our everyday living and working environments," said Steven F. Zornetzer, associate center director for Ames. "This building brings NASA technologies down to Earth to leverage taxpayer investment and improve the quality of life for everyone."

Space Medicine = Earth Benefits

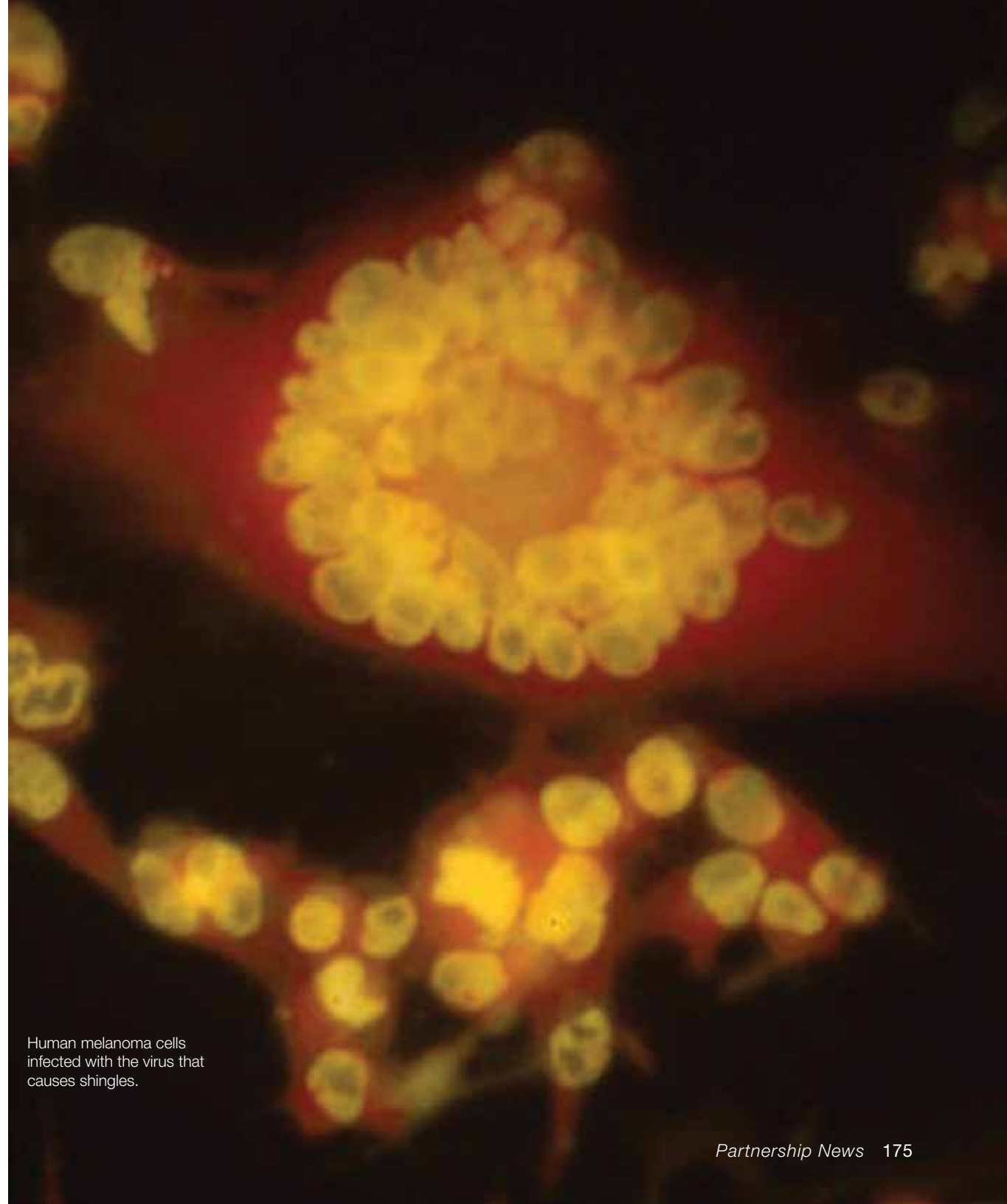
NASA has developed technologies that can detect immune changes early enough to begin treatment before the symptoms of shingles, a herpes virus disease, emerge in astronauts and people on Earth.

Spaceflight alters some elements of the human immune system. NASA scientists are concerned about how the immune system will function over the long stays in space that may be required for exploration missions. The stress associated with spaceflight, for example, can result in decreased immunity that reactivates the virus that causes shingles, a disease punctuated by painful skin lesions.

Johnson Space Center researchers partnered with physicians at the University of Texas Health Science Center in Houston to study the early detection and treatment of shingles. The study utilized polymerase chain reaction (PCR) assays to facilitate early diagnosis of the condition. But the PCR assay requires large, complex equipment and is not practical for space flight.

In response, NASA developed a rapid method of detection of the shingles-causing virus in bodily fluids. The new technology requires only a small sample of saliva to detect the disease and is currently patent-pending.

Another collaborative study involving NASA and the University of Colorado Health Science Center in Denver led to the development of a collection tool for the assessment of salivary stress hormones during space missions. These studies demonstrate the potential value of bringing to the general public a technology that could prevent a painful and debilitating condition in up to one million people each year in the United States alone.



Human melanoma cells infected with the virus that causes shingles.



An Earthshaking Idea

A space-based technology that lets GPS-equipped motorists constantly update their precise location will undergo a major test of its ability—in this case, for rapidly pinpointing the location and magnitude of strong earthquakes across the western United States. Results from the new Real-time Earthquake Analysis for Disaster Mitigation Network, or READI, soon could be used to assist prompt disaster response and more accurate tsunami warnings.

The new research network builds on decades of technology development supported by NASA, the National Science Foundation, the Department of Defense, and the US Geological Survey (USGS). The network uses real-time GPS measurements from nearly 500 stations throughout California, Oregon, and Washington. When a large earthquake is detected, GPS data are used to automatically calculate its vital characteristics including location, magnitude and details about the fault rupture.

“With the READI network we are enabling continued development of real-time GPS technologies to advance national and international early warning disaster systems,” said Craig Dobson, natural hazards program manager in the Earth Science Division at NASA Headquarters in Washington, DC.

Accurate and rapid identification of earthquakes of magnitude 6.0 and stronger is critical for disaster response and mitigation efforts, especially for tsunamis. Acquiring this type of data for very large earthquakes is a challenge for traditional seismological instruments that measure ground shaking.

High-precision, second-by-second measurements of ground displacements using GPS have been shown to reduce the time needed to characterize large earthquakes and to increase the accuracy of subsequent tsunami predictions. After the capabilities of the network have been fully demonstrated, it is intended to be used by appropriate natural hazard monitoring agencies.

The READI network is a collaboration of many institutions including NASA’s Jet Propulsion Laboratory (JPL), Scripps at the University of California in San Diego, Central Washington University in Ellensburg, the University of Nevada in Reno, UNAVCO, and the University of California at Berkeley. NASA, the National Science Foundation, USGS, and other Federal, state, and local partners support the GPS stations in the network.

“The relatively small investments in GPS-based natural hazards systems have revolutionized the way we view the Earth and allowed us to develop this prototype system with great potential benefits for the infrastructure and population in earthquake-prone states in the western United States,” said Frank Webb, Earth Science Advanced Mission Concepts program manager at JPL.

Launching Solutions

LAUNCH is a social entrepreneurship enterprise that breaks new ground with public-private partnerships to find solutions to sustainability challenges around the world. The concept of LAUNCH is based on a foundation of collaboration across non-traditional disciplines and organizations. NASA, USAID, the Department of State, and Nike Inc. joined together to form LAUNCH in an effort to identify, showcase and support innovative approaches to sustainability challenges through a series of forums.

Sustaining quality of life on Earth and in space requires transformative advances in science and technology, along with new models, policies and behaviors that will guide human development. For example, the search for innovative technology solutions to ensure healthy astronauts orbiting the planet mirrors healthcare challenges faced by providers throughout the world. The same requirements for simple, rugged, ultra portable, low power devices to provide remote diagnostic capability serves dual needs for humans living within the extreme environments on and off the planet.

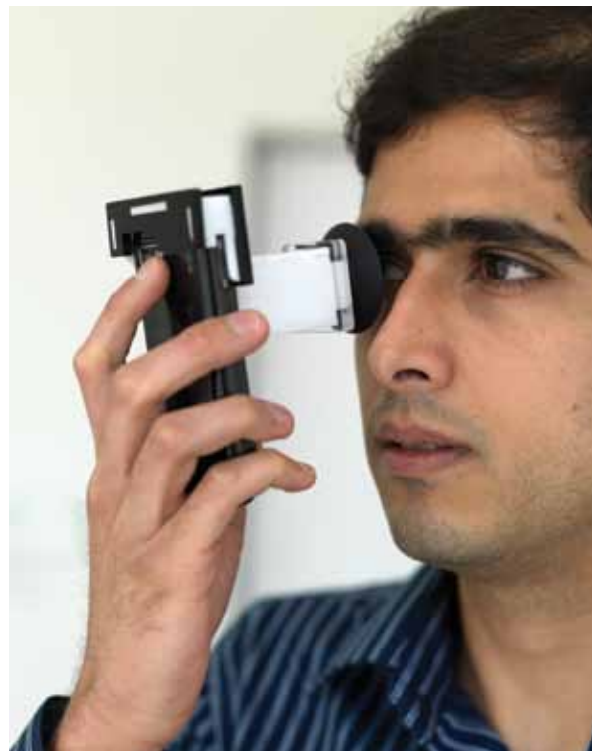
To date, LAUNCH Water, LAUNCH Health, LAUNCH Energy, and in 2012, LAUNCH Beyond Waste have tackled some of the planet's biggest, most pressing problems. Through LAUNCH, NASA has hosted conversations with experts about potential solutions to the world's most perplexing sustainability problems. NASA brings to the table a problem-solving culture, deep technical expertise on sustainable systems such as the International Space Station, and a unique capacity to capture and analyze data about our home planet. The partnership allows the Agency to share, offer, and promote the emergence of transformative technology to solve global problems.

Them Bones, Them Bones

Collaborative research between NASA and Arizona State University has resulted in a technique for the early detection of bone loss that is more sensitive and less risky for patients. The new technique is more effective than the standard X-ray method, employing calcium isotopes to detect the signs of osteoporosis, and does not expose patients to radiation.

The NASA-funded study is a clear example of how research for space exploration provides benefits on Earth.

"NASA conducts these studies because astronauts in microgravity experience skeletal unloading and suffer bone loss," said the study's co-author, NASA nutritionist Scott M. Smith. "It's one of the major problems in human spaceflight, and we need to find better ways to monitor and counteract it. But the methods used to detect the effects of skeletal unloading in astronauts are also relevant to general medicine."



LAUNCH events have yielded technologies aimed at solving global problems. Some examples include the Chlorine Bank, a system of community stores for water purification products and information (left), the NETRA low cost eye diagnostic device (middle) and the vaccine delivery bioneedle (right).

A Historic Flight for Commercial Space

Just before noon EDT on May 31, 2012, SpaceX's Dragon capsule splashed down in the Pacific Ocean, marking the successful end of the first mission by a commercial company to resupply the International Space Station (ISS).

The capsule delivered to the station 1,014 pounds of supplies including experiments, food, clothing, and technology. On its return trip to Earth, Dragon carried science experiments that will be returned to researchers hoping to gain new insights provided by the unique microgravity environment in the station's laboratories. In addition to the experiments, the spacecraft returned a total of 1,367 pounds of hardware and cargo no longer needed aboard the station.

"Now that a US company has proven its ability to resupply the space station, it opens a new frontier for commercial opportunities in space—and new job creation opportunities right here in the United States," NASA Administrator Charles Bolden said. "Now more than ever we are counting on the inventiveness of American companies and American workers to make the International Space Station and other low Earth orbit destinations accessible to any and all who have dreams of space travel."

Dragon's journey to the space station was SpaceX's second demonstration mission under NASA's Commercial Orbital Transportation Services (COTS) Program, which provides investments to stimulate the commercial space industry in America. The mission began May 22 as the capsule launched from Cape Canaveral Air Force Station in Florida aboard a SpaceX Falcon 9 rocket. Following a series of tests of its maneuverability and abort systems, the capsule was grappled and berthed to the space station by the crew members of Expedition 31 aboard the orbiting complex.

"This flight is an important milestone as NASA and SpaceX develop the next generation of US spacecraft to carry the critically important experiments, payloads, and supplies to our remarkable laboratory in space," said William Gerstenmaier, associate administrator for

NASA's Human Exploration Operations Directorate at the Agency's Headquarters in Washington, DC.

In parallel to COTS, NASA's Commercial Crew Program is helping spur innovation and development of new spacecraft and launch vehicles from the commercial industry to develop safe, reliable, and cost-effective capabilities to transport astronauts to low Earth orbit and the ISS.

NASA is also developing the Orion spacecraft and Space Launch System (SLS), a crew capsule and heavy-lift rocket that will provide an entirely new capability for human exploration beyond low Earth orbit.

"By handing off space station transportation to the private sector," said Bolden, "NASA is freed up to carry out the really hard work of sending astronauts farther into the solar system than ever before."



SpaceX's historic launch took place at night (left), with the Dragon capsule later successfully docking with the ISS (top), before safely splashing down in the Pacific Ocean (middle). To celebrate the unprecedented mission, NASA Administrator Charlie Bolden visited the SpaceX facility in Hawthorne, California (bottom).



SpaceX's Dragon capsule, about to be grappled by the ISS' Canadarm2 robotic arm. For a deeper look at NASA's support of commercial space endeavors, scan this code.



“We are counting on the inventiveness of American companies and American workers to make the International Space Station . . . accessible to any and all who have dreams of space travel.”

—Charlie Bolden, NASA Administrator

Green Skies

NASA has awarded the largest prize in aviation history, created to inspire the development of more fuel-efficient aircraft and spark the start of a new electric airplane industry. The technologies demonstrated by the CAFE Green Flight Challenge, sponsored by Google, may end up in general aviation aircraft, spawning new jobs and new industries for the 21st century.

The first place prize of \$1.35 million was awarded to team Pipistrel-USA.com of State College, Pennsylvania. The second place prize of \$120,000 went to team eGenius, of Ramona, California. The competition was managed by the Comparative Aircraft Flight Efficiency (CAFE) Foundation under an agreement with NASA. This prize competition is part of the NASA Centennial Challenges program, part of the Space Technology Program, managed by the NASA Office of the Chief Technologist.

The winning aircraft had to fly 200 miles in less than two hours and use less than one gallon of fuel per occupant, or the equivalent in electricity. The first and second place teams, which were both electric-powered, achieved twice the fuel efficiency requirement of the competition, meaning they flew 200 miles using just over a half-gallon of fuel equivalent per passenger.

“Two years ago the thought of flying 200 miles at 100 mph in an electric aircraft was pure science fiction,” said Jack W. Langelaan, team leader of Team Pipistrel-USA.com. “Now, we are all looking forward to the future of electric aviation.”



The winning Pipistrel-USA team celebrates its first-place finish in the NASA Green Flight Challenge with NASA and CAFE Foundation officials.



NASA's Green Flight Challenge, managed by the CAFE Foundation and sponsored by Google, was designed to spark the development of electric, highly fuel-efficient aircraft. For a deeper look at the Green Flight Challenge, scan this code.



A Zooniverse Awaits

“Somewhere, something incredible is waiting to be known,” wrote Carl Sagan.

And now you can be the one to find it, thanks to Zooniverse, a unique citizen science website. Zooniverse volunteers, who call themselves “Zooites,” are working on a project called Galaxy Zoo, classifying distant galaxies imaged by NASA’s Hubble Space Telescope.

“Not only are people better than computers at detecting the subtleties that differentiate galaxies, they can do things computers can’t do, like spot things that just look interesting,” explains Zooniverse director Chris Lintott, an astronomer at the University of Oxford.

Lintott started Zooniverse in 2007 to solve a very large and unique problem: “I had too many galaxies on my hands,” he explains. Lintott was faced with classifying, by shape, 1 million galaxies imaged by the Sloan Digital Sky Survey. Despite enlisting the help of a graduate student, the project remained overwhelming. They decided to test the viability of completing the work by using volunteers. Zooniverse, and its first project Galaxy Zoo, were born.

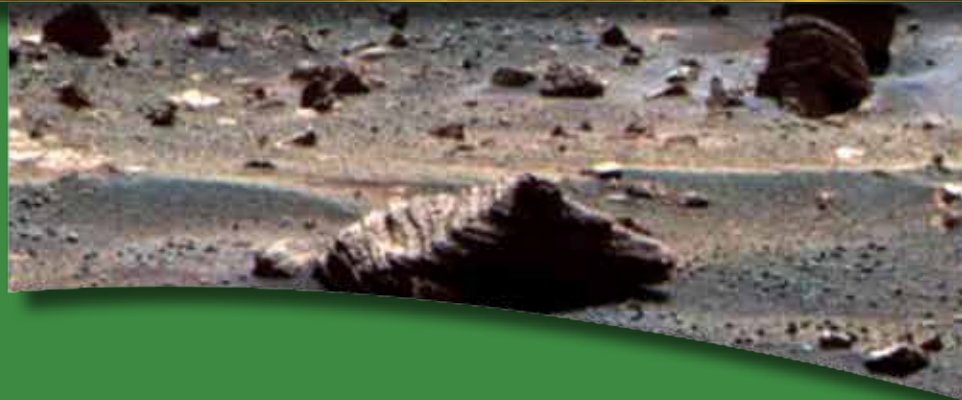
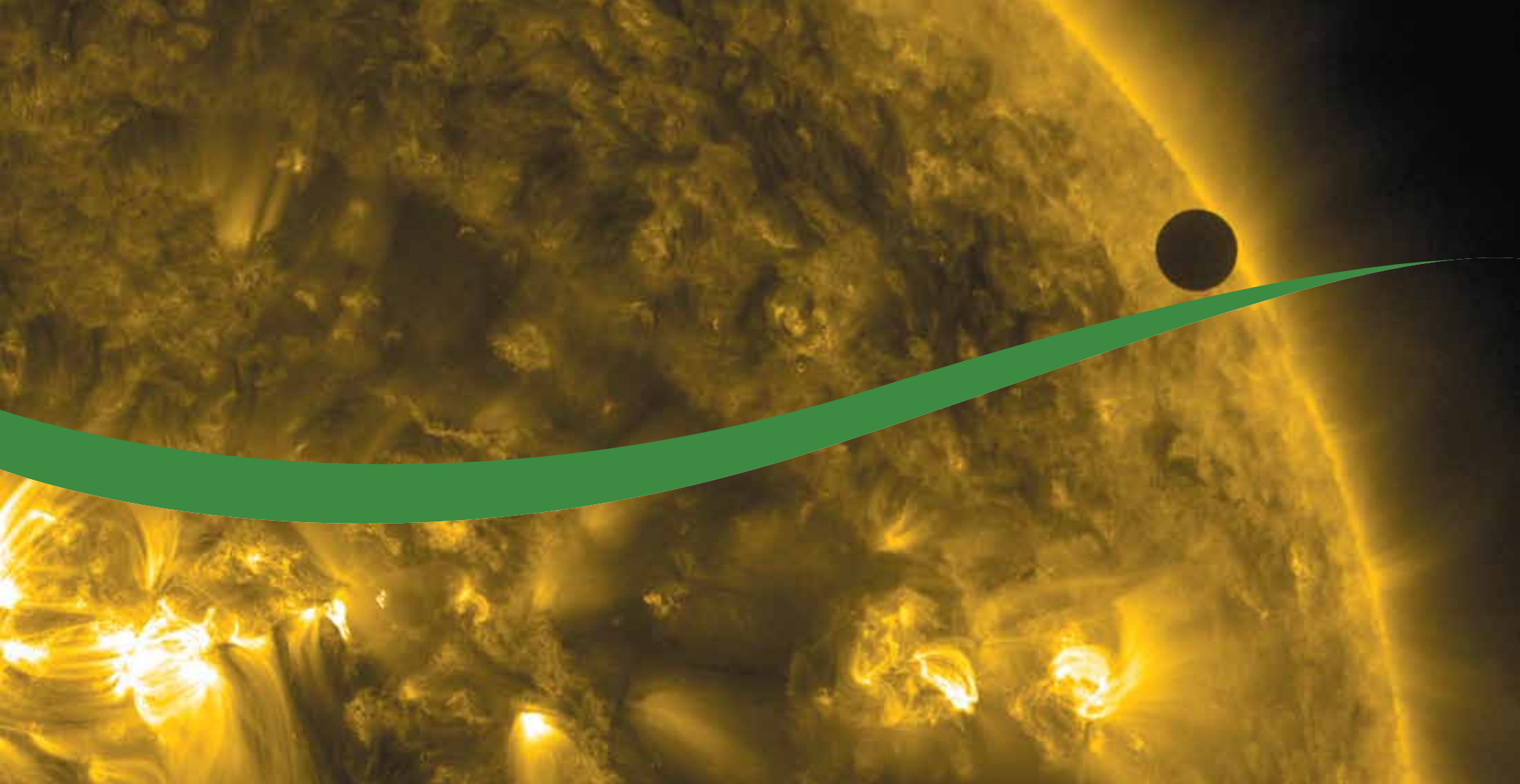
Galaxy Zoo presents images of galaxies from the Hubble Space Telescope to users and asks them to classify any features they see. The crowdsourcing model became so successful that Zooniverse soon expanded its citizen scientist offerings, and several of these projects use NASA data. For example, Moon Zoo volunteers use data from NASA’s Lunar Reconnaissance Orbiter to count craters, helping write the history of the moon. And the Milky Way Project provides infrared images gathered by the Spitzer Space Telescope that are processed by Zooites to catalogue the galaxy’s features.

One of the projects, Planet Hunters, posts data from the Kepler observatory that volunteers use to find exoplanets. It made headlines in late 2011 when two potential planets discovered by Zooites were confirmed by NASA as candidates. As with the images of galaxies that first sparked Zooniverse, human minds have proven a valuable supplement to computer-run data processing in the hunt for other worlds. ❖

Award-Winning Technologies

NASA *Spinoff* features many technologies that are honored as remarkable innovations in their fields. This year, NASA inventors and partners have received recognition for unique contributions to aircraft design, thermal insulation, solar energy, robotics software, and more—acknowledging the remarkable benefits of NASA research and development.





Award-Winning Technologies

Hall of Fame Honors for a NASA Spinoff Technology

During a ceremony at the Space Foundation's 2012 National Space Symposium, the Space Technology Hall of Fame inducted flexible aerogels, originally developed by NASA and today found in a wide variety of materials and goods.

"The judges had many high-caliber nominations to consider for 2012," said Kevin Cook, Space Foundation Director of Space Awareness. He referred to the 2012 inductees as "extraordinary examples of how space research and development can, eventually, make our lives on Earth safer, more comfortable, and more environmentally sustainable."

Aerogel, an open-celled substance composed of more than 95 percent air, has the lowest thermal conductivity of any known solid. Its remarkable characteristics first attracted NASA for cryogenic insulation applications—for example, keeping rocket fuel hundreds of degrees below zero. The problem, however, was that aerogel was too fragile to handle in its solid form and too expensive to manufacture.

NASA contracted with James Fesmire, senior principal investigator of the Cryogenics Test Laboratory at Kennedy Space Center, and the startup company Aspen Systems Inc. to produce affordable and easy-to-use aerogel composite blankets for space applications. Through continuing partnerships with NASA, Aspen Systems developed a manufacturing process that cut production time and costs while improving the technology. The result was a practical, new form of aerogel that showed promise for both NASA missions and commercial applications.

Aspen Aerogels Inc., a spinoff company of Aspen Systems, continued its development of the product to produce three variations—Cryogel, Pyrogel, and

Spaceloft (*Spinoff* 2001)—that are now used in industrial, construction, refrigeration, automotive, medical, and consumer applications. Examples include shoe insoles for mountain climbers and endurance runners, a wrap that helps sufferers of circulatory disease, and insulation that is as much as 30 percent more efficient (*Spinoff* 2010).

Aspen Aerogels is the leading provider of aerogel in the United States, producing nearly 20 million square feet of the material per year. The individuals honored at the symposium for this technology were Kang Lee, president and CEO of Aspen Systems; George Gould, vice president of research and development of Aspen Aerogels; Jae Ryu, director of advanced technology with Agiltron Inc.; and James Fesmire of Kennedy.



From left to right: George Gould, James Fesmire, and Kang Lee, at the 2012 National Space Symposium Hall of Fame induction ceremony.





Image courtesy of Cessna



The Cessna Citation CJ4 aircraft (left) flies with the help of a NASA technology that received honorable mention for NASA's Invention of the Year award. Another Glenn Research Center spinoff was recognized (above) with a technology transfer award. In the photo, from left to right, are James Poulos, Federal Laboratory Consortium (FLC) Awards Committee Chair; Ramona Travis, Center Chief Technologist, Stennis Space Center; Theresa Baus, FLC Vice Chair; Michael Piszczor, Award Winner; Kim Dagleish-Miller, Chief, Innovation Projects Office at Glenn Research Center; and Mojdeh Bahar, FLC Chair.

Glenn Research Center Technologies Recognized for Commercial Success

In 2012, four technologies with significant commercial potential that were developed by researchers at NASA's Glenn Research Center in Cleveland were nominated for or won awards in three different venues.

At the Federal Laboratory Consortium National Meeting Awards Ceremony in Pittsburgh in May 2012, a team including Glenn's Mike Piszczor and Mark O'Neill and Almus McDanal of Entech Solar Inc. received the Award for Excellence in Technology Transfer. The award was given in recognition for their work, entitled "Stretched Lens Array: Ultra-Light, Affordable Green Energy Technology," which was successfully commercialized in Entech's new product, the SolarVolt module (see page 108).

Entech's SolarVolt module—a concentrating lens that focuses sunlight using curved and grooved surfaces—can be used to generate electricity for a variety of applications, including utility-scale power plants, distributed energy for smart grid systems, communications systems,

industrial building power systems, and government and military power systems.

Two technologies developed at Glenn were selected as finalists for the 2012 NorTech Innovation Award during the annual awards ceremony in March 2012 at LaCentre in Westlake, Ohio, with one of the teams receiving the award.

Phil Neudeck and David Spry of Glenn, along with Andrew Trunek of the Ohio Aerospace Institute (OAI), J.A. Powell of Sest Inc., and Andrew Woodworth of Oak Ridge Associated Universities won the NorTech Innovation Award for their work, entitled "A Radically New Crystal Growth Concept, Large Tapered Crystal to Achieve Nearly Perfect Silicon Carbide." The concept is an innovative method for growing semiconductor grade boules of silicon carbide, which greatly reduces the number of crystal defects from millions per wafer to as few as one defect per wafer.

Glenn's second finalist, the "Development of New High Temperature Shape Memory Alloys," was developed by center researcher Michael Nathal, Darrell Gaydos of OAI, and Anita Garg, a University of Toledo researcher

working at Glenn. Shape memory alloys can act as light-weight actuators—agents of mechanical movements—in aerospace, automotive, and general household applications. These can replace today's actuators based on electric-motor, hydraulic, or pneumatic systems. They also promise lighter weight, smaller footprints, and simpler, low-maintenance designs with fewer moving parts.

Finally, a technology that has been incorporated into jet engines and is now flying on the Cessna Citation CJ4 aircraft was awarded Honorable Mention for NASA Invention of the Year. The inventors of "Composite Case Armor for Jet Engine Fan Case Containment and Associated Testing/Validation Tools" include Glenn's Gary Roberts, Mike Braley of A&P Technology Inc., and James Dorer of Williams International.

The innovative jet engine fan case is 30 percent lighter than metal fan cases and strong enough to contain a released titanium blade. The resulting weight reduction translates directly into improved fuel efficiency, lower greenhouse gas emissions, increased payload, greater aircraft range, and enhanced flight safety.

NASA Aerodynamics Genius Welcomed into Aviation Hall of Fame

Aeronautics engineer Richard Whitcomb, whose legendary research contributions at NASA's Langley Research Center made supersonic flight practical, will soon join other aerospace pioneers in the National Aviation Hall of Fame, located at the National Museum of the United States Air Force in Dayton, Ohio. The National Aviation Hall of Fame announced that Whitcomb, who died in 2009 at age 88, is among the three 2012 honorees.

According to its website, the National Aviation Hall of Fame is dedicated to honoring individuals who have uniquely contributed to America's rich legacy of aviation achievement. Since 1962 it has inducted more than 200 of the nation's premier air and space pioneers into the organization, including the Wright Brothers, Amelia Earhart, Charles Lindbergh, and astronauts John Glenn and Neil Armstrong, among others.

Richard Whitcomb may not be as much of a household name as others, but aviation historians say his role in aeronautics research is virtually unmatched. "Dick Whitcomb's intellectual fingerprints are on virtually every commercial aircraft flying today," said Tom Crouch, noted aviation historian at the Smithsonian Institution.

Whitcomb spent his career at what is now NASA's Langley Research Center. Relatively early in his career, he discovered and experimentally verified a revolutionary aircraft design principle that became known as the "area rule." Whitcomb discovered if he narrowed the fuselage of an airplane so it's shaped more like an old-fashioned soda bottle, he could reduce drag and increase the speed of a transonic aircraft without the need to add additional power. The area rule has been applied to almost every US supersonic aircraft designed since then (*Spinoff* 2003). The achievement earned him the prestigious 1954 Collier Trophy for the most important aeronautical advance of the year.



Richard Whitcomb checks a model aircraft designed using his "area rule." This photo was taken at Langley Research Center in 1955.

If the area rule was Whitcomb's major accomplishment of the 1950s, his supercritical wing revolutionized the design of jet liners in the 1960s. The key was the development of a swept-back wing airfoil that delayed the onset of increased drag, increasing the fuel efficiency of aircraft flying close to the speed of sound (*Spinoff* 1998).

And in the 1970s, Whitcomb came up with winglets, wingtip devices that reduce yet another type of drag and further improve aerodynamic efficiency. Many airliners and private jets currently sport wingtips that are angled up for better fuel performance—saving billions of dollars in fuel costs every year (*Spinoff* 2010).

In addition to his induction into the National Aviation Hall of Fame and the Collier Trophy, Whitcomb was

presented the National Medal of Science by President Richard Nixon in 1973 and received the US Air Force Exceptional Service medal in 1955, the first NACA Distinguished Service Medal in 1956, the NASA Exceptional Scientific Achievement Medal in 1959, and the National Aeronautics Association's Wright Brothers Memorial Trophy in 1974. He was also inducted into the National Inventors' Hall of Fame in 2003, the National Academy of Engineering in 1976, and the Paul E. Garber First Flight Shrine at the Wright Brothers National Memorial in North Carolina. Whitcomb's alma mater, Worcester Polytechnic Institute, awarded him an honorary doctorate and its presidential medal.

“Dick Whitcomb’s intellectual
fingerprints are **on** virtually **every**
commercial **aircraft flying today.**”

— Tom Crouch,
The Smithsonian Institution



Winglets, or wingtip devices that reduce the drag caused by an airplane’s wings, have saved billions of dollars in fuel costs over the last decade as they have become widespread. For a deeper look into this technology and its NASA connection, scan this code.

Ames Research Center Honored for 2011 NASA Government Invention of the Year

NASA's Ames Research Center has won the 2011 NASA Government Invention of the Year. Ames received the award for developing Toughened Uni-piece Fibrous Reinforced Oxidation-Resistant Composite (TUFROC)—a low-cost, lightweight, two-piece, thermal protection system (TPS) for use on space vehicles during atmospheric reentry at hypersonic speed. TUFROC, a patented technology invented by David A. Stewart and Daniel B. Leiser of Ames, has been successfully demonstrated on the X-37B Reusable Launch Vehicle.

The technology consists of a high temperature, impregnated carbonaceous cap mechanically attached to a lightweight fibrous silica-base material. The key innovations enable the integration of the surface treated carbon cap with the silica base insulation, which otherwise would fail from mechanical, chemical or thermal factors. TUFROC is the first lightweight, low cost, flight proven, reusable TPS with sustained operational capabilities at temperatures above 3,000 °F.

"It's truly an honor to win NASA's Government Invention of the Year again in 2011," said Ames Director Pete Worden. "I am extremely proud of our advances in thermal protection systems. This award not only exemplifies the major contributions in TPS research at Ames over the past five decades but signals that Ames will continue to lead the way in advancing entry systems for future NASA and commercial spacecraft."

The X-37B Orbital Test Vehicle on the launchpad in 2010.



Glenn's Mary Ann Meador poses with a piece of polyimide aerogel, which can withstand the weight of a car without being crushed.

NASA Advancements Win R&D 100 Awards

Technologies developed at NASA's Glenn Research Center are among those in the top 100 technologically significant new products in 2012, as announced by *R&D Magazine*.

The SolarVolt module (see page 108), developed by a team that included Glenn's Michael Piszczor, was primarily developed for terrestrial use by Mark J. O'Neill, A.J. McDanal and Robert Walters, of Fort Worth, Texas-based Entech Solar Inc., incorporating NASA space power technology advancements. This module is a highly efficient photovoltaic solar panel that can compete with fossil fuels to provide utility grid-scale power due to a unique solar concentrator design. It offers a combination of increased efficiency and reliability with lower weight and cost, and demonstrates how space technology can be adapted for our use here on Earth.

The other winner was polyimide aerogel technology developed by Glenn's Mary Ann Meador and Haiquan Guo of Ohio Aerospace Institute, Cleveland. These aerogels are highly flexible, lightweight, thin and 500 times stronger than conventional silica aerogels, while maintaining the excellent insulation properties for which silica aerogels are known. This innovation is technologically significant and unparalleled in the aerogel marketplace, as no other aerogel possesses the compressive and tensile strength with simultaneous flexibility to contour to whatever shape is needed.

The R&D 100 Awards have long been a benchmark of excellence for industry sectors as diverse as telecommunications, high-energy physics, manufacturing and biotechnology. Previous winners of the R&D 100 Awards include the halogen lamp, HDTV, and the automated teller machine.

NASA Presents Software of the Year Award

Autonomous Exploration for Gathering Increased Science (AEGIS), a novel autonomy software that has been operating on the Mars Exploration Rover Opportunity since December 2009, is NASA's 2011 Software of the Year recipient.

The AEGIS software, developed by NASA's Jet Propulsion Laboratory in Pasadena, California, autonomously directs Opportunity's cameras to interesting science targets. AEGIS was developed to enhance the usual targeting process involving scientists on the ground, which can require the rover to stay in the same place for a day or more while data are transmitted to Earth and targets are selected from preliminary images.

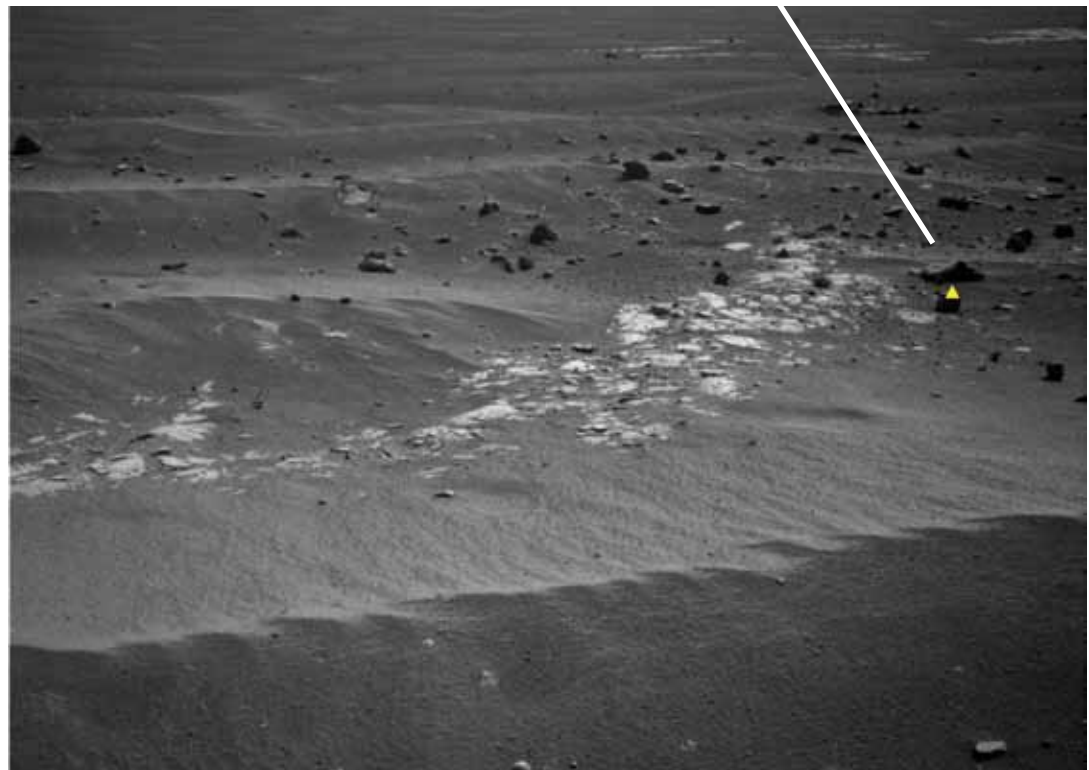
With AEGIS, the rover software analyzes images onboard, detects and prioritizes science targets in those images, and autonomously obtains novel, high quality science data on the selected targets within 45 minutes—all while requiring no communication with Earth. AEGIS chooses science targets based on pre-specified criteria set by the mission science team. The software can be used as soon as the rover reaches a new area and is especially beneficial during and after long drives. It enables high-quality data to be collected more often and in a significantly reduced timeframe.

The AEGIS capability was developed as part of a larger autonomous science framework called the Onboard Autonomous Science Investigation System (OASIS), which is designed to allow a rover to identify and react to serendipitous science opportunities. The AEGIS system takes advantage of the OASIS ability to detect and characterize interesting terrain features in rover images.

This technology was created with assistance from NASA's Mars Exploration Rover Project and with funding from the New Millennium Program, the Mars Technology Program, the JPL Research and Technology Development Program, the JPL Interplanetary Network Development Program and the Intelligent Systems Program. ❖

Autonomously spotting an object of interest (bottom, yellow arrow), AEGIS directed Opportunity to take a close up photo with its panoramic camera (top).

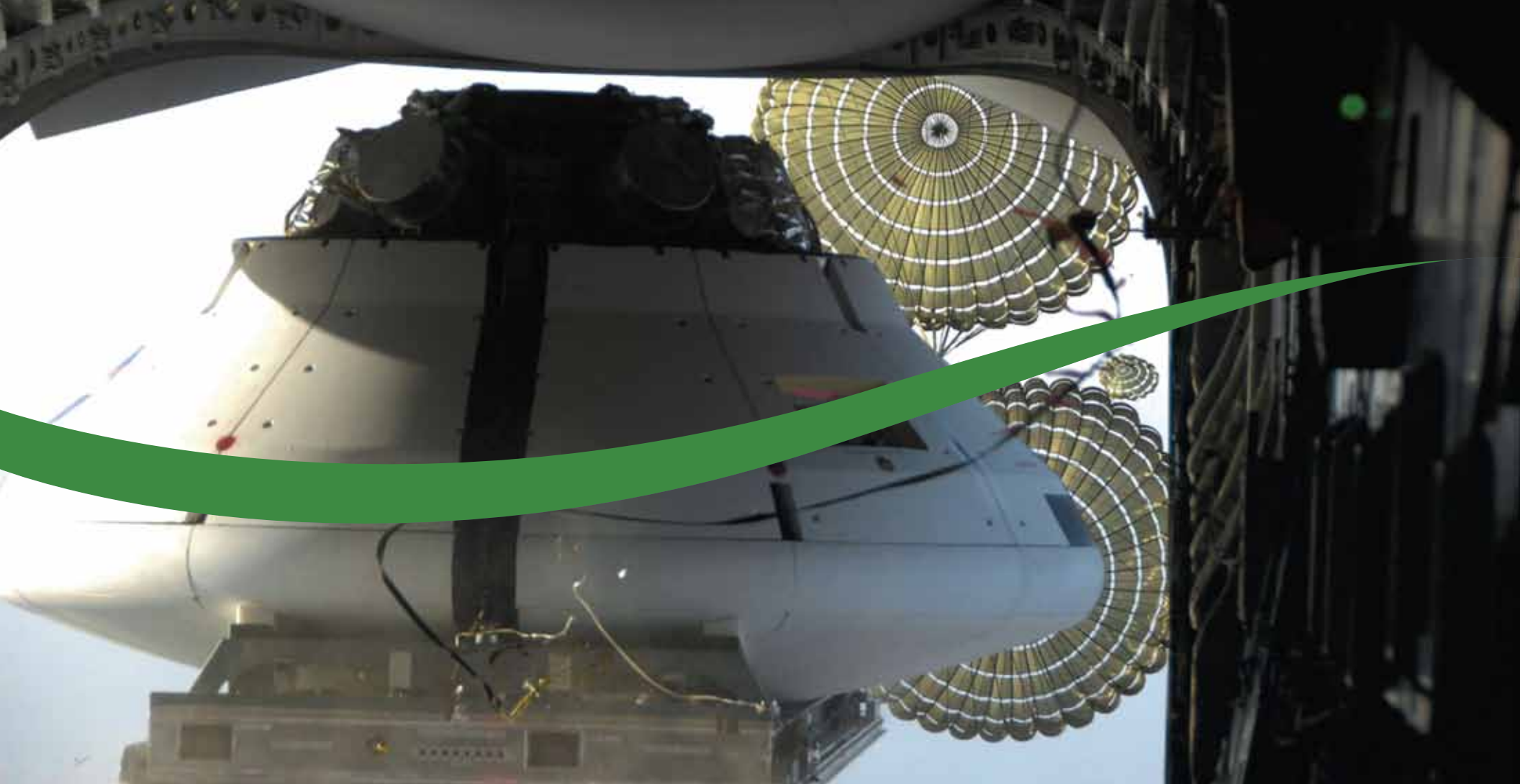
This was the first target ever selected autonomously by a spacecraft on Mars.



Space Technology for Tomorrow

NASA's Office of the Chief Technologist (OCT) and Space Technology Program (STP) seek out and develop emerging technologies and game-changing ideas to drive NASA's exploration of space farther than ever before. Through partnership-driven programs and activities, OCT and STP engage with innovators in business, industry, academia, and other sources to advance the Nation's aerospace capabilities while at the same time yielding tangible social and economic benefits for its citizens.





Space Technology for Tomorrow

Through investments in technology and innovation, NASA is driving advances to help solve the economic, national security, and geopolitical challenges our country is facing today.

America's Space Program continues to dream big. NASA's future aeronautics, science, and exploration missions are grand in scope and bold in stature. By investing in high payoff, disruptive space technology that industry cannot tackle today, we mature the technology required for NASA's future missions in science and exploration while improving capabilities and lowering the cost for other Government agencies and commercial space activities.

NASA's investment in space technology allows the Agency and our Nation to remain at the cutting edge. Space technology investments are NASA's contribution to revitalize research, technology, and innovation for NASA and the Nation. NASA's innovative, high-risk, high-return technology program contributes to America's global competitiveness and creates new products and services; new businesses and industries; and high-quality, sustainable jobs.

The *Spinoff* publication demonstrates how NASA's investments in technology make a difference in our lives every day. Emergency management tools enabled by

Earth-observing spacecraft, efficiency improvements in both ground and air transportation, medical technologies that advance research and help save lives, devices that monitor water quality for drinking, systems that make firefighting safer and more effective, and many other innovations have been born out of our Nation's investments in aerospace technology. Through cutting-edge space technology and its resulting commercialization, NASA continues to make a difference in the world around us.





Chief Technologist Mason Peck (left in left image), seen here at Wallops Flight Facility, has visited multiple NASA centers and partner companies while guiding NASA's efforts in innovation and technology transfer. One such project is the Inflatable Reentry Vehicle Experiment (IRVE-3, below), developed to demonstrate that inflatable heat shields may be used to protect future spacecraft. IRVE-3 is one of NASA's many research efforts to develop new technologies for space travel. It is part of the Hypersonic Inflatable Aerodynamic Decelerator project within the Office of the Chief Technologist's Game Changing Development Program. An inflatable heat shield could change the way we explore other worlds by accommodating larger payloads that could deliver more science instruments and tools for exploration.



Office of the Chief Technologist

NASA's chief technologist serves as the Agency's principal adviser and advocate on matters concerning Agency-wide space technology policy, programs, and prioritization. In this role, the chief technologist is responsible for the direct executive management of NASA's Space Technology Program. The Office of the Chief Technologist (OCT) and Space Technology Program (STP) coordinate technology across the Agency, including the mission-focused investments made by the NASA mission directorates, and perform strategic technology integration to ensure the Agency's future technology needs are identified and met. To widely disseminate NASA's technology advancements, OCT documents, demonstrates, and communicates the many everyday benefits of NASA technology.

OCT also leads technology transfer and commercialization opportunities across the Agency through the Innovative Partnerships Office (IPO). IPO develops and executes innovative technology partnerships, technology transfer, and commercial activities for NASA.



Technology Transfer and Commercialization

OC^T and STP engage the larger aerospace community, including other Government agencies, to develop partnerships and leverage shared resources and expertise, efficiently developing breakthrough capabilities. They work with all NASA mission directorates and centers to ensure NASA makes available Agency-developed technologies, processes, discoveries, and knowledge to the private sector. Technology transfer and commercialization is conducted through various means including releasing licenses, forming partnerships, and through cooperative activities.

At its core, the NASA technology transfer program is focused on creating benefits for society through transferring the Agency's inventions and innovative knowledge to outside organizations so they may be brought to the commercial market. These transferred technologies are used to create products, services, cascading innovations, and other discoveries to fuel the Nation's economic engine and improve our quality of life. NASA shares the benefits of its work with academia during formal scientific collaborations and while working with commercial firms on mission-related development projects.

On October 28, 2011, President Obama charged all Federal agencies with accelerating technology transfer activities and thereby the benefits of Federally-funded research and development investments. NASA is strategically positioned to answer that call, building on a legacy of leadership in technology and transfer of space and aeronautics research for public benefit.

As part of its continued commitment to this legacy, NASA operates a technology transfer office at each of its

NASA's partners in commercial space are advancing a new industry with the Agency's help. Deputy Administrator Lori Garver visits Blue Origin (top); Sierra Nevada Corporation's Dream Chaser spacecraft (middle) is currently in development; NASA and SpaceX team members test the seating arrangement in a prototype version of the company's Dragon capsule designed for human spaceflight.

10 field centers and coordinates Agency-wide programs for moving its aeronautics and space technologies into the public sphere. These programs consist of both direct mechanisms (such as execution of invention-patent licenses) and indirect mechanisms (such as publication of scientific data). Further, NASA is exploring ways to enhance or improve its ability to increase the rate, volume, and quality of technology transfer to industry, academia, and other Government agencies. In doing so, we expect to increase the economic impact and public benefit of these Federal technology investments. Specifically, NASA has identified seven key objectives:

- fuel the technology transfer pipeline with a renewed, Agency-wide emphasis in technology research and development;
- revise the Agency's policies on commercialization to ensure alignment with NASA's current focus on technology development and best practices in technology transfer;
- build partnerships for technology development, transfer, and mutual benefit;
- tie the technology transfer process into all stages of technology development, ensuring that formal technology transfer is considered even at the earliest stages, when programs and activities are being formulated and acquisitions planned;
- increase the number of new technologies reported by NASA civil servants and contractors;
- improve licensing processes and outcomes; and
- evaluate an increased use of Cooperative Research and Development Agreement authority at the Agency to accelerate licensing of resulting technologies.

To help the Agency fulfill its technology transfer goals and objectives, NASA has also identified broad technology transfer metrics related to new invention disclosures, patent applications, licenses executed, software usage agreements, and success stories as ways to measure progress.

Prioritizing Space Technology Investments

Each NASA mission takes years of planning and development to ensure its success. And every NASA mission has been made possible by pushing the technology envelope. The National Research Council (NRC) emphasized the importance of a stable technology enterprise at the Agency in its review of NASA's Space Technology Roadmaps.

As the NRC stated in February 2012 that "the productivity and the effectiveness of technology development programs are diminished when the direction, content, and/or funding of those programs abruptly change from year to year." If NASA and this Nation are to reach the goals set for us by this Congress, we must drive to innovate. As the NRC observed, "Success in executing future NASA space missions will depend on advanced technology developments that should already be underway."

The NRC's review of the space technology roadmaps is complete, and it released its final report in February 2012. In preparing it, the NRC engaged broad and crosscutting segments of NASA's external stakeholders. The report's findings and recommendations represent a true consensus of the aerospace community, and as such, clearly motivate future investments in space technology, whether competitively awarded or guided. Although NASA is already investing at some level in all 16 of the high-priority research technologies referenced in the report, NASA is using the NRC's prioritization to balance its investments in technologies that will be infused into future missions conducted by NASA, industry, or other Government users.

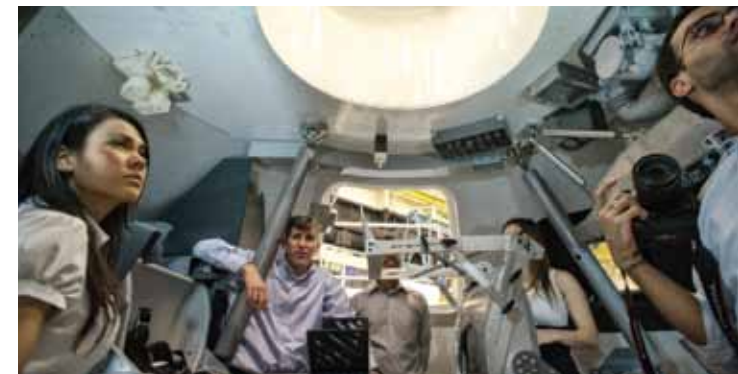
Since February 2012, OCT began an Agency-wide analysis and coordination effort to inform NASA's future technology investments on the basis of the NRC report. This effort has culminated in a Strategic Space Technology Investment Plan (SSTIP).

The SSTIP identifies strategically linked technology investments that will be planned and managed collectively, across NASA, to provide capabilities that contribute to the nation's ability to explore and extend the human presence in space. The SSTIP incorporated applicable recommendations from the National Research Council's

Report, and targeted high priorities from NASA, other government Agencies, the international partners and the US space commercial sector. In addition, the SSTIP optimized the composition of the Agency's technology portfolio and communicated the Agency's priorities and needs to provide a context for future partnerships.



NASA's in-development MAVEN spacecraft, set for an unprecedented mission to study the Martian upper atmosphere, is just one of NASA's efforts to enhance our understanding of the universe.



NASA's next manned spacecraft, Orion (a model of which is seen at top during wind tunnel testing), promises not only a new era in American spaceflight but a host of new technologies as well. University students (middle) visit a mockup of Orion as part of the Students Shaping America's Next Spacecraft program. Robonaut 2 (bottom), seen here on the ISS, is a prime example of partnership—in this case between NASA and General Motors—that can provide benefits in space and on Earth.

NASA is currently developing the Space Launch System (SLS), a rocket that will take astronauts farther into space than ever before. The SLS will launch NASA's Orion spacecraft and other payloads, and provide an entirely new capability for human exploration beyond low Earth orbit. Like programs before it, such as Apollo and the space shuttle, the SLS promises secondary benefits, including innovative spinoffs that may one day improve daily life.



Space Technology to Spur Innovation

Within the Space Technology program, NASA produces a comprehensive portfolio of projects with a range of technology readiness levels (TRL) including early stage conceptual studies, ground-based and laboratory testing aimed at demonstrating technical feasibility, relevant environment flight demonstrations, and technology test beds, including the International Space Station (ISS).

Projects engage the technology community through student fellowships, grants, prize competitions, prototype developments and technology demonstrations. NASA also participates in national technology-development initiatives such as the National Robotics Initiative, the National Nanotechnology Initiative, and the Advanced Manufacturing Partnership to increase opportunities for collaborative technology development.

Space Technology includes the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. SBIR and STTR continue to support early-stage research and development performed by small businesses through competitively awarded contracts. These programs produce innovations for both Government and commercial applications. SBIR and STTR provide the high-technology small business sector with an opportunity to develop technology for NASA, and commercialize that technology in order to provide goods and services that address other national needs based on the products of NASA innovation.

In all, the new Space Technology Program has already funded roughly 1,000 technology projects and engaged thousands of engineers and technologists since its inception in 2011. Many of these projects have hardware ready to test and fly in FY 2013 as they mature their technology for infusion into a future mission or capability.

So far in FY 2012, we have selected 48 students for Space Technology Research Fellowships. They join Space Technology's inaugural class of 79 student researchers returning to continue their research. NASA recently selected 260 SBIR Phase I and 85 SBIR Phase II awards, and 40 STTR Phase I and 10 STTR Phase II awards. On the ISS, we have demonstrated precise maneuvers with the robotic refueling mission, an effort we co-fund with the Human Exploration and Operations directorate at NASA. In addition, we have been remotely controlling robots on the ISS, including Robonaut, NASA's humanoid robot handyman.

To safely extend human presence to multiple destinations throughout the solar system robustly, sustainably, and affordably, NASA supports the development, testing, and evolution of an array of space technologies for human missions beyond low Earth-orbit. These include propulsion, logistics and resupply, life sciences and human systems, communications, and many others. Space technology funding will be used to support a rigorous technology portfolio by taking informed risks and a "when we fail, fail fast and learn in the process" approach. By taking this approach, NASA will achieve disruptive innovation. With success, the future will no longer be a straight line, repositioning NASA on the cutting edge. ❖

Through cutting-edge
space **technology** and its
commercialization,
NASA continues to make
a **difference** in the **world**
around us.






A robot surveys its surroundings during NASA's Sample Return Robot Centennial Challenge. The Centennial Challenges, an OCT program, seek to drive progress in aerospace technology, encourage participation in aerospace research and development, and find the most innovative solutions to technical challenges through competition and cooperation. For a deeper look at the Centennial Challenges, scan this code.

NASA Office of the Chief Technologist Network Directory



The 2012 Office of the Chief Technologist (OCT) network extends from coast to coast. For specific information concerning technology partnering activities, contact the appropriate personnel at the facilities listed or visit the Web site: <http://www.nasa.gov/oct>. General inquiries may be forwarded to the Spinoff Program Office at spinoff@sti.nasa.gov.

To publish a story about a product or service you have commercialized using NASA technology, assistance, or know-how, contact the Spinoff Program Office at the email listed above, or visit: <http://spinoff.nasa.gov/contributor.html>.

-  **NASA Headquarters** manages the Spinoff Program.
-  **The Office of the Chief Technologist** at each of NASA's 10 field centers represent NASA's technology sources and manage center participation in technology transfer activities.
-  **Allied Organizations** support NASA's OCT objectives.

- NASA HQ** — NASA Headquarters
- ARC** — Ames Research Center
- CASI** — NASA Center for AeroSpace Information
- DFRC** — Dryden Flight Research Center
- FLC** — Federal Laboratory Consortium
- GRC** — Glenn Research Center
- GSFC** — Goddard Space Flight Center
- JPL** — Jet Propulsion Laboratory
- JSC** — Johnson Space Center
- KSC** — Kennedy Space Center
- LaRC** — Langley Research Center
- MSFC** — Marshall Space Flight Center
- SF** — Space Foundation
- SSCS** — Stennis Space Center
- Tech Briefs** — Tech Briefs Media Group



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www.techbriefs.com

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NP-2012-11-912-HQ

