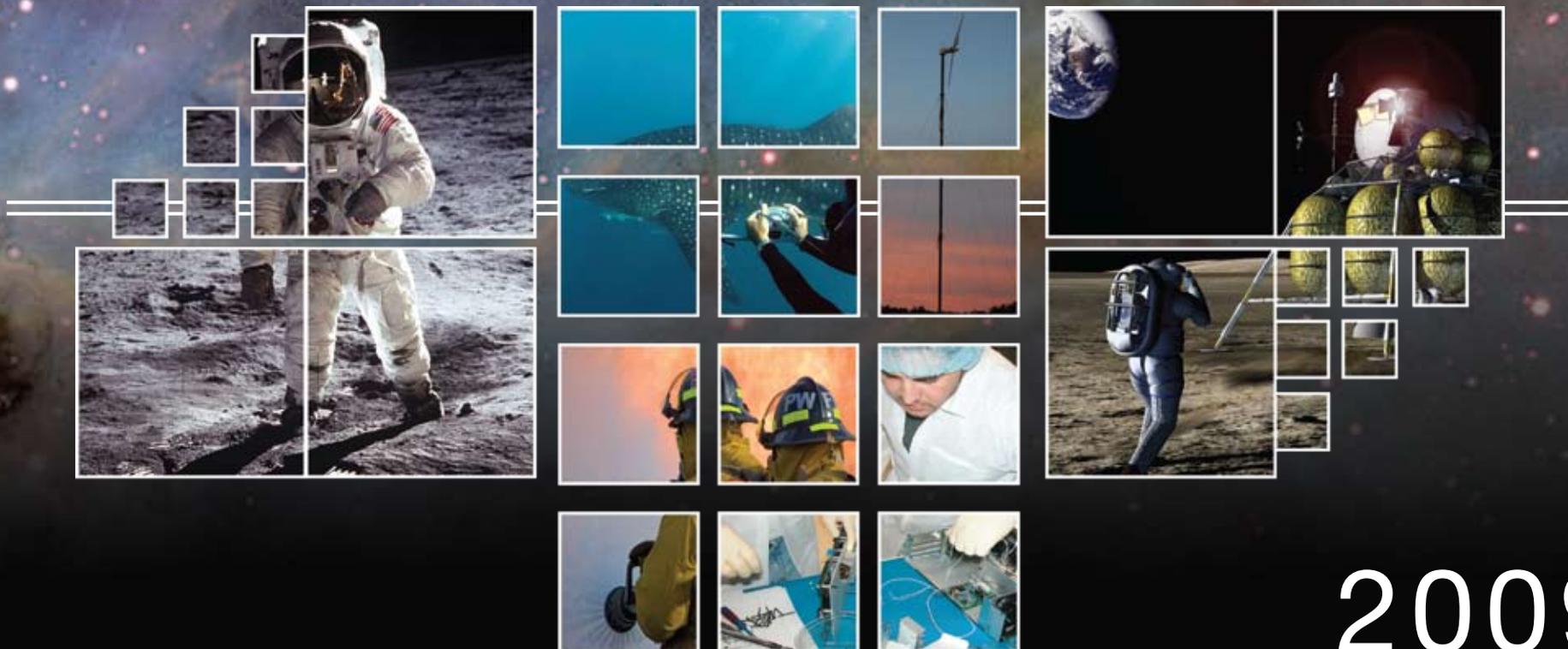




# SPINOFF



2009





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Denotes that *R&D Magazine* has awarded the technology with its “R&D 100” award.



Indicates that the Space Foundation has inducted the technology into the Space Technology Hall of Fame.



Signifies that the technology has been named as a NASA “Invention of the Year.”

For a list of all *Spinoff* award winners since publication began in 1976, please see page 192.

**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.**

# Foreword

On the 40th anniversary of the Apollo 11 lunar landing, President Obama observed that the remarkable accomplishment “inspired an entire generation of scientists and engineers that ended up really sparking the innovation, the drive, the entrepreneurship, the creativity back here on Earth.” The President went on to note that “it’s very important for us to constantly remember that NASA was not only about feeding our curiosity, that sense of wonder, but also had extraordinary practical applications.”

In an earlier speech to the National Academy of Sciences, President Obama again lauded NASA’s practical benefits. “That Apollo program produced technologies that have improved kidney dialysis and water purification systems; sensors to test for hazardous gasses; energy-saving building materials; fire-resistant fabrics used by firefighters and soldiers. More broadly, the enormous investment in that era—in science and technology, in education and research funding—produced a great outpouring of curiosity and creativity, the benefits of which have been incalculable.” The President was referring to the myriad spinoffs that have come out of the Nation’s investment in NASA’s aerospace research, benefits that continue today just as NASA’s missions continue to shape our world.

Perhaps no organization has done more to ingrain these investments in our culture than NASA. For 51 years, the Agency’s exploration and research efforts across a wide range of space-related endeavors have benefited people here on Earth. The resulting technologies have provided dramatic new advances in the quality of our lives that have touched not only Americans but also people around the globe.

This edition of NASA’s annual *Spinoff* publication is designed to highlight the Agency’s recent work to “research, develop, verify and transfer advanced aeronautics, space, and related technologies.” Some of the more noteworthy NASA-derived technologies included in *Spinoff* 2009 are:

- A star-mapping algorithm developed for the Hubble Space Telescope, now adapted to identify unique pattern markers on animals like whale sharks and polar bears, that is helping ecologists track and study these and other endangered species.
- A device NASA invented to study cell growth in simulated weightlessness that is now enabling medical research into treatments for conditions as diverse as heart disease, diabetes, and cirrhosis.
- A satellite-responsive buoy used for monitoring currents in the North Pacific that now is used for tracking debris fields on the high seas.
- A gravity-loading technology designed to help astronauts stay in shape while in orbit that has been incorporated in an “anti-gravity” treadmill to help ease physical therapy.
- Spacesuits incorporating sun-blocking fabric and special cooling systems that have been adapted into clothing offering protection to ordinary beachgoers and patients with light sensitivities.

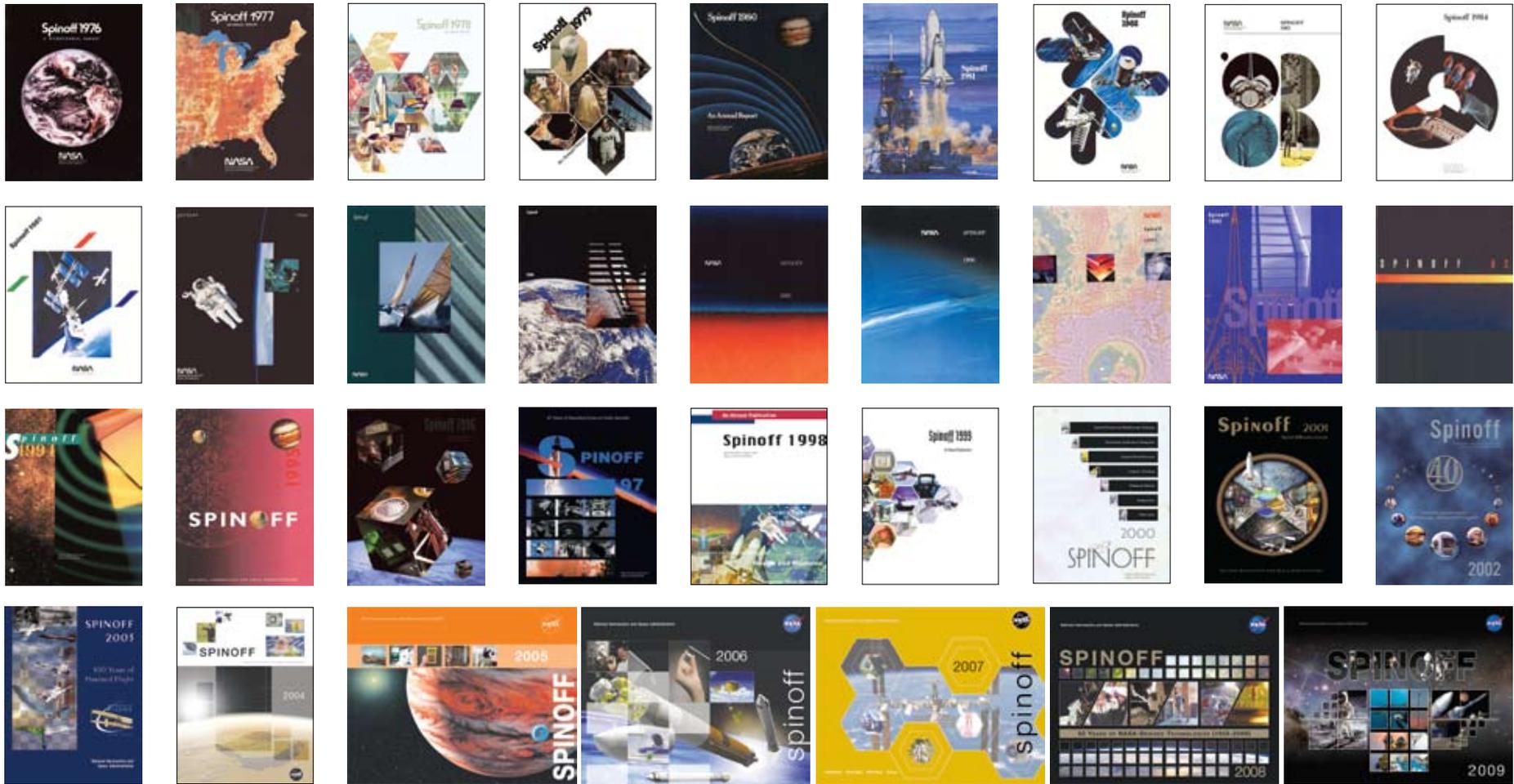
These technologies are all rooted in NASA’s ongoing mission of exploration and discovery. During the past year, the Agency continued to scout our home planet and the rest of the solar system with robotic probes, conducted cutting-edge research aboard the International Space Station, safely flew the Space Shuttle, and made advances in the development of a new generation of human spacecraft and launch systems that eventually will take astronauts back to the Moon and beyond.

United States leadership in space and aeronautics research not only helps to improve our lives, but is also critical for keeping America competitive in an ever-changing global economy. This leadership and competitiveness is largely because of the ingenuity and dedication of the men and women of NASA. Their innovation continues to push the limits of our knowledge and technology on Earth and beyond.



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.



For over 50 years, NASA has created new technologies with direct benefit to the private sector, supporting global competition and the economy. The resulting commercialization has contributed to over 1,800 recorded developments in products and services in the fields of health and medicine, industry, consumer goods, transportation, public safety, computer technology, and environmental resources. Since 1976, NASA has featured these technologies in its *Spinoff* publication.

# Introduction

On July 20, 1969, Apollo 11 astronaut Neil Armstrong became the first human being to set foot on our Moon. “I think we are going to the Moon because it is in the nature of the human being to face challenges,” said Armstrong. “We are required to do these things, just as salmon swim upstream.” The innate human drive to confront difficulty and overcome the seemingly impossible drove development of the new tools and capabilities NASA needed to send humans to the Moon and return them safely to the Earth. This year we celebrated the 40th anniversary of Apollo’s landmark achievement, and this edition of *Spinoff* recaps how Apollo continues to provide tangible benefits to the everyday lives of people in this country and around the world. The tools and capabilities needed for Apollo continue to serve many other purposes including safeguarding firefighters and soldiers, protecting the Alaskan pipeline, preserving nutrients in food while increasing shelf life, and simplifying kidney dialysis.

As with Apollo, NASA’s ongoing efforts to push frontiers in space and aeronautics—from the International Space Station and Hubble Space Telescope to the Mars rovers that continue to probe the Red Planet’s mysteries—continue to yield advanced technologies that are making a significant impact here on Earth. Since 1976, *Spinoff* has been documenting some of the best examples each year—more than 1,600 so far—of space technologies that, through productive partnerships with industry, entrepreneurs, universities, and research institutions have resulted in products and services that elevate health and public safety; augment industrial productivity, computer technology, and transportation; and enhance daily work and leisure. In this edition you will find these notable examples and more:

- An insulating and sound-dampening structural foam originally designed for protecting the shuttle’s external tank is now being used in boat and shipbuilding and

has earned the designation of NASA “Commercial Invention of the Year.”

- Originally designed to monitor astronauts’ alertness while in orbit, NASA-funded “cognitive fitness” software for personal digital assistants has now been adapted into a Web-based job-readiness assessment tool for employers.
- A tiny sensor, small enough to be worn on clothing, now monitors voltage changes near sensitive instruments, after being created to alert Agency workers of dangerous static buildup near fuel operations and avionics.

“We went to explore the Moon, and in fact discovered the Earth,” said Apollo 17 astronaut Eugene Cernan. One of Apollo’s legacies has been the increased awareness of the beauty and fragility of our home planet, inspired by such images as the famous “Earthrise” photograph, captured in 1968 by Apollo 8 astronaut Bill Anders. NASA programs like the Earth Observing System continue to reveal new insights into the health of our planet and how its complex systems operate and interact. NASA’s field centers are promoting institutional sustainability by exploring renewable energy options, improving waste disposal, and employing “green” building design. This edition of *Spinoff* highlights how NASA’s efforts are contributing to the sustainability of our planet and its resources, with examples such as:

- A protective fabric originally created for the space suits of the Apollo astronauts has resulted in a unique roofing material—architecturally practical, visually appealing, and energy efficient—that now adorns landmark buildings around the globe.
- NASA’s remote sensing work—much of which focuses on the oceans and their health—has led to the development of satellite-communicating ocean buoys that help locate errant drift nets posing a hazard to coral reefs, sea turtles, and marine mammals.



Douglas A. Comstock  
*Director*  
Innovative Partnerships Program

A handwritten signature in black ink, appearing to read "Doug Comstock". The signature is fluid and cursive.

- A pattern recognition algorithm developed for star-mapping with the Hubble Space Telescope is helping to track endangered animals from polar bears to whale sharks.
- A power model invented in the 1980s by a NASA engineer is still used today by wind turbine manufacturers to accurately predict airfoil performance at high wind speeds, enabling the advancement of wind energy as a practical, renewable power source.

At NASA, the pioneering spirit that Neil Armstrong described as natural to all humans is alive and well. While pushing frontiers is what drives us, we also seek out other applications of the advances we develop so that hospital patients, public servants, business leaders, athletes, homeowners, and countless others continue to benefit from the Nation’s investment in space and aeronautics.

# Apollo Spinoffs

With the success of the Apollo program, NASA delivered great progress in the fields of rocketry and aeronautics, as well as the fields of civil, mechanical, and electrical engineering. Lesser known accomplishments are some of the many spinoffs that came from the Apollo program—partnerships created between NASA and industry to commercialize the technologies developed for the historic missions to the Moon.





# 40th Anniversary of the First Lunar Landing

Forty years ago, as astronaut Michael Collins orbited alone above the lunar surface, Neil Armstrong and Buzz Aldrin planted an American flag on the Moon. It was July 20, 1969, the crowning achievement of the 8-day Apollo 11 mission, and one of the greatest accomplishments in the history of humanity. Not only was this the first time that people had set foot on the Moon, it was the first time that people had ever left the home planet to travel to another world.

During their 2½ hour moonwalk, Armstrong and Aldrin planted the flag, collected rock samples, deployed scientific instruments, and unveiled a plaque with the inscription “Here men from planet Earth first set foot upon the Moon. July 1969 A.D. We came in peace for all mankind.”

Eight years prior, in May 1961, President John F. Kennedy had charged NASA with the responsibility of sending astronauts to the Moon and back again safely within the decade. This proclamation signaled not only an

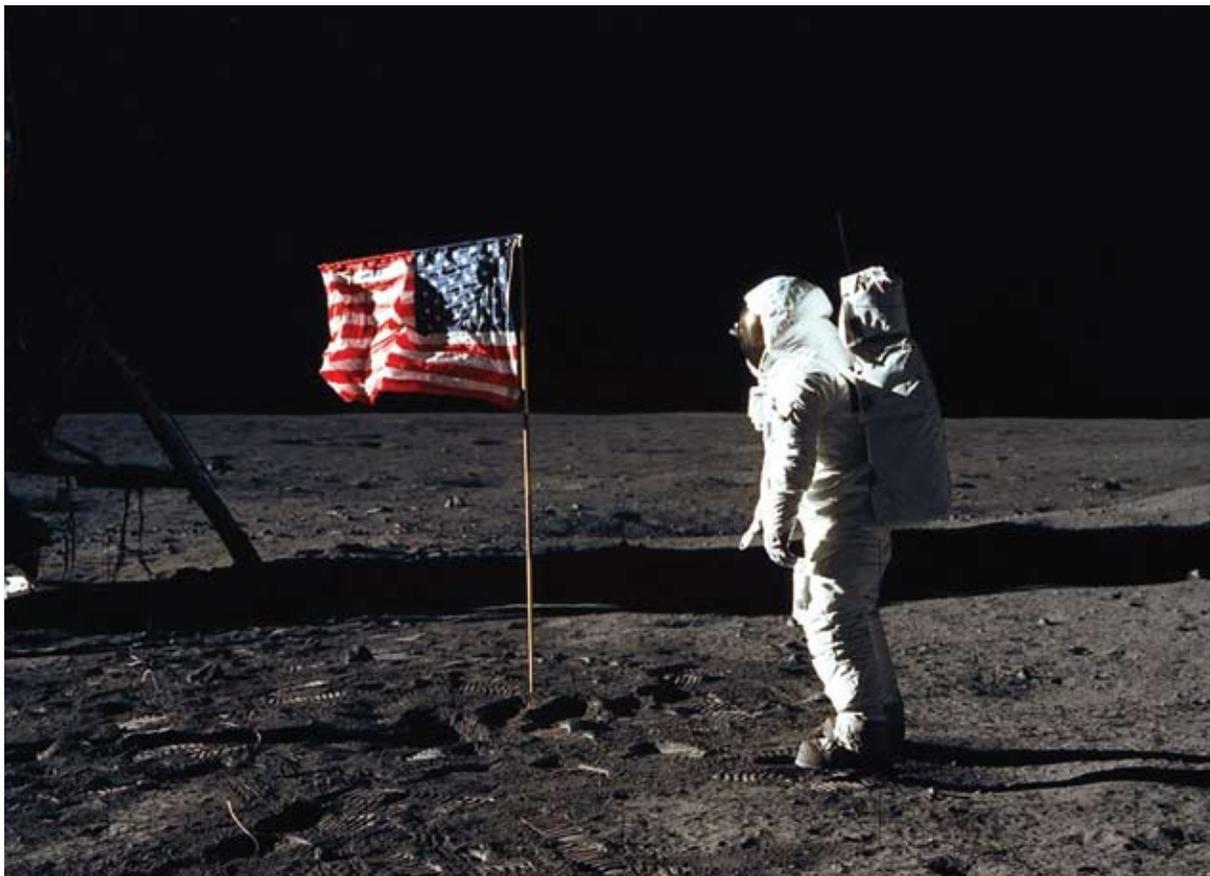
administrative dictum, but a national effort—the country was united toward a common goal of establishing U.S. preeminence in space. With that goal came the building of one of the most complex engineering feats ever carried out by people—and yet to be rivaled.

NASA’s third human space flight program, Apollo, lasted from 1961 to 1975 and included two Earth orbiting missions, two lunar orbiting missions, a lunar swing-by, and a total of six lunar landings. Apollo relied upon a three-part spacecraft: the command module, which included the crew’s quarters and flight control section; the service module for the propulsion and spacecraft support systems; and the lunar module, to take two of the crew to the lunar surface, support them on the Moon, and return them to the other two components waiting in lunar orbit. The entire Apollo spacecraft was launched atop the Saturn V rocket.

Not since Apollo have people travelled beyond low Earth orbit or set foot on another celestial body. The challenge that was Apollo is still as great today as it was then, and the program heralded significant technological achievements. Most of these advances are obvious: With the success of the Apollo Program, NASA delivered great progress in the fields of rocketry and aeronautics, as well as the fields of civil, mechanical, and electrical engineering. Lesser recognized, though still known, are the Apollo Program’s contributions to telecommunications, computers, and medicine. What follows are a few of the even lesser known advances—some of the many spinoffs that came from the Apollo Program—partnerships created between NASA and industry to commercialize the technologies developed for the historic missions to the Moon.

## Computers Automate Retail Transactions, Streamline Utilities

While today almost every transaction involves a computer, this was not always the case. In the 1970s, automatic checkout equipment which analyzed and tested many of the Apollo subsystems at each step of their pro-



In one of the iconic images of the 20th Century, astronaut Buzz Aldrin salutes the American flag on the Moon.



Apollo computer systems led to the automation of retail checkout systems.

gression from manufacture to launch, was applied to the banking and retail industries—improving the speed and accuracy of transactions, credit authorizations, and inventory control. Implementation of the NASA-developed computer programs allowed for faster, smoother, more dependable transactions between retailers and point-of-sale terminals and between banks and teller facilities. The same technology was also applied to a national credit database, where a central computer containing 10 million credit records allowed cash registers to pose credit inquiries when customers presented credit cards for payment.

The complex checkout system was also adopted by several utility companies around the country. The system allowed the utility companies to monitor and control the generation and distribution of power throughout their networks. It also enabled operators to more quickly identify, isolate, and correct power distribution problems.

## Freeze-Dried Foods Preserve Nutrients, Increase Shelf Life

Feeding the Apollo astronauts during their multi-day journeys presented a problem. Food is heavy, it spoils, and it is absolutely necessary. NASA worked with industry partners to develop freeze drying technologies. Freeze drying foods preserves nutritional value and taste, while also reducing weight and increasing shelf life. To freeze dry foods, water is extracted from freshly cooked food by dehydration—accomplished by reducing temperatures to as low as  $-50^{\circ}\text{F}$ . The food is then stored in airtight, moisture-proof containers and can last indefinitely without refrigeration. Over the years, this food storage method has proven useful in delivering meals to people in remote locations; keeping soldiers, hikers, and backpackers nourished; and providing the dehydrated fruit found in today's cereals. It is also still employed by NASA on space shuttle missions.



Food preservation for the early Space Program led to freeze-drying technologies.

## Green Buildings Employ Space Suit Textiles

The same fabric used for Apollo-era space suits has been spun off into a cost-effective, environmentally-friendly building material. Used on structures around the world, the Teflon-coated fiberglass fabric creates a permanent, tent-like roof. Less expensive than conventional roofing materials, the durable white fabric allows natural light to shine through, saving a significant amount of energy. To



Apollo-era space suit fabric proved useful for designing visually intriguing, large-scale, permanent tensile fabric roofs, like the one seen here at Chicago's Navy Pier.

date, these visually stunning fabric roofs have appeared on hundreds of buildings throughout the world, including the Denver International Airport terminal, Chicago's Navy Pier, Reliant Stadium in Houston, and Olympic Stadium in Rome, Italy.



The liquid-filled, temperature-controlled tubes the astronauts wore under their space suits proved valuable for many terrestrial uses.

### Cooling Suits Comfort Hot People

Another Apollo space suit technology is helping people on Earth stay comfortable in extreme situations. Underneath the bulky white exteriors of the space suits, astronauts wear a liquid-cooled undergarment. Similar to long underwear, but containing a series of temperature-controlled, liquid-filled tubes, this under layer protects astronauts from temperature fluctuations experienced during extravehicular activity. Cool suits, which kept Apollo astronauts comfortable during moonwalks, are today worn by racecar drivers, nuclear reactor technicians, shipyard workers, people with multiple sclerosis, and people with a congenital disorder known as hypohidrotic

ectodermal dysplasia, which results in a reduced ability to sweat. The same cooling garments have also been applied to physical therapy and sports rehabilitation equipment. A new generation of cool suits now also protects patients with severe light sensitivities.

### Measurement and Calibration System Automates Refineries

The computer system that provided measurements used to calibrate telemetry equipment in the Saturn launch vehicles that boosted the Apollo spacecraft was applied to a petrochemical pipeline system moving a variety of refined petroleum products across the country. The same pipes carried a variety of different products—such as kerosene, gasoline, jet fuel, and fuel oil—and the task of controlling, measuring, and monitoring the flow of all of these different chemicals was automated using computerized NASA control and communications systems.



The early Apollo computer systems helped automate oil refineries.

### Insulation Protects Alaskan Pipeline

Metal-bonded polyurethane foam insulation developed for protecting Apollo-era spacecraft was also applied to the Alaskan pipeline, where its temperature controlling properties were in high demand. In order to maintain its fluidity, the oil needs to be kept at relatively high temperatures (180 °F), a tall order in the Arctic. The NASA-derived insulation solved this problem.



Insulation developed for the harsh conditions of space found uses in the extreme climates of Alaska.

### Lightning Detector Makes the Skies Safer

When a lightning strike temporarily knocked out the main electrical power system on a just-launched rocket—headed to the Moon and carrying astronauts—NASA began development of a lightning-detection system. Developed at Kennedy Space Center, the system detects and measures lightning strikes—a boon to both NASA missions and commercial aircraft. Prior to this technology, news of lightning was general and spread by word-of-mouth after someone had seen a strike. Now

mission controllers and pilots had access to more precise information. The NASA-designed system is capable of detecting electrical charge build-up before a lightning storm even develops—allowing air traffic controllers to reroute air traffic away from trouble zones.



Concerns over lightning strikes near launch facilities led to a lightning detection system that is keeping commercial aircraft out of danger.

### Heat Shield Material Protects Skyscrapers

The Apollo heat shield was coated with an ablative material whose purpose was to burn and thus dissipate energy. The burned material charred to form a protective coating that blocked heat penetration beyond the outer surface. This material developed into a spinoff application in the arena of fire protection—specifically, the development of fire-retardant paints and foams for aircraft. This led to the production of the world's first intumescent epoxy material, which expands when exposed to heat or flames and acts as an insulating barrier. It also retains its



The thermal protection coatings developed for the Apollo crew capsule can coat the steel structures of skyscrapers, helping them stand up to the intense heat of fires.

space-age ablative properties and dissipates heat through burn-off. It is now widely used on the steel support beams on America's high-rise buildings and public structures. In a fire, the simple coating provides up to 4 hours of fire protection and helps prevent steel infrastructures from collapsing prematurely, in turn giving building occupants more time to evacuate safely.

### Flame-Resistant Textiles Safeguard Firefighters, Soldiers

On January 27, 1967, the severity and immediacy of the danger of fire faced by astronauts was made terribly



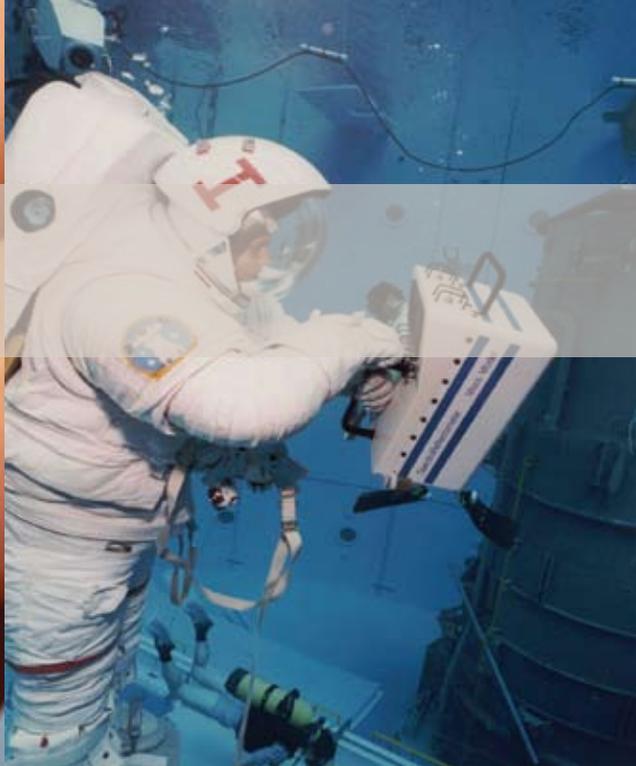
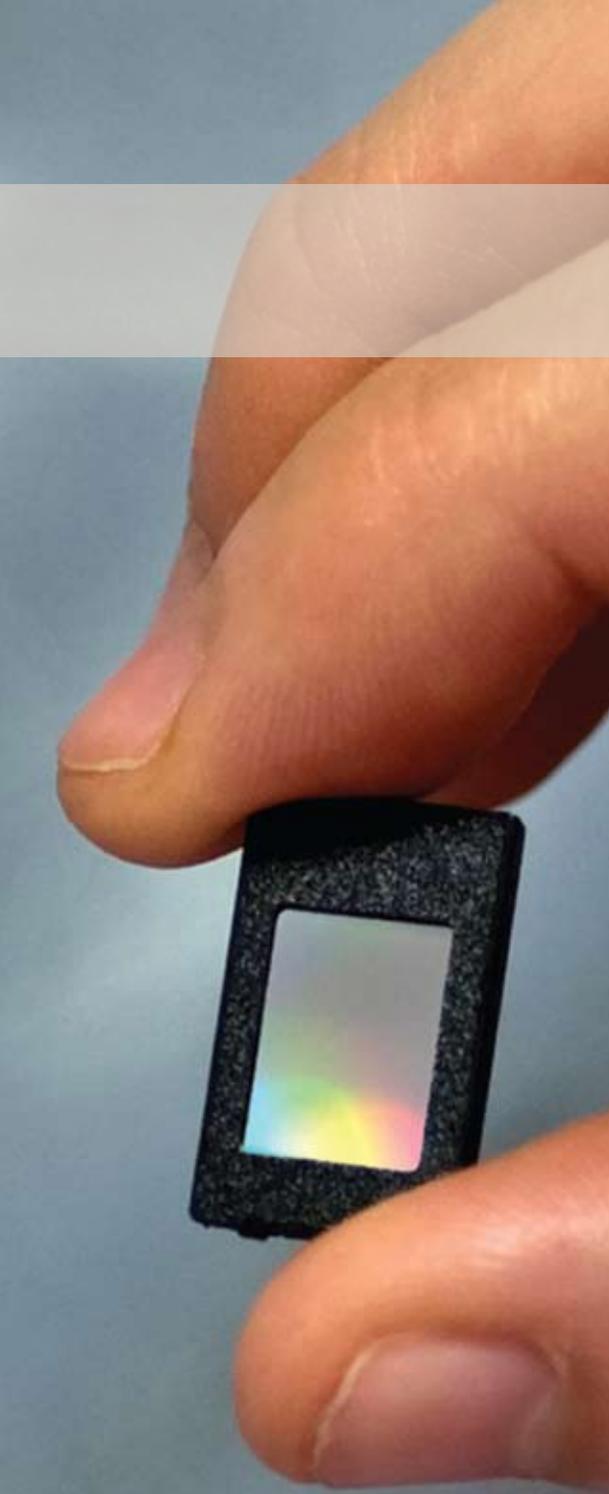
Fire-resistant textiles created for space suits and vehicles now protect people who work in extreme environments.

clear when a flash fire occurred in command module 012 during a launch pad test of the Apollo Saturn space vehicle being prepared for the first piloted flight, the AS-204 mission (also known as Apollo 1). Three astronauts, Lieutenant Colonel Virgil I. Grissom, a veteran of Mercury and Gemini missions; Lieutenant Colonel Edward H. White II, the astronaut who had performed the first U.S. extravehicular activity during the Gemini program; and Lieutenant Commander Roger B. Chaffee, an astronaut preparing for his first space flight, died in this tragic accident. After the Apollo 1 fire, NASA worked with private industry to develop a line of fire-resistant textiles for use in space suits and vehicles. These materials are now used in numerous firefighting, military, motor sports, and other applications. ❖

Teflon® is a registered trademark of E. I. du Pont de Nemours and Company.

# Executive Summary

In accordance with congressional mandates cited in the National Aeronautics and Space Act of 1958 and the Technology Utilization Act of 1962, NASA has nurtured partnerships with the private sector to facilitate the transfer of Agency-developed technologies for the greater good of the public. These partnerships fuel economic and technological development nationally and globally, resulting in commercial products and services enabled on Earth by NASA's mission to the stars. Since 1976, NASA *Spinoff* has profiled the most compelling of these technologies, annually highlighting the best and brightest of partnerships and innovations in the fields of health and medicine, transportation, public safety, consumer goods, environmental and agricultural resources, computer technology, and industrial productivity.



# Executive Summary

**N**ASA *Spinoff* highlights the Agency's most significant research and development activities and the successful transfer of NASA technology, showcasing the cutting-edge research being done by the Nation's top technologists and the practical benefits that come back down to Earth in the form of tangible products that make our lives better. The benefits featured in this year's issue include:



## Health and Medicine



### Image-Capture Devices Extend Medicine's Reach

Johnson Space Center, Henry Ford Hospital in Detroit, and Houston-based Wyle Laboratories collaborated on NASA's Advanced Diagnostic Ultrasound in Microgravity (ADUM) experiment, which developed revolutionary medical ultrasound diagnostic techniques for long-distance use. Mediphan, a Canadian company with U.S. operations in Springfield, New Jersey, drew on NASA expertise to create frame-grabber and data archiving technology that enables ultrasound users with minimal training to send diagnostic-quality ultrasound images and video to medical professionals via the Internet in near-real time—allowing patients as varied as professional athletes, Olympians, and mountain climbers to receive medical attention as soon as it is needed.

*page 32*



### Medical Devices Assess, Treat Balance Disorders

Dr. Lewis Nashner's NASA-funded, pioneering work in the 1980s on balance assessment and rehabilitation led to the invention of the EquiTest computerized dynamic posturography system, used by Johnson Space Center to evaluate astronauts' balance upon their return to Earth's gravity. Commercialized by NeuroCom International Inc., of Clackamas, Oregon, the EquiTest has since been joined by

a wide range of other balance-related medical devices and options. NeuroCom now has over 2,000 systems in use around the world in a variety of medical fields, including neurology, geriatrics, orthopedics, and sports medicine.

*page 34*



### NASA Bioreactors Advance Disease Treatments

Houston-based biotechnology firm Regenotech Inc. acquired the licenses for NASA bioreactor technology from Johnson Space Center. The NASA bioreactor, which allows for the rapid cultivation of healthy cells in simulated weightlessness, is now the foundation of Regenotech's thriving intellectual property business that is providing researchers with the tools to make adult stem cell therapy—a potential source of treatment for conditions like heart disease, diabetes, and sickle cell anemia—viable for the public.

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### Robotics Algorithms Provide Nutritional Guidelines

Using robotics expertise gained while working as an engineer for a major telerobotics program funded by NASA Headquarters, Joe Graves founded a unique, online nutrition company called Vitabot, based in Beltsville, Maryland. Making use of some of the same concepts and style of algorithms Graves developed for NASA's Ranger Neutral Buoyancy Vehicle robot, Vitabot helps users set health goals, plan balanced meals, and lose weight through proper nutrition. Available through corporate wellness programs and health clubs, Vitabot now has nearly 1,000 company clients and has

experienced over 1,500-percent growth in the health club industry—as its users have been shedding pounds through healthy eating.

*page 38*



### 'Anti-Gravity' Treadmills Speed Rehabilitation

A former Ames Research Center engineer, Dr. Robert Whalen, invented a treadmill that he licensed to a Menlo Park, California, company, Alter-G Inc. The company's G-Trainer is an enclosed treadmill that uses air pressure to help patients feel up to 80-percent lighter, easing discomfort during rehabilitation. A patient desiring more weightlessness during a workout can simply press a button and the air pressure increases, lifting the body and reducing strain and impact. The U.S. Food and Drug Administration cleared the G-Trainer for medical use in January 2008, and researchers are now assessing the G-Trainer's effectiveness in aiding patients with various neurological or musculoskeletal conditions.

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### Crew Management Processes Revitalize Patient Care

In 2005, two physicians, former NASA astronauts, created LifeWings Partners LLC, in Memphis, Tennessee, and began using Crew Resource Management (CRM) techniques developed at Ames Research Center in the 1970s to help improve safety and efficiency at hospitals. According to the company, when hospitals follow the LifeWings training, they can see major improvements in a number of areas, including efficiency, employee satisfaction, operating room turnaround, patient

advocacy, and overall patient outcomes. LifeWings has brought its CRM training to over 90 health care organizations, and annual sales have remained close to \$3 million since 2007.

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### **Hubble Systems Optimize Busy Hospital Schedules**

Don Rosenthal, a former Ames Research Center computer scientist who helped design the Hubble Space Telescope's scheduling software, co-founded Allocade Inc., of Menlo Park, California, in 2004. Allocade's OnCue software helps hospitals reclaim unused capacity and optimize constantly changing schedules for imaging procedures. After starting to use the software, one medical center soon reported noticeable improvements in efficiency, including a 12-percent increase in procedure volume, 35-percent reduction in staff overtime, and significant reductions in backlog and technician phone time. Allocade now offers versions for outpatient and inpatient magnetic resonance imaging (MRI), ultrasound, interventional radiology, nuclear medicine, positron emission tomography (PET), radiography, radiography-fluoroscopy, and mammography.

*page 44*



### **Web-Based Programs Assess Cognitive Fitness**

The National Space Biomedical Research Institute, based in Houston and funded by NASA, began funding research for Harvard University researchers to design Palm software to help astronauts monitor and assess their cognitive functioning. The MiniCog Rapid Assessment Battery (MRAB) was licensed by the Criteria Corporation in Los Angeles and

adapted for Web-based employment testing. The test battery assesses nine different cognitive functions and can gauge the effect of stress-related deficits, such as fatigue, on various tasks. The MRAB can be used not only for pre-employment testing but also for repeat administrations to measure day-to-day job readiness in professions where alertness is critical.

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### **Electrolyte Concentrates Treat Dehydration**

Wellness Brands Inc. of Boulder, Colorado, exclusively licensed a unique electrolyte concentrate formula developed by Ames Research Center to treat and prevent dehydration in astronauts returning to Earth. Marketed as The Right Stuff, the company's NASA-derived formula is an ideal measure for athletes looking to combat dehydration and boost performance. Wellness Brands also plans to expand with products that make use of the formula's effective hydration properties to help treat conditions including heat stroke, altitude sickness, jet lag, and disease.

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### **Transportation**



### **Tools Lighten Designs, Maintain Structural Integrity**

Collier Research Corporation, of Hampton, Virginia, licensed software developed at Langley Research Center to reduce design weight through the use of composite materials. The first license of NASA-developed software, it has now been used in everything from designing next-generation cargo containers, to airframes, rocket engines, ship hulls, and train bodies. The company now has sales of the NASA-derived software topping

\$4 million a year and has recently received several Small Business Innovation Research (SBIR) contracts to apply its software to nearly all aspects of the new Orion crew capsule design.

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### **Insulating Foams Save Money, Increase Safety**

Scientists at Langley Research Center created polyimide foam insulation for reusable cryogenic propellant tanks on the space shuttle. Meanwhile, a small Hialeah, Florida-based business, PolyuMAC Inc., was looking for advanced foams to use in the customized manufacturing of acoustical and thermal insulation. The company contacted NASA, licensed the material, and then the original inventors worked with the company's engineers to make a new material that was better for both parties. The new version, a high performance, flame retardant, flexible polyimide foam, is used for insulating NASA cryogenic propellant tanks and shows promise for use on watercraft, aircraft, spacecraft, electronics and electrical products, automobiles and automotive products, recreation equipment, and building and construction materials.

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### **Polyimide Resins Resist Extreme Temperatures**

To combat the high temperatures in aerospace applications, Dr. Ruth Pater of Langley Research Center developed RP-46, a polyimide resin capable of withstanding the most brutal temperatures while still being lightweight (less than half the weight of aluminum), chemical and moisture resistant, strong, and flexible. Designed as an environmentally friendly alternative to other high-temperature resins, the RP-46 polyimide resin system was

awarded a 1992 “R&D 100” award, named a 2001 “NASA Technology of the Year,” and later, due to its success as a spinoff technology, 2004 “NASA Commercial Invention of the Year.” Unitech LLC, of Hampton, Virginia, received a nonexclusive license from NASA for commercialization of the material, and it is now in widespread industrial use.  
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### Sensors Locate Radio Interference

After receiving a NASA SBIR contract from Kennedy Space Center, Soneticom Inc., based in West Melbourne, Florida, created algorithms for time difference of arrival and radio interferometry, which it used in its Lynx Location System (LLS) to locate electromagnetic interference that can disrupt radio communications. Soneticom is collaborating with the Federal Aviation Administration (FAA) to install and test the LLS at its field test center in New Jersey in preparation for deploying the LLS at commercial airports. The software collects data from each sensor in order to compute the location of the interfering emitter.  
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### Surface Operations Systems Improve Airport Efficiency

With SBIR contracts from Ames Research Center, Mosaic ATM Inc., of Leesburg, Virginia, created software to analyze surface operations at airports. Surface surveillance systems, which report locations every second for thousands of air and ground vehicles, generate massive amounts of data, making gathering and analyzing this information difficult. Mosaic’s Surface Operations Data Analysis and Adaptation (SODAA) tool is an off-line support tool that can analyze how well the airport surface operation is

working and can help redesign procedures to improve operations. SODAA helps researchers pinpoint trends and correlations in vast amounts of recorded airport operations data.  
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### Nontoxic Resins Advance 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 Ltd., based in Japan with its 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.  
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### Public Safety



### Sensors Provide Early Warning of Biological Threats

Early Warning Inc., of Troy, New York, licensed powerful biosensor technology from Ames Research Center. Incorporating carbon nanotubes tipped with single strands of nucleic acid from waterborne pathogens, the sensor can detect even minute amounts of targeted, disease-causing bacteria, viruses, and parasites. Early Warning features the NASA biosensor in its water analyzer, which can alert organizations to potential biological hazards in water used for agriculture, food and beverages, showers, and at beaches and

lakes—within hours instead of the days required by conventional laboratory methods.  
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### Robots Save Soldiers’ Lives Overseas

Marshall Space Flight Center mobile communications platform designs for future lunar missions led to improvements to fleets of tactical robots now being deployed by the U.S. Army. The Multi-function Agile Remote Control Robot (MARCbot) helps soldiers search out and identify improvised explosive devices. NASA used the MARCbot to test its mobile communications platform, and in working with it, made the robot faster while adding capabilities—upgrading to a digital camera, encrypting the controllers and video transmission, as well as increasing the range and adding communications abilities. They also simplified the design, providing more plug-and-play sensors and replacing some of the complex electronics with more trouble-free, low-cost components. Applied Geo Technologies Inc., a tribally-owned corporation in Choctaw, Mississippi, was given the task of manufacturing the modified robots. The company is now producing 40 units per month, 300 of which have already been deployed overseas.  
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### Apollo-Era Life Rafts Save Hundreds of Sailors

To keep life rafts holding astronauts and frogmen from capsizing from the downdraft of rescue helicopters after Apollo-era splashdown landings, engineers at NASA’s Johnson Space Center designed and patented a self-righting life raft capable of resisting tipping in choppy seas and fierce winds. Givens Marine Survival

Co. Inc., of Tiverton, Rhode Island, patented this invention and now manufactures and markets the rescue rafts—under the name Givens Buoy Life Raft—in a variety of sizes and models for everything from sailboats to larger ocean-going vessels. To date, Givens has sold several thousand of the ballasted, inflatable life rafts, and this space-age technology is credited with saving the lives of over 450 sailors.

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### **Circuits Enhance Scientific Instruments and Safety Devices**

In 1996, Thomas Crowe and William Bishop founded Virginia Diodes Inc. (VDI), based in Charlottesville, Virginia. VDI now has over 30 full-time employees and grows 30 percent per year, growth Crowe credits to its terahertz products developed under SBIR contracts with Goddard Space Flight Center. Because of the unique characteristics of terahertz radiation—such as its ability to image hidden items and to detect and identify a wide range of chemicals—there is a growing demand for terahertz components. Applications include security imaging systems, hazardous chemical and biological-agent detectors, plasma diagnostic instruments, and industrial process monitors. The company has over 200 customers in over two dozen countries.

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### **Tough Textiles Protect Payloads and Public Safety Officers**

In order to create the Mars Pathfinder's mission-critical airbags in the 1990s, NASA's Jet Propulsion Laboratory collaborated with New Ipswich, New Hampshire's Warwick Mills Inc. to weave multilayer textiles for the airbags for both Pathfinder and the Mars Exploration Rovers. Warwick Mills applied

techniques from the collaboration to its puncture- and impact-resistant TurtleSkin product line. The company's metal flex armor (MFA) vests offer stab protection comparable with rigid steel plates, and over 50,000 of the vests have sold. The SoftPlate body armor offers protection from handgun bullets, and like the MFA, is designed to be more comfortable than rigid vests. International public safety and military customers are now benefiting from the TurtleSkin products.

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### **Consumer, Home, and Recreation**



### **Forecasting Tools Point to Fishing Hotspots**

Private weather forecaster WorldWinds Inc., of Slidell, Louisiana, has employed satellite-gathered oceanic data from Marshall Space Flight Center to create a service that is every fishing enthusiast's dream. The company's FishBytes system uses information about sea surface temperature and chlorophyll levels to forecast favorable conditions for certain fish populations. Transmitting the data to satellite radio subscribers, FishBytes—with about 8,500 subscribers so far—provides maps that guide anglers to the areas where they are most likely to make their favorite catch.

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### **Air Purifiers Eliminate Pathogens, Preserve Food**

NASA-funded researchers produced an ethylene reduction device for a plant growth unit. KES Science and Technology Inc., a Kennesaw, Georgia-based company specializing in sustaining perishable foods, licensed the ethylene scrubbing technology. KES partnered

with Akida Holdings, of Jacksonville, Florida, which now markets the NASA-developed technology as AiroCide. According to the company, it is the only air purifier that completely destroys airborne bacteria, mold, fungi, mycotoxins, viruses, volatile organic compounds (like ethylene), and odors. What's more, the devices have no filters that need changing and produce no harmful byproducts, such as the ozone created by some filtration systems.

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### **Fabrics Protect Sensitive Skin from UV Rays**

Late Johnson Space Center engineer Dr. Robert Dotts headed a team to develop cool suits for children suffering from life-threatening sun sensitivities. Dotts hoped to develop ultraviolet-blocking technology in a fabric that—unlike in a bulky space suit—could remain comfortable, light, and breathable in the sun and heat. The team worked with the Solar Protective Factory Inc. (SPF), of Madison, Wisconsin, to design ultraviolet-blocking cool suits, which protect sun-sensitive patients and enable them to experience life outdoors safely. Using knowledge gained during the NASA collaboration, SPF created an entire line of ultraviolet-blocking apparel.

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### **Phase Change Fabrics Control Temperature**

Originally featured in *Spinoff* 1997, Outlast Technologies Inc. (formerly Gateway Technologies Inc.) has built its entire product line on microencapsulated phase change materials developed in SBIR contracts with Johnson Space Center after initial development for the U.S. Air Force. The Boulder, Colorado-based company acquired the

exclusive patent rights and now integrates these materials into textiles or onto finished apparel, providing temperature regulation in bedding materials and a full line of apparel for both ordinary and extreme conditions.

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### **Tiny Devices Project Sharp, Colorful Images**

Displaytech Inc., based in Longmont, Colorado, and recently acquired by Micron Technology Inc., of Boise, Idaho, first received an SBIR contract in 1993 from Johnson Space Center to develop tiny, electronic, color displays, called microdisplays. Displaytech has since sold over 20 million microdisplays and was ranked one of the fastest growing technology companies by Deloitte and Touche in 2005. Customers currently incorporate the microdisplays in tiny pico projectors, which weigh only a few ounces and attach to media players, cell phones, and other devices. The projectors can convert a digital image from the typical postage stamp size into a bright, clear, 4-foot-wide projection. The company believes sales of this type of pico projector may exceed \$1.1 billion within 5 years.

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### **Environmental and Agricultural Resources**



### **Star-Mapping Tools Enable Tracking of Endangered Animals**

Software programmer Jason Holmberg, of Portland, Oregon, partnered with a Goddard Space Flight Center astrophysicist to develop a method for tracking the elusive whale shark using the unique spot patterns on the fish's skin. Employing a star-mapping algorithm

originally designed for the Hubble Space Telescope, Holmberg created a photograph database and pattern-matching system that can identify whale sharks by their spots and match images contributed to the database by photographers from around the world. The system has been adapted for tracking other rare and endangered animals, including polar bears and ocean sunfish.

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### **Nanofiber Filters Eliminate Contaminants**

With support from SBIR funding from Johnson Space Center, Argonide Corporation, of Sanford, Florida, tested and developed its proprietary nanofiber water filter media. Capable of removing more than 99.99 percent of dangerous particles like bacteria, viruses, and parasites, the media was incorporated into the company's commercial NanoCeram water filter, a 2002 "R&D 100" award winner and 2005 inductee into the Space Foundation's Space Technology Hall of Fame. In addition to its drinking water filters, Argonide now produces large-scale nanofiber filters used for industrial and municipal water purification.

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### **Modeling Innovations Advance Wind Energy Industry**

In 1981, Glenn Research Center scientist Dr. Larry Viterna developed a model that predicted certain elements of wind turbine performance with far greater accuracy than previous methods. The model was met with derision from others in the wind energy industry, but years later, Viterna discovered it had become the most widely used method of its kind, enabling significant wind

energy technologies—like the fixed pitch turbines produced by manufacturers like Aerostar Inc., of Westport, Massachusetts—that are providing sustainable, climate friendly energy sources today.

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### **Thermal Insulation Strips Conserve Energy**

Flexible aerogel technology developed by Aspen Aerogels, of Northborough, Massachusetts, under SBIR contracts with Kennedy Space Center, is now being employed in a building insulation application by Tampa, Florida-based Acoustiblok Inc. The company's Thermablok flexible aerogel strips—easy-to-install and environmentally friendly—are applied to wall studs in buildings to break the thermal bridging between the interior and exterior walls, boosting the insulation factor by as much as 42 percent.

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### **Satellite-Respondent Buoys Identify Ocean Debris**

As part of its ocean-observing work, NASA partnered with NOAA and private industry to develop remote sensing technologies for protecting the seas of the North Pacific from derelict fishing gear. As part of this program, Airborne Technologies Inc. (ATI), of Wasilla, Alaska, developed a system using satellite-respondent buoys to monitor the convergence of currents in order to track high seas debris. ATI has now built over 900 of the buoys, and that original work has also led to the development of a prototype unmanned aircraft system and unique complementary software designed to process ocean images to detect debris fields.

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### Mobile Instruments Measure Atmospheric Pollutants

Under SBIR contracts from Glenn Research Center, Billerica, Massachusetts-based Aerodyne Research Inc. (ARI) has created spectrometers for use in mobile laboratories to study ground-based air pollution. ARI developed its tunable infrared laser differential absorption spectrometers to detect a range of more than 15 of the most important greenhouse gasses and air pollutants, including carbon dioxide, nitrogen dioxide, and methane. In addition to mobile measurements from van, aircraft, and ship platforms, ARI and its customers use the instruments to determine the magnitude of pollutant emissions. The company's products are currently in use in numerous climate change laboratories on five continents.

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### Cloud Imagers Offer New Details on Earth's Health

Boulder, Colorado-based Stratton Park Engineering Company Inc. (SPEC) has won numerous SBIR contracts to develop atmospheric instrumentation, including a Phase II SBIR from NASA's Jet Propulsion Laboratory for cloud particle imagers. The SPEC Cloud Particle Imager (CPI) has been installed on NASA's high-altitude research aircraft and has been sold to universities and agencies around the world. Mounted to airplane exteriors, the CPI system captures images of cloud particles, enabling further analysis for climate predictions and research.

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### Antennas Lower Cost of Satellite Access

SeaSpace Corporation, of Poway, California, worked with NASA's Jet Propulsion Laboratory under two SBIR contracts to reduce the cost of satellite ground tracking. The resulting hardware and software not only complement NASA's remote sensing capabilities but also benefit the greater research community, tracking low-Earth orbit satellites for remote sensing; science; communications; and telemetry, tracking, and command applications, providing true full hemispherical coverage. The company's ground-based receivers are now in continuous operation on all seven continents, with customers including aerospace and defense clients, the scientific community, national and local weather services, the research industry, and public safety organizations.

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### Feature Detection Systems Enhance Satellite Imagery

Supported by SBIR contracts with Stennis Space Center, Geospatial Data Analysis Corporation of State College, Pennsylvania, invented software for automatically identifying clouds in satellite imagery without the use of thermal data—an important development for satellites that forgo expensive thermal imaging equipment. The company's software provides highly accurate cloud identification for private remote sensing imagery firms, and the technology's feature detection capabilities are also being applied to a range of land features, helping researchers study the effects of population growth and climate change on crop field acreage, flood zones, and plant cover.

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### Chlorophyll Meters Aid Plant Nutrient Management

Spectrum Technologies, headquartered in Plainfield, Illinois, licensed a hand-held plant chlorophyll meter developed from Stennis Space Center's research on satellite sensors. The meter measures light to determine a plant's chlorophyll content—a strong indicator of plant health. Spectrum improved the NASA technology and commercialized it as its FieldScout meters. Growers and agricultural researchers can now use the meters to determine the nutrient needs of crops like wheat, rice, cotton, and corn. The meters are also effective nutrient management tools for turf grass, making them ideal for the maintenance of golf courses and athletic fields.

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### Computer Technology



### Telemetry Boards Interpret Rocket, Airplane Engine Data

Through a Space Act Agreement with Kennedy Space Center, telemetry innovator Ulyssix Technologies Inc., of Frederick, Maryland, is furthering its long-standing NASA relationship and expanding its commercial telemetry expertise. Ulyssix's telemetry hardware—like its TarsusPCM processing board used by Kennedy to gather and translate data on rocket and space shuttle launches—is being employed for jet engine and airplane testing and development, as well as ground support equipment for satellites. The hardware may also become a part of private space industry projects, all while still supporting NASA efforts, such as testing for the Constellation Program.

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### Programs Automate Complex Operations Monitoring

Command and Control Technologies Corporation (CCT), of Titusville, Florida, licensed software created to automate mission-critical applications at the Kennedy Space Center launch complex. The company now applies the same management technologies created for NASA launches to other complex yet critical operations: weapons test ranges, borders protection, and large industrial processes, like monitoring and managing power plants.

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### Software Tools Streamline Project Management

Three innovative software inventions from Ames Research Center (NETMARK, Program Management Tool, and Query-Based Document Management) are finding their way into NASA missions as well as industry applications. The three software tools have been bundled together for the purpose of executing a nonexclusive patent license, and JumpStart Solutions LLC, of Cave Creek, Arizona, licensed them for use in its PanOptica product suite. The company now offers customers a cost-effective, scalable, easy-to-use suite of tools to manage projects, portfolios, and knowledge bases and documents.

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### Modeling Languages Refine Vehicle Design

Cincinnati, Ohio's TechnoSoft Inc. is a leading provider of object-oriented modeling and simulation technology used for commercial and defense applications. With funding from SBIR contracts issued by Langley Research Center, the company continued development

on its adaptive modeling language, or AML, originally created for the U.S. Air Force. TechnoSoft then created what is now known as its Integrated Design and Engineering Analysis Environment, or IDEA, which can be used to design a variety of vehicles and machinery. IDEA's customers include clients in green industries, such as designers for power plant exhaust filtration systems and wind turbines.

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### Radio Relays Improve Wireless Products

Signal Hill, California-based XCOM Wireless Inc. developed radio frequency microelectromechanical systems (RF MEMS) relays with a Phase II SBIR contract through NASA's Jet Propulsion Laboratory. In order to improve satellite communication systems, XCOM produced wireless RF MEMS relays and tunable capacitors that use metal-to-metal contact and have the potential to outperform most semiconductor technologies while using less power. These relays are used in high-frequency test equipment and instrumentation, where increased speed can mean significant cost savings. Applications now also include mainstream wireless applications and greatly improved tactical radios.

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### Industrial Productivity



### Advanced Sensors Boost Optical Communication, Imaging

Brooklyn, New York-based Amplification Technologies Inc. (ATI) employed SBIR funding from NASA's Jet Propulsion Laboratory to forward the company's solid-state photomultiplier technology. Under the SBIRs, ATI developed a small, energy-

efficient, extremely high-gain sensor capable of detecting light down to single photons in the near infrared wavelength range. The company has commercialized this technology in the form of its NIRDAPD photomultiplier, ideal for use in free space optical communications, lidar and ladar, night vision goggles, and other light sensing applications.

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### Tensile Fabrics Enhance 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 1956 to a multi-million-dollar specialty contractor today.

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### Robust Light Filters Support Powerful Imaging Devices

Infrared (IR) light filters developed by Lake Shore Cryotronics Inc., of Westerville, Ohio—using SBIR funding from NASA's Jet Propulsion Laboratory and Langley Research Center—employ porous silicon and metal mesh technology to provide optical filtration even at the ultra-low temperatures required by many IR sensors. With applications in the astronomy community, Lake Shore's SBIR-developed filters are also promising tools for use in terahertz imaging, the next wave of technology for applications

like medical imaging, the study of fragile artworks, and airport security.  
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### **Thermoelectric Devices Cool, Power Electronics**

Nextreme Thermal Solutions Inc., based in Research Triangle Park, North Carolina, licensed thermoelectric technology from NASA's Jet Propulsion Laboratory. This has allowed the company to develop cutting edge, thin film thermoelectric coolers that effectively remove heat generated by increasingly powerful and tightly packed microchip components. These solid-state coolers are ideal solutions for applications like microprocessors, laser diodes, LEDs, and even potentially for cooling the human body. Nextreme's NASA-enabled technology has also resulted in embedded thermoelectric generators capable of powering technologies like medical implants and wireless sensor networks.  
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### **Innovative Tools Advance 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). The technique creates a superior weld to traditional fusion methods, but 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.  
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### **Methods Reduce Cost, Enhance 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.  
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### **Gauging Systems Monitor Cryogenic Liquids**

With SBIR awards from Kennedy Space Center, Sierra Lobo Inc. (SLI), based in Fremont, Ohio, developed the Cryo-Tracker Mass Gauging System (Cryo-Tracker MGS). The Cryo-Tracker MGS is a three-part system that integrates the use of software, electronics, and the "R&D 100" award-winning Cryo-Tracker probe. SLI is marketing the Cryo-Tracker MGS to companies that use and store cryogenics, including medical organizations, metals processors, and semiconductor manufacturers, which use the Cryo-Tracker MGS to monitor mass, liquid levels, temperature, and pressure for

stored liquid helium, hydrogen, nitrogen, or oxygen. SLI began with only nine employees in 1993, and now has an ISO 9001:2008 registration and over 370 employees.  
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### **Voltage Sensors Monitor Harmful Static**

A tiny sensor, small enough to be worn on clothing, now monitors voltage changes near sensitive instruments after being created to alert Space Agency workers to dangerous static buildup near fuel operations and avionics. San Diego's QUASAR Federal Systems Inc. received an SBIR contract from Kennedy Space Center to develop its remote voltage sensor (RVS), a dime-sized electrometer designed to measure triboelectric changes in the environment. One of the unique qualities of the RVS is that it can detect static at greater distances than previous devices, measuring voltage changes from a few centimeters to a few meters away, due to its much-improved sensitivity.  
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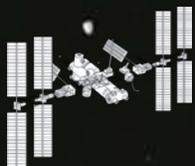


### **Compact Instruments Measure Heat Potential**

Based in Huntsville, Alabama, AZ Technology Inc. is a woman- and veteran-owned business that offers expertise in electromechanical-optical design and advanced coatings. AZ Technology has received eight SBIR contracts with Marshall Space Flight Center for the development of spectral reflectometers and the measurement of surface thermal properties. The company uses a variety of measurement services and instruments, including the Spectrafire, a compact spectral emissometer it used to assist General Electric Company with the design of its award-winning Giraffe Warmer for neonatal intensive care units.  
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# NASA Technologies Enhance Our Lives on Earth

## International Space Station



## Space Telescopes and Deep Space Exploration



## Satellites and Imaging Technology



Innovative technologies from NASA's space and aeronautics missions (above) transfer as benefits to many sectors of society (below). Each benefit featured in *Spinoff 2009* 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



Extend Medicine's Reach  
page 32



Assess, Treat Balance Disorders  
page 34



Advance Disease Treatments  
page 36



Provide Nutritional Guidelines  
page 38



Speed Rehabilitation  
page 40



Revitalize Patient Care  
page 42



Optimize Busy Hospital Schedules  
page 44



Assess Cognitive Fitness  
page 46



Treat Dehydration  
page 48



### Transportation



Lighten Designs, Maintain Structural Integrity  
page 52



Save Money, Increase Safety  
page 54



Resist Extreme Temperatures  
page 56



Locate Radio Interference  
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Improve Airport Efficiency  
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Advance Aerospace Manufacturing  
page 62



### Public Safety



Provide Early Warning of Biological Threats  
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Save Soldiers' Lives Overseas  
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Save Hundreds of Sailors  
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Enhance Scientific Instruments and Safety Devices  
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Protect Payloads and Public Safety Officers  
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### Consumer, Home, and Recreation



Point to Fishing Hotspots  
page 78



Eliminate Pathogens, Preserve Food  
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Protect Sensitive Skin from UV Rays  
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Control Temperature  
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Project Sharp, Colorful Images  
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## Space Transportation



### Environmental and Agricultural Resources



**Enable Tracking of Endangered Animals**  
*page 90*



**Eliminate Contaminants**  
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**Advance Wind Energy Industry**  
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**Conserve Energy**  
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**Identify Ocean Debris**  
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**Measure Atmospheric Pollutants**  
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**Offer New Details on Earth's Health**  
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**Lower Cost of Satellite Access**  
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**Enhance Satellite Imagery**  
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**Aid Plant Nutrient Management**  
*page 110*



## Astronaut Life Support



### Computer Technology



**Interpret Rocket, Airplane Engine Data**  
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**Automate Complex Operations Monitoring**  
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**Streamline Project Management**  
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**Refine Vehicle Design**  
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**Improve Wireless Products**  
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## Aeronautics Research



### Industrial Productivity



**Boost Optical Communication, Imaging**  
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**Enhance Architecture Around the World**  
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**Support Powerful Imaging Devices**  
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**Cool, Power Electronics**  
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**Advance Revolutionary Weld Technique**  
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**Reduce Cost, Enhance Quality of Nanotubes**  
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**Monitor Cryogenic Liquids**  
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**Monitor Harmful Static**  
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**Measure Heat Potential**  
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# NASA Partnerships Across the Nation



## Health and Medicine

- 1 Image-Capture Devices Extend Medicine's Reach (NJ)
- 2 Medical Devices Assess, Treat Balance Disorders (OR)
- 3 NASA Bioreactors Advance Disease Treatments (TX)
- 4 Robotics Algorithms Provide Nutritional Guidelines (MD)
- 5 'Anti-Gravity' Treadmills Speed Rehabilitation (CA)
- 6 Crew Management Processes Revitalize Patient Care (TN)
- 7 Hubble Systems Optimize Busy Hospital Schedules (CA)
- 8 Web-Based Programs Assess Cognitive Fitness (CA)
- 9 Electrolyte Concentrates Treat Dehydration (CO)



## Transportation

- 10 Tools Lighten Designs, Maintain Structural Integrity (VA)
- 11 Insulating Foams Save Money, Increase Safety (FL)
- 12 Polyimide Resins Resist Extreme Temperatures (VA)
- 13 Sensors Locate Radio Interference (FL)
- 14 Surface Operations Systems Improve Airport Efficiency (VA)
- 15 Nontoxic Resins Advance Aerospace Manufacturing (NY)



## Public Safety

- 16 Sensors Provide Early Warning of Biological Threats (NY)
- 17 Robots Save Soldiers' Lives Overseas (MS)
- 18 Apollo-Era Life Rafts Save Hundreds of Sailors (RI)
- 19 Circuits Enhance Scientific Instruments and Safety Devices (VA)
- 20 Tough Textiles Protect Payloads and Public Safety Officers (NH)



## Consumer, Home, and Recreation

- 21 Forecasting Tools Point to Fishing Hotspots (LA)
- 22 Air Purifiers Eliminate Pathogens, Preserve Food (FL)
- 23 Fabrics Protect Sensitive Skin from UV Rays (WI)
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## Environmental and Agricultural Resources

- 26 Star-Mapping Tools Enable Tracking of Endangered Animals (OR)
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- 29 Thermal Insulation Strips Conserve Energy (FL)
- 30 Satellite-Respondent Buoys Identify Ocean Debris (AK)
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- 32 Cloud Imagers Offer New Details on Earth's Health (CO)
- 33 Antennas Lower Cost of Satellite Access (CA)
- 34 Feature Detection Systems Enhance Satellite Imagery (PA)
- 35 Chlorophyll Meters Aid Plant Nutrient Management (IL)



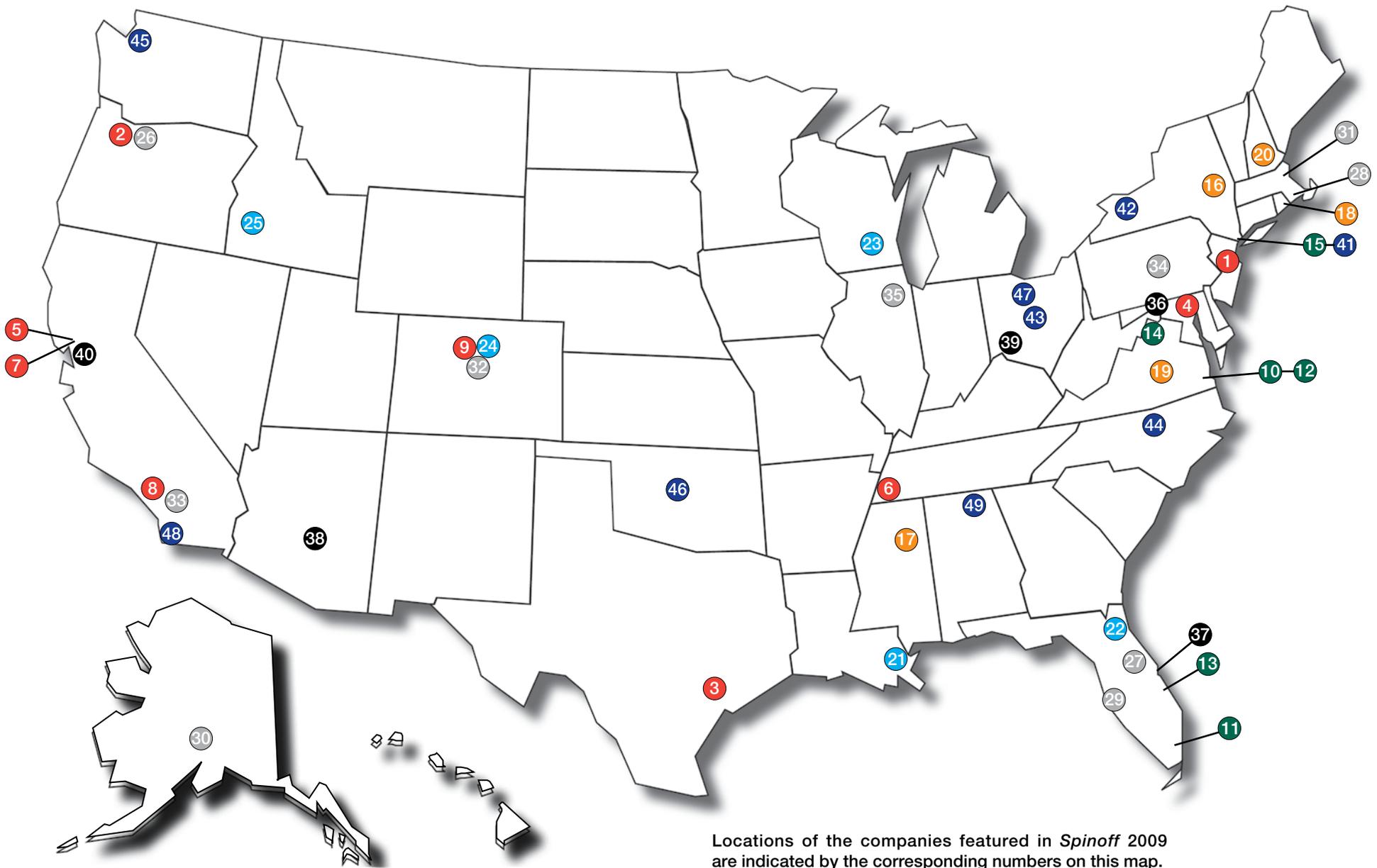
## Computer Technology

- 36 Telemetry Boards Interpret Rocket, Airplane Engine Data (MD)
- 37 Programs Automate Complex Operations Monitoring (FL)
- 38 Software Tools Streamline Project Management (AZ)
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## Industrial Productivity

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- 46 Methods Reduce Cost, Enhance Quality of Nanotubes (OK)
- 47 Gauging Systems Monitor Cryogenic Liquids (OH)
- 48 Voltage Sensors Monitor Harmful Static (CA)
- 49 Compact Instruments Measure Heat Potential (AL)



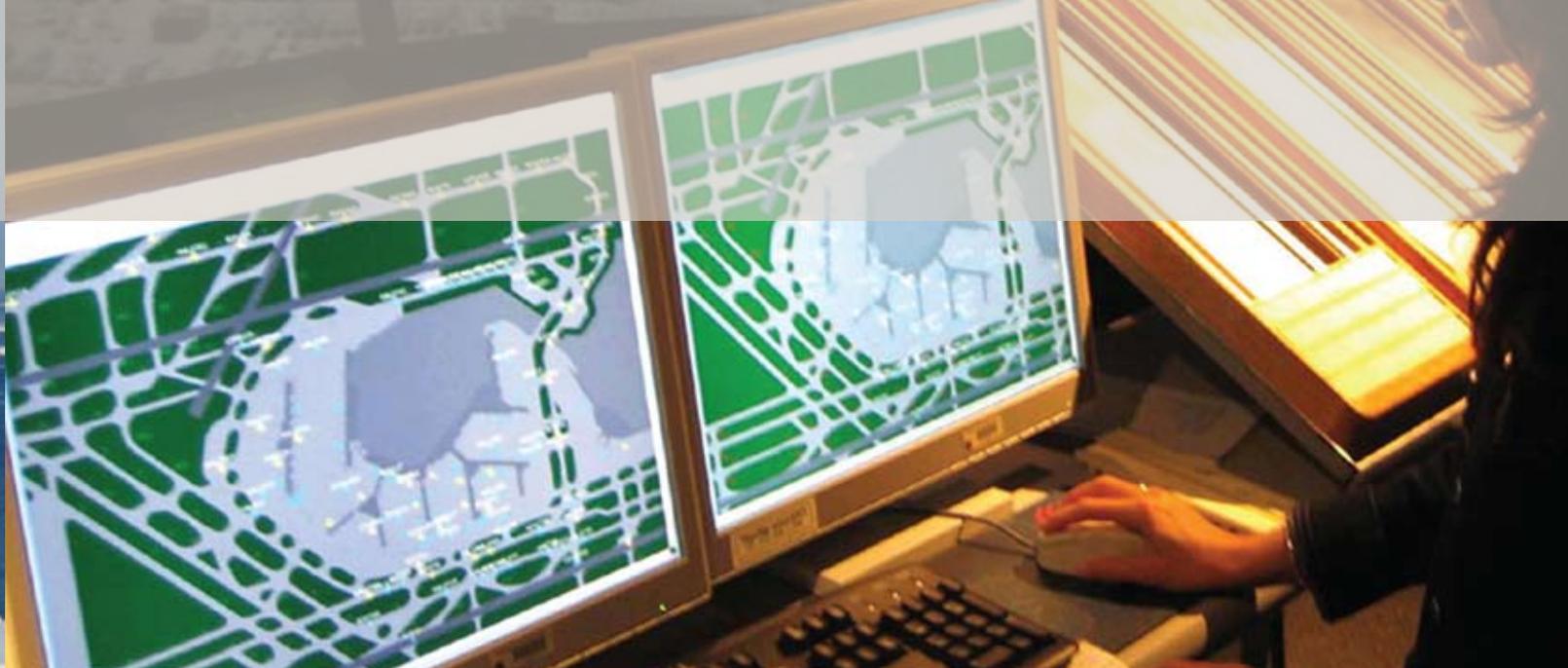
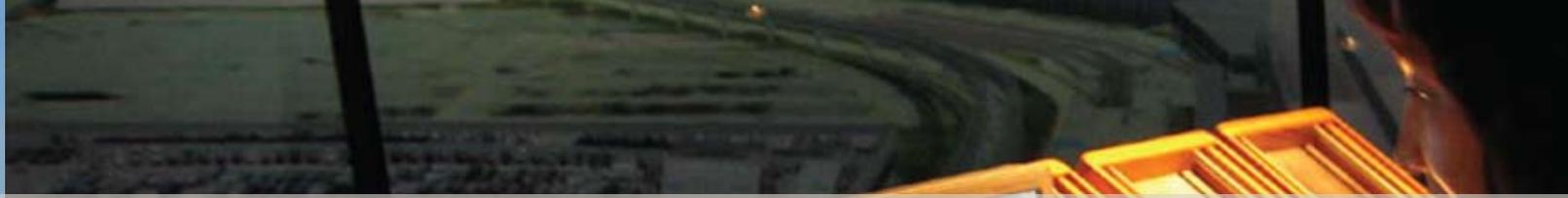
The Nation's investment in NASA's aerospace research has brought practical benefits back to Earth in the form of commercial products and services in the fields of health and medicine; transportation; public safety; consumer, home, and recreation goods; environmental and agricultural resources; computer technology; and industrial productivity. *Spinoff*, NASA's premier annual publication, features these commercialized technologies. Since its inception in 1976, *Spinoff* has profiled NASA-derived products from companies across the Nation. An online archive of all stories from the first issue of *Spinoff* to the latest is available in the *Spinoff* database at [www.sti.nasa.gov/spinoff/database](http://www.sti.nasa.gov/spinoff/database).

Visit the Innovative Partnerships Program at <http://www.ipp.nasa.gov>.

# NASA Technologies Benefiting Society

As part of NASA's mission, the Agency facilitates the transfer and commercialization of NASA-sponsored research and technology. These efforts not only support NASA, they enhance the quality of life in our hospitals, homes, and communities, contributing to the ways that we live. The technologies featured in these stories cover a wide variety of benefits, from management systems that make hospitals more efficient to new methods for the manufacture of carbon nanotubes and from software to build vehicles out of new composite materials to a series of satellite-communicating ocean buoys that help locate marine debris fields. The one thing all of these benefits have in common, though, is that they were enabled by NASA's aerospace research, an investment in the future.





# Health and Medicine



From experiments on the International Space Station to astronaut life support, NASA research results in spinoffs that improve fitness, treat disease, and save lives. The technologies featured in this section:

- Extend Medicine's Reach
- Assess, Treat Balance Disorders
- Advance Disease Treatments
- Provide Nutritional Guidelines
- Speed Rehabilitation
- Revitalize Patient Care
- Optimize Busy Hospital Schedules
- Assess Cognitive Fitness
- Treat Dehydration



# Image-Capture Devices Extend Medicine's Reach

## Originating Technology/NASA Contribution

In spring 2008, Dr. Scott Dulchavsky diagnosed high-altitude pulmonary edema in a climber over 20,000 feet up the slope of Mount Everest. Dulchavsky made the diagnosis from his office in Detroit, half a world away. The story behind this long-distance medical achievement begins with a seemingly unrelated fact: There is no X-ray machine on the International Space Station (ISS).

On the ISS, diagnosing an injury or other medical issue can be problematic; bulky medical imaging devices like X-ray, CAT, or MRI machines are too large and heavy for costly transportation into space. And while crew medical officers receive some diagnostic training, the nearest doctors and fully equipped hospitals are 250 miles away on Earth. Future astronauts on long-term Moon or Mars expeditions will face even greater challenges.

The ISS does have an ultrasound machine—at 168 pounds, much smaller than its imaging technology counterparts—installed as part of the Human Research Facility for experiments on the effects of microgravity on human health. During medical use, the ultrasound machine's hand-held transducer emits high-frequency sound waves that partially reflect at points of differing density, such as between soft tissue and bone. The machine's computer translates the echoes into a two- or

three-dimensional video representation. On Earth, ultrasound is commonly used for imaging fetus development, abdominal conditions like gallstones, and blood flow in patients with arterial disease. Unconventional applications, like diagnosing broken bones or collapsed lungs, were not explored given the ready availability of X-ray and MRI machines in hospitals and the high density differences of bone and air, which completely reflect the ultrasound waves and prevent clear images of deeper tissue.

That changed in 2000, when NASA approached Dulchavsky, chair of the Department of Surgery at Henry Ford Hospital in Detroit, to make ultrasound a more versatile diagnostic technique and to adapt it for remote use on the ISS. Dulchavsky tested new ultrasound applications and found that, in many cases, such as with collapsed lungs, the technique worked better than X-ray imaging. He became lead investigator for the Advanced Diagnostic Ultrasound in Microgravity (ADUM) experiment, a collaborative effort between

Johnson Space Center, Henry Ford Hospital, and Wyle Laboratories Inc. in Houston.

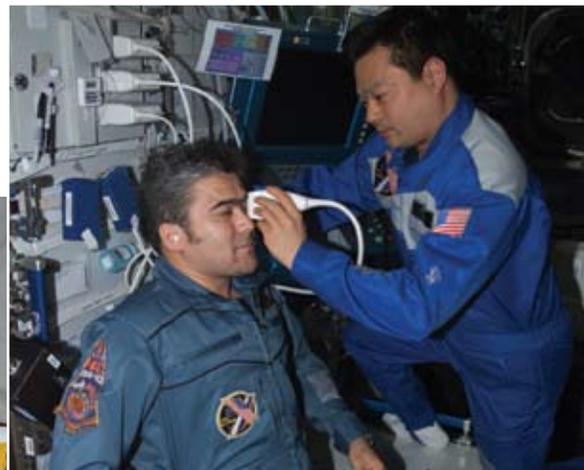
Aided by Onboard Proficiency Enhancer (OPE) software, cue cards, and direct communication with doctors on Earth, ISS crewmembers with only minimal ultrasound training (about 3 hours as opposed to about 500 hours for a professional) used non-traditional ultrasound techniques pioneered by Dulchavsky's team for imaging of a wide range of body parts. These novel ultrasound techniques can evaluate infections in the teeth or sinus cavities or judge the effects of space flight on the central nervous system by measuring changes in the diameter of the eye's optic nerve sheath as a gauge of pressure around the brain. Experts on the ground received diagnostic-quality images from the ISS through satellite downlink, demonstrating the effectiveness of ultrasound as a multipurpose, remote diagnostic tool in space.

## Partnership

In keeping with NASA's mandate to translate space technologies into applications for terrestrial use, Henry Ford Hospital doctors and Wyle engineers worked to find ways to overcome a major obstacle to bringing the ADUM-developed remote ultrasound procedures down to Earth: There were no cost-effective, technologically viable methods for sending ultrasound scans over long distances without a loss of image quality.

"We have a great satellite hookup and a big telemedical network at NASA, but we don't have these for common terrestrial use," says Dulchavsky.

To overcome this problem, they collaborated with Epiphan Systems Inc., a computer-imaging industry leader headquartered in Canada with offices in Springfield, New Jersey. The cooperation resulted in the formation of [Mediphan](#), a remote medical diagnostics technology company. Mediphan drew on NASA expertise to adapt Epiphan's video-streaming innovations into a practical solution.



Remote ultrasound procedures provide for medical diagnoses to areas as far-flung as Mount Everest (left) and the International Space Station (above)—miles from professional medical personnel.

## Product Outcome

Mediphan has developed and commercialized two tools for terrestrial telemedical use.

DistanceDoc, an external video frame grabber, makes use of Epiphan's video graphics array (VGA) capture technology to take diagnostic-quality and Digital Imaging and Communications in Medicine (DICOM) standard stills or video from the ultrasound monitor (or any other medical device with a video display, such as an electrocardiogram or ventilator). It then allows the ultrasound operator to transmit the images securely over the Internet in real time and at near-original resolution. The second tool, MedRecorder, is a similar device that captures diagnostic-quality and DICOM imaging, then stores and archives it for later reference, like an external hard drive.

Each device plugs into the VGA port of any standard ultrasound machine and then connects to a computer by a universal serial bus (USB) 2.0. A non-physician can, with minimal technical know-how, install Mediphan's technology and use it to send medical imaging for consultation with experts. Coupled with the highly portable General Electric LOGIQ laptop ultrasound machine and the NASA-developed OPE instructional software now modified for broader use, even the medically inexperienced can consult with distant doctors to diagnose medical issues when and where they occur.

"Immediacy in point of care is essential," says Dulchavsky. "We can now have non-skilled individuals onsite doing what traditionally only highly skilled individuals are able to do."

The applications of remote ultrasound diagnostic capabilities are widespread and increasing. The major professional sports teams in Detroit are all using the ultrasound procedure, OPE software, and Mediphan devices for immediate locker-room diagnoses of injuries that happen during practice and games. Olympians at the 2006 Winter Olympic Games in Torino, Italy, benefitted from the telemedical procedure, as did athletes



Mediphan's MedRecorder and DistanceDoc devices enable the remote ultrasound techniques developed for space to be employed on Earth. By capturing, transmitting, and storing diagnostic-quality ultrasound imagery and video, the devices allow doctors to diagnose injuries and other conditions while not in the same room, building, or even hemisphere as their patients.

at last year's Summer Olympic Games in Beijing, China. Currently, the procedure is used for day-to-day oversight of Olympians in training facilities across the United States. It also allows trainers to establish baseline evaluations of athletes' body structures, making for easier recognition of damage due to injury. More than 345 musculoskeletal ultrasound examinations have been performed on Olympians and professional athletes so far, a number of these with remote guidance.

The technology is also helping improve education, allowing a medical student on duty to share diagnostic information with an attending doctor elsewhere. The MedRecorder offers medical students the ability to archive personal portfolios documenting proficiency in diagnostic techniques and provides an affordable way to store and maintain records.

Meanwhile, the United Nations Millennium Project, which has among its goals improved maternal care in underserved areas, plans to use the telemedical procedure in developing countries. Dulchavsky and NASA engineers are currently working to create a highly versatile,

environmentally robust device that could serve as a kind of information node connecting patients in remote areas to distant experts via Mediphan technology. Then, Dulchavsky says, "we could utilize the techniques and technologies that we developed for use on the ISS to diagnose a wide variety of medical issues, such as traumatic injury, problematic pregnancies, and certain infectious diseases."

Last year, working at a distance with a NASA team in the Mars-like environment of Devon Island in northern Canada, Dulchavsky performed the first-ever remote guidance of a simulated appendectomy. One day, the same technique may be used to do the real thing in a village in Madagascar, on the slope of Everest, or on Mars itself. ❖

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# Medical Devices Assess, Treat Balance Disorders

## Originating Technology/NASA Contribution

You may have heard the phrase “as difficult as walking and chewing gum” as a joking way of referring to something that is not difficult at all. Just walking, however, is not all that simple—physiologically speaking. Even standing upright is an undertaking requiring the complex cooperation of multiple motor and sensory systems including vision, the inner ear, somatosensation (sensation from the skin), and proprioception (the sense of the body’s parts in relation to each other). The compromised performance of any of these elements can lead to a balance disorder, which in some form affects nearly half of Americans at least once in their lifetimes, from the elderly, to those with neurological or vestibular (inner ear) dysfunction, to athletes with musculoskeletal injuries, to astronauts returning from space.

Readjusting to Earth’s gravity has a significant impact on an astronaut’s ability to balance, a result of the brain

switching to a different “model” for interpreting sensory input in normal gravity versus weightlessness. While acclimating, astronauts can experience headaches, motion sickness, and problems with perception. To help ease the transition and study the effects of weightlessness on the body, NASA has conducted many investigations into post-flight balance control, realizing this research can help treat patients with balance disorders on Earth as well.

In the 1960s, the NASA-sponsored Man Vehicle Laboratory at the Massachusetts Institute of Technology (MIT) studied the effects of prolonged space flight on astronauts. The lab’s work intrigued MIT doctoral candidate Lewis Nashner, who began conducting NASA-funded research on human movement and balance under the supervision of Dr. Larry Young in the MIT Department of Aeronautics and Astronautics. In 1982, Nashner’s work resulted in a noninvasive clinical technique for assessing the cooperative systems that allow the body to balance, commonly referred to as computerized dynamic posturography (CDP). CDP employs a series of dynamic protocols to isolate and assess balance function deficiencies. The technology was based on Nashner’s novel, engineering-inspired concept of balance as an adaptable collaboration between multiple sensory and motor systems. CDP proved useful not only for examining astronauts, but for anyone suffering from balance problems. Today, CDP is the standard medical tool for objectively evaluating balance control.

The effects of space flight on astronauts’ ability to balance has long been a focus of NASA research. This 1964 photo shows a NASA scientist testing astronaut John Glenn’s inner ear balance mechanism by running cool water into his ear and measuring the effect on Glenn’s eye motions.



## Partnership

In 1984, Nashner founded [NeuroCom International Inc.](#), headquartered in Clackamas, Oregon, and continued his research to refine the clinical role of CDP. Within 2 years, the company had developed the EquiTest, the first commercially available CDP device. NASA has employed NeuroCom’s CDP systems for its research and continues to use EquiTest for the routine evaluation and balance rehabilitation of its astronauts at Kennedy Space Center and Johnson Space Center. NeuroCom’s EquiTest and Balance Master systems—the latter created based on CDP concepts to meet increasing demand from physical therapists—were first featured in *Spinoff* 1996.

“When I joined NeuroCom in 1988, the concepts of a systems approach to balance and vestibular rehabilitation were basically unknowns,” says Jon F. Peters, Ph.D., NeuroCom’s vice president and general manager. “Researchers were keen on the ideas, but it wasn’t common practice. Out of Dr. Nashner’s work grew a whole new approach for looking at these problems.”

## Product Outcome

NeuroCom now has over 2,000 systems in use around the world in a variety of medical fields including neurology, geriatrics, otolaryngology (ear, nose, and throat specialists), orthopedics, and sports medicine.

Under the Balance Manager concept, NeuroCom’s products are cast into two broad categories: systems based on either dynamic or fixed force plate technology. NeuroCom’s dynamic models, which include EquiTest, SMART EquiTest, SMART Balance Master, and PRO Balance Master, offer the ability to control the support surface as well as the visual surround. The patient stands on the system’s dynamic force plate, a platform that shifts while recording the vertical forces applied by the feet as the patient attempts to maintain balance. Supported by a safety harness to prevent falls, the patient faces into the booth’s three-sided visual surround, which also tilts to

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test the visual component of the patient's balance mechanisms. The system provides comprehensive reports that identify sensory and motor impairments and allow for comparison to normal data for the patient's age range. The information gathered can be teased apart, says Peters, to help understand where the patient's balance problems lie. The same

system can then be used in a biofeedback mode (a video screen provides visual biofeedback), retraining sensory and motor systems to regain balance control.

NeuroCom's fixed force plate models include the Balance Master and Basic Balance Master systems, which have a physical therapy focus and help identify specific daily performance issues and possible underlying sensory and motor impairments affecting balance. A stroke patient, for example, can be examined using a fixed force plate system to see what movements (getting up from a chair, for example) are contributing most to the patient's difficulty. After therapists identify the problem, they can then use visual biofeedback to help the patient learn new cues to perform tasks more safely.

All of NeuroCom's systems can be enhanced with optional protocols and capabilities. Among these is the *inVision* package, which measures changes in a patient's visual acuity as a function of balance and head motion. The electromyography option analyzes the response of a patient's gastrocnemius and tibialis muscles (both located in the lower leg) to unexpected external balance challenges. The NeuroGames package provides video games like Solitaire and NeuroPong that offer a fun way to rehabilitate balance control. Patients play the games on a Balance Master or SMART EquiTest system by shifting their center of gravity to control the action.

The versatility of the technology is essential; even patients with the same diagnosis, like Parkinson's disease,

can suffer from different balance impairments with different immediate causes. The same applies to the elderly. While about one-third of Americans over 65 experience falls each year according to the National Safety Council, the impairments that lead to these falls vary. The balance analysis and therapy offered by NeuroCom's NASA-developed technology can help reduce the Centers for Disease Control and Prevention's estimate of over \$19 billion spent each year to treat fall-related injuries.

The company continues to push its technology into new clinical realms, says Peters. "Applications have gone well beyond patients with vertigo and dizziness," he notes. The company is exploring the relationship between balance disorders and cognitive issues like learning problems and attention deficit disorder. Peters says NeuroCom looks to sources like NASA as "guideposts for our efforts."

"Because NASA has to deal with the complex problems of flying people in space," he says, "their research tends to be more applied and closer to what we need to take hold of and put into general medical practice." ❖

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Developed from balance assessment research supported with NASA funding, NeuroCom's systems provide a versatile range of balance analysis and therapy options.

# NASA Bioreactors Advance Disease Treatments

## Originating Technology/NASA Contribution

The International Space Station (ISS) is falling. This is no threat to the astronauts onboard, however, because falling is part of the ISS staying in orbit.

The absence of gravity beyond the Earth's atmosphere is actually an illusion; at the ISS's orbital altitude of approximately 250 miles above the surface, the planet's gravitational pull is only 12-percent weaker than on the ground. Gravity is constantly pulling the ISS back to Earth, but the space station is also constantly traveling at nearly 18,000 miles per hour. This means that, even though the ISS is falling toward Earth, it is moving sideways fast enough to continually miss impacting the planet. The balance between the force of gravity and the ISS's motion creates a stable orbit, and the fact that the ISS and everything in it—including the astronauts—are falling at an equal rate creates the condition of weightlessness called microgravity.

The constant falling of objects in orbit is not only an important principle in space, but it is also a key element of a revolutionary NASA technology here on Earth that may soon help cure medical ailments from heart disease to diabetes.

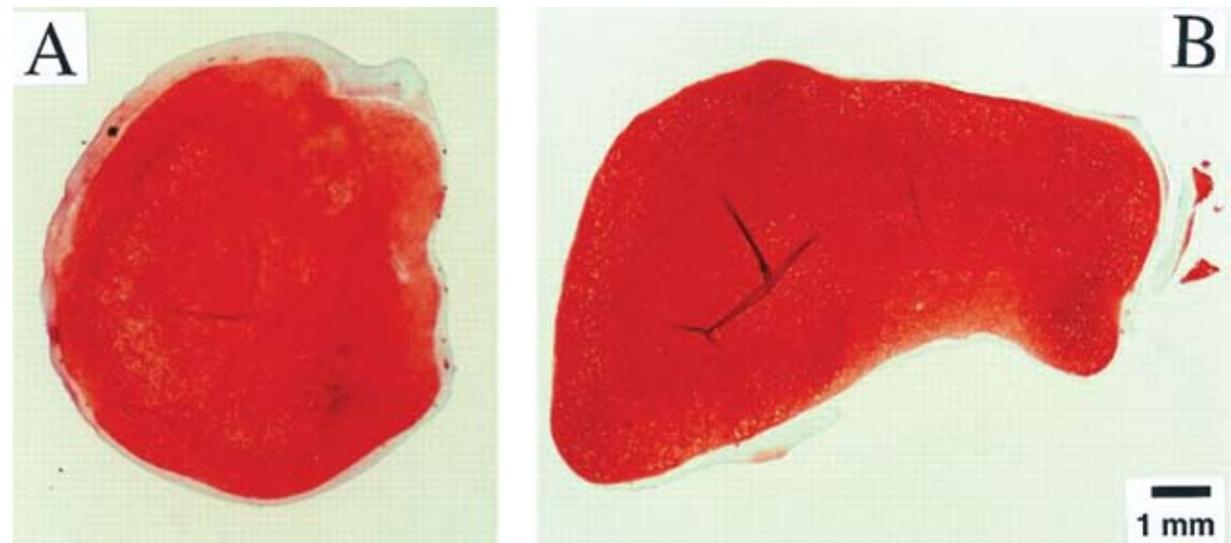
In the mid-1980s, NASA researchers at Johnson Space Center were investigating the effects of long-term microgravity on human tissues. At the time, the Agency's shuttle fleet was grounded following the 1986 Space Shuttle Challenger disaster, and researchers had no access to the microgravity conditions of space. To provide a method for recreating such conditions on Earth, Johnson's David Wolf, Tinh Trinh, and Ray Schwarz developed that same year a horizontal, rotating device—called a rotating wall bioreactor—that allowed the growth of human cells in simulated weightlessness. Previously, cell cultures on Earth could only be grown two-dimensionally in Petri dishes, because gravity would cause the multiplying cells to sink within their growth medium. These cells do not

look or function like real human cells, which grow three-dimensionally in the body. Experiments conducted by Johnson scientist Dr. Thomas Goodwin proved that the NASA bioreactor could successfully cultivate cells using simulated microgravity, resulting in three-dimensional tissues that more closely approximate those in the body. Further experiments conducted on space shuttle missions and by Wolf as an astronaut on the Mir space station demonstrated that the bioreactor's effects were even further expanded in space, resulting in remarkable levels of tissue formation.

While the bioreactor may one day culture red blood cells for injured astronauts or single-celled organisms like algae as food or oxygen producers for a Mars colony, the technology's cell growth capability offers significant opportunities for terrestrial medical research right now. A small Texas company is taking advantage of the NASA technology to advance promising treatment applications for diseases both common and obscure.

## Partnership

In 2002, Houston-based biotechnology firm [Regenotech Inc.](#) (then called BioCell Innovations) acquired the licenses for the NASA bioreactor and a number of related patents for use in the burgeoning field of adult stem cell research. (Unlike ethically controversial embryonic stem cells, adult stem cells are harvested from sources such as blood and bone marrow.) Employing a novel business model that takes advantage of sponsored research agreements with major medical institutions like the University of Texas M.D. Anderson Cancer Center in Houston, Regenotech was able to begin testing and adapting the bioreactor's capabilities for use with human stem cells with a first year budget of only \$100,000. A NASA Space Act Agreement that saw the company share resources with Goodwin at Johnson, as well as additional licensing agreements between the company and the



Cells grown in microgravity (A) tend to become more spherical than those grown on Earth (B). This demonstrates that tissues can grow and differentiate into distinct structures in microgravity. NASA's rotating wall bioreactor simulates weightlessness to mimic this effect on Earth.

Agency, enabled Regentech to further complement the bioreactor with its own proprietary improvements.

## Product Outcome

Regentech has built upon its licensed NASA technology to create a thriving intellectual property business that is providing researchers with the tools to make adult stem cell therapy viable for the public.

Adult stem cells are found in some types of body tissue. These cells are multipotent, meaning they can differentiate into a specific range of specialized cells. This makes them appealing possibilities for treating diseases—the stem cells differentiate into healthy replacements for sick or damaged cells. Blood stem cells, for example, can transform into red blood cells, white blood cells, and platelets; these cells could provide a potential treatment for blood diseases like sickle cell anemia.

One of the richest sources of adult stem cells is bone marrow.

“There are about 70 different conditions and diseases where bone marrow stem cells have been used to regenerate tissue or treat disease,” says Donnie Rudd, Regentech’s chief scientist and director of intellectual property. Stem cells can be harvested from a patient’s bone marrow through a procedure called bone marrow apheresis—a process that like any medical procedure carries some level of risk. The problem with alternative methods of adult stem cell harvest is getting enough of the cells to have therapeutic value, which is where Regentech’s Inrifuge cellXpansion technology comes to bear.

“We can take a sample of peripheral blood from a patient’s arm, separate the stem cells, put that into our improved NASA bioreactor, and then multiply the cells to a therapeutic level without all the trauma of bone marrow apheresis,” says Rudd.

Regentech’s Inrifuge rotating wall bioreactor cradles a soup can-sized, rotating chamber that is used to expand, or multiply, harvested stem cells. The cell sample, con-

tained in a growth fluid, is placed in the rotating chamber equipped with a membrane for oxygenation and gas exchange. As the chamber rotates, the cells are suspended in a constant state of falling—similar to an object in space orbit. This condition is enabled by a rotating inner wall that reduces shear from the nutrient fluid. In this simulated weightlessness, the cells do not get damaged and die from bouncing off the sides of the chamber. They multiply rapidly (50–200 times in size in as few as 6 days) into healthy populations, providing a quicker and cheaper source of stem cells for therapy or medical research. Regentech’s cellXpansion process is being tested for further enhancement by a NASA-developed electromagnetic coil that surrounds the canister and which NASA developed to stimulate nerve cell growth. The coil, also patented by the NASA bioreactor development team and licensed by Regentech, produces time varying electromagnetic conditions.

Regentech started producing revenue only 5 years after its founding, and since acquiring the original NASA licenses, it has developed over 300 of its own patents and

patent applications and has licensed out its technologies on a global scale. The company generates its revenue through research partnerships and licensing its patents to stem cell researchers in pursuit of treatments for everything from heart disease to diabetes to liver cirrhosis. It is currently engaged in sponsored research agreements with major universities to develop stem cell therapy for type 1 diabetes, study blood stem cells, and create stem cell veterinary orthopedic treatments using the company’s Inrifuge cellXpansion technology.

Through an agreement with NASA, Regentech is also able to offer significant help to researchers pursuing treatments of rare diseases that affect less than 200,000 people in the United States and thus do not offer enough return on drug development investment. NASA allows the company to charge as little as \$1,000 to \$10,000 to license its NASA-developed technologies to researchers of such rare diseases.

“Our relationship with NASA has allowed us to get this technology out into the field for those diseases that otherwise might never be treated,” says Rudd. ❖



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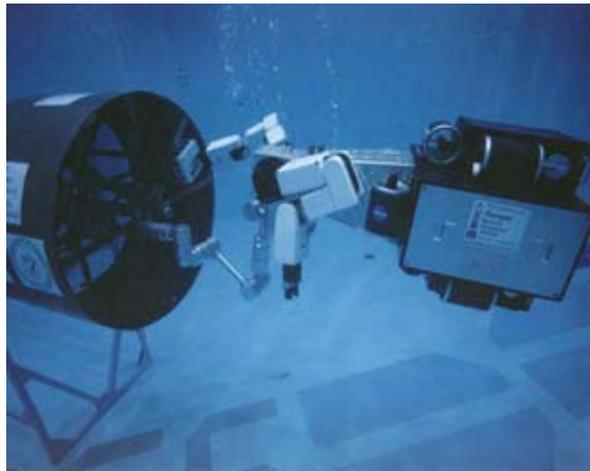
Regentech scientists examine the company’s bioreactors. Licensed from NASA, the bioreactor technology allows for rapid, healthy cell growth, providing for a quicker, cheaper source of adult stem cells for therapy and medical research.

# Robotics Algorithms Provide Nutritional Guidelines

## Originating Technology/NASA Contribution

On July 5, 1997, a small robot emerged from its lander like an insect from an egg, crawling out onto the rocky surface of Mars. About the size of a child's wagon, NASA's Sojourner robot was the first successful rover mission to the Red Planet. For 83 sols (Martian days, typically about 40 minutes longer than Earth days), Sojourner—largely remote controlled by NASA operators on Earth—transmitted photos and data unlike any previously collected.

Sojourner was perhaps the crowning achievement of the NASA Space Telerobotics Program, an Agency initiative designed to push the limits of robotics in space. Telerobotics—devices that merge the autonomy of robotics with the direct human control of teleoperators—was already a part of NASA's efforts; probes like the Viking landers that preceded Sojourner on Mars, for example, were telerobotic applications. The Space Telerobotics Program, a collaboration between Ames Research Center, Johnson Space Center, Jet Propulsion Laboratory (JPL),



Developing NASA's Ranger Neutral Buoyancy Vehicle provided Joe Graves with the robotics experience he used to create the online nutritional program Vitabot.

and multiple universities, focused on developing remote-controlled robotics for three main purposes: on-orbit assembly and servicing, science payload tending, and planetary surface robotics. The overarching goal was to create robots that could be guided to build structures in space, monitor scientific experiments, and, like Sojourner, scout distant planets in advance of human explorers.

While telerobotics remains a significant aspect of NASA's efforts—as evidenced by the currently operating Spirit and Opportunity Mars rovers, the Hubble Space Telescope, and many others—the Space Telerobotics Program was dissolved and redistributed within the Agency the same year as Sojourner's success. The program produced a host of remarkable technologies and surprising inspirations, including one that is changing the way people eat.

## Partnership

The Space Systems Laboratory (SSL), focusing on space robotics, artificial intelligence, and space simulation, was originally founded at Boston's Massachusetts Institute of Technology in 1976. The lab conducted experiments on large-scale space structure assemblies and telerobotics using Marshall Space Flight Center's Neutral Buoyancy Simulator, a water tank used to mimic conditions in space (NASA's neutral buoyancy facility is now located at Johnson). Along with Marshall, SSL spearheaded the 1985 Experimental Assembly of Structures in Extravehicular Activities (EASE) experiment, which studied astronaut proficiency in assembling structures during spacewalks, as well as possible building and maintenance techniques. The success of the EASE experiment boosted interest in telerobotic applications for construction in space. In 1990, SSL moved to the University of Maryland, College Park, where it built a Neutral Buoyancy Research Facility—a 50-foot-diameter, 25-foot-deep water tank—that became the site of one of the Space Telerobotics Program's major projects: the Ranger Telerobotic Flight Experiment.

Funded through what was then the Telerobotics Intercenter Working Group, part of the NASA Headquarters Office of Space Sciences (now the Science Mission Directorate), Ranger was SSL's effort to produce a free-flying robot capable of assisting astronauts with tasks such as structural repairs, assembly, and on-orbit refueling. The lab developed a test robot for underwater operation—the Ranger Neutral Buoyancy Vehicle (NBV).

“Ranger was designed to easily transition from water to space,” says Joe Graves, who as a master's and later PhD candidate served as a lead engineer for Ranger NBV. “The robot was not necessarily designed to replace astronauts. We were trying to determine how a robot could be helpful to human operations.”

Though Ranger NBV is no longer part of an official NASA program, Graves has moved on to a new project, one that leverages the telerobotics experience he developed from the Ranger program to help revolutionize an entirely different field: nutrition.

## Product Outcome

In 2003, Graves founded [Vitabot](#), an online nutrition company headquartered in Beltsville, Maryland, that uses some of the same robotics and computer science concepts that he developed for the Ranger NBV—in this case, to offer a product that helps customers determine and maintain their ideal diet. Graves hit on the idea when he noticed the disconnect between the vast amounts of nutritional data available to the public and how that data is actually used. He noted that the U.S. Department of Agriculture (USDA) offers complete breakdowns of what composes various foods—far beyond what is offered on

*Vitabot has nearly 1,000 company clients and has experienced over 1,500-percent growth in the health club industry.*

food labels—and that the Institute of Medicine, a non-profit division of the National Academies of Science, publishes reports that gather research from around the world to determine nutritional needs.

“On one end, you have the USDA putting out exactly what’s in food, and on the other you have the Institute of Medicine putting out the nutrition you should have,” says Graves. The problem he saw was that the public had no convenient way to make use of this information. “If I could think of one field in which the data and the application of the data are so incredibly removed from each other, it would be nutrition,” he says.

Graves realized this challenge was similar to one he faced with the Ranger NBV. The robot has more than 20 computers controlling different joints, navigation systems, and thrusters, all requiring complex data to manipulate. “We had this enormously intricate system with all these equations to position the arms and all these controllers to manipulate the arm positions, but as the human operator, I don’t want to think about all that,” he says. “I just want to reach out and grab something.” For the Ranger NBV, the solution was to create intelligent software to mediate between the operator and the robotics data. Graves saw the same idea could work for nutrition.

“Vitabot uses the exact same style of algorithms that we developed between the robot and the operator,” says Graves. The result is an easy-to-use online program that allows users to set health goals like desired weight and then plan balanced meals using a food database featuring tens of thousands of choices. Available through corporate wellness programs and health clubs, Vitabot centers around an interactive report card that grades how food choices measure up to users’ nutritional needs in a wide range of categories including calories, fat, electrolytes, minerals, and vitamins. Users can build complete menus of favorite foods that also match their nutritional needs, allowing them to make real, individually tailored use of the previously overwhelming quantities of available nutritional data. Vitabot’s algorithms guide the users’ choices



Vitabot uses robotics algorithms to help users take advantage of vast amounts of detailed nutritional data and develop balanced meal plans.

to help them get complete nutritional balance. The resulting balanced menus are then shared through Vitabot’s Ultimate Mealplan Project, where other users can then modify and improve these menus, guided by Vitabot’s suggestions. “This creates a massive group experiment where individuals, guided by their own personal tastes and the requirements of the Institute of Medicine, are mapping out an enormous space of carefully balanced meal plans,” says Graves.

Though the focus of Vitabot is on balanced nutrition and not weight loss, the latter is often a result of the former, Graves says. The company now counts the likes of HBO and Warner Bros. among its nearly 1,000 company clients and has experienced over 1,500-percent growth in the health club industry in the last year, with major

chains like Gold’s Gym offering Vitabot to its members. Recently, the U.S. Air Force has started using Vitabot at several of its bases.

Graves credits Vitabot’s unusual origins for much of its success; most nutritional planning systems do not come out of a space program, he says.

“It’s a different paradigm that has created a different solution.” ❖

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# ‘Anti-Gravity’ Treadmills Speed Rehabilitation

## Originating Technology/NASA Contribution

On Earth, gravity can cause a lot of stress to a person’s bones and muscles, whether the stress is caused by running a marathon or simply climbing a staircase. However, in space, the lack of gravity can also cause problems for astronauts’ bodies. NASA is seeking ways to combat these problems, and the solutions are finding application here on Earth.

While he was studying the biomechanics of exercise, Ames Research Center scientist Robert Whalen proposed using differential air pressure in space to mimic the Earth’s gravity to prevent bone loss and muscle deterioration. As a National Research Council post-doctoral Fellow at Ames from 1988 to 1989, Whalen helped develop effective exercise regimens for NASA’s astronauts, and when Whalen’s fellowship ended, NASA hired Whalen to a full-time research position.

In his research, Whalen developed the hypothesis that musculoskeletal maintenance in space requires Earth-equivalent functional loading (or weighting), which is loading bones and muscles with activities and force levels in space similar to daily activity on Earth. In space, most bone loss and muscle atrophy occur in the lower body. Whalen explains, “On Earth, our most significant musculoskeletal loading particularly of the lower body occurs during normal upright activities, such as standing, walking, and stepping off a curb.” These various activities impart different levels of musculoskeletal loading, which keep our leg muscles able to support our weight.

Astronauts do not have these types of functional activities in space and must replace them with treadmill exercise using a loading harness to hold the astronaut in place on the treadmill. However, the treadmill loading harness is uncomfortable and prevents astronauts from exercising normally and with the same intensity as on Earth. Whalen suggested using air pressure as an effective way of applying a high force, equal to body weight, to astronauts during treadmill exercise to replace the harness system.

## Partnership

After patenting his gravity differential technology in 1992, Whalen licensed his patent in 2005 to a private company to help rehabilitate patients needing support as they learned (or re-learned) to stand, walk, and run. Based in Menlo Park, California, [Alter-G Inc.](#) adapted the technology for athletic and medical uses here on Earth in the



In space, in order to prevent bone loss and muscle atrophy, astronauts exercise on treadmills equipped with a loading harness.

form of a specialized treadmill called the G-Trainer. This rehabilitation device applies air pressure to a patient’s lower body in order to unload weight, which reduces the stress placed on the lower body during rehabilitation.

Whalen explains the G-Trainer evolved directly from his original idea of using air pressure for the opposite effect—to add weight to an astronaut’s body during treadmill exercise in the low gravity of space. A variety of patients—whether suffering from brain injury, neurological disorders, athletic injuries, or other stresses on the joints such as arthritis or morbid obesity—now use the NASA-derived technology in physical therapy.

## Product Outcome

Lars Barfod, Alter-G’s president and CEO, says that rehabilitation clinics are a major market for the G-Trainer, and he notes that the G-Trainer has been a successful option in military hospitals for orthopedic and neurological uses, including helping patients rehabilitate after traumatic brain injury to transition from ambulatory assistive devices to independent movement. Someone who is recovering from a brain injury can re-learn proper balance and gait while getting as much physical support from the G-Trainer as needed.

According to Barfod, another market for the G-Trainer is professional athletic teams and athletic departments at universities, which use the G-Trainer to help athletes recover from stress injuries. Many teams in the National Basketball Association (NBA), the National Football League (NFL), and the National Collegiate Athletic Association (NCAA) have G-Trainers.

Whatever the cause of an injury, rehabilitation can be painful, and patients often alter their gait, stride length, or body position to over-compensate for the pain. The G-Trainer reduces the effect of gravity and weight, which makes it more comfortable for a patient to focus on a normal, correct gait instead of worrying about more injury and pain. This allows patients to develop good habits and condition their muscles while their bodies are still



After the patient's lower body is sealed in an airtight enclosure, the system performs a calibration, adjusting to the person's size and weight. If a patient desires more unloading—more weightlessness—a button is simply pressed on a touch screen, and the air pressure increases, lifting the body, reducing strain, and further minimizing impact on the legs.

healing. The G-Trainer is comfortable like water training, but offers more realistic support of the lower limbs in their free-swing phase, allowing the legs to swing more normally than they would in water. Precision is another advantage the G-Trainer offers over water rehabilitation.

The ability to change the amount of patient support precisely and incrementally is a major advantage the G-Trainer offers over other rehabilitation devices and methods, such as harness systems and water training. Like an ordinary treadmill, the G-Trainer stores information and allows for incremental adjustments to the workout,

such as increasing incline or speed. It also allows for incremental adjustment to the air pressure, which controls the amount of weight lifted from the patient. Depending on what users specify, the air pressure system can reduce body weight in 1-percent increments—useful to fine-tune treatment with improvement—to as much as an 80-percent reduction, for instance, for a patient who weighs 160 pounds but can only support 32 pounds of weight.

The comfort of the G-Trainer is an improvement over harness systems, Barfod explains, because the support

remains constant, even when the system is supporting a high percentage of weight or a patient weighing several hundred pounds. Conversely, harness systems chafe and can become uncomfortable quickly, especially if a patient is obese or needs a larger percentage of weight lifted. In a harness system, there is typically no reliable, precise method to change or record the amount of weight on a weak or injured limb and no digital readout to keep patient and trainer informed.

In order for the G-Trainer to control air pressure effectively, users first have to don specifically designed shorts, which attach to a waist-level enclosure. This enclosure—in essence a large airtight bag that surrounds the patient's lower body and the running platform—attaches to the treadmill system. After the patient's lower body is sealed in the enclosure, the system performs a calibration, adjusting to the person's size and weight. Then, the patient chooses a running speed, incline amount, and decides what percent weight should be removed. If a patient desires more unloading—more weightlessness—a button is simply pressed on a touch screen, and the air pressure increases, lifting the body, reducing strain, and further minimizing impact on the legs.

After the U.S. Food and Drug Administration (FDA) cleared the G-Trainer for medical use in January 2008, studies at major hospitals and universities began to assess G-Trainer's effectiveness for patients with cardiovascular complications, lower-limb arthritis, ankle fractures, and mobility issues associated with Parkinson's disease. Alter-G is also considering developing the G-Trainer for other patients, including children with cerebral palsy or other disorders that interfere with the ability to walk.

Meanwhile, the company is working hard on making the product more affordable. "By doing that, we think the G-Trainer will become a standard of care in rehabilitation," Barfod says. ♦

G-Trainer™ is a trademark of Alter-G Inc.

# Crew Management Processes Revitalize Patient Care

## Originating Technology/NASA Contribution

In January 2009, birds struck the engines of US Airways Flight 1549 and forced an emergency landing into the Hudson River. Everyone on board survived, and the crew was lauded for remaining calm under pressure and keeping passengers safe. The pilot, Captain Chesley Sullenberger, is a former U.S. Air Force pilot, trained in Crew (or cockpit) Resource Management (CRM) which originated at NASA in 1979. Even before



Astronauts and pilots receive line oriented flight training (LOFT) in simulators, such as the one shown here. LOFT prepares crews for both routine and hazardous situations through highly realistic simulations.

they knew they had an emergency, the crew was using specific training for safe and effective operations: all parts of key NASA CRM methods required by US Airways since 1995.

In June 1979, John Lauber in the Aviation Safety Research office at Ames Research Center chaired a workshop that presented formal studies and discussions on human error in aviation. The workshop, *Resource Management on the Flight Deck*, presented research from over a dozen commercial and military pilots, university researchers, as well as Ames employee Hugh Patrick “H.P.” Ruffell Smith, whose data showed human error was the primary cause of aviation accidents.

Lauber and Ruffell Smith suggested that these human errors were caused by failures on a variety of levels: interpersonal communications, inadequate leadership, failure to prioritize and delegate, preoccupations with minor mechanical problems, and lack of situational awareness, which is the ability to recognize warning signs and anticipate potential danger. Another problem the researchers discovered was a failure to use available resources, including maps, navigation equipment, or others’ expertise.

Initially referred to as simply Resource Management, the proposed solutions evolved into CRM, a series of management techniques geared at reducing human error and improving safety through effective coordination of all resources. These skills, which can be improved through mock situations and simulations, include effective teamwork, meaningful communication, task coordination through checklists, and situational awareness.

In order to keep workflows predictable and as error-free as possible, CRM advocates using simple checklists to coordinate both tasks and communications among crewmembers. Without clear, predictable steps, disasters have occurred when captains assumed co-pilots had handled a seemingly minor problem, such as a malfunctioning light on an instrument panel. With CRM, crewmembers are taught to make no assumptions, but to follow printed

checklists, communicate clearly, and maintain constant awareness.

In CRM, everyone learns to articulate a discrepancy between what is happening and what should be happening—a moment in which one’s training in situational awareness becomes critical. Untrained operators may not notice this discrepancy, or may ignore it, which can lead to a serious situation, mistake, or fatality. CRM techniques include clearly expressing concerns and problems, after which everyone commits to a solution. While this may sound like common sense, the 1979 research showed that subordinates regularly hesitated to correct their supervisors out of a traditional—but sometimes dangerous—respect for authority.

Ruffell Smith also suggested a CRM-related program now known as Line Oriented Flight Training (LOFT), in which crews fly complete, realistic missions in simulators. In debriefings after the simulations, crew and instructors discuss, in detail, what areas need more training.

The Federal Aviation Administration (FAA), the military, several commercial airlines, and of course NASA, use NASA’s CRM and LOFT to prepare flight crews—like that of US Airways Flight 1549—for both routine and hazardous situations.

## Partnership

Cardiologist Drew Gaffney flew as a payload specialist in 1991 on STS-40, the first Spacelab mission dedicated to biomedical studies. On the mission, he worked with fellow physician and astronaut Rhea Seddon. Seddon became an astronaut in August 1979 and ultimately spent 722 hours in space, acting as a mission specialist on STS-51D (1985) and STS-40, and then as payload commander on STS-58 (1993). NASA prepared Seddon and Gaffney for both routine and emergency situations in their missions through extensive CRM skill training and LOFT simulations. In 2005, Seddon and Gaffney collaborated with two former FedEx Corporation CRM trainers and U.S. Navy top gun pilots, Steve Harden and

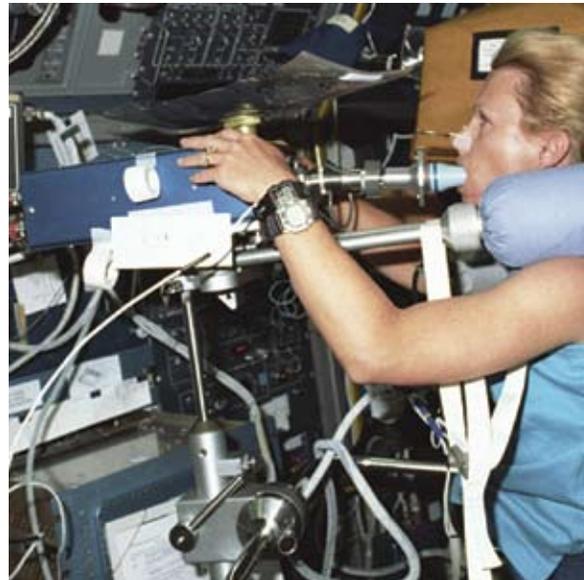
Alan Mullen, to found [LifeWings Partners LLC](#), based in Memphis. The LifeWings founders had realized the medical industry was a natural fit for NASA's CRM and could benefit from techniques that helped crews function in stressful, fast-paced environments.

## Product Outcome

Situational awareness, peer monitoring, simulation training, and procedural checklists have long been a part of NASA's astronaut training, and the LifeWings partners discovered the need for these same tools in medicine. In medicine like with space missions, Gaffney explains, "There was a lot of routine, but a lot of stress. Decisions were high-consequence." As a result, LifeWings designed an approach to help hospitals use the same cockpit training and tools that had been so useful in making commercial aviation safe and reliable. LifeWings provides customized, in-depth CRM training to health care teams, which begins with onsite evaluations and focus groups, progresses with customized realistic simulations and extensive training in CRM techniques, and concludes with team assessments and interviews.

One skill that LifeWings stresses in its training is situational awareness. Doctors, nurses, and other hospital staff learn to notice subtle changes in their surroundings and to check in regularly with teammates. Gaffney explains that the LifeWings CRM training helps "create a culture that is psychologically and administratively safe," so that any employee can spot and report potential hazards without fear. Everyone shares responsibility for patient safety, and having team accountability works far more effectively than individual accountability alone.

This ongoing peer monitoring helps eliminate costly (and sometimes dangerous) medical mistakes, such as duplicating the administration of a drug, because everyone is aware of what a teammate is (or is not) doing. Gaffney says, "Because of their CRM training, if there is any confusion, everyone is expected to speak up and raise a concern," intervening with clearly stated questions



Rhea Seddon became an astronaut in August 1979 and ultimately spent 722 hours in space, acting as a mission specialist on STS-51D (1985) and STS-40 (1991), and then as payload commander on STS-58 (1993). In this image, Seddon performs cardiovascular experiments as part of the biomedical studies on STS-40's Spacelab mission.

or observations. Using good CRM, another teammate or the team leader acknowledges the question and responds; the added information and teamwork protect the patient from avoidable errors. Eventually, this cycle becomes routine and part of the culture, resulting in significant reduction in medical errors.

LifeWings uses simulations to evaluate new clients and see how their health care teams respond to different stressful situations, such as staff or room shortages, procedural bottlenecks, and various patient emergencies. These simulations help LifeWings identify focus areas for training or re-training, enabling the company to improve efficiency in both emergencies and routine procedures, such as getting a patient's results from a hospital laboratory or reducing waiting times. Health care teams, like astronaut

crews, benefit from rehearsing responses to realistic situations, and after being trained in CRM, the crews are better able to follow proper procedures, regardless of the situation.

Research published in January 2009 in *The New England Journal of Medicine* describes how doctors using a simple checklist before surgery were able to reduce post-surgical deaths by more than 36 percent. According to LifeWings president Steve Harden, when hospitals follow the LifeWings CRM training, they have seen major improvements, such as in risk-adjusted patient mortality. Harden explains, "We've seen decreases from 1.2 to 0.68," in observed to expected deaths, indicating an almost 50-percent improvement.

Focus group interviews performed by LifeWings indicated medical staff felt, after CRM training, they had better teamwork, less waste, greater efficiency, and better overall patient outcomes. The LifeWings data showed 51-percent improvement in operating room turnaround, 40-percent decrease in post-operative infections, and vast improvements in team members' willingness to speak out about possible problems and advocate for patient safety. Hospital administrators also note that the LifeWings CRM training seems to improve employee satisfaction, reduce patient stays and time in routine procedures, and reduce employee turnover.

In its first operating year of 2005, LifeWings had sales of close to \$500,000. Since 2007, sales have remained close to \$3 million, despite a struggling U.S. economy. Since 2005, LifeWings has brought its CRM training to over 90 health care organizations. ❖

LifeWings<sup>SM</sup> is a service mark of LifeWings Partners LLC.

***LifeWings has brought its CRM training to over 90 health care organizations.***

# Hubble Systems Optimize Busy Hospital Schedules

## Originating Technology/NASA Contribution

Beginning in 1985, a team of engineers at the Space Telescope Science Institute in Baltimore began developing software to manage various time-consuming tasks for the Hubble Space Telescope, launched in 1990. In the early phases of development, the complexity of scheduling different tasks became clear when the engineers realized Hubble's power restrictions.

When it first became operational, Hubble functioned under a variety of scheduling restraints. For example, in order to conserve energy, it could have only two scientific instruments operating at one time. This was further complicated by the length of time it took to move the instruments into position. Changing Hubble's orientation to a new target, or slewing, was a slow process, moving only 90 degrees per hour. Likewise, the instruments themselves could take up to 24 hours to shift from standby to operative modes. Further complicating the schedule was the fact that certain tasks only operated during specific times, needing protection from (or exposure to) direct sunlight, or requiring specific angles, locations, or other conditions.

In order to compensate for these scheduling constraints, Hubble's software team designed a knowledge-based system that worked around these scheduling conflicts using a variety of methods, such as backward and forward chaining—"If X is a near-infrared spectrometer, then X operates only when facing away from the Sun"—logical arguments used to design computer systems and software.

## Partnership

One of the team members who worked on Hubble, NASA computer scientist Don Rosenthal, helped develop the scheduling system, refining the algorithms in the programming and consequently increasing the telescope's efficiency. After working on Hubble, Rosenthal acquired intellectual property rights to the scheduling technology.

He then ran the artificial intelligence application group at Ames Research Center, where he developed programming for the Mars Exploration Rovers, the Pioneer spacecraft, and a system for human space flight.



A team of engineers at the Space Telescope Science Institute developed software to manage time-consuming tasks for the Hubble Space Telescope, launched in 1990 and shown here during its last servicing mission in May 2009. The scheduling technology is now used in software that helps hospitals reclaim unused capacity.

Rosenthal went on to co-found Menlo Park, California's [Allocade Inc.](#) in 2004, and is now chief technical officer of the company and chair of the board of directors. Using Rosenthal's experience with Hubble's software, Allocade created its On-Cue software suite, which optimizes ever-changing hospital schedules.

## Product Outcome

On-Cue is a software solution that enables hospitals to reclaim their unused capacity. The system helps hospital departments handle dynamic rescheduling issues by allocating resources and managing disruptions in real time for inpatient and outpatient imaging procedures. In the past, staff made these time-consuming adjustments through numerous phone calls, whiteboards, handwritten notes, and faxes, which caused delays and frustration for both patients and staff.

By automating the rescheduling process, Allocade helps hospitals manage frequent changes more efficiently, which can reduce operating costs and wait times. The emergency, transport, and radiology departments have immediate access to the latest schedules, and the system alerts staff to pending tasks with instant messages and other visual cues. When there is an unexpected flood of emergency procedures, for instance, the system can reallocate staff and resources, telling a transport member to keep a scheduled patient comfortable in her room until later, and freeing up transport for unexpected emergent cases.

In order to reschedule radiology procedures, On-Cue pulls data from and synchronizes with a facility's radiology information, picture archiving, and communication systems. It can then direct patient data to the best resource, automatically rescheduling procedures and having information readily available for use and analysis. The system displays live updates on monitors in high-traffic areas, which allows staff to track patient status and procedures quickly. On-Cue, which is compatible with standard personal computers and existing intranets, also provides

the ability to balance loads between different machines, and makes specific recommendations when rescheduling, taking into consideration various department and hospital policies and constraints. As a result, hospitals can manage staff and patient flow far more efficiently, which increases satisfaction and profit.

Allocade offers the On-Cue system in three modules: the On-Cue Navigator Optimization Engine, On-Cue Communicator, and On-Cue Aviator Workstation Software Client. As the core technology in the On-Cue solution, Navigator is the optimizer that adjusts to new schedules as needs arise. Communicator, meanwhile, is in charge of collecting and displaying information to clinical areas and updating displays in real time, enabling staff to make decisions on patient care efficiently. Aviator tracks all resources, connecting information from the other two modules in a snapshot view. Allocade can also adjust the On-Cue system to specific workflow preferences and can pull data from existing feeds.

One of the first customers for Allocade's system was the California Pacific Medical Center (CPMC) in San Francisco. Prior to adopting the On-Cue software, CPMC had 2 weeks of backlog in its computerized tomography (CT) department. Schedules changed constantly, and staff began to realize that traditional tracking methods simply wasted too much time. The radiology department was thrown into chaos when the inevitable emergency procedures would take precedence over scheduled procedures, and other departments had no way of efficiently tracking changes to their patients' visits to radiology.

CPMC adopted the On-Cue software for beta testing in 2006. The medical center soon reported noticeable improvements to efficiency, including a 12-percent increase in procedure volume, 35-percent reduction in staff overtime, and significant reductions in backlog and technician phone time. Allocade began shipping the full commercial version of On-Cue for CT departments in January 2008, and now offers versions for both outpatient and inpatient magnetic resonance imaging (MRI),



Image courtesy of Allocade Inc.

ultrasound, interventional radiology, nuclear medicine, positron emission tomography (PET), radiography, radiography-fluoroscopy, and mammography. Customers can buy the software for just a few departments or as a software suite for an entire radiology department.

In 2009, Pennsylvania's Harrisburg Hospital became the first medical center on the East Coast to adopt On-Cue. ❖

On-Cue™ is a trademark of Allocade Inc.

On-Cue helps hospital departments handle dynamic rescheduling issues by allocating resources and managing disruptions in real time for inpatient and outpatient imaging procedures. By automating the rescheduling process, the software can reduce operating costs and wait times.

# Web-Based Programs Assess Cognitive Fitness

## Originating Technology/NASA Contribution

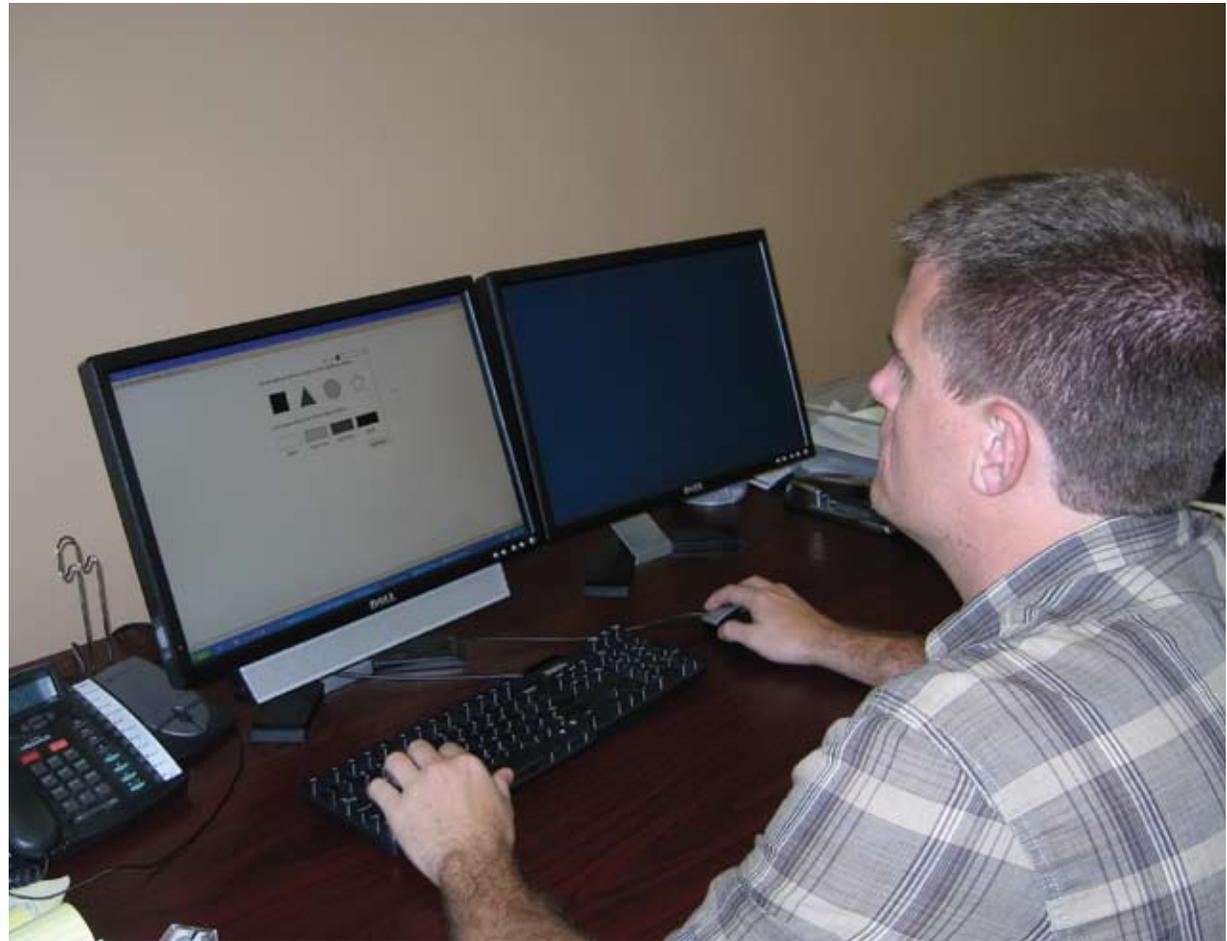
Astronauts, pilots, air traffic controllers, truck drivers, shift workers, and mountain climbers have something in common: All are at risk for impaired cognitive abilities due to stress or sleep deprivation. Whether in space or on Earth, stress and sleep loss can cause a reduction in certain cognitive abilities, such as working memory, reaction time, and problem solving. Because mission safety and success depend on being able to think clearly and function well, NASA began exploring a small, portable way for astronauts to monitor themselves and their cognitive fitness while in space, especially on future missions to Mars that will require extended periods in stressful environments.

## Partnership

The National Space Biomedical Research Institute (NSBRI), based in Houston and funded by NASA, leads a science and technology program to develop solutions to the health-related problems and physical and psychological challenges men and women face on long-duration space flights. The research results and medical technologies developed often have impact for conditions experienced on Earth.

In 2001, the NSBRI began funding research by Harvard University researcher, Dr. Stephen Kosslyn, now dean of social sciences, and research assistant, Jennifer Shephard. The project included the development of cognitive task scripting and administration software for personal digital assistants (PDAs) and an accompanying set of portable cognitive fitness tests, the MiniCog Rapid Assessment Battery (MRAB).

The test battery, which Kosslyn refers to as “a blood-pressure cuff for the mind,” assesses nine different cognitive functions and is intended to gauge the effects of stress-related deficits, such as fatigue, on astronauts as well as professionals on Earth. The original hand-held MRAB enabled someone to test his or her own alertness quickly



The MiniCog Rapid Assessment Battery (MRAB) measures the ability to sustain attention and vigilance, as well as the ability to divide one's attention. A test subject's aptitude in these areas correlates with fitness to perform attention-demanding tasks.

and easily; depending on the assessment, users might realize they should take a nap or drink coffee instead of proceeding with any sort of risky or complex activity. In 2003 and 2004, in collaboration with the NSBRI, Mount Everest climbers self-administered the MRAB on Palm PDAs to test themselves for cognitive deficits in the oxygen-poor higher altitudes.

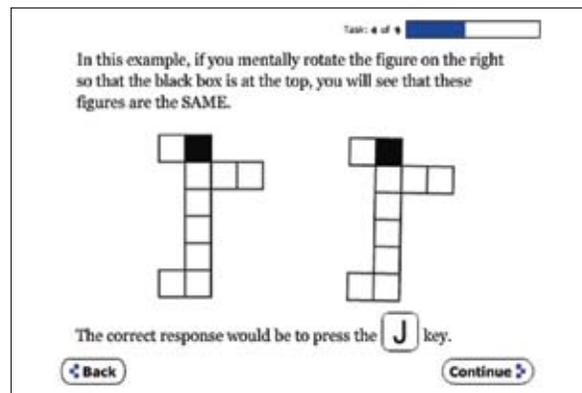
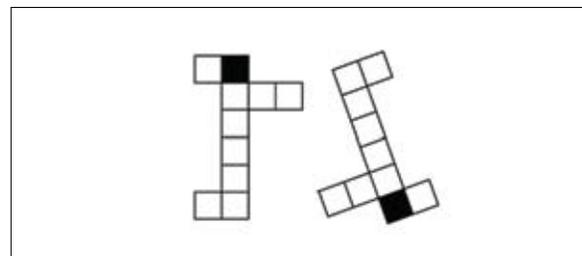
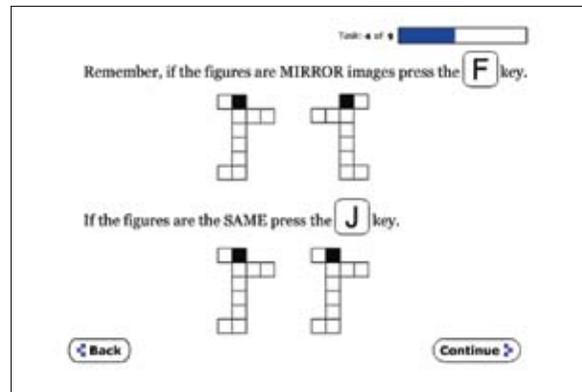
Harvard owns the software copyright, and a patent is pending. Although NSBRI funding ended for the MRAB in 2007, a California company now is using the battery in Web-based employment tests. In 2005, Drs. Josh Millet, Eric Loken, and David Sherman founded [Criteria Corporation](#), based in Los Angeles. Now the company's chief research scientist, Loken knew of Kosslyn's research

from his own experiences at Harvard and recommended the MRAB to Millet, a fellow Harvard graduate and Criteria's CEO. After hearing about the MRAB, Criteria decided to license it from Harvard and adapted a Web-based version of it for delivery in 2006.

## Product Outcome

Criteria offers subscription-based employment testing, and the MRAB is included in the company's HireSelect subscription service along with about 15 other tests. The MRAB can be used not only for pre-employment testing but also for repeated administrations to measure day-to-day fluctuations of mental functioning. Unlike other aptitude tests, such as traditional college assessment exams, the MRAB focuses less on verbal skills and more on working memory, concentration, and problem-solving; testing involves tasks such as recognizing patterns within time limits and reacting accurately to information while attention is divided.

The MRAB consists of nine short Web-based exercises that measure a person's information-processing functions. It takes about 25 minutes to complete, and users are instructed that final scores will be based on both speed and accuracy. Subtests measure the subject's ability to focus while ignoring irrelevant information: Users are required, for instance, to rapidly indicate the number of digits in "6666" by pressing "4" rather than "6," the numeral that is actually repeating. Other subtests measure working memory, functioning similarly to the game Concentration, quizzing the user on where or when a numeral appeared on the screen. Mental rotation, the ability to identify whether shapes are flipped versus merely rotated, is a problem-solving skill that MRAB tests, as is verbal reasoning, assessed by asking users whether a series of statements are logically connected. Perceptual reaction time is a subtest that requires a user to press keys corresponding to red-flashing numerals as quickly as possible. The MRAB also measures the ability to sustain attention



The MRAB consists of nine short Web-based exercises that measure a person's information-processing functions. Subtests measure the subject's ability to focus while ignoring irrelevant information. The tests also measure working memory, mental rotation, verbal reasoning, and perceptual reaction time.

and vigilance, as well as the converse ability to divide one's attention.

A test subject's aptitude in these areas correlates, Millet says, with fitness to perform attention-demanding tasks. "The MRAB is based on neuroscientific research that focuses on understanding the brain as an information processing unit. Because the MRAB measures mental fitness, attention, and concentration, it's gotten significant traction in the transportation and logistics industries as a tool to help select drivers," he says. It can also be used after a candidate is hired; truck drivers or pilots can self-test their alertness before beginning long trips. Millet, however, sees the potential for wider applicability in other industries: "For example, things like divided attention, focus, and concentration would be very helpful in someone who is screening bags and doing surveillance at the airport."

Although Kosslyn and the Harvard team have no current plans for pursuing additional development of the MRAB, Millet says Criteria probably will investigate additional applications for the software with Kosslyn's advice on product direction and development as a member of the company's scientific advisory board. "We certainly have a number of validity studies in progress to explore new applications of the MRAB, specifically with respect to job performance," Millet says. ❖

Palm® is a registered trademark of Palm Inc.

HireSelect® is a registered trademark of Criteria Corporation.

# Electrolyte Concentrates Treat Dehydration

## Originating Technology/NASA Contribution

For astronauts returning to Earth, adjusting to full gravity can be just as demanding as any of the challenges they faced in space. While readjusting to Earth's gravitational pull, astronauts can experience difficulties moving and balancing, headaches, nausea, and even fainting spells.

While the exact reasons for this latter effect are still unknown, the tendency for astronauts to experience orthostatic intolerance—dizziness, lightheadedness,

and fainting among other symptoms—arises from the effects of microgravity on the body's circulatory and balance systems. On Earth, gravity pulls the body's blood and other fluids toward the feet, creating higher blood pressure in the feet than in the brain or around the heart. In space, however, the lack of gravity results in greater than normal amounts of fluid shifting to the upper body and head. One outcome is that the body mistakenly thinks there are excess fluids that need eliminating; as a result, astronaut blood plasma levels can decrease by about 12 percent in space, and their total body water drops

2–3 percent. (Under normal conditions, about two-thirds of the body's water is contained inside cells, while the rest is found outside of cells; much of this latter amount is blood plasma.) Astronauts thus return to Earth in a state of dehydration and low blood volume—one possible factor leading to the orthostatic intolerance that troubles as many as 80 percent of astronauts following long-term space missions.

To help address this concern, astronauts traditionally tried to rehydrate before and after landing by taking salt tablets with water. (Sodium helps regulate extracellular fluid volume.) This method, though, proved inconvenient and unpleasant for the astronauts, as well as impractical in space where water supplies are limited. The high levels of sodium in the tablets could even lead to greater dehydration if not managed carefully.

After years of extensive Agency research and testing, Ames Research Center physiologist Dr. John Greenleaf developed and patented a better alternative: an electrolyte concentrate composed of a specific ratio of sodium chloride and sodium citrate. The isotonic formula, containing optimal proportions of water and salts for absorption into the body, provides for fast, easy, and effective rehydration in amounts practical for use in space. Astronauts currently use the patented formula on missions.

“We developed this product to perform optimally under the most extreme conditions. The health of our highly trained astronauts was paramount,” says Greenleaf, now retired from NASA. “With all that Americans and the Government have invested in the Space Program and our astronauts, this is one clear way to protect and maximize that investment.” The value of Greenleaf's electrolyte formula is not limited to countering the effects of microgravity, however. Thanks to a NASA partnership, he says, the public will now benefit from this research.

## Partnership

In early 2009, Boulder, Colorado-based [Wellness Brands Inc.](#) exclusively licensed the concentrated elec-



Vigorous exercise while in space is one measure astronauts can take, along with hydration efforts, to help mitigate difficulties adjusting to Earth's gravity upon return from long-term missions.

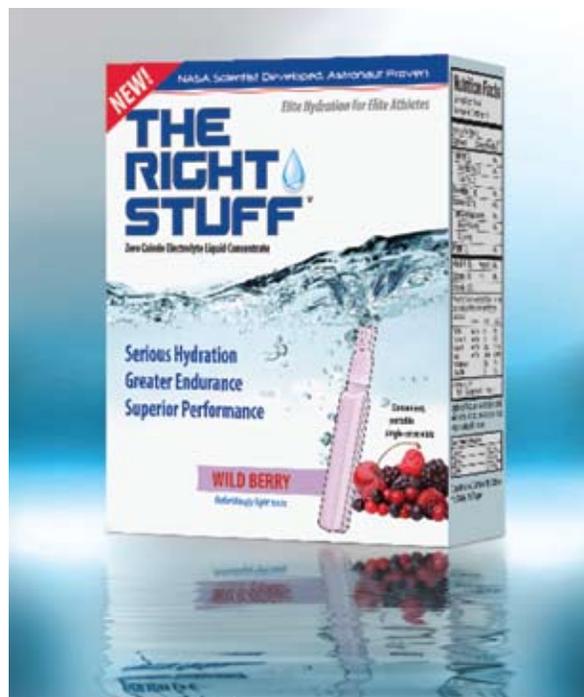
trolyte formula from Ames. David Belaga, the company's president and CEO with more than 15 years of experience in licensing and technology transfer, built the startup Wellness Brands around the NASA innovation after discovering the licensing opportunity while researching the Agency's patent databases. The electrolyte formula fit Belaga's interest in a NASA technology with consumer market applications, and his familiarity with the endurance athletes attracted to Colorado's high-altitude conditions for training made the partnership an "immediately intriguing opportunity."

"As is typical, NASA put their scientists on developing a superior technology, in this case to relieve and prevent the ravages of dehydration," Belaga says. "NASA spent about 15 years working through various combinations to get to the optimal formula."

## Product Outcome

That formula is now available to the public as the liquid electrolyte concentrate called The Right Stuff. Packaged in single-serving, 16.5 milliliter recyclable plastic vials, the Wellness Brands concentrate contains the original sodium chloride and sodium citrate blend, along with a small amount of sucralose sweetener and citric acid to counter the saltiness of the electrolytes. Available in citrus blend, wild berry, or unflavored varieties, The Right Stuff is added to water or any training beverage to significantly enhance rehydration.

The effectiveness of The Right Stuff is backed by extensive NASA testing, says Belaga. "Every human has receptors throughout the body, both intracellular and extracellular, that ensure the balance of hydration in the body," he explains. Whether you are an astronaut returning to Earth, an Olympian, or in training for your first marathon, human physiology and its needs and challenges remain the same, he says. Dehydration can cause tiredness, headaches, muscle cramps, decreased blood pressure, dizziness, and fainting. Severe dehydration can lead to delirium, unconsciousness, and even death. Athletes



A NASA-developed and tested electrolyte concentrate formula, The Right Stuff has been demonstrated to boost athlete endurance.

training for long periods or in hot conditions must constantly resupply the water they lose through sweating and breathing, and Belaga notes that rigorous NASA testing has shown that the electrolyte formula of The Right Stuff is ideal for meeting this need.

"NASA scientists compared this formula to water, to carbohydrate-based sports drinks, to hybrid drinks with extra sugars and glycogens, and this product beat them all," Belaga says. The researchers determined that the quantities of carbohydrates found in most common sports drinks may actually impede the body's ability to absorb the rehydrating electrolytes. The Right Stuff contains no carbohydrates, caffeine, or sugar, and Belaga cites one study that demonstrated the product not only effectively

rehydrated users, but it also led to a 20-percent increase in endurance.

"More endurance means superior performance," Belaga says.

Wellness Brands is in discussions with college and professional sports teams and will start stocking specialty sporting goods retailers with The Right Stuff this year. The company is targeting elite athletes and endurance sport enthusiasts as its initial consumers, but notes that its NASA-developed formula is the "right stuff" for everyone.

"Since it works so well for astronauts, imagine what it will do for elite athletes," says Belaga. "If it works for the elite athletes, imagine what it could do for the average person."

Not only athletes will benefit from the electrolyte formula. Under the exclusive NASA license, Wellness Brands plans to expand with other products for situations when proper hydration is critical. Dehydration, for example, is a problem for airline passengers on long-distance flights during which water is lost in the dry air of the pressurized airplane cabins. Dehydration is also a factor in jet lag and altitude sickness, and can be a deadly outcome of various diseases that cause diarrhea and vomiting, such as cholera, and conditions like heat stroke.

The formula's NASA origins position The Right Stuff to make an immediate market impact and start providing its benefits to the public, says Belaga.

"It's a great asset to have this technology come out of NASA," he says. "Its credibility with the American populace is almost incalculable." ❖

The Right Stuff™ is a trademark of Wellness Brands Inc.

# Transportation



NASA engineering prowess and advances in new materials affect the way we get around, whether in the form of quieter, more fuel-efficient aircraft or in the behind-the-scenes operations of airports. The technologies featured in this section:

- Lighten Designs, Maintain Structural Integrity
- Save Money, Increase Safety
- Resist Extreme Temperatures
- Locate Radio Interference
- Improve Airport Efficiency
- Advance Aerospace Manufacturing





# Tools Lighten Designs, Maintain Structural Integrity

## Originating Technology/NASA Contribution

While working on designs for a new high-speed aircraft, a group of software engineers at NASA's Langley Research Center developed a program that helps create lighter weight vehicles, while still maintaining strength and structural integrity. Part of the National Aerospace Plane project, the software was necessary to allow designers to easily experiment with new materials and structures, trying a variety of different options for building what would have been the world's fastest aircraft, the X-30—capable of taking off from an airport in Washington, DC, accelerating to over 20 times the speed of sound, and landing in Tokyo in under 2 hours.

In an aircraft like the X-30, what President Ronald Reagan said could potentially be the next "Orient Express," the benefits realized by weight reduction become critical, while the demands placed on the vehicle's structure are greatly magnified. Weight reduction translates directly into fuel savings, increased payload, and greater flight range, but that kind of speed places an incredible strain on an aircraft.

Named "ST-SIZE" and developed over the course of several years from 1988 to 1995, the software NASA developed for solving this issue allowed for weight reduction through optimizing use of composite materials—helping designers quickly and easily experiment with the full range of effects that individual parts composed of varied and nontraditional materials would have on the vehicle.

## Partnership

While the Agency had long been known for bringing its cutting-edge technologies to the public sector in the forms of commercial spinoffs, it was not until 1996 that NASA had ever licensed software to a private company. In that year, the National Aerospace Plane project came to an end, unrealized, but with many technologies ready

to be applied to new missions and additional aerospace research. It was then that Langley's Craig Collier licensed the ST-SIZE software he had helped develop for the X-30 and struck out on his own to bring the software to the broader market.

As Collier explains, the company founders knew "NASA would again need the capabilities, but in a commercially robust software package, so it made sense to step up the development for the purpose of making it better so that customers like NASA would want to use it."

The company he formed, [Collier Research Corporation](#), of Hampton, Virginia, wrote a more capable and robust code based on the ST-SIZE software and now markets it under the name HyperSizer. It has been used in everything from designing next-generation cargo containers, to airframes, rocket engines, ship hulls, and train bodies. Most recently, it was adopted by Bombardier Inc. for design and analysis of the new all-composite Learjet 85. With over 300 companies, projects, and divisions using the software and sales topping \$4 million a year, the small software startup has been expanding rapidly in recent years.

As Collier originally intended, the technology has also taken a spin back into NASA, where it is now being used to analyze designs for NASA's newest space vehicles. "In the beginning," Collier says, "it was a scenario where we were taking NASA technology and applying it to industry, but we have been able to work with industry to understand new details and issues and then take these lessons learned from industry and build capabilities. NASA now benefits from these newfound capabilities in designing hardware and making components."

After years of modifications and updates through applying the software to work on high profile projects with Langley, Marshall Space Flight Center, Glenn Research Center, Ames Research Center, Lockheed Martin Corporation, Boeing, Gulfstream, Scaled Composites, Goodrich, Bombardier, and the Air Force Research Laboratory, the company received several

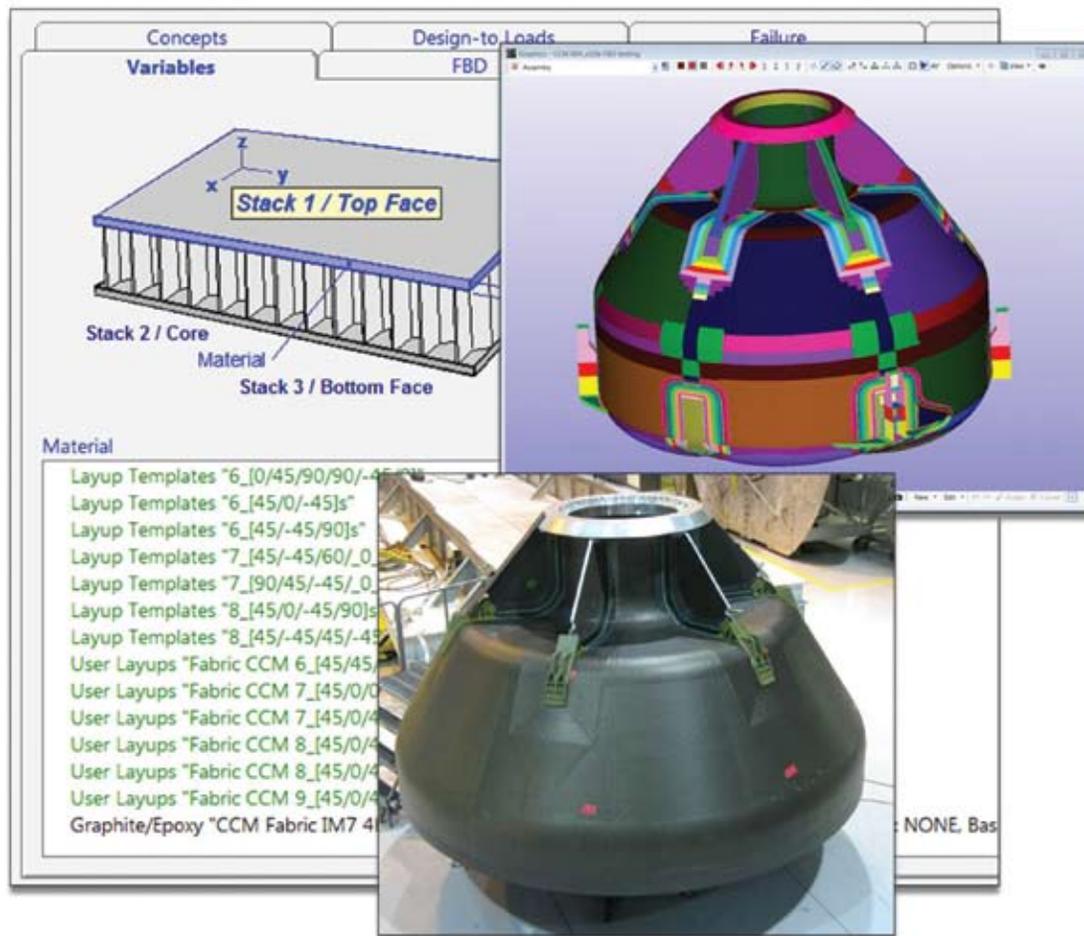
**Small Business Innovation Research (SBIR)** contracts to apply HyperSizer to nearly all aspects of the new Orion crew exploration vehicle design. The company is now also fundamentally involved in the development of both the Ares I and Ares V launch vehicles.

Collier cites the NASA-licensed technology as helping the company gain audience with new customers, but says that it is really the continued partnership with the Space Agency that has kept the company competitive. "Just the association has gotten the foot in the door," he explains, "but that only goes so far. The other thing is to be able to demonstrate that it is good technology and to do that we have continued to stay in step with NASA's technology. It keeps us on the cutting edge."

## Product Outcome

The company has added features to the program, making it more user-friendly and adaptable to different projects. Now, aerospace industry designers and airframe stress analysts use HyperSizer for examining the structural integrity of new designs using both traditional metallic materials, such as aluminum and steel, and more advanced materials, such as composite laminates.

HyperSizer software is not another computer-aided design or finite element analysis (FEA) program. It is an integration of aerospace structural design best practices with modern structural vehicle analysis software. The program integrates with the user's current design software, allowing analyses of new configurations for weight, potential buckling of panels, crippling of posts, the durability of joints, and overall composite strength, including damage tolerance and temperature variables. Rather than being a new program, it is a complementary analysis software suite divided into three distinct products that share and build upon the same database. The three products, HyperSizer Material Manager, HyperSizer Basic, and HyperSizer Pro are available as a suite or can be used individually. One feature they all share, though,



is that the software blends seamlessly with standard design software and uses a familiar Windows interface.

The use of a Windows platform was one of the first risks the company took in developing HyperSizer. In the 1990s, when this product was first being developed, most design software was Unix-based and ran on very expensive workstations. Company founders made the early decision to write and code for the Windows platform, gambling

correctly that the future was in the personal computing platform and widespread acceptance of Windows within the engineering community. Another gamble was investing in developing composite material technology early on, and that decision was similarly validated by the increasing acceptance of composite materials within the aerospace industry and the growing need for the NASA-derived software suite.

HyperSizer is being used to help design the new Orion crew exploration vehicle composite crew module.

The simplest of the three products, HyperSizer Material Manager, eases the design process by offering an easy-to-use materials database with interactive graphics depicting different metals, foams, honeycomb structures, ply tapes, and fabrics. The software allows users to create composite laminates from these various materials using standard Windows copy and paste functions. The software will then analyze the materials and structures using a variety of composite failure theories, as well as preliminary analysis for stiffness, thermal behavior, and structural strength. The software also creates graphs for display of variables with temperature dependencies, failure envelopes, and stress/strain profiles.

HyperSizer Basic includes all of the features and capabilities of the Material Manager, but adds additional analysis for 50 different panel and beam concepts, as well as the ability to analyze other combinations of materials and structures. HyperSizer Pro includes all the features of HyperSizer Basic, but adds full vehicle design analysis. It works with FEA programs for system-level analysis and automatic finite element model resizing, and it generates stress report results for documenting complete vehicle structural design details.

The software continues to mature, and its capabilities grow. When it was first developed at NASA, it was primarily employed for lightweight designs but was not considered a final design tool. It is now being used for final designs on larger projects. Companies are using HyperSizer to gain certification for flight readiness with the Federal Aviation Administration. Customers, including NASA, are placing a lot of trust in the answers it generates. ❖

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# Insulating Foams Save Money, Increase Safety

## Originating Technology/NASA Contribution

Researchers at the Advanced Materials and Processing Branch at Langley Research Center created a superior polyimide foam as insulation for reusable cryogenic propellant tanks on the space shuttle. At the time, the foam insulation on the tanks had a limited lifetime: one launch, which did not suit NASA's need for reusable launch systems.

The foam on the shuttle's external tanks needed to insulate the super-cooled liquid propellant, preventing ice from forming on the tanks and surrounding areas and posing catastrophic risk from debris during launch. The insulation also needed to be able to withstand the high temperatures that the tanks would experience during ignition and launch. The researchers named their new foam TEEK.

A partnership with a small business in Florida improved the chemical structure of the NASA-developed foam, leading to a new product, FPF-44 with commercial applications in the boat-building business, as well as further applications within the Space Program. The partnership also earned NASA scientists, Roberto J. Cano, Brian J. Jensen, and Erik S. Weiser, as well as their industry counterpart, Juan Miguel Vazquez, the coveted designation of "NASA Commercial Invention of the Year."

## Partnership

A small Hialeah, Florida-based business, [PolyuMAC Inc.](#), was looking for advanced foams to use in the customized manufacturing of acoustical and thermal insulation. PolyuMAC is a state-of-the-art manufacturer of foams for use in the marine industry. One of the company's customers had requested newer, advanced materials for use on U.S. Navy ships. The goal, then, was to find an advanced, insulating material—lighter weight, manufacturable in-house, easy to work with, increased insulating capabilities, and affordable. The hunt was on for better foam.

During this search, Juan Miguel Vazquez, new product development lead as well as founder and president of PolyuMAC, came across information about the TEEK foam developed at Langley. Vazquez read about TEEK and contacted Langley for samples and technical data sheets.

He reviewed the materials and began his own testing, investigating the foam's properties. He determined, however, that TEEK was not the right density for his needed applications, and furthermore, producing the material in the large quantities he needed would have been cost-prohibitive. Rather than dismiss the endeavor altogether, though, he contacted the inventors and asked for help tweaking the TEEK chemistry to bring it more in line with his company's needs. They agreed, and he licensed the foam from NASA to begin the modifications. After multiple visits between the company's laboratory and the NASA field center, the researchers had made the foam lighter in weight and cheaper to produce. They named this new generation of foam FPF-44, and the patent is now held by the three Langley scientists and Vazquez. NASA tested FPF-44 at the White Sands Test Facility, a rocket test site in the dunes of New Mexico operated by the Johnson Space Center. There, scientists simulated launch facility conditions to test for ice mitigation on the liquid oxygen feedline on the space shuttle's external fuel tank. The specific goal was to prove that FPF-44 was a viable option for addressing a chief safety concern—a gap between the liquid oxygen feedline and the external tank support brackets, which is exposed to cryogenic temperatures, allowing moisture to collect on the oxygen tank and turn to ice. During tanking, de-tanking, and launch, the feedline articulates, opening and closing the small gap. The insulation needed to be flexible to allow for the articulation of the exposed metal parts to prevent ice from forming. The Langley-PolyuMAC team thermal-formed the foam into the exact shape needed for that gap, with added flexibility to keep it in place and prevent damage when the feedline moved. The success of this test makes it



Engineers at Langley Research Center developed insulating foam for the space shuttle's external fuel tanks.

a candidate for future shuttle applications and insulation on next-generation space vehicles. The NASA-PolyuMAC team is continuing to collaborate on the foam, trying to further reduce density while maintaining its insulating properties. Future applications could include the next generation of commercial aircraft. Commercial aircraft, which currently use fiberglass as an acoustic sound absorber, could perhaps benefit from the next-generation foam, since it has improved handle-ability while providing the same—if not improved—insulating qualities. The test will be if the scientists can lower the density of the foam enough to make it a compelling alternative and if they can develop manufacturing processes capable of accommodating the scale and quantity necessary to infiltrate the large commercial aircraft industry.

## Product Outcome

Commercial production of the joint NASA-PolyuMAC foam began in summer 2007, with the company marketing the foam under the trade name Polyshield. The commercialized version offers the same qualities as the NASA next-generation, high performance, flexible polyimide foam, and shows promise for use on watercraft, aircraft, spacecraft, electronics and electrical products, automobiles and automotive products, recreation equipment, and building and construction materials.

Consumers appreciate its flame retardant qualities, thermal insulation and acoustic insulation factors, and the weight reduction it provides, but the chief advantage Polyshield has over the TEEK foam is that it is roughly one-fifth the cost to manufacture. The durable polyimide

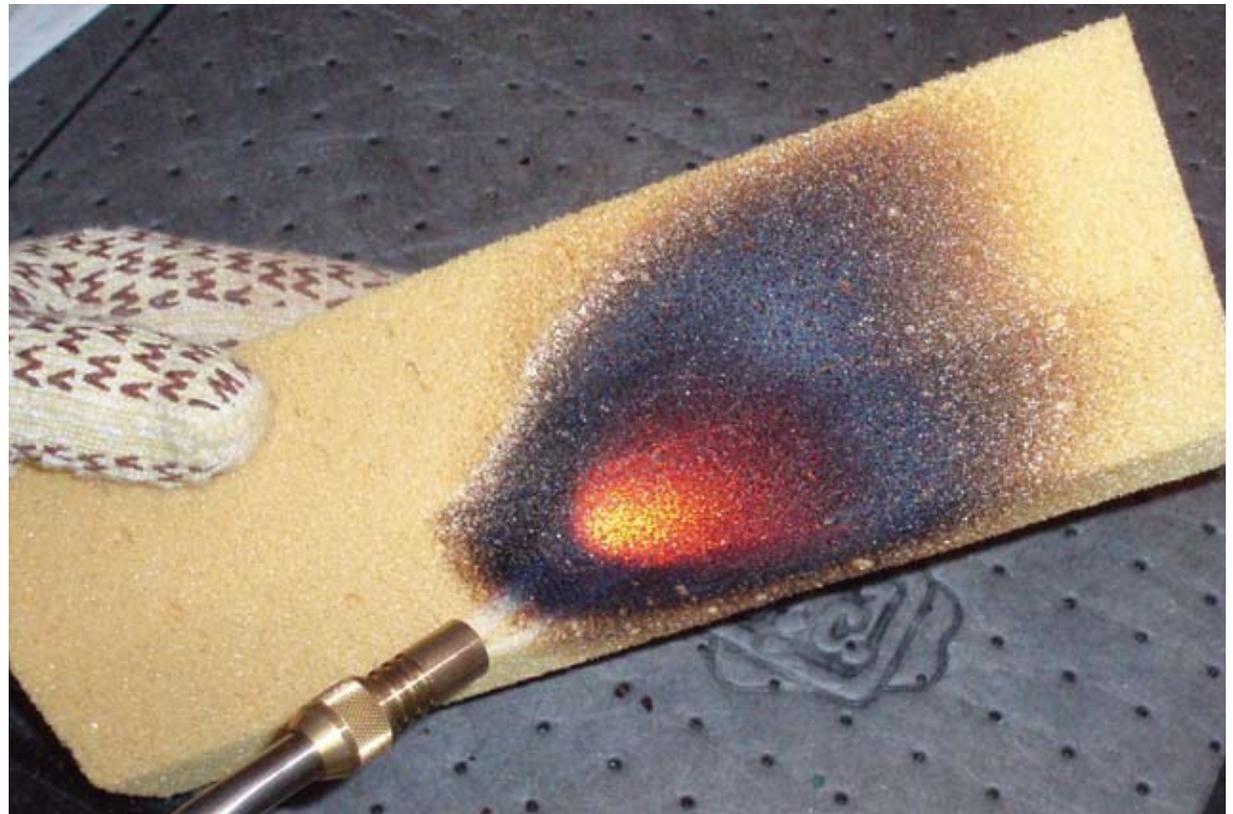


foam is formed at room temperature and then cured using large microwaves, which reduces costs and increases the company's production rates. The finished product can be flexible or rigid, structural or non-structural, and is always highly durable. This affordable insulating foam can also be applied to gaskets and seals, vibration damping pads, spacers in adhesives and sealants, extenders, and flow-leveling aids.

The products provide excellent insulation for sound, cryogenics, and heat, and can be used for fire protection. In fact, one of the chief advantages of this material is that, while it holds at very high temperatures, if it does

burn, it will not produce smoke or harmful byproducts, a critical concern on boats, submarines, airplanes, and other contained environments.

While the company has the capacity to thermal-form the material into any shape required by clients, it typically provides sheets of the foam to customers, who then cut and shape it as needed for their specific applications. The user can then cover it with various cloths. PolyuMAC will, on demand, make specially fitted shapes, and densities can be tailored according to the intended use. ❖



The commercial Polyshield foam is flexible, flame-retardant, and provides excellent thermal and acoustical insulating properties.

# Polyimide Resins Resist Extreme Temperatures

## Originating Technology/NASA Contribution

Spacecraft and aerospace engines share a common threat: high temperature. The temperatures experienced during atmospheric reentry can reach over 2,000 °F, and the temperatures in rocket engines can reach well over 5,000 °F.

To combat the high temperatures in aerospace applications, Dr. Ruth Pater of Langley Research Center developed RP-46, a polyimide resin capable of withstanding the most brutal temperatures. The composite material can push the service temperature to the limits of organic materials.

Designed as an environmentally friendly alternative to other high-temperature resins, the RP-46 polyimide resin system was awarded a 1992 “R&D 100” award, named a “2001 NASA Technology of the Year,” and later, due to its success as a spinoff technology, “2004 NASA Commercial Invention of the Year.” The technology’s

commercial success also led to its winning the Langley’s “Paul F. Holloway Technology Transfer Award” as well as “Richard T. Whitcom Aerospace Technology Transfer Award” both for 2004. RP-46 is relatively inexpensive and it can be readily processed for use as an adhesive, composite, resin molding, coating, foam, or film. Its composite materials can be used in temperatures ranging from minus 150 °F to 2,300 °F. No other organic materials are known to be capable of such wide range and extreme high-temperature applications.

In addition to answering the call for environmentally conscious high-temperature materials, RP-46 provides a slew of additional advantages: It is extremely lightweight (less than half the weight of aluminum), chemical and moisture resistant, strong, and flexible.

Pater also developed a similar technology, RP-50, using many of the same methods she used with RP-46, and very similar in composition to RP-46 in terms of its thermal capacity and chemical construction, but it has different

applications, as this material is a coating as opposed to a buildable composite.

A NASA license for use of this material outside of the Space Agency as well as additional government-funded testing proved that RP-46 is even more exceptional than originally thought.

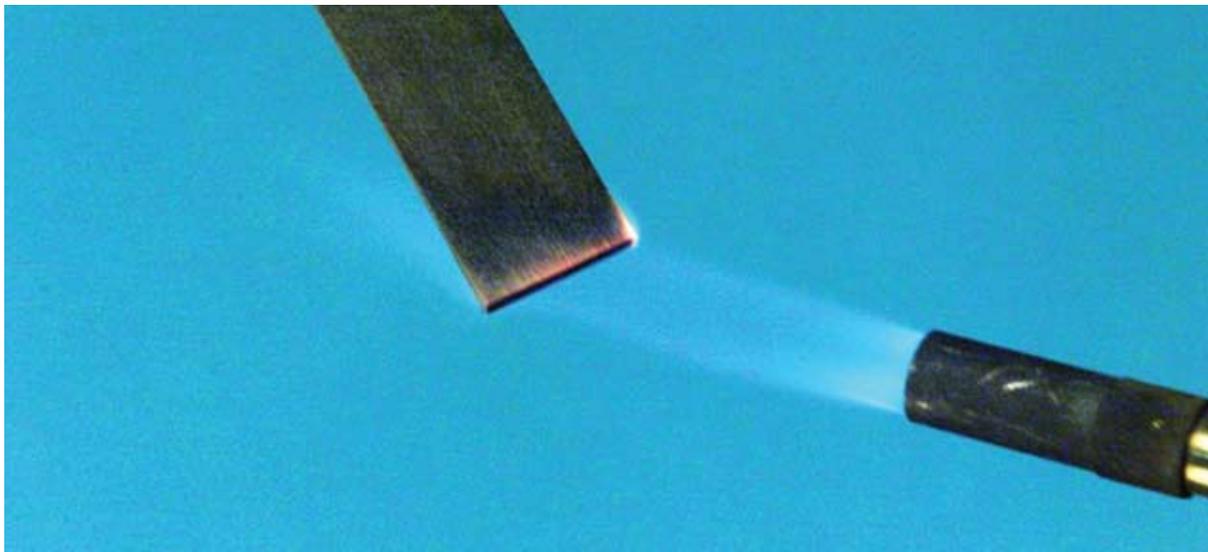
## Partnership

Unitech LLC, of Hampton, Virginia, is an advanced materials solutions provider specializing in advanced materials technology, engineering, manufacturing, research and development, and prototyping services. In 2001, Unitech received a nonexclusive license from NASA for commercialization of the cost-effective, weight- and space-saving high-temperature material RP-46 and the RP-50 coating.

Using the NASA-developed technology, Unitech applied for a **Small Business Innovation Research (SBIR)** contract with the U.S. Navy to develop insulation for an all-electric ship that was under consideration. One of the considerations the Navy had was the need for an extremely fire-resistant material. While initial NASA testing had proven that RP-46 could withstand temperatures in the range of 700 °F, the Navy was looking for a material that could withstand anywhere from 8,000 to 250,000 volts of electricity. Under this Navy SBIR, independent testing showed that RP-46 could withstand temperatures up to 2,300 °F. This discovery made it ideal for use in the original Navy application, but also opened up the possibility that the material could be used in future applications, like in high-voltage insulation for high-rise buildings, where great amounts of power run long distances.

## Product Outcome

Unitech now commercially manufactures RP-46, the high-temperature polyimide resin matrix system, and RP-50, the high-temperature polyimide coating. In addition to the host of technical specifications that make



Dr. Ruth Pater of Langley Research Center developed RP-46, a polyimide resin capable of withstanding the high temperatures of aerospace applications.



The temperatures in rocket engines can reach well over 5,000 °F.

RP-46 an incredible invention, one of the key features that makes RP-46 so appealing commercially is its versatility; the polyimide can be used as a molding, adhesive, coating, composite matrix resin, foam, or film. It is available as a liquid for prepreg of carbon, glass, or quartz fabric; or as a powder for compression molding. Although specifically designed for the Space Program, industry uses abound.

The traditional use of RP-46 is to impregnate fibers (such as glass, carbon, Kevlar, etc.) with the resin to produce rolls of fabric that can then be cut and shaped. These pieces, which are then heat and pressure cured, can be used in a traditional lay-up to make a structural part. Users employ this method for creating any number of pieces, primarily for use in high-temperature aerospace applications. It can serve as a composite material for thermal skins on aircraft and spacecraft and sees many uses in aerospace engines and exhaust duct systems, where the material is prized for its light weight, durability, and temperature resistance. Similar applications include the high-speed motor sports industry, where the company has already seen interest from NASCAR, Formula One, and motorcycle racing groups.

Parts built from RP-46 are also finding use in rocket nose cones, where in addition to the light weight and temperature resistance, the dielectric, insulating properties are prized. Rocket nose cones often experience a great deal of heat while also carrying sensitive electronics. The nose cone of a missile, for example, may contain that weapon's guidance system, so RP-46 would be able to provide the temperature resistance as well as be able to butt against the electronics without risk.

RP-46 can also be used as a molding material. In this application, rather than using the prepregged fabrics, a customer would receive a powder form of the resin and then, depending on the intended use, employ various additives and fillers to create the desired composition. The material comes heated and staged but not completely cured. Once the customer mixes the powder, it is then compression-molded into the specific part. So far, one of the most common uses of this method has been to create bearings for high-temperature industry uses. Another application is in creating grinding wheels. The wheels use RP-46 to bond industrial diamonds in place for grinding extremely hard materials. Grinding wheels made from this material last longer and work longer at higher temperatures.



Unitech LLC received a license from NASA for commercialization of the cost-effective, weight- and space-saving high-temperature material.

RP-50 is a coating material that shares many of the same qualities as RP-46, but would not be used for structural applications or making parts. Uses include high-temperature electrical insulation and flexible circuitry, where its electrical and thermal insulating properties are well-suited. ❖

Kevlar® is a registered trademark of E. I. du Pont de Nemours and Company.

# Sensors Locate Radio Interference

## Originating Technology/NASA Contribution

While many air travelers are accustomed to rules against electronic devices during takeoff and landing, they might not be aware that these devices are banned because they can cause electromagnetic interference (EMI) with navigation equipment. Because similar problems can occur near launch sites for space missions, NASA began investigating technologies for tracking this interference in order to protect sensitive mission instrumentation. This electronic encroachment is partly due to a myriad of modern communication devices in the marketplace, but unfortunately could also be due to

intentional and malicious transmissions. Uninterrupted communication between range activities, mission control, and the flight deck is critical to human safety and mission security, so NASA worked with a company that develops custom communication systems to design a system for locating sources of radio interference.

## Partnership

In 2005, Kennedy Space Center awarded a Phase I **Small Business Innovation Research (SBIR)** contract to Soneticom Inc., in West Melbourne, Florida. Recognizing the inability of existing tools to locate radio interference,

the company developed a network of sensors to locate EMI sources, controlled by algorithms and receivers the company also developed under the contract. With a follow-on Phase II agreement in 2006, the company continued to develop the algorithms and receivers that were then integrated with software for data collection and analysis in the company's Lynx Location System (LLS).

In 2009, Soneticom began collaborating with the Federal Aviation Administration (FAA) to install and test the LLS at its field test center in New Jersey in preparation for deploying the LLS at commercial airports. The FAA reports that each year there are many cases of inadvertent interference and intentional disruptions of cockpit to tower communications at major airports. With a Phase III SBIR contract, Soneticom also plans to begin testing a new field strength mapping feature for the LLS in the near future.

## Product Outcome

Soneticom's LLS is an EMI precision geolocation system with two major components: the Control Station, a software package that runs on a laptop; and multiple compact, rugged, unattended processing sensors, which rely on the NASA-funded receiver components. The software collects data from each sensor in order to compute the location of the interfering emitter. The sensors can be mounted with existing infrastructure for power and wireless communications, or Soneticom can provide an independent power system on a tripod with battery or solar power options.

Before locating interference, the LLS establishes a baseline by capturing and averaging radio frequency (RF) readings. Ron Cobb, Soneticom's vice president of



The Space Shuttle Atlantis (foreground) and the Space Shuttle Endeavour (background) at Kennedy Space Center. Securing launches against radio interference has been one of the goals of Soneticom Inc.



Soneticom's Lynx Location System is an electromagnetic interference geolocation system that relies on NASA-derived receiver components.

advanced communications systems, explains that the company deploys three or more sensors to an area, whereupon the system confirms receipt of a signal from the software. After the Control Station confirms communication from the sensors, it compares this baseline with real-time data to locate interference in a process called radio interferometry (RI), which uses NASA-developed algorithms to cross-correlate a fringe pattern produced when multiple antennas are tuned to a specific frequency.

Using another algorithm called time difference of arrival (TDOA), which was also developed under the NASA SBIR, Cobb says the system locates disruptive signals down to small footprints, or "dots on a map." The system then begins to differentiate between harmless radio traffic, such as from a recreational boater, and an intentional threat. The LLS begins alerting users to unusual activity on the RF spectrum, including changes in radiated power, signal strength, and EMI levels.

Dwayne Free, senior systems engineer at Soneticom, says that one of the applications of the LLS system will be keeping runway (and launch) operations free from radio frequency interference. Because uninterrupted communication between crews in the tower (or mission control) and in the cockpit is critical to safety, the threat mitigation system could

secure communications before flight, while a vehicle waits for takeoff.

NASA and the FAA are not the only government agencies interested in locating (and preventing) security threats from radio interference. Other agencies and security firms that need to monitor anomalous RF emissions have purchased Soneticom's LLS. The company has had a number of sales to private customers, all interested in preventing electronic encroachment, and although some frequencies differ between industries and organizations, the technology and processes are the same. Soneticom hopes to add the U.S. Air Force to its list of customers, seeing an easy transfer of the LLS to the Air Force's launch needs at Cape Canaveral and Vandenberg Air Force Base. Another potential customer is the Federal Communications Commission, which could use the LLS to enforce radio frequency licenses.

Plans for the LLS and Soneticom's related RI/TDOA services include adapting the technology into smaller tracking devices, both for objects and for people, in an approach called cooperative tracking. An RI/TDOA personnel tracking device could track individuals in high-security or high-risk locations; astronauts, military personnel, firefighters, miners, and other individuals at risk could wear small beacons that would track their locations for their safety, and could also identify individuals without proper access. Security personnel and military forces approaching an area of operations could use RF tracking to secure an area from physical intrusion, not just radio interference. The system could also monitor and secure radio traffic during demolition explosions at construction sites. In 2009, Soneticom hopes to complete an enhanced mapping product, the EMI Image, which will be compatible with the LLS and has been developed with NASA SBIR funding.

Parsippany, New Jersey's DRS Technologies, a supplier of integrated products to military forces and intelligence agencies, announced with Soneticom in May that DRS has agreed to acquire the Florida company. ❖

# Surface Operations Systems Improve Airport Efficiency

## Originating Technology/NASA Contribution

As part of its research to make air travel safer, NASA began collaborating with the Federal Aviation Administration (FAA) in 2005 to develop what are now called surface traffic management systems (STMS). Both agencies have expressed a need to gather and organize data on airport surface operations, the management of all airport vehicle activities on or near runways, including the movement of aircraft, baggage vans, fuel trucks, catering vehicles, security personnel, and any other ground traffic. STMS continuously record data to determine the position of aircraft using a transponder signal, GPS onboard the aircraft, or primary radar. These surface surveillance systems, which report locations every second for thousands of air and ground vehicles, generate massive amounts of data, making gathering and analyzing this information difficult. To record and help analyze airport operations data with the eventual goal of automating airport ground traffic, NASA sought assistance from private industry.

## Partnership

In 2005, [Mosaic ATM Inc.](#), of Leesburg, Virginia, developed the Surface Operations Data Analysis and Adaptation (SODAA) tool with funding from Ames Research Center through the **Small Business Innovation Research (SBIR)** program. In essence, says Chris Brinton, Mosaic ATM's president and a former Ames employee, "SODAA is an off-line support tool that can be used to analyze how well the airport surface operation is working, and to help in redesigning procedures and decision-making processes to improve airport operations." Mosaic ATM continued its work with a Phase II SBIR in 2006.

After identifying what NASA, the FAA, and the aviation industry required, Mosaic ATM built and then systematically improved upon a prototype for SODAA. These improvements included advanced query, visualization, and data analysis capabilities to allow researchers

to pinpoint trends and correlations in vast amounts of recorded airport operations data. Now widely used, SODAA has two main capabilities: supporting analysis of surface operations and developing STMS adaptation data, which provide airport configuration parameters for STMS. Mosaic ATM designers have also made a special effort to reduce the time needed to build STMS adaptation data sets, with options that include predefined functions.

## Product Outcome

Mosaic ATM's SODAA helps airports and carriers avoid the significant costs of aviation delays by providing analysis tools to help refine and improve airport operational procedures. Even a small airstrip manages numerous variables for each aircraft and ground vehicle, and collecting data 24 hours a day on hundreds of different vehicles and situations can become unwieldy quickly.



The Aviation Systems Division at Ames Research Center has contributed to surface automation research by helping to develop surface traffic management systems, which are decision-support tools designed to aid surface traffic planning.

Working with current airport surface surveillance systems, SODAA manages these large amounts of data, revealing where slowdowns or irregularities occur.

SODAA presents this data in a graphical user interface (GUI), allowing for immediate, useful interpretation, such as when changes in the flight schedules at the airport cause inefficiencies. Using the GUI, users can define queries—and areas of concern—which SODAA can plot on a map, display in a graph or a table, or export to other software. SODAA pulls raw airport data and STMS log files into its database, and then flags data that may be of interest.

SODAA imports data after receiving updates from the STMS, which allows for post-operations analysis for a variety of uses: long-term airport planning, highly accurate operations billing, assessing noise abatement issues, and routine management of ground traffic. Based on the data it collects, SODAA identifies busy runway crossings and choke points, calculates waiting times and taxi times, and determines how frequently and for what duration taxiways and runways are used. The software analyzes these runway assignments, flight profiles, and taxi routes in order to help managers make key decisions and be alert to potential or recurring slowdowns; SODAA displays key factors like proximity to a conflict point, such as a bottlenecked runway, taxiway, or ramp area. SODAA can then create new scenarios for departure and arrival traffic by using customized management strategies. Airport planners can also adapt the tool to suit different needs and conditions, such as a taxiway that cannot be used on certain dates due to construction.

In addition to inefficiencies, the SODAA tool can also help analysts recognize possible safety concerns, such as a particular driver who regularly follows the wrong route. By preventing or catching a surface deviation early, an analyst or airport manager may help avoid a costly or dangerous delay. User-friendly graphics also allow users to view these vehicle paths, and to drill down to see more specific information and statistics, such as how closely



In 2005, Mosaic ATM Inc. developed Surface Operations Data Analysis and Adaptation (SODAA), an off-line support tool for analyzing and improving airport surface operations.

and regularly a vehicle is adhering to its assigned route, and how often it is out of compliance.

In order to create detailed views of the various airport operation levels, the software uses statistical correlation, clustering, and modeling in its data analysis. Brinton explains that these analytical techniques allow information about the airport operation to be automatically derived by SODAA and provided to the user. “For example,” Brinton says, “if flights parked at one concourse experience more delays than flights parked at other concourses, SODAA will identify this correlation and display it to the user.” This analysis depends on the collection of large

amounts of surface data from STMS to identify consistent characteristics.

Customers such as air traffic specialists, airline managers, and airport authorities use SODAA to improve operations efficiency and to help make long-term planning decisions at airports. Brinton explains, “The significant costs of aviation delays and the opportunity to reduce such delays through this effort result in a strong market for the SODAA technology.” Currently, Mosaic ATM continues the commercialization and development of SODAA under a Phase III SBIR contract. ❖

# Nontoxic Resins Advance Aerospace Manufacturing

## Originating Technology/NASA Contribution

In the late 1980s, scientists and engineers at Langley Research Center began to develop technology for future commercial supersonic air travel, which could reduce travel time across the Pacific or Atlantic Ocean to less than half the time possible with modern subsonic jets. Although British Airways and Air France offered high-speed travel across the Atlantic on the Aérospatiale-BAC Concorde aircraft at speeds of about 1,350 miles per hour (Mach 2.05, or 2.05 times the speed of sound, depending on altitude), NASA hoped to develop quieter, more fuel-efficient, faster supersonic jets that would travel at Mach 2.4 and carry up to 300 passengers, 3 times the number on Concorde. Supported by a team of U.S. aerospace companies, the Agency's High-Speed Research (HSR) program began to explore the possibility of making these supersonic passenger jets a reality.

For the new jets, the HSR program needed a structural material with higher temperature capability than Concorde's aluminum alloy, which would not tolerate the aerodynamic heating at higher altitudes at sustained speeds above Mach 2.2. Because wind friction can cause the outer surface of an aircraft to reach a temperature of 177 °C (350 °F) at Mach 2.4, the HSR team investigated new materials that retained their mechanical integrity at 177 °C for 60,000 hours—the anticipated service life of a commercial supersonic aircraft.

## Partnership

Chemicals manufacturer [Ube Industries Ltd.](#), based in Ube City, Japan, has its North American headquarters, Ube America Inc., in New York. At the same time that Ube was seeking applications for a unique monomer (a small molecule that can be used as a building block for advanced high-performance polymers), Langley scientists Dr. John Connell, Paul Hergenrother (now retired), and Dr. Joseph G. Smith, Jr. were investigating these chemical building blocks that could impart specific physical,



PETI-330 is the first resin created specifically for high-temperature composites formed with resin transfer molding and resin infusion. Offering processability, toughness, and high-temperature performance, the resin has a low-melt viscosity and, when cured, a high glass transition temperature.

thermal, and mechanical properties into high-temperature polymers for the HSR program. Ultimately, NASA was seeking a partner in private industry that could provide materials and manufacturing capability for a high-temperature resin that met the property requirements for structural applications on supersonic aircraft. A colleague from the Japanese Aerospace Exploration Agency (JAXA), Dr. Rikio Yokota, introduced the two teams, and they formed an informal collaboration in which Ube provided a unique monomer to the Langley researchers for chemical evaluation. "We used Ube's monomer to prepare over 50 resin formulations, measured properties, and honed in on the best performing material," says Connell.

The monomer was a byproduct from the synthesis of another chemical used in the microelectronics industry. However, Connell explains, "This unique monomer was difficult and expensive to synthesize directly, so we collaborated with Ube to obtain the monomer and to investigate the effect of this monomer on polyimide matrix resins." Although the HSR program was phased out in 1999, the Agency continued development with Connell's team at Langley, who recognized that this material might fill a need in aerospace manufacturing for a high-temperature resin that could be easily processed.

Connell also credits Dr. Jim Criss, Jr., of M&P Technologies Inc., a small company in Marietta, Georgia, for refining the resin infusion (RI) and resin transfer

molding (RTM) manufacturing processes for use with this high-temperature resin system. RTM is a standard process in aerospace manufacturing, traditionally for lower-temperature resin systems, such as epoxies. “As we were developing the resin system, he was developing the equipment and process for RTM, which at the time did not exist for high-temperature resins,” says Connell.

This polyimide matrix resin was named PETI-330, for its phenylethynyl-terminated imide and glass transition temperature of 330 °C. PETI-330 met the team’s requirements for a substance that performed well at high temperatures and had the unique capability to be processed into composites by RTM and RI processes.

Langley issued Ube America a non-exclusive license in 2004 for the manufacture of PETI-330, and according to Stewart Bain, product director of aerospace materials at Ube, the license was strategic for the company, which wanted to have a larger aerospace role for its specialty and chemicals division.

Based on the sales to date and the potential of PETI-330, NASA awarded the Langley team the “Commercial Invention of the Year” award for 2008. Connell believes the NASA award will help with the ongoing transfer to the commercial marketplace: “Ideally it will provide more visibility for the material and help further its progression into aerospace-related products.”

## Product Outcome

The aerospace industry fabricates composites through non-autoclave techniques such as RTM, RI, vacuum-assisted RTM, and conventional autoclave processes using pre-impregnated material (prepreg). PETI-330 is the first resin created specifically for high-temperature composites formed with RTM and RI. Offering processability, toughness, and high-temperature performance, the resin has a low-melt viscosity and, when cured, a high glass transition temperature. These properties typically oppose each other, but are both highly desirable in manufacturing.

Bain explains that the composite manufacturing process is far simpler and faster using PETI-330 than competing materials because Ube’s resin only requires a one-step curing process. “The resin is heated to 288 °C and then de-gassed,” he explains. “Then it is injected into a mold, the temperature is increased to 371 °C, and left for an hour and subsequently cooled. You then have your part.” Curing cycles for other resins can have as many as 15 steps, Bain explains, and can take 24 hours. Because PETI-330 has low-melt viscosity, it is able to penetrate large area carbon fiber molds (preforms) without changing flow characteristics—an important characteristic for resins during this process. Connell says, “The low-melt viscosity gives us that advantage in the processing.” Machining of the composite is also possible after molding, thus enabling the precise manufacture of a variety of shapes and sizes.

Another advantage PETI-330 offers, Bain says, is strength with a lower weight than metal alloys, which enables the resin to replace them—particularly titanium alloys—in many components. Consequently, the resin can reduce the weight of high-temperature parts. Because



PETI-330 was used in resin transfer molding to fabricate this F-frame. Composite manufacturing is simpler and faster with PETI-330, because it needs only a one-step curing process.

of its strength and toughness, the cured resin (and composites) also resists microcracks that often result from frequent expansions and contractions with temperature fluctuations. Bain explains that when heat is combined with humidity in extended operation, a part tends to degrade much more quickly, but PETI-330 tends to maintain its strength even in these conditions. This can make PETI-330 especially useful for aerospace applications, where components must be both lightweight and resistant to cracks and damage from temperature swings.

One important feature of the PETI-330 that Connell and Bain are particularly proud of is its safety. Whereas traditional approaches use toxic monomers, the new resin is “completely nontoxic,” says Bain. Other high-temperature resin matrix composites, he says, contain unreacted aromatic diamines, such as 4,4’-diaminodiphenylmethane (called MDA), many of which are carcinogenic and require special handling and dedicated facilities to protect workers. He says, “PETI-330 is guaranteed not to contain unreacted aromatic diamines, which is an important feature when you consider the health of the workers who are handling the material.” The diamines used in PETI-330 are fully reacted into the resin, Connell says. Consequently, it is stable and has a long shelf life. Neither specialized protective equipment nor dedicated facilities are required for PETI-330, which can help reduce costs.

Because of the resin’s high-temperature performance and processability, Connell says, the NASA resin is well suited for use in and around jet engines (including inlet frames, insulation, nacelles, air ducts, and compressor vanes) where temperatures may reach 260–288 °C (500–550 °F) and remain at high temperatures for thousands of hours. Recently, Ube began collaborating with Boeing Aerospace for high-temperature applications on commercial aircraft. The resin is also under evaluation by a number of other aerospace companies for applications that may take advantage of PETI-330’s unique qualities. ❖

# Public Safety



NASA's emphasis on safety translates not just to its rocket launches and laboratory practices, but also to our everyday lives. The technologies featured in this section:

- Provide Early Warning of Biological Threats
- Save Soldiers' Lives Overseas
- Save Hundreds of Sailors
- Enhance Scientific Instruments and Safety Devices
- Protect Payloads and Public Safety Officers



# Sensors Provide Early Warning of Biological Threats

## Originating Technology/NASA Contribution

The Centers for Disease Control and Prevention (CDC) estimates there are between 4 and 11 million cases of acute gastrointestinal illnesses in the United States each year—caused by pathogens in public drinking water. The bacteria *Escherichia coli* (*E. coli*) and *Salmonella* have within the past few years contaminated spinach and tomato supplies, leading to nationwide health scares. Elsewhere, waterborne diseases are devastating populations in developing countries like Zimbabwe, where a cholera epidemic erupted in 2008 and claimed over 4,000 lives.

Scientists have found an unexpected source of inspiration in the effort to prevent similar disasters: the search for life on Mars. The possibility of life on the Red Planet has been a subject of popular and scientific fascination since the 19th century. While Martian meteorites have turned up controversial hints of organic activity, and NASA's exploratory efforts have delivered important discoveries related to potential life—the presence of water ice, and plumes of methane in Mars's atmosphere—direct evidence of organisms on our closest planetary relative has yet to be found.

In order to help detect biological traces on Mars, scientists at Ames Research Center began work on an ultrasensitive biosensor in 2002. The chief components of the sensor are carbon nanotubes, which are the major focus of research at the Center for Nanotechnology at Ames—the U.S. Government's largest nanotechnology research group and one of the largest in the world. Tubes of graphite about 1/50,000th the diameter of a human hair, carbon nanotubes can be grown up to several millimeters in length and display remarkable properties. They possess extreme tensile strength (the equivalent of a cable 1 millimeter in diameter supporting nearly 14,000 pounds) and are excellent conductors of heat and electricity.



Containing millions of carbon nanotubes, the NASA biosensor can alert inspectors to minute amounts of potentially dangerous organic contaminants.

It is the nanotubes' electrical properties that Ames researchers employed in creating the biosensor. The sensor contains a bioreceptor made of nanotubes tipped with single strands of nucleic acid of waterborne pathogens, such as *E. coli* and *Cryptosporidium*. When the probe strand contacts a matching strand from the environment, it binds into a double helix, releasing a faint electrical charge that the nanotube conducts to the sensor's transducer, signaling the presence of the specific

pathogens found in the water. Because the sensor contains millions of nanotubes, it is highly sensitive to even minute amounts of its target substance. Tiny, requiring little energy and no laboratory expertise, the sensor is ideal for use in space and, as it turns out, on Earth as well.

## Partnership

“Carbon nanotubes are the wonder material of nanotechnology,” says Neil Gordon, president of [Early Warning Inc.](#), based in Troy, New York. “The opportunity was ripe to put that technology into a product.” Gordon encountered the director of the Center for Nanotechnology, Meyya Meyyappan, at a number of industry conferences, and the two discussed the possible terrestrial applications of NASA's biosensor. In 2007, Early Warning exclusively licensed the biosensor from Ames and entered into a Space Act Agreement to support further, joint development of the sensor through 2012.

## Product Outcome

Early Warning initially developed a working version of the NASA biosensor calibrated to detect the bacteria strain *E. coli* O157:H7, known to cause acute gastrointestinal illness. It also detects indicator *E. coli*, commonly used in water testing. In the process, the company worked out a method for placing multiple sensors on a single wafer, allowing for mass production and cost-effective testing. In April, at the 2009 American Water Works Association “Water Security Congress,” Early Warning launched its commercial Biohazard Water Analyzer, which builds upon the licensed NASA biosensor and can be configured to test for a suite of waterborne pathogens including

*The water analysis process takes about 2 hours, a drastic improvement over typical laboratory-based water sampling, which can take several days.*

*E. coli*, *Cryptosporidium*, *Giardia*, and other bacteria, viruses, and parasitic protozoa. The analyzer uses a biomolecule concentrator—an Early Warning invention—to reduce a 10-liter water sample to 1 milliliter in about 45 minutes. The concentrated sample is then processed and fed to the biosensor. The entire process takes about 2 hours, a drastic improvement over typical laboratory-based water sampling, which can take several days to a week. The sensor operates in the field via a wired or wireless network and without the need for a laboratory or technicians, allowing for rapid, on-the-fly detection and treatment of potentially dangerous organic contaminants.

“The sensor is incredibly sensitive and specific to the type of pathogen it is calibrated to detect in the water,” says Gordon. “Instead of just detecting coliforms in the water that may or may not indicate the presence of pathogens, we will know if there are infectious strains of *Salmonella*, *E. coli*, or *Giardia* that could sicken or even kill vulnerable people if consumed.” (Coliform bacteria levels typically indicate water and food sanitation quality.)

The water analyzer has multiple applications, notes Gordon. Early Warning’s system can monitor recreational water quality at beaches and lakes, which can be contaminated by animal feces, farming activities, and infectious pathogens in human waste. Agricultural companies may use the analyzer to test feed water for cattle, and food and beverage companies may employ the sensor to ensure the purity of water used in their products. Health care organizations have expressed interest in using the analyzer to test water from showers and other potential sources of pathogens like *Legionella*, which causes the flu-like Legionnaires’ disease.

Early Warning and Kansas State University, in Manhattan, Kansas, are collaborating on sensor enhancements such as improving the safety of imported produce. Since the skins of fruits and vegetables are potential sites of dangerous pathogens, inspectors could collect water sprayed on the produce and, using the analyzer, know



Early Warning’s analyzer feeds a concentrated water sample to its biosensor, providing rapid pathogen detection.

within a few hours whether a particular shipment is contaminated. Last year, Kansas State was selected as the home for the U.S. Department of Homeland Security’s new National Bio and Agro-Defense Facility, which could also benefit Early Warning.

“We’re eager to show how the private sector, government agencies, and academia can work together to evolve this platform into products that benefit our citizens,”

says Gordon. With an aging U.S. water and wastewater infrastructure, increasingly severe weather systems, global travel and food imports affecting the proliferation of disease-causing organisms, and more than 1 billion people worldwide without access to safe water (according to the World Health Organization), the fruits of this partnership may be more necessary than ever. ❖

# Robots Save Soldiers' Lives Overseas

## Originating Technology/NASA Contribution

NASA intends to return people to the Moon, but this time to stay. Future plans include living quarters, scientific laboratories, a permanent lunar community, and a training ground for a future mission to Mars. Ahead of these first 21st century boots on the Moon, though, the Space Agency needs to make sure a couple of things are in place, including one thing that most of us here on Earth have begun to accept as a necessary part of any human existence: the Internet.

NASA is designing a mobile communications platform so that a planned series of scouting robots can communicate with one another, astronauts on the Moon, and mission controllers on Earth. These robot scouts will initially serve as beacons to help triangulate coordinates,

including potential landing sites. They will also carry simple science experiments for studying the new locale, taking dust measurements, profiles of local geochemistry, and astronomical readings.

Once in place, though, NASA wants these scouts to begin acting as relay points for a wireless communications network—essentially putting the Internet on the Moon. This network, while essential for NASA's own purposes, will also eliminate many compatibility issues for communicating with international partners who join us on the lunar surface. With each nation designing its own space hardware, universal wireless communications reduce the difficulties of connecting communications equipment.

Working toward this goal, engineers at Marshall Space Flight Center, as part of the Science Mission Directorate's

Self-Aware Surface Network project, are designing a prototype of a communications network which will enable sensor-webs, data sharing, communications, and navigation on the Moon's surface.

As an unexpected early benefit of this NASA research, the U.S. Army received a souped-up reconnaissance tool that is now being deployed to keep soldiers safer in war zones.

## Partnership

Huntsville, Alabama-based Marshall engineers provided their counterparts at the Army's nearby Redstone Arsenal with unexpected design upgrades for one of its remotely operated reconnaissance robots. The Multi-function Agile Remote Control Robot (MARCBot) is a device that the Army has been deploying to Iraq since 2004 to help soldiers search out and identify improvised explosive devices (IEDs). It was developed for the Army by an engineering consulting firm, Exponent Inc., headquartered in Menlo Park, California, with 19 offices across the country and representing over 90 scientific and technical disciplines.

NASA became involved with the project, not just because of the proximity to Redstone or because both the Space Agency and the Army are actively engaged in studying how best to integrate and coordinate humans and robots to do some of the hardest jobs in the universe. Rather, NASA saw the low-cost MARCBots being tested and bought two from its neighbor to test its mobile communications platform.

While tinkering with the devices, the Marshall engineers made a few design changes, making the robot simpler and faster while adding myriad capabilities. They essentially gutted the device and replaced all of its electronics, upgrading from an analog camera to a digital setup, encrypting the controllers and video transmission, as well as significantly increasing the range and adding communications abilities. Despite all of these upgrades, they also managed to simplify the design, providing more



The Multi-function Agile Remote Control Robot (MARCBot) pictured here on display at WIRED NextFest, an annual showcase of innovative technologies transforming the world, is a tele-operated reconnaissance robot developed to identify explosives from a safe distance.



The MARCbot received multiple upgrades from engineers at NASA's Marshall Space Flight Center, and hundreds have now been deployed by the U.S. military overseas to help soldiers identify improvised explosive devices.

plug-and-play sensors and replacing some of the complex electronics with more trouble-free, low-cost components.

When they demonstrated the modified robot to its former owners, the Army was impressed and wanted these design changes reproduced in future models. The Huntsville-based Von Braun Center for Science and Innovation, a local NASA-affiliated nonprofit, helped coordinate this partnership, which involved the transfer of intellectual property between two large government agencies and the contracting of two private companies to carry out the work on a third company's existing product. Schafer Corporation, also in Huntsville, had designed the control system for the updated robot, and [Applied Geo Technologies Inc. \(AGT\)](#), a tribally-owned corporation

in Choctaw, Mississippi, was given the task of manufacturing the modified Exponent MARCbots.

AGT is currently producing 40 new systems per month, upgrading the original Exponent product to make the MARCbot IV-N, the "N" designating its NASA roots. It has completed over 300 of these units, all of which are on their way overseas for active duty. They are also producing a kit so that already-deployed units can be upgraded in the field.

### Product Outcome

According to the U.S. Department of Defense, IEDs have been responsible for approximately half of all U.S. and coalition force casualties and combat injuries in Iraq.

These devices disrupt supply convoys, destroy assets, and have been credited with killing or maiming thousands of soldiers. The MARCbot is a remotely operated reconnaissance robot specifically developed to identify IEDs and maintaining a safe distance—allowing a soldier to assess whether an object is a potential IED while avoiding close (and perhaps dangerous) physical proximity. It is used to hunt down threats to soldiers by allowing a suspected IED to be examined remotely.

The small-wheeled robot is easy to use. It operates with a standard laptop using Windows software and is operated with a common video game controller. In fact, when looking for components, the NASA engineers actually stopped by a series of local pawn shops and purchased used video game controllers, knowing that these parts were readily-accessible, cheap, and most importantly, would be used intuitively by the average young soldier. Although it operates much like a remote-controlled toy car, this robot has features not found under the Christmas tree: It is several times more rugged than even the most robust toy and comes equipped with a video camera, GPS, compass, and an articulated arm. Once it travels so far, it also has way-finding features, so the operator can instruct the robot to find its own way back, following a memorized path.

Reports have come back from the battlefield of soldiers giving their MARCbots names, honorary medals and ranks, and mourning their loss in combat.

Currently, one user operates a single MARCbot IV-N, but future plans are to have one operator oversee a fleet of semi-autonomous robots in order to gain complete situational awareness. Future plans also include adding radiation sensors and plume detection for dirty bomb cleanup and mitigation. ❖

Windows® is a registered trademark of Microsoft Corporation.

# Apollo-Era Life Rafts Save Hundreds of Sailors

## Originating Technology/NASA Contribution

The space shuttle is unique among spacecraft in that it glides back to Earth and lands like an airplane, usually touching ground near where it launched at Kennedy Space Center, but sometimes, in poor weather, gliding into the back-up landing site at Dryden Flight Research Center and then catching a ride back to the Cape on the back of a modified Boeing 747. Before NASA began flying the shuttle, though, astronauts had a longer, more involved trip back to base after a mission. Their capsule, called the command module, would plunge through the atmosphere before releasing a series of



Apollo astronauts and a Navy frogman in biological isolation garments await pickup from a helicopter.

parachutes that would slow the craft enough for it to land on the water without too significant of an impact. Called a splashdown, this type of landing put the astronauts out in the ocean, where a specially designated U.S. Navy ship would then deploy a helicopter to retrieve the space travelers. Waiting for the rescue, the astronauts would release a highly visible marker dye into the water, then leave the command module and climb aboard a life raft.

These early space pioneers had traveled thousands of miles and then landed safely back on Earth. The journey's end was in sight, but they had one more obstacle. The rotor downdraft from the helicopter coming to retrieve them, reaching sometimes as much as 100 knots per hour, was enough to flip a typical flat-bottomed life raft.

Not willing to be thwarted after coming so far, NASA engineers began devising a solution. They knew they needed a highly stable inflatable raft capable of riding out the rough winds, and the solution was to make use of the most abundant resource available: water. Engineers at NASA's Johnson Space Center went to work designing and patenting a hydrodynamically stabilized ballast system that would prevent a life raft from tipping in choppy seas and fierce winds.

## Partnership

While NASA was working on its rescue raft designs, inventor Jim Givens was similarly at work, designing a canopied raft with a hemispheric ballast chamber capable of withstanding the strongest winds and waves. Givens patented his similar system and then obtained an exclusive license for the patented NASA system.

[Givens Marine Survival Co. Inc.](#), of Tiverton, Rhode Island, now manufactures and markets the rescue rafts—under the name Givens Buoy Life Raft—in a variety of sizes and models for everything from sailboats to larger ocean-going vessels.

To date, Givens has sold several thousand of the ballasted inflatable life rafts, and this space-age technology is credited with saving the lives of over 450 seamen.

## Product Outcome

The Givens raft, like the NASA design, relies upon a heavy, water-filled ballast. A flapper valve allows large amounts of water—hundreds of gallons—to enter the hemispheric chamber. This water provides the ballast that keeps the center of gravity constant, much like the thousands of pounds of lead keel used to stabilize sailboats. This design makes the raft nearly impossible to capsize. If, however, a large wave breaks over the top of the life



Givens Marine Survival Co. Inc. licensed the self-righting life raft design from NASA and has since crafted thousands of the life-saving rafts.

raft, carrying it upside down, it is designed to somersault and right itself, the momentum of the water in the ballast chamber continuing across the top of the canopy and leveling it upright again. While not the most comfortable sensation, this feature is what keeps crews alive and out of the water.

With a typical, flat-bottomed life raft, there is little or no ballast and no momentum to help a capsized craft right itself. An inverted life raft begins to fill with seawater, increasing exponentially the risks of hypothermia or drowning. Righting the raft involves the disoriented occupants leaving the craft and attempting the procedure from outside, a task that could result in dangerous exposure to the elements and sailors being swept away.

It is not just strong winds and waves that flip the typical inflatable life raft, though. Something as simple as someone trying to climb aboard, or occupants shifting inside, could flip a standard life raft. The Givens-designed valve system, however, employs multiple stabilizers to accommodate for boarders and shifting of occupants as well as varying wave angles and swells.

Both the Navy and U.S. Coast Guard have tested the Givens Buoy Life Raft. Coast Guard testing, as part of its routine testing of all available certified marine safety gear, demonstrated that the raft could not be capsized by rough seas or strong winds. The testing included simulated rescue hoists from Coast Guard rescue helicopters, simulated hurricane force winds from a C-130 aircraft slipstream, drift tests, weight distribution and stability tests, and “at-sea” testing. In each instance, the Givens life raft withstood the most brutal of punishments.

Testing, no matter how well-designed, can never really account for all of the variables that could happen at sea, so it is the testimonials from people whose lives have been saved by these rafts that really speak to their ruggedness. In 1980, the lives of four sailors were saved by a Givens life raft. It was August and the four men were caught in the middle of Hurricane Allen, at that time the second worst storm ever recorded on the Atlantic. With winds



Available in a variety of sizes, the Givens Buoy Life Raft can be used on small sailboats or large fishing vessels and fully self-inflates in under 12 seconds.

gusting to 190 knots per hour, their 30-ton ketch capsized, and the crew sought refuge in their Givens Buoy Life Raft. The four men rode 35-foot waves over the next 42 hours before being rescued, with the raft at times being submerged under several feet of water, flipping, and then righting itself. As Bob Harvey, one of the survivors tells, “We didn’t feel comfortable, but we did feel secure.”

The standard Givens Buoy Life Raft comes equipped with water-activated lights, an automatically inflated canopy, a system for capturing rainwater, insulated floors, and an automatic inflation system. ❖

# Circuits Enhance Scientific Instruments and Safety Devices

## Originating Technology/NASA Contribution

Since its founding in 1958, NASA has pioneered the use of different frequencies on the electromagnetic spectrum—including X-ray, microwave, and infrared wavelengths—to gather information about distant celestial bodies. During the 1962 Mariner 2 mission, NASA used microwave radiometers that operated in the range of 15–23 gigahertz (GHz) to assess the surface temperature of Venus and to determine the percentage of water vapor in its atmosphere.

Today, there is another area on the spectrum proving uniquely useful to scientists: the terahertz (THz) range, spanning from about 100 GHz–10,000 GHz. (1 THz equals approximately 1,000 GHz.) Terahertz frequencies span the lesser-known gap on the electromagnetic spectrum between microwave radiation and infrared (and visible) light, falling within the spectral range where most simple molecules resonate. This molecular resonance



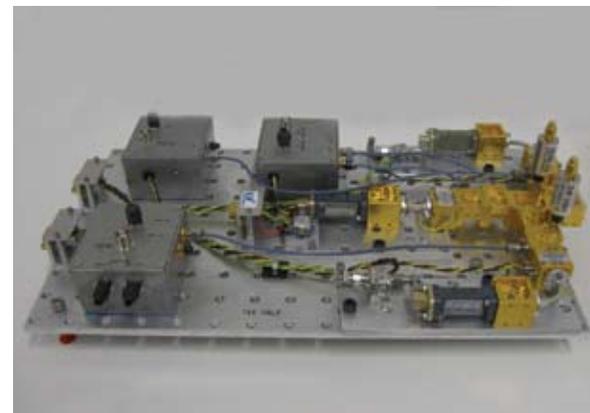
Virginia Diodes Inc. (VDI) has found commercial success with its high-frequency integrated diodes, which are key components in VDI's vector network analyzer (VNA) extenders.

makes terahertz particularly useful for chemical spectroscopy and the remote sensing of specific molecules. In the 1990s, NASA began using frequencies above 300 GHz (more than an order of magnitude higher than the instrumentation on Mariner 2) to perform spectral analysis of molecular clouds and planetary atmospheres. Instruments using these higher frequencies have included the Microwave Limb Sounder (MLS) on the Upper Atmosphere Research Satellite (UARS), deployed from 1991–2001, and the Microwave Instrument for the Rosetta Orbiter (MIRO), launched in 2004. With UARS-MLS, NASA used advanced terahertz receivers to measure the emission signatures from atmospheric molecules, providing researchers with valuable data about the changes in the Earth's protective ozone layer. MIRO, set to rendezvous with the comet 67P Churyumov-Gerasimenko in 2014, will use terahertz instrumentation to analyze the comet's dust and gasses.

Although NASA has been a driving force behind the development of terahertz technology, scientific equipment for terahertz research—including transmitters, receivers, and basic test and measurement equipment—is not widely available, making scientific experiments in this range between traditional electronics and quantum photonics more costly and greatly limiting commercial development in the field. Given NASA's interest in studying distant bodies in space as well as in improving life on Earth, the Agency has collaborated with private industry to develop terahertz technologies.

## Partnership

In the early 1980s, University of Virginia professor Thomas Crowe and research scientist William Bishop worked with NASA to develop high-frequency diodes for UARS-MLS instrumentation. In 1996, Bishop and Crowe founded [Virginia Diodes Inc. \(VDI\)](#), based in Charlottesville, Virginia. A few years later, the company began developing and selling terahertz components and subsystems, with a mission to make the terahertz region



VDI's VNA extenders enable engineers to create and test products in the terahertz range. Products that use terahertz span a variety of areas in research, manufacturing, and security monitoring.

of the electromagnetic spectrum as useful for scientific, military, and commercial applications as the microwave and infrared frequency bands have become.

As a subcontractor on a 1999 Phase I **Small Business Innovation Research (SBIR)** contract from the Goddard Space Flight Center, VDI collaboratively developed three state-of-the-art frequency multipliers with output center frequencies of 182 GHz, 250 GHz, and 384 GHz. Building on these early successes with concurrent Phase II SBIR contracts from Goddard and the Jet Propulsion Laboratory in 2001, VDI developed a highly compact 870 GHz receiver and a compact frequency tunable source for frequencies at 1.5 THz.

Today Goddard uses these VDI technologies in the airborne Conical Scanning Submillimeter-wave Imaging Radiometer to make airborne measurements of ice crystals as proof of concept for the next generation of spaceborne instruments for Earth and space exploration. In addition to its continuing collaboration with NASA to develop terahertz technology for current and future missions, VDI has found commercial success with its

terahertz components and testing equipment, particularly its integrated diode circuits, which are key components in VDI's vector network analyzer (VNA) extenders.

## Product Outcome

Because of the unique characteristics of terahertz radiation—such as its ability to image items hidden behind common materials (such as clothing), and to detect and identify a wide range of chemicals—there is a growing demand for terahertz components for a variety of systems. Applications include security imaging systems to detect concealed items, hazardous chemical and biological-agents detectors, plasma diagnostic instruments, and industrial process monitors. In order to create these new products, engineers need components that can operate in the terahertz range, such as high-frequency mixers and multipliers, amplifiers that operate in terahertz frequencies, and advanced testing equipment like VNAs.

VDI's advanced integrated diode circuits have increased the frequency range of VNAs (and VNA extenders) by an order of magnitude, from 100 GHz to 1,000 GHz (1 THz). The company's extenders now expand the range of current commercial 4-port VNAs to the 780–850 GHz range while maintaining high dynamic range (80 decibels). “The frequency multipliers and frequency mixers are the key technology,” says Crowe, now VDI's president. “They have diode circuits that were primarily developed under the SBIRs.” Crowe also states that VDI's advantage in the VNA extender field is the company's ability “to make very efficient and cost effective mixers and multipliers that work all the way to 1 THz and beyond.” These VNA extenders allow engineers to design systems and make measurements that were scarcely possible only 5 years ago.

While most customers—including many universities—come to VDI for components for high-frequency test systems, Crowe expects VDI's terahertz-ready VNA extenders and diodes will spur the development for many other research instruments and commercial products,



New security imaging products use the VDI diodes to detect passive terahertz waves, which can reveal images hidden behind common materials. The image on the left, returned from the security system, shows a gun hidden under the man's jacket.

including security imaging systems. One security system currently using terahertz components from VDI is ThruVision's T5000 Imaging System, now in use at some international airports. Because terahertz radiation is a shorter wavelength than radio or microwave frequencies, a terahertz scan of a person displays hidden objects with higher spatial resolution. It also can detect a greater variety of materials, including metals, wood, ceramics, and plastics. Terahertz photons also have very low energy and, unlike X-rays, terahertz radiation is non-ionizing and not considered to be harmful to people. In fact, terahertz imaging systems like the T5000 can be totally passive, detecting only the terahertz energy that is naturally emitted by the subject.

These imaging systems are possible only because of developments in terahertz components and test equipment, and Crowe expects demand to increase noticeably in the coming years as VDI's terahertz components improve. VDI's goals include increasing the dynamic range to greater than 100 decibels throughout the entire frequency

range, and extending the modular systems to greater than 1 THz. Transmitter power will improve as more power inevitably becomes available from broadband amplifiers. VDI also expects continued improvement of the multipliers, particularly near the band edges.

According to Crowe, VDI has grown to over 30 full-time employees and continues to grow at 30 percent per year, growth he credits to the company's successful commercialization of terahertz products developed under the NASA contracts. The company has over 200 customers in over two dozen countries, including major university and government research laboratories. ❖

***VDI grows  
30 percent  
per year, thanks  
to the company's  
successful  
commercialization  
of terahertz  
products developed  
under the NASA  
contracts.***

# Tough Textiles Protect Payloads and Public Safety Officers

## Originating Technology/NASA Contribution

Special textiles have been mission-critical components for successful space missions since the early years of NASA's first parachutes and space suits in the late 1950s. One of the Agency's more recognizable uses for textiles, the Mars Pathfinder airbags, provided a cushioned, instrument-friendly landing in 1997. This same technology also successfully protected the Mars Exploration Rovers when they landed on the Red Planet in 2004.

These were not the ordinary airbags found in automobiles. Because the success of the missions depended on the payloads remaining undamaged, NASA had specific, exacting requirements for the airbag design. A lightweight fabric that could maintain inflation was required, but that fabric would have to be tough enough to withstand



The Mars Pathfinder's airbags incorporated multiple layers (up to four, depending on the location of the airbag) of lightweight fabric. When Pathfinder landed on Mars, the vehicle and its delicate payload were protected by 24 inflated spheres woven by Warwick Mills Inc.

extreme temperatures (both in space and in the Martian atmosphere). The fabric balloons would have to inflate after passing through the atmosphere and then maintain inflation during impact on the rocky, sharp, and unpredictable Martian terrain. In July 1997, when the Mars Pathfinder landed on Mars, 24 interconnected, inflated spheres protected the vehicle and its delicate payload as the craft bounced 15 times after an initial impact speed of 18 meters per second (40 mph).

## Partnership

In order to create Pathfinder's mission-critical airbags, NASA's Jet Propulsion Laboratory (JPL) collaborated with Frederica, Delaware's ILC Dover, which solicited a bid from New Ipswich, New Hampshire's [Warwick Mills Inc.](#) to weave the textiles. Founded in 1888, Warwick Mills has a long history in weaving textiles and a long history with NASA as well, having woven fabrics for reentry parachutes and the Apollo recovery floats in the 1960s. The company began developing high-performance flexible composites in 1991 in order to address needs in the military, industrial, marine, and aerospace markets.

According to John Cronin, one of Warwick's public safety equipment program managers, the company was one of the first weavers of Vectran, a liquid-crystal polyester fiber noted for its strength as well as its resistance to impact and abrasion. After receiving a request from JPL to weave a lightweight and yet strong fabric for the Mars airbags, Warwick, in collaboration with the engineering team at ILC Dover, decided to use a blend of coated Vectran fibers, due to Vectran's strength and reliability in cold temperatures. Warwick's team also engineered a process to apply thin coatings to the woven Vectran, which added strength while remaining lightweight.

After Warwick wove the fabric, the completed airbag prototypes first underwent tests at ILC Dover and then at Glenn Research Center's Plum Brook Station Space Power Facility in a simulated Martian atmosphere. According to Chuck Sandy, chief engineer at ILC Dover,

"Warwick provided valuable insight to the team as a number of iterations of candidate materials (different weaves, weights, and layup combinations) were fabricated and subjected to customized rock impingement testing at ILC." During this testing, the JPL team discovered that the most effective design would incorporate multiple layers (up to four, depending on the location of the airbag) of lightweight fabric. The outer layers could tear and absorb more energy from impact while protecting the inner layers.

Charlie Howland, Warwick's chief engineer and CEO, explains that the collaborative design and testing with NASA and ILC Dover yielded several benefits for Warwick, including new enthusiasm for design possibilities. "What this project provided for us was this innovative spark," he says. "This was able to really get our engineering staff excited and looking at high-performance fibers that were emerging." In addition, the company also learned new techniques for improving the fiber's tear resistance and refining test methods.

Warwick also benefited enormously from learning how to weave textiles in new ways and incorporate coatings. "What makes Warwick Mills unique," Howland says, "is our patented weaving and finishing technique, which we developed for the Mars airbags."

## Product Outcome

From the late 1800s until the early 1990s, Warwick's core business was weaving textiles. Today, however, the company is known primarily as an engineering firm with a range of manufacturing capabilities. In its TurtleSkin line, Warwick Mills offers protective apparel and safety products, using similar weaving techniques the company used in developing the Mars airbags and applying different composites and laminates to fabric. "From the knowledge and engineering experience we gained while working on the airbags," Cronin says, "we were able to develop high-performance protective products for public safety."



Available in the TurtleSkin line are puncture-resistant and needle-resistant clothing, such as these gloves. The TurtleSkin products are in use by various law enforcement groups around the world.

Many of the company's products are based on the company's uniquely tight weaving technique, Cronin says. "We have made a series of modifications to high-speed rapier looms to control warp yarn tension and support extremely high weaving forces." The result, Howland adds, is that the fabric has the tightest weave possible. To penetrate TurtleSkin fabrics, sharp objects must actually break the fibers, rather than simply push them to the side. Howland notes that in protective applications, this allows the creation of significantly lighter and more flexible fabric than had previously been possible.

The TurtleSkin products offer resistance from a variety of forces, and include ballistic-resistant body armor, stab-resistant body armor, and puncture-resistant clothing. According to Cronin, the body armor uses a tightly woven

blend of Vectran, Dyneema, and Twaron to protect the wearer from knife injuries (in stab armor and cell extraction vests) and blunt impact and firearms (in the SoftPlate body armor). Cronin explains that the tight weave in the stab- and spike-resistant fabrics is the critical element for protection from various weapons: "When you stitch a button on your shirt, you don't actually make a hole in the fabric; the tip of the needle simply gets between the weave and spreads the fibers apart momentarily so you can drag the thread through. With TurtleSkin, the fibers don't shift." Because the fibers do not shift, weapons or bullets are far less able to separate the fibers and pierce the skin.

Using this tight weaving technique, Warwick Mills also created Metal Flex Armor (MFA), and SoftPlate body armor. MFA offers stab protection from ice picks, hypodermic needles, and knives, and is a composite of hard steel elements laminated to Twaron woven fabric. This flexible laminate offers protection comparable with rigid steel plates in other body armor products, but with higher mobility and comfort. Over 50,000 MFA vests have sold. Like the MFA, the SoftPlate body armor offers flexibility, comfort, and armor concealment, but is designed to defeat handgun bullets (instead of piercing weapons). The manufacturing process for both of these laminates combines the tightly woven fabric with proprietary coating and finishing techniques developed during the NASA collaboration.

Public safety and military customers now benefiting from the TurtleSkin products include the United States Marine Corps, the New York State Department of Corrections, the Federal Bureau of Prisons, and police departments throughout the United States. The products are also in use by civilian law enforcement groups throughout the world including agencies in the Netherlands, Korea, and Peru.

Warwick Mills continues to reap new benefits from its NASA collaboration as it plans to offer a new TurtleSkin product soon: flexible ballistic vests that resist rifle rounds.

Like the MFA line, this new technology "combines the benefits of ceramic and high-performance textiles that are direct descendants of the Mars bags," says Cronin. ❖

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Using a tight weaving technique, Warwick Mills created SoftPlate body armor, which offers flexibility, comfort, and armor concealment.

# Consumer, Home, and Recreation



NASA's aerospace research often comes back to Earth in surprising but very practical ways, improving the quality of our everyday lives. The technologies featured in this section:

- Point to Fishing Hotspots
- Eliminate Pathogens, Preserve Food
- Protect Sensitive Skin from UV Rays
- Control Temperature
- Project Sharp, Colorful Images





# Forecasting Tools Point to Fishing Hotspots

## Originating Technology/NASA Contribution

Sport fishing is an uncertain pastime. Some days the fish are biting; others, not. But for captains of charter fishing boats and recreational fishermen making the most of a day off from work, returning without a catch is more than just a disappointment—it can have a financial impact as well, from wasted gas to frustrated clients taking their business elsewhere. Thanks to an evolving commercial partnership, oceanic data gathered by NASA satellites is now helping take the guesswork out of finding fishing hotspots.

In 1997, NASA launched the first of more than 20 satellites that now comprise the Earth Observing System (EOS). EOS was designed to provide space-based measurements and imagery of Earth's surface and atmosphere to help scientists understand climate change and humans' role in it on a long-term, global scale. However, NASA soon realized that the EOS was making unique observations of weather and the ocean, as well.

In 2002, NASA established the Short-term Prediction Research and Transition Center (SPoRT) at Marshall Space Flight Center to facilitate the use of real-time EOS measurements for short-term weather forecasting—the prediction of weather on a scale of hours, rather than days or weeks. SPoRT uses EOS and other satellite data to provide a suite of NASA products to address challenging forecast issues such as visibility reduction due to clouds and fog at night; the timing and location of severe weather; flood potential due to runoff from snow melt; and the prediction of cloud cover, temperature changes, and precipitation in coastal regions associated with sea breeze fronts. SPoRT repackages the satellite data into useful formats and shares it, along with other tools like forecast models, with government entities like the National Oceanic and Atmospheric Administration (NOAA) and the National Weather Service, as well as private sector organizations like television's The Weather Channel.



FishBytes, featuring a database of 18 fish species, uses sea surface temperature and chlorophyll levels measured by NASA satellites to help anglers locate the best areas for their favorite catches.

“We don’t just throw data over the fence,” says Dr. Gary Jedlovec, SPoRT’s principal investigator. “We work closely with these end users to understand what their forecast problems are and then match our data capabilities to their forecast problems.”

## Partnership

**WorldWinds Inc.**, a private weather forecasting company based in Slidell, Louisiana, approached SPoRT in 2006 seeking use of the program’s oceanic data. WorldWinds has an extensive history of NASA partnership; it was originally a part of User Systems

Enterprises Inc., developed from founder and former Jet Propulsion Laboratory scientist Walt McCandless’s Phase I and II **Small Business Innovation Research (SBIR)** contracts with Stennis Space Center in the early 1990s. (McCandless used his SBIR research to help address the lack of atmospheric and meteorological data over the open ocean, using radar backscatter off the water to determine wind speeds.) WorldWinds was established from User Systems’ Stennis office in 2000. Beginning in 2003, the company conducted Phase I and II SBIR research on high-resolution, radar-based digital elevation models to determine accurate storm surge predictions.

***XM WX has about 8,500 subscribers receiving FishBytes data on XM Satellite GPS devices.***

WorldWinds, which gathers weather and oceanic information from multiple sources and packages it into publicly useable products, was impressed by SPoRT's data capabilities related to sea surface temperature (SST) and chlorophyll, the light-absorbing, energy-producing material found in plants like tiny, oceanic phytoplankton. SPoRT had developed an algorithm that compensates

for holes in SST data caused by cloud cover that interferes with satellite readings. WorldWinds was interested in utilizing SPoRT's SST capacities and developing a similar cloud-hole compensating algorithm for chlorophyll data. The company entered into a cooperative agreement with SPoRT to produce the algorithm, which was recently completed.

"WorldWinds is what I call a value-added forecaster," Jedlovec says. "They take some of these basic building blocks that NASA is providing and create tailored products for a specific end user in the commercial sector."

## Product Outcome

WorldWinds was featured in *Spinoff* 2002 with an eponymous weather forecasting product that utilized NASA satellite data for weather forecasting accurate to 1 kilometer. Since then, the company has expanded its product capabilities. In 2006, Baron Services Inc.—a Huntsville, Alabama weather solutions company that also evolved from a NASA partnership and was featured in *Spinoff* 1993—approached WorldWinds to develop a fisherman's dream: a method of forecasting favorable conditions for certain fish populations. The result, which incorporates SPoRT SST and chlorophyll data, is FishBytes.

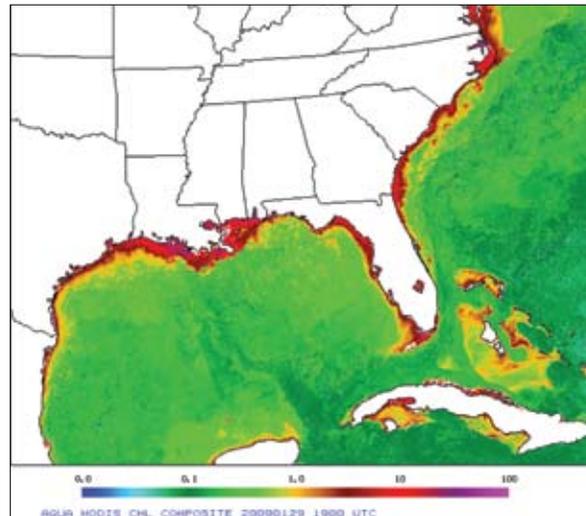
FishBytes guides fishing enthusiasts to areas most likely to be populated by target species. The system

operates using two main components. First, it features a current database of 18 pelagic fish species popular with anglers, including tuna, mahi-mahi, sailfish, marlin, and tarpon. The database contains information such as known SST and salinity preferences for each species, as well as the fish's favored proximity to land, depth ranges, and attraction to underwater geological features.

Second, the system gathers environmental information from a range of sources, including SPoRT, and compares these numbers to its fish preferences database. The results are remarkably accurate predictions of specific fish population locations within a 2-kilometer range.

"We've had great feedback from people saying FishBytes works even better than they expected," says Elizabeth Valenti, WorldWinds president. "The fishermen love it."

The key to the system's effectiveness, says Valenti, is its ability to detect the lines between temperature and chlorophyll differences in the ocean. FishBytes uses a proprietary edge-detection algorithm to determine where



FishBytes draws on chlorophyll data like that from NASA's Aqua satellite, used to generate this composite map.

these edges occur. "Fish tend to congregate at these chlorophyll or SST lines," says Valenti. "We use other data to make our predictions, but these two characteristics seem to be the most important." Small fish are attracted to areas high in chlorophyll-containing phytoplankton, a source of food; these fish in turn attract the larger species that anglers like to target.

WorldWinds sends the FishBytes data to the WxWorx division of Baron Services, which then broadcasts the service as part of XM WX Satellite Weather's Master Mariner package, which also includes WorldWinds weather data that enables anglers to track storms as well as fishing hotspots. XM WX is part of XM Satellite Radio, the Nation's leading satellite radio service. So far, Valenti says, XM WX has about 8,500 subscribers receiving FishBytes data on XM Satellite GPS devices.

Besides its effectiveness at pinpointing fish hangouts, FishBytes has significant range; while most current fish forecasting systems are limited to small regions, Valenti notes, FishBytes covers the Atlantic, Caribbean, and Gulf of Mexico (with coverage of the Pacific coming soon). The XM Satellite footprint reaches 600 miles offshore in all directions from the continental United States.

WorldWinds plans to expand its database of fish species, helping anglers save gas and time tracking down their favorite catches, all with the continued partnership of NASA.

"As a taxpayer, you see millions of dollars being invested in NASA, and technology transfer programs like SPoRT help people realize benefits from the tax dollars used to fund this research," says Valenti. "It's something that they deserve." ♦

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# Air Purifiers Eliminate Pathogens, Preserve Food

## Originating Technology/NASA Contribution

In order for NASA astronauts to explore the solar system, they will need to travel not just as pioneers but as settlers, learning to live off the land. Current mission needs have NASA scientists exploring ways to extract oxygen from the lunar soil and potable water from human wastes. One of the basic goals, however, will be for pioneering space travelers to learn to grow and manage



Dr. Weijia Zhou (left), director of the Wisconsin Center for Space Automation and Robotics at the University of Wisconsin-Madison, inspects soybeans grown in the plant growth unit aboard the International Space Station (ISS). Coating technology used inside the miniature plant greenhouse removes ethylene, a chemical produced by plant leaves that can cause plants to mature too quickly.

their own crops. This requires the development of space-age greenhouses where astronaut farmers can experiment with harvesting large-scale food crops.

In the 1990s, researchers at the Wisconsin Center for Space Automation and Robotics, a NASA research partnership center at the University of Wisconsin in Madison, sponsored by Marshall Space Flight Center's Space Product Development program, produced an ethylene reduction device for a plant growth unit. Ethylene is a naturally occurring, odorless, colorless gas given off by plants that hastens the ripening of fruits and the aging of flowers, encouraging decay. Comprised of carbon and hydrogen, in closed growing environments, like on a spacecraft or in a terrestrial greenhouse, ethylene builds up quickly and plants mature too fast. Removing ethylene, therefore, is important to preserving crops not just in space, but also on Earth, where grocers and florists have an interest in reducing the gas that ultimately shortens the shelf life of their products.

The ethylene reduction device, also called the ethylene "scrubber," draws air through tubes coated in thin layers of titanium dioxide ( $\text{TiO}_2$ ). The insides of the tubes are exposed to ultraviolet light, which creates a simple chemical reaction, converting the ethylene ( $\text{C}_2\text{H}_4$ ) into trace amounts of water ( $\text{H}_2\text{O}$ ) and carbon dioxide ( $\text{CO}_2$ ), both of which are actually good for plants.

The ethylene scrubber first launched aboard Space Shuttle Columbia mission STS-73 in 1995, where onboard the spacecraft the device was used successfully to preserve a crop of potato seedlings. Subsequent evolutions of the technology were flown aboard numerous International Space Station (ISS) expeditions.

## Partnership

KES Science & Technology Inc., a Kennesaw, Georgia-based company specializing in sustaining perishable foods, licensed the ethylene scrubbing technology from the University of Wisconsin (*Spinoff* 2001 and 2002). KES partnered with [Akida Holdings](#), of Jacksonville, Florida,

which now markets the NASA-developed technology as AiroCide. According to the company, it is the only air purifier that completely destroys airborne bacteria, mold, fungi, mycotoxins, viruses, volatile organic compounds (like ethylene), and odors. What's more, the device has no filters that need changing and produce no harmful byproducts, such as the ozone created by some filtration systems.

Now in widespread use, the device is still helping preserve fresh foods, but has also seen applications in the medical and dental fields as well as in killing airborne pathogens, including anthrax and dust mites. One of the most recent applications of this NASA technology now available is in a new line of home refrigerators. Other companies have begun looking at using the device for treating whole house systems.

## Product Outcome

KES and Akida categorize the AiroCide customer-base into three distinct fields: food preservation, health care, and private spaces. As Marc Anderson of the University of Wisconsin explains, "One of the great uses of this device is for removing ethylene, but it really cleans any organic material from the air, including odors, bacteria, volatile organic compounds of all sorts, and will even remove inorganics, like sulfur compounds."

Food preservation customers include supermarkets like Whole Foods; produce distribution facilities like those operated by Del Monte; food processing plants; wineries; distilleries; restaurants; and large floral shops. Reeves Floral, an AiroCide user, reported 92-percent reductions in airborne mold and a 58-percent drop in airborne bacteria levels in just the first 24 hours it had the units operating in its floral storage warehouse. The AiroCide units can be used in walk-in coolers to preserve freshness of produce during storage and transport, to increase safety in food preparation areas, to kill bacterial contaminants in flowers (botrytis), and to protect against spoilage and contaminants.



Now in widespread use, the ethylene-removal technology developed for the ISS is still helping preserve fresh foods and has also seen applications in the medical and dental fields, as well as in killing airborne pathogens, including anthrax and dust mites.

AeroCide has seen new consumer applications in food preservation. The technology is now incorporated into a line of refrigerators, high-end consumer models that preserve freshness and reduce food waste. The refrigerator recycles the air every 20 minutes, reducing odors, viruses, and bacteria, as well as eliminating the presence of veggie-wilting ethylene.

The same technology has also seen use in remote regions of the world, where harsh environments and underdeveloped infrastructure complicate food storage and distribution. AeroCide units have currently been deployed to India and the Gulf Cooperation Council, which includes the countries of Bahrain, Kuwait, Qatar, Oman, Saudi Arabia, and the United Arab Emirates.

In these areas, where refrigerated trucks carry groceries from rural farmland to towns miles away, the AeroCide unit preserves freshness and prevents food spoilage. The units are also found in food storage facilities, preventing mold growth and the spread of disease.

In the health care arena, AeroCide units have been incorporated into doctors' clinics and operating rooms, as well as in waiting areas, an oft overlooked location rife with germs and bacteria like respiratory influenza or mycobacterium tuberculosis and frequented by people with compromised immune systems. Operating rooms are similarly prone to germ and bacteria infiltration. The rooms are cleaned and sanitized initially, but the incoming doctors, equipment, and even the patients contaminate the air. With AeroCide units mounted in the ceiling, an operating room becomes safer for all inhabitants, as harmful bacteria like methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Enterococcus*, and the fungi *Penicillium* and *Aspergillus* are removed from the air. In addition to eliminating virtually all known airborne germs and diseases, the technology reduces the burden on high-efficiency particulate air (HEPA) filters and laminar flow environments. These same air-cleaning properties have also been applied to neonatal wards.

In addition to preserving produce and maintaining healthy air in medical settings, the AeroCide units have been adapted for use in everyday living environments. In hotels, for example, the units eliminate mold, mildew, germs, and unwanted odors. These same features are also useful in offices, where illnesses caused by airborne organisms can lower productivity. In homes, the AeroCide units help eliminate the growth of mold and fungi as well as eliminate allergens like pet dander and dust mites. ❖

AeroCide® is a registered trademark of KesAir Technologies LLC.

# Fabrics Protect Sensitive Skin from UV Rays

## Originating Technology/NASA Contribution

Beginning in 1968, NASA began researching garments to help astronauts stay cool. The Agency designed the Apollo space suits to use battery-powered pumps to circulate cool water through channels in the inner layers of the garments. This led to commercial cooling vests for patients with heat control disorders (first featured in *Spinoff* 1979) and for workers in heat stress occupations (featured in *Spinoff* 1982).

Space suits not only keep astronauts cool, but also use multiple layers of heavy fabric to block the Sun's ultraviolet (UV) rays from burning the skin. The first commercial cool suits had been designed primarily to keep patients cool, but were not designed specifically to block UV rays.

In 1997, late Johnson Space Center engineer Robert Dotts, assistant director of Technology Transfer and Commercialization, headed a team to continue the research from the first generation of cool suits after receiving a request for help from a family with two children suffering from life-threatening sun sensitivities. In order to both prevent the Sun's light from damaging their skin and also to keep the patients cool, Dotts hoped to develop UV-blocking technology in a fabric that—unlike in a bulky space suit—could remain comfortable, light, and breathable in the sun and heat. Dotts, engineers Dominic Del Rosso and Evelyne Orndoff, and NASA physician Smith Johnston discussed requirements, identified materials, and then began testing fabrics from private industry at NASA's White Sands Test Facility.

## Partnership

In the summer of 1997, Dotts contacted Terry Breese, president of [Solar Protective Factory Inc. \(SPF\)](#), a Madison, Wisconsin-based company that had been developing commercial UV-resistant fabrics since 1989. "Dr. Dotts was very concerned about the manufacturing standards and testing methods we employed to measure



A team from Johnson Space Center worked with Solar Protective Factory Inc. (SPF) to create cool suits that enable sun-sensitive patients to play outdoors.

ultraviolet transmittance," Breese says, remembering when NASA first contacted his company to request fabrics for testing.

With NASA's input, SPF developed its "Solarpro-tiferous" process, which enhances fabric reflectivity and UV absorption with special chemical treatments added during the dyeing process. In this process, SPF uses charcoal, coconut, and titanium in its fabrics to reflect UV rays or to help transfer UV light into heat, which then disperses quickly. Dotts and NASA engineers provided SPF with feedback on fiber structure during development, suggesting combinations of high-loft synthetic fibers and spandex blends (to keep the fabric as tightly knit as possible while also being comfortable, breathable, moisture-wicking, and reflective. Too much elasticity, the engineers explained, would allow too much UV light through when the fabric stretched. The team

determined the optimal amount of spandex in the suits was 8–9 percent when blended with a high-loft nylon thread. Because of the life-threatening sensitivity of these patients to light or heat, the Johnson team required the fabric, according to Breese, "to perform at the highest possible protection level and still be comfortable."

The prototypes for the second generation of protective cool suits consisted of a hat, gloves, socks, pants, scarf, goggles, and jacket—truly covering the wearer from head-to-toe—that incorporated the earlier built-in water channels under layers of UV-blocking fabric, thereby protecting patients with both light and heat sensitivities.

Del Rosso, the cooling system specialist on the project, explains that the Johnson team used NASA's research and experience in cooling astronauts to adapt the cool suits for the young, sun-sensitive patients. These improved cool suits were far lighter than the first generation of cool suits from a decade before, enabling pediatric patients to play outdoors in sunlight for the first time. The new prototypes still used two layers of garments like before, but now the UV-blocking outer fabric was far lighter and more breathable.

In subsequent versions of the suit, the team replaced the water tubing with simple pockets that held refrigerated gel packs. These gel packs were not as effective at keeping patients cool, but they were far less costly and less cumbersome than the tubing, which had required a motorized pump attached to a belt. The gel packs also allowed young patients more freedom of movement than the tubing, adding a level of independence to their new outdoor activities.

NASA helped SPF further enhance the suits' safety by using lapped seams with non-overlying stitch lines, which prevent light from entering through seams. According to Del Rosso, this lap stitching is used in some NASA pressure garments to prevent stitch holes from compromising suits' protective qualities.

After deciding on the fabric blend and overall suit design, the Johnson team collaborated with SPF and the

Hypohidrotic Ectodermal Dysplasia (HED) Foundation (later called the Sarah Moody Foundation), in Hampton, Virginia, to provide over 1,000 suits to patients with severe light sensitivities and heat disorders. These disorders include the namesake HED, a lack of sweat glands that can lead to severe and sometimes fatal heat exhaustion; Xeroderma Pigmentosum, in which the DNA cannot repair ordinary skin damage caused by sun exposure; and polymorphic light reaction syndrome (PLRS), severe skin blistering caused by exposure to ordinary sunlight. Patients with neurological pain caused by neuropathy and multiple sclerosis also benefit from the cooling effects of the suits.

In the fall of 1997, Breese, Del Rosso, Dotts, and Johnston accompanied PLRS patients Ryan and Kyle

Richards as the boys experienced their first time in the Florida sun, on a family trip to Walt Disney World that would not have been possible without the cool suits. Calling the trip one of the highlights of his life, Breese is proud of having worked with NASA to design the UV-blocking fabric and looks forward to future collaboration. “If it weren’t for NASA’s development of their space suits with the cooling vest technology,” Breese says, “none of this project could have happened.”

### Product Outcome

In 2009, SPF’s 20th year in business, ordinary beachgoers are now benefiting from the NASA and SPF partnership. The UV-blocking fabric, first used to help protect the most sensitive patients from damaging sun

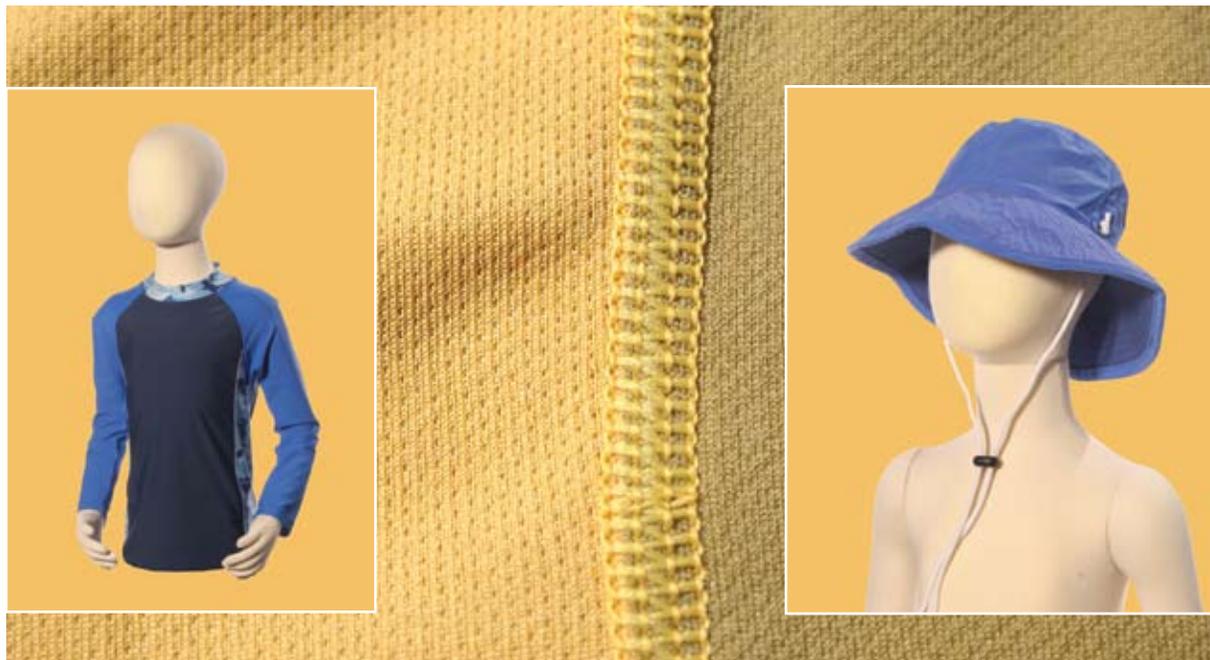
and heat, is now being used in swimwear and clothing for the public.

SPF categorizes its UV-blocking fabrics into two main categories: Solarweave and Solarknit, which include lines of woven or knit fabrics, respectively. The NASA fabric is incorporated into the Solarknit products, which have more stretch while still providing UV protection. The NASA collaboration, Breese says, allowed them to create a comfortable fabric that has the benefits of both the UV-blocking ability of a knit and the breathability and elasticity of a weave.

Breese reports that customers feel cooler in the SPF clothing, which he attributes to its NASA-tested fabric. “The type of fibers we use, along with highly controlled knitting and weaving techniques, create a denser shade under the fabric that enhances the cooling effect,” he says.

SPF’s newest sun-protective fabric, Aquaweave, uses the NASA-derived Solarprotiferous technology to provide better skin protection at the beach or pool than ordinary swimwear. In order to produce the UV-protective swim-suits, SPF added chlorine resistance and more elasticity to the original NASA-derived UV-blocking fabric. The apparel blocks at least 98 percent of UV rays, a feature that lasts for at least 40 machine washings. In addition to swimwear, SPF also offers a full line of machine-washable sun-protective clothing, which uses the NASA fabric. “Our partnership with NASA has helped us develop all levels of sun-protective apparel,” Breese says. Whether the fabric is worn by sun-sensitive patients, or just by sun-bathers, the technology from NASA’s original space suits is now protecting more than just astronauts. ❖

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SPF uses UV-blocking fabrics it developed with NASA in its Aquaweave and Solarknit product lines. The apparel blocks at least 98 percent of ultraviolet rays, in part due to special stitching and SPF’s Solarprotiferous process, which enhances fabric reflectivity and UV absorption by applying charcoal, coconut, and titanium in a finishing process.

# Phase Change Fabrics Control Temperature

## Originating Technology/NASA Contribution

Since designing the first space suits in the 1950s, NASA has been interested in developing materials to keep astronauts comfortable and cool. In order to protect an astronaut from the extreme temperatures in space, engineers at Johnson Space Center created liquid-cooled garments that run water in small channels throughout the suit in what is called an active control system. However, in the 1980s, NASA began to investigate passive control strategies—fabric that could control temperature without pumped liquids—building on work by the U.S. Air Force.

Phase change materials (PCMs) control temperature swings in textiles using passive control strategies. These PCMs change state at different temperatures, such as when wax melts and reforms as it heats up and cools off. In 1987, Johnson began actively seeking collaboration with private industry to develop PCMs for space suits and particularly for use in astronaut gloves during extravehicular activities.

## Partnership

Triangle Research and Development Corporation (TRDC), of Research Triangle Park, North Carolina, participated in two Phase I **Small Business Innovation Research (SBIR)** contracts in 1987 and 1988 with Johnson to assist in the creation of phase change materials for NASA. Prior to these contracts, the company demonstrated the value of manufacturing textiles containing microencapsulated phase change materials (mPCMs) for the Air Force.

Boulder, Colorado-based Gateway Technologies Inc. (first featured in *Spinoff* 1997) then acquired the exclusive patent rights for incorporating phase-change technology in commercial fibers and fabrics from TRDC. In 1997, Gateway Technologies changed its name to **Outlast Technologies Inc.** and incorporated the mPCMs, which the company calls Thermocules, into all of its products.

These mPCMs are now integrated into textiles and onto garments to provide greater comfort and temperature control for consumers in bedding, medical supplies, outdoor gear, and a full line of apparel for both ordinary and extreme conditions.

## Product Outcome

With over 20 patents in fabric technologies, Outlast is a leader in creating new applications and products for mPCMs. The company regularly announces new products, which include active, casual, and nighttime apparel for men and women, as well as leather jackets, gloves, and winter sporting apparel from dozens of company partners in the United States and around the world. Some of these well-known partners include the Burton Corporation, the Timberland Company, Dillard's Inc., Eddie Bauer Inc., Jos A. Bank Clothiers Inc., and Marks & Spencer PLC.

The Outlast Thermocules react to temperature fluctuations, with the encapsulated materials changing from liquid to solid and vice-versa as they release or absorb excess heat, depending on the environment. This feature allows Thermocules to be used in a variety of clothing and consumer goods to maintain more comfortable, slow-changing temperatures near the body. Thermocules are incorporated into or onto fibers, fabrics, and finished garments.

Since creating its first process with the Thermocules, Outlast has added new techniques for applying the temperature-controlling technology to different fabrics. Initially, Outlast only offered its products in acrylic fiber as well as coating the technology onto fabrics through a process called matrix coating technology (MCT), but the company has since added three new ways to offer this temperature-regulating benefit: Outlast matrix infusion coating (MIC), Outlast infusion technology, and Outlast viscose fiber.

In 2006, in partnership with fiber manufacturer Kelheim Fibres GmbH, Outlast announced its manufactured cellulosic viscose, similar in texture to rayon or

silk. This lightweight, easy-to-clean material enables temperature control in delicate garments, including blouses, intimate apparel, dresses, and sleepwear. Outlast has also used viscose to complete its line of bedding products by offering viscose sheets, which, when used with Outlast's existing line of bedding products already in the market, offer consumers new control over temperature fluctuations during sleep, simply through the fabrics around them. New Outlast brand nightshirts, made with a cotton viscose blend, may also help mitigate discomfort from night sweats.

Most of the bedding products offered by Outlast are created with the original MCT process, which allows for the most loading of Thermocules. Fabrics using this process tend to be stiffer and heavier and less ideal for soft items worn close to the skin, but the benefits of having more Thermocules are especially noticeable in car seat covers, outerwear (including jackets, hats, and shoes), rugged outdoor clothing (including winter boots), and bedding (including mattress pads, blankets, duvets, and pillows).

In 2008, Outlast revealed its new MIC process to help improve the temperature-adapting qualities of natural fiber products and its mattress products, and to expand the types of fabric offering Thermocules in general. The MIC process, in essence, screenprints an advanced formulation of microscopic Thermocules onto flat fabrics, providing manufacturers a more affordable method of adding temperature regulation to existing fabric prior to garment construction. Previous coatings were often too heavy for next-to-skin applications, but this new process is lightweight, and according to Outlast technical director Mark Hartmann, "It gives the temperature-regulation benefits of Outlast technology needed for next-to-skin applications and the wicking capabilities of polyester." It is especially useful for woven fabrics like cotton and polyester for polo shirts and sleepwear. Some of the brands offering apparel in this line are Reebok and Marks & Spencer. In spring 2008, Outlast announced this technology would be incorporated in the COCOON



Images courtesy of Outlast Technologies Inc.



Outlast Technologies Inc. incorporates microencapsulated phase change materials (mPCMs) into all of its products, including automobile seat covers, bedding products, and a full line of apparel for both ordinary and extreme conditions. These mPCMs provide greater comfort by trapping and then releasing stored heat as needed.

MummyLiner sleeping bag product by Design Salt USA; the MIC process allows these liners to be breathable and have wicking abilities, while keeping the sleeper comfortable in the outdoors.

The Outlast infusion technology, also initiated in 2008, is a spray process created for finished apparel such as t-shirts, socks, underwear, and shirts, and is not for thick or layered products. This technology offers manufacturers an easy way to apply Outlast technology to existing apparel without changing texture.

Outlast has seen success in its phase change products, increasing its sales by 400 percent from 2002 to 2008, and the company announces new products regularly. CEO Greg Roda says the company's research and development team is regularly "innovating and developing new applications" for the phase-change technology. Other new products are motorcycle apparel, snowboarding boots, and wheelchair seat cushions and covers, which keep skin drier and cooler to prevent pressure ulcers (also called bedsores).

"Outlast is proud to be in the Space Technology Hall of Fame, which recognizes life-changing technologies emerging from America's space program," says Roda. He concludes, "The relationship with NASA gives us credibility within our various market segments to develop products that bring comfort to people on Earth." ❖

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# Tiny Devices Project Sharp, Colorful Images

## Originating Technology/NASA Contribution

Johnson Space Center, NASA's center for the design of systems for human space flight, began developing high-resolution visual displays in the 1990s for telepresence, which uses virtual reality technology to immerse an operator into the environment of a robot in another location. Telepresence is used by several industries when virtual immersion in an environment is a safer option, including remote training exercises and virtual prototyping, as well as remote monitoring of hazardous environments. Microdisplay panels, the tiny screens that comprise the visual displays for telepresence, are also used in some electronic viewfinders for digital video and still cameras.

## Partnership

In 1993, Johnson Space Center granted a **Small Business Innovation Research (SBIR)** contract to [Displaytech Inc.](#), based in Longmont, Colorado, and recently acquired by Micron Technology Inc., of Boise, Idaho. Under Phase I of this contract, Displaytech began developing miniature high-resolution displays based on its ferroelectric liquid-crystal-on-silicon (FLCOS) technology. Displaytech proposed that pixels could be made small enough to fit a complete high-resolution panel onto a single integrated circuit.

Displaytech first determined how to make a panel that could reproduce grayscale using only standard complementary metal-oxide-semiconductor (CMOS) logic circuitry, which just recognizes binary values (such as a "0" for black and a "1" for white) and was not well suited for subtle shades of gray. Dr. Mark Handschy, Displaytech's chief technology officer, explains the company perfected time-based grayscale techniques in a Phase II follow-on NASA contract: "Because our ferroelectric liquid crystal material can switch faster than the eye can follow, a sequence of displayed black and white images is averaged by the eye into a single grayscale image."

For FLCOS panels to work well, Handschy explains, they need a smooth and shiny wafer top surface. Without this, the pixel mirrors form in the last metal layer on the semiconductor wafer, scatter, and then absorb light,

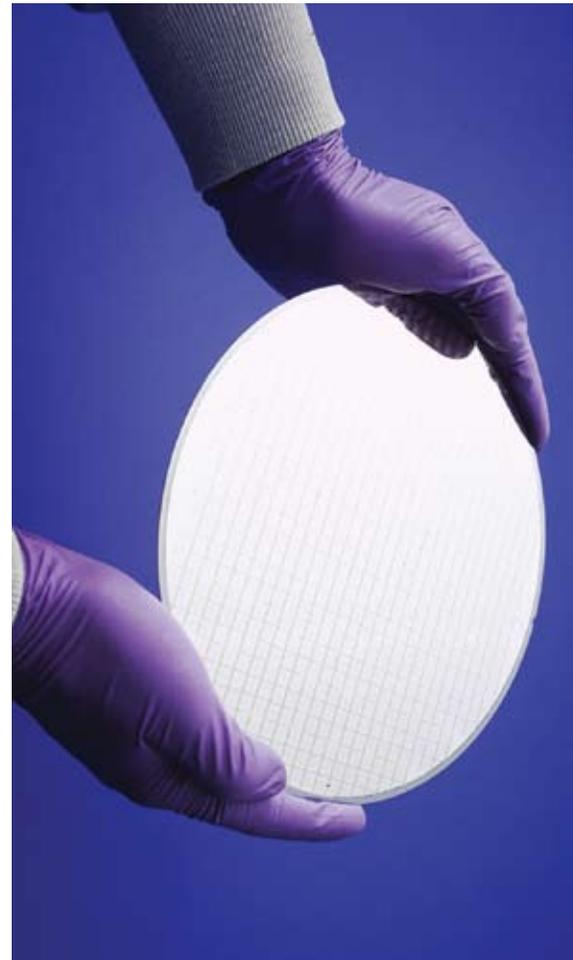


Image courtesy of Displaytech Inc. and Micron Technology Inc.

Ferroelectric liquid-crystal-on-silicon (FLCOS) panels need a smooth and shiny wafer top surface, which is possible with chemical mechanical planarization (CMP), a special technique of polishing semiconductor wafers to allow more metal layers—and smoother integrated-circuit surfaces.

resulting in a dim appearance. "The Phase II of our NASA SBIR came at a very opportune time," Handschy says. "We were able to have an SXGA [super-extended video graphics array] CMOS backplane we'd designed under the NASA project using one of the first commercially available CMP silicon processes." Chemical mechanical planarization (CMP) is a special technique of polishing semiconductor wafers to allow more metal layers—and smoother integrated-circuit surfaces—and was one of the factors that led to Displaytech's success.

Another important development during the mid-1990s was the introduction of efficient blue light-emitting diodes (LEDs). Displaytech took these bright blue LEDs and combined them with red and green LEDs to illuminate its panels, rapidly sequencing through the color LEDs to create the illusion of different hues as they reflect off the panels. "In this SBIR program, we developed grayscale and color for microdisplay panels," Handschy says, "And that was a first for us. We've since leveraged that into a line of products."

## Product Outcome

Displaytech uses its FLCOS technology to apply active matrix displays (individual switching elements) to a tiny silicon chip, with a final product smaller than a thumbnail. These silicon chips are essentially encased in a glass window, Handschy says. "There's this thin layer of fast-switching liquid crystal material which allows that circuitry to drive reflective pixels on the surface of the chip."

The company's first microdisplay panels were used in electronic viewfinders in camcorders and digital still cameras. Since 1990, Displaytech has shipped over 20 million microdisplays to some of the world's largest consumer electronics companies, including JVC America, the Eastman Kodak Company, Olympus Corporation, Hitachi Ltd., Konica Minolta Holdings Inc., Kyocera Communications Inc., and the Hewlett-Packard Company.

Handschy says the company's LightView products, "which all have NASA heritage," are now being used in a new product: pocket projectors, or "pico" projectors. (A pico is a metric unit smaller than a nano.) Until

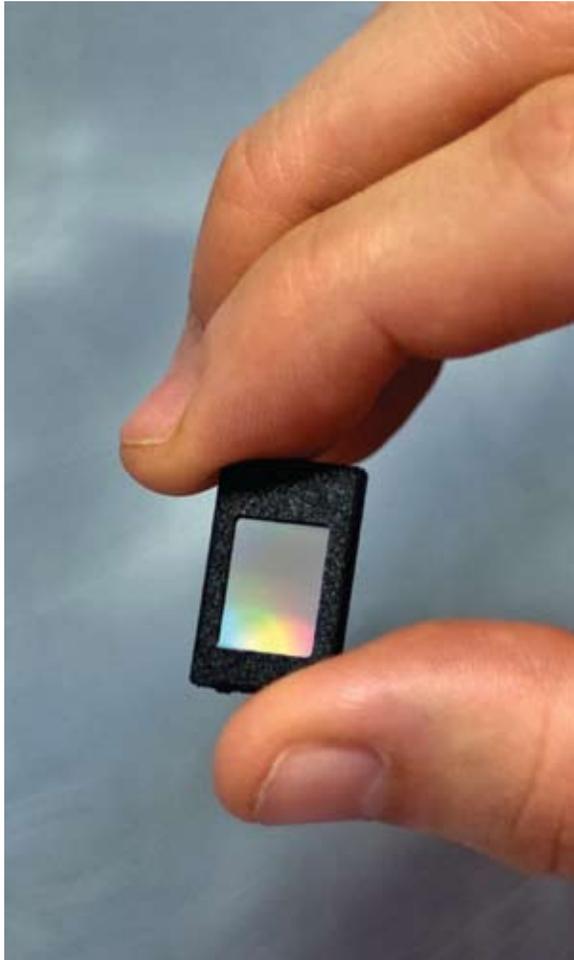


Image courtesy of Displaytech Inc. and Micron Technology Inc.

Displaytech Inc. uses its FLCOS technology to apply active matrix displays to a tiny silicon chip, with a final product smaller than a thumbnail. A thin layer of fast-switching liquid crystal material allows the circuitry to drive reflective pixels on the surface of the chip.

recently, images and videos displayed on media players and cell phones were constrained by tiny, hard-to-see screens, making it difficult to share images, such as for a business presentation.

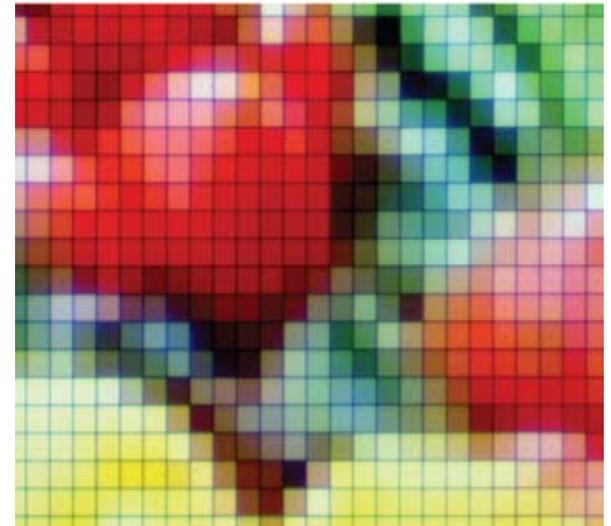
Currently, these pico projectors are sold as separate "accessory projectors" for existing hand-held devices, and attach via a universal serial bus cable. (Future media players and cellular phones will incorporate the pico projectors in their design and will not need any attachments for projection.) In these tiny devices, high-brightness LEDs shine through the microdisplays, magnifying the tiny images into large, colorful, sharp images 50 inches across, projected onto walls or screens large enough for groups of people to view together.

Handschy says the microdisplays are the company's most popular products, whether for camera viewfinders or the new projectors. Currently, camcorders and digital cameras comprise the main market for Displaytech's microdisplays, but pico projectors are soon expected to dominate the company's sales.

"We hope to sell a lot more in the new market of pico projectors," Handschy says. Displaytech customer 3M currently incorporates the microdisplay in its Micro Professional Projector, an accessory projector that weighs only 5.6 ounces and is sold in major office suppliers and electronics retailers. Displaytech believes sales of pico projectors may exceed \$1.1 billion within 5 years. Today, the company's research and development is funded primarily from product revenue, but Handschy says Displaytech is still open to more contracts or collaborations with NASA.

In May 2009, Displaytech and Micron Technology Inc. announced Micron's acquisition of Displaytech to broaden its semiconductor offerings, including products for pico projectors. ❖

Displaytech® is a registered trademark of Micron Technology Inc.  
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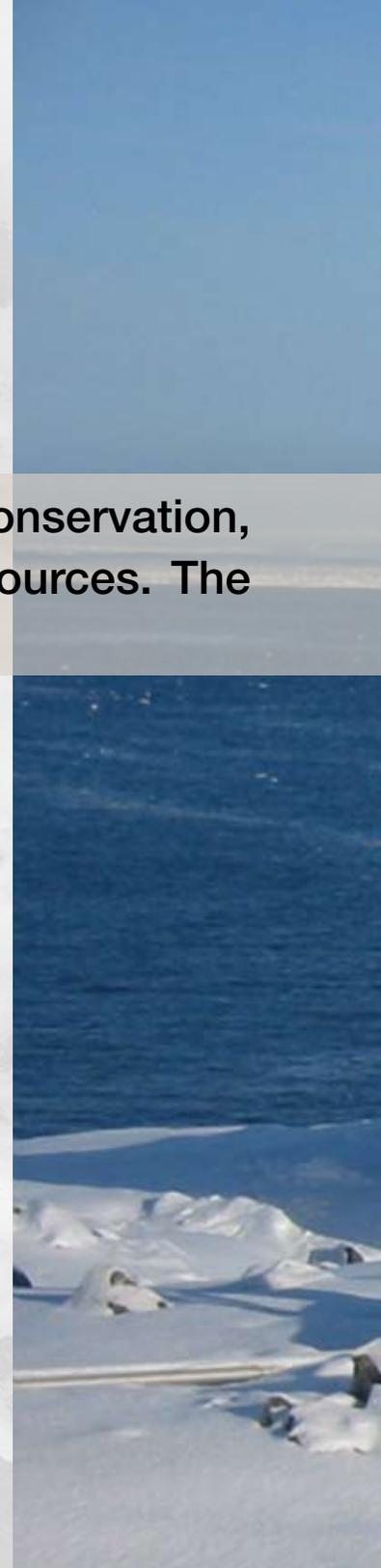
The individual pixels in Displaytech's LV-SVGA panels display a greater range of colors than previous microdisplays, due in part to technology the company developed with an SBIR from Johnson Space Center.

# Environmental and Agricultural Resources



Whether through satellite observations or advances in energy conservation, NASA research helps to sustain our Earth and its valuable resources. The technologies featured in this section:

- Enable Tracking of Endangered Animals
- Eliminate Contaminants
- Advance Wind Energy Industry
- Conserve Energy
- Identify Ocean Debris
- Measure Atmospheric Pollutants
- Offer New Details on Earth's Health
- Lower Cost of Satellite Access
- Enhance Satellite Imagery
- Aid Plant Nutrient Management





# Star-Mapping Tools Enable Tracking of Endangered Animals

## Originating Technology/NASA Contribution

**T**ry this: Print out a lower-case letter “o” in Times New Roman, 10-point font. Now hold the paper at arm’s length. Viewed from this distance, the area inside the “o” is approximately equal to the area observed in the Hubble Ultra Deep Field, an image taken by the Hubble Space Telescope. Within that space—only one thirteen-millionth of the sky’s total area—Hubble revealed approximately 10,000 galaxies, each containing billions of stars. The observable universe as a whole contains some 80 billion galaxies and anywhere between 30 and 70 billion trillion stars.

In order to map the intimidating fields of stars Hubble—among other sensitive telescopes—would uncover following its launch in 1990, astronomers needed a powerful tool for comparing and matching star configurations within the telescope’s collected images. In 1986, Princeton University physics professor Edward J. Groth, supported by the Hubble Space Telescope program, invented a pattern-matching algorithm that addressed the challenge. The Groth algorithm forms triangles between every possible triplet of stars in an image (each star’s position being represented by an x-y coordinate pair). It then

compares the triangles’ measurements to those in other images, determining any matches. Because certain properties of a triangle do not change if the triangle is rotated or altered in size, the algorithm allows astronomers to effectively map star locations using images of different magnification and orientation.

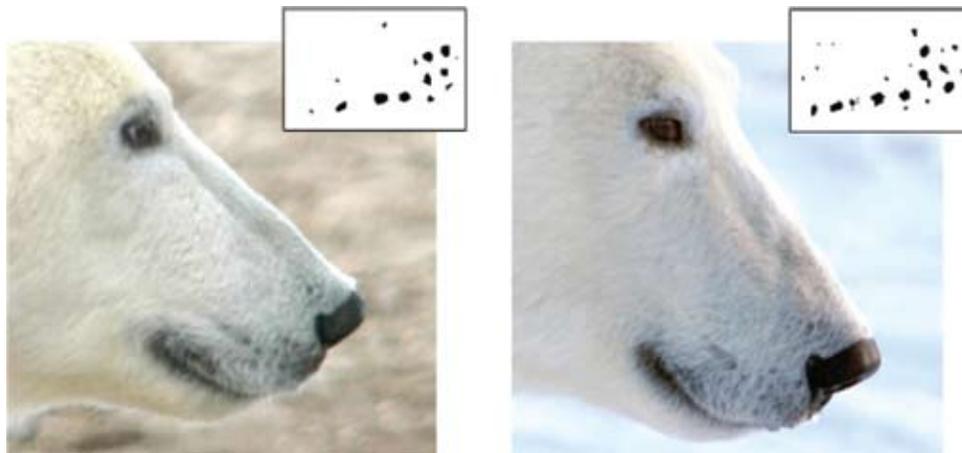
The Groth algorithm was incorporated into the Space Telescope Science Data Analysis System (STSDAS), a software suite for calibrating, analyzing, and reducing data gathered by Hubble. An updated version of the algorithm is still part of STSDAS, which is available to the public from the Space Telescope Science Institute, a NASA partner located in Baltimore, involved with management of Hubble and the currently under-development James Webb Space Telescope.

## Partnership

In 2002, Portland, Oregon, software programmer and technical writer Jason Holmberg had a rare encounter with a whale shark while scuba diving in the Red Sea. Growing to lengths of up to 40 feet, the filter-feeding whale shark is the world’s largest—and among its least understood—fish species. It is also listed as vulnerable to

extinction by the International Union for Conservation of Nature. Fascinated, Holmberg began toying with ideas to help improve methods for tracking the unusual fish. (Physically tagging the sharks for satellite tracking proves inefficient because the tags are frequently lost or rendered inoperative within weeks or a few months; with plastic visual tags, less than 1 percent are spotted again after tagging.) Holmberg eventually teamed with marine biologist Brad Norman, founder of the Perth, Australia, nonprofit [ECOCEAN](#), which studies the whale sharks that migrate annually through Western Australia’s Ningaloo Marine Park. Norman had been tracking the Ningaloo sharks by photographing and identifying each shark from the distinctive white spots on its skin, a marker as unique as fingerprints are in humans. The process was a tedious one; Norman had to examine and compare all photos by eye.

For help conceiving a computer-based tracking system, Holmberg turned to friend Dr. Zaven Arzoumanian, an astrophysicist with Universities Space Research Association on contract at Goddard Space Flight Center, who contributed to the undertaking as a side project independent of his NASA duties. The pair were contemplating the challenge of identifying whale sharks in an automated way when they encountered the Groth algorithm, which provided an ideal basis for creating a pattern-matching program using shark spots instead of stars in the universe. (Fittingly, the whale shark’s name in Madagascar, “marokintana,” means “many stars,” while “geger lintang,” its Javanese name, means “stars in the back.”) Holmberg and Arzoumanian modified the algorithm, applying a technique called blob extraction to pinpoint single-color pixel groups—a useful tweak since the whale shark’s spots are larger and more irregular in shape than stars in photographs. They also introduced rotation correction and contrast enhancement elements to clarify photos, compensate for perspective issues (the sharks are rarely photographed in perfect profile), and take into account 3-D qualities not present in space images.



Researchers at the University of Central Florida track polar bears by using the bears’ unique whisker spot patterns to match photographs taken by researchers and tourists.

“What we did in practice was make a very precise algorithm a little less precise,” says Arzoumanian. Since its completion in 2005, the modified Groth algorithm has proven to be highly effective: When a match between photographs is made, the algorithm ranks the correct shark as the first of all possible matches more than 90 percent of the time.

## Product Outcome

Holmberg built a database system around the algorithm that allows anyone, from researchers to tourists, to submit whale shark photographs for comparison and identification online. Called the ECOCEAN Whale Shark Photo-identification Library, the system has been used by ECOCEAN to collect images of over 1,600 whale sharks so far, providing a continuing data span that is helping researchers to learn more about the life histories and migration patterns of the elusive fish, as well as the status of the whale shark’s threatened population.

“We’re getting reliable population models, and we’re challenging a lot of previous conceptions about whale sharks,” says Holmberg, who notes that findings indicate the sharks may not be as massively migratory as once thought, nor may their numbers be declining, at least at Ningaloo Marine Park, as with most shark species. Photographs are now streaming into the ECOCEAN database from places as diverse as California, Mozambique, Belize, Honduras, and the Maldives. Holmberg credits this to the impact of ecotourism and the “citizen scientist,” the average person contributing valuable scientific information.

“The general public collects a lot of data,” he says. “We’re talking about an animal considered to be rare, maybe a couple of hundred documented sightings in all of history. Now, just this year, we’ll get over 2,400.” Holmberg is now working on a simplified version of the software for easier use by individual researchers studying other species.



Thanks to a modified NASA algorithm, the general public can now help marine biologists track rare species like whale sharks.

The successful application of the modified Groth algorithm has attracted significant attention from scientific circles. Last year, researchers at the University of Central Florida (UCF), in Orlando, adapted the whale shark algorithm as part of a package for tracking polar bears. A threatened species in the United States, polar bears can be tracked using their own individually unique trait: the whisker spots on their muzzles. UCF researchers are compiling a database of photographs with the help of tourists visiting Churchill, Canada, a popular destination for polar bear enthusiasts. The polar bear population at Churchill has been declining dramatically, according to the Canadian Wildlife Service.

“This virtual mark-recapture capability allows people who are going to an ecotourism environment to have a positive effect on the animals. They all become our field assistants in a way,” says Jane Waterman, associate professor of biology and one of the principal investigators of the polar bear project. The database will provide an essential resource for understanding bear behavior and monitoring

the bear population as the species suffers the effects of global warming.

The polar bear library is only the most recent application of the pattern-matching algorithm. “We’ve had lots of people approach us from various animal-tracking communities,” says Arzoumanian. California researchers are considering adapting the algorithm to track *Mola mola*, the ocean sunfish that frequents the waters off the Galápagos Islands. And the Megafishes Project, a collaboration between the National Geographic Society and the World Wildlife Fund, may apply it to track giant Eurasian trout in Mongolia. In theory, the algorithm can be applied to track any animal with unique spotting that does not change as it ages.

“There’s a groundswell of data we’re getting,” says Holmberg, “and it all goes back to the algorithm Edward Groth wrote years ago.” ❖

# Nanofiber Filters Eliminate Contaminants



## Originating Technology/NASA Contribution

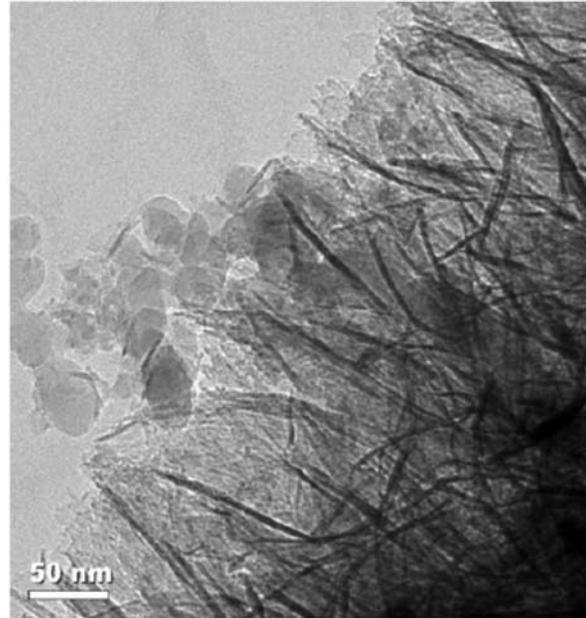
Water, an increasingly precious commodity on Earth, has always been priceless in space; but “priceless” is a figure of speech—water in space does have a price, and it is an expensive one. A single gallon of water costs over \$83,000 to launch just into low-Earth orbit. Despite recent NASA innovations that allow astronauts to derive potable water from their own sweat and urine and technologies that may one day extract water from buried glaciers on Mars, the availability of water in space is not likely to exceed its necessity. This means methods for recycling and purifying water remain a top concern for the Space Program.

## Partnership

NASA’s Johnson Space Center awarded [Argonide Corporation](#), a nanomaterials company, headquartered in Sanford, Florida, a Phase I **Small Business Innovation Research (SBIR)** contract in 2000 and a Phase II SBIR contract in 2002. Argonide had developed unique filtration media with the potential to revolutionize water purification and provide methods for sanitizing recycled water in space. Working toward a basic tool for water recirculation during long-term space flight, Argonide used its Phase I research to build on its proprietary technology, initially developing laboratory filter discs and syringes. During Phase II, it researched and tested the nanofiber media’s virus filtration properties and its ability to absorb DNA and RNA. Argonide also developed NanoCeram cartridges providing superior purification for drinking water applications. The NanoCeram

*“Our NASA-funded research provided us with information, know-how, and techniques that enabled us to develop our current technology.”*

cartridges providing superior purification for drinking water applications. The NanoCeram



The NanoCeram water filter’s nanoalumina fibers are shown here capturing fumed silica particles of a similar size to viruses.

water filter was an *R&D Magazine* “R&D 100” award-winning technology in 2002 and was inducted into the Space Foundation’s Space Technology Hall of Fame in 2005.

The special ingredients of Argonide’s nonwoven filtration media are nanoalumina fibers made up of the mineral boehmite. The NanoCeram fibers—each 2 nanometers in diameter and 200–300 nanometers in length (for comparison, a sheet of paper is roughly 100,000 nanometers thick)—are attached to microglass strands. The result looks like nanosize mascara brushes. With a surface area of as much as 500 square meters per gram, the fibers produce an electropositive charge when water flows through them. Many impurities carry a slight negative charge and are thus absorbed by the nanoalumina. A single layer of the resulting media,



The filtration capabilities of these NanoCeram PAC cartridges are enhanced by powdered activated carbon. The Disruptor media can retain virtually any nanopowder, adapting to remove specific contaminants from water.

though it has a pore size of about 2 microns, is capable of removing greater than 99.99 percent of 0.025 micron particles, thanks to this property. (Three layers remove up to 99.9999 percent.) Some of the many impurities the filter media remove are bacteria, viruses, cysts, organic debris, parasites, and dissolved and particulate metals such

as iron and lead. Its large pore size relative to the particles it eliminates means the filter achieves the grail of filtration media: high flow with high dirt-holding capacity and low pressure drop.

“Our NASA-funded research provided us with information, know-how, and techniques that enabled us to develop our current technology,” says Fred Tepper, Argonide’s founder and president.

## Product Outcome

Since Argonide’s nanoalumina filtration media was first featured in *Spinoff* 2004, its production has expanded, thanks to a licensing agreement that has resulted in a host of new applications and recognitions. In 2006, the company exclusively licensed the filter media to Ahlstrom Corporation, a leading specialty paper and nonwoven roll goods manufacturer, headquartered in Finland, with multiple plants and offices in the United States. Ahlstrom began mass-producing and globally promoting the technology under the name Disruptor.

Ahlstrom’s large-scale production capabilities gave Argonide access to mass quantities of the nanofiber media for large-scale production of its NanoCeram filter cartridges. It scaled up the size of its cartridges, ultimately producing 4½-inch-diameter by 40-inch-long cartridges, which according to Tepper allowed Argonide to move beyond the retail market and into the industrial and municipal sectors.

In mid-2007, Argonide’s new NanoCeram filters caught the eye of major automobile manufacturer Toyota. Concerned with reducing the size of its U.S. plants’ “water footprint”—the amount of water the plants consume—the company had committed to scaling back its water use during manufacturing from the Toyota-standard 900 gallons per car to 300 gallons. In order to purify recycled water, Toyota uses reverse osmosis (RO) membranes, which tend to foul easily, even with the use of standard prefilters. Toyota was using prefilters that let through too many RO-membrane-fouling particles; in one plant, this

required the expensive membranes to be replaced every 2 to 3 months. Since utilizing the NanoCeram cartridges as prefilters in that plant, the RO membranes have yet to require cleaning or replacement. Toyota has also used NanoCeram filters to cleanse the roughly 16 miles of chill water pipes in a typical plant. The filters have solved a long-standing corrosion problem by removing its cause: iron oxide and the bacteria that feeds on it.



Argonide’s SBIR-developed NanoCeram filters are already yielding significant benefits for industrial water filtration and may soon do the same for municipal water supplies.

Argonide’s filtration media continues to evolve. Ahlstrom is now producing the nanoalumina media with a new component: powdered activated carbon (PAC), which is retained by the nanofibers and enhances the media’s filtration abilities even further. The Disruptor PAC media, which Argonide uses to create its NanoCeram PAC cartridges, has been certified for the purification of drinking water by NSF International, a nonprofit, non-governmental group that certifies products for public health and safety. Tepper notes that the nanoalumina media can retain virtually any nanopowder desired, meaning it can be adapted to remove specific contaminants from water.

That kind of efficiency and versatility has the nanofiber media poised to be a major player in a number of burgeoning applications. Tepper expects that, by 2011, the U.S. Environmental Protection Agency (EPA) will require municipalities to monitor their water for viruses. (Currently, only bacteria monitoring is required, though Tepper says viruses cause roughly 50 percent of water-borne gastrointestinal illnesses.) The EPA has expressed satisfaction with the NanoCeram filter as a virus sample collector in such a monitoring capacity. In addition, “The desalination business is growing by leaps and bounds,” says Tepper, who points out that the RO membranes used in extracting fresh water from our planet’s oceans will benefit, like Toyota’s, from NanoCeram prefilters that remove the cellular material that causes membrane biofouling. And, he notes, all municipal water ultimately will be RO treated as well, providing another opportunity for Argonide and NASA to benefit Earth’s water supplies. ❖

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Disruptor™ is a trademark of Ahlstrom Corporation.

# Modeling Innovations Advance Wind Energy Industry

## Originating Technology/NASA Contribution

One morning in 1990, a group of Glenn Research Center (then Lewis Research Center) employees arrived to find their workspace upended by an apparent hurricane. Papers were scattered, lights blown out. All eyes turned to the door connecting the office to its neighbor: a 20-foot wind tunnel.

The employees did not know it, but they had Dr. Larry Viterna to thank for the state of their workspace. An innovation by the NASA researcher may have led to the accidental trashing of their office, but it would go on to benefit the entire field of wind energy.

Viterna joined NASA in 1977, during a time when the country was in an energy crisis. Growing anxiety over fuel costs and environmental impacts led the U.S. Government to explore alternative and renewable energy sources. In a time prior to the formation of the Department of Energy (DOE), the government turned to other agencies like NASA to develop solutions. Glenn had a history of energy research stemming from its work in fuel-efficient aeronautics during World War II and in alternative fuels and related aerospace engines at the start of the Space Age in the 1950s. When Viterna joined the Center, it had already assumed the lead role in the Nation's wind energy program. NASA's goal was to develop technology for harnessing the wind's power and transfer it to private industry.

"Our center had an expertise in propellers, propulsion, rotating equipment, and power systems," making Glenn a natural choice for the job, explains Viterna. The Center's efforts, he says, ultimately laid the foundations for much of the wind technologies and industry that exist today.

Glenn constructed its initial experimental 100-kilowatt (kW) wind turbine at the Center's Plum Brook Station facility in Sandusky, Ohio in 1975. The Mod-0 turbine was a two-bladed, horizontal turbine. By 1978, the 2-megawatt (MW) Mod-1, the world's



first multimewatt wind turbine, was developed—capable of providing electricity to thousands of homes. Successive experimental models (13 in all) were built throughout the country. Viterna notes that these were also record setting in size and output; the 4-MW capability of the WTS-4 turbine, built in 1982 in Medicine Bow, Wyoming, was not surpassed for about 25 years.

"That's how far ahead the program was in terms of developing this technology," Viterna says.

NASA's efforts also led to other industry innovations that are standard today. As Glenn researchers explored ways of reducing the weight and cost of turbine structures, they developed steel tube towers that replaced the rigid truss towers traditionally used. "Today, virtually every large wind turbine uses a steel, tubular tower, which was novel technology at the time," says Viterna.

Despite the advances made by the NASA-led program, there were still significant challenges. "One of the key things then and now is to accurately predict the forces exerted on a wind turbine," Viterna says. On a basic level, wind turbines function by the same forces that allow airplanes and helicopters to fly. Wind blowing over the turbine's blades, or airfoils, creates lift that turns the blades, spinning a shaft that connects to an electricity-producing

For over 20 years, NASA's 4-megawatt WTS-4 wind turbine held the world record for maximum power output.

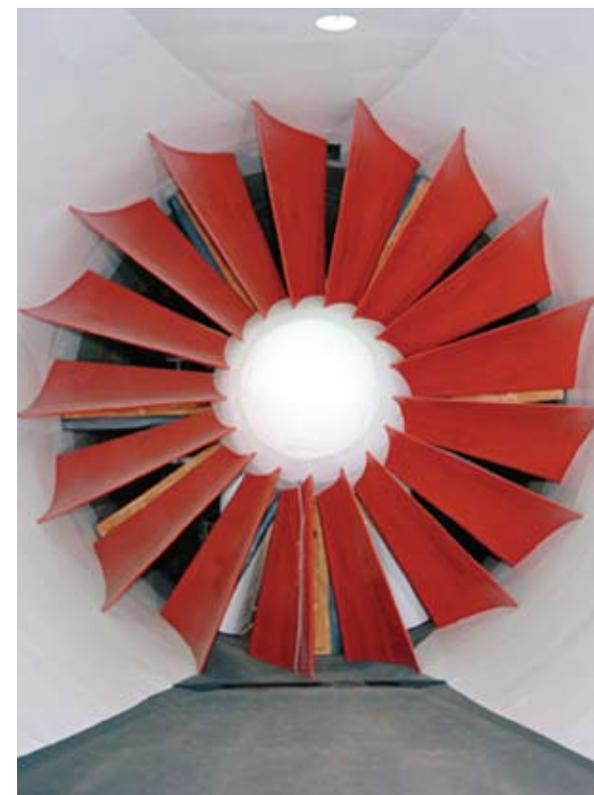


Glenn Research Center's Icing Research Tunnel (IRT), built at the end of World War II to study aircraft icing, is one of the world's largest refrigerated wind tunnels and currently the Center's busiest facility.

generator. When engineers first began to model the impact of these forces on wind turbine airfoils in high-wind conditions, they would produce results that were off by at least 50—and sometimes as much as 100—percent.

The problem was that wind turbines, unlike most other airfoil-based systems, operate at a high angle of attack—the angle formed between the chord of an airfoil

and the direction of the airflow. (A chord is an imaginary line through an airfoil's cross-section, joining the tip of the trailing edge to the center of the leading edge.) In airplanes, when the angle gets too large, the laminar air flow that typically hugs the wing begins to detach and become turbulent, reducing lift and increasing drag; at a certain point, the plane stalls and drops out of the



By shaving the IRT's wooden fan blades in accordance with the results of Dr. Larry Viterna's model, Glenn engineers boosted the tunnel's top wind speed by over 130 miles per hour.

sky. (This could theoretically happen with helicopter blades as well, but these vehicles do not operate near stall conditions.) Wind turbines, especially in high-wind conditions, can routinely stall, limiting the ability of the turbine to produce electricity. The inability to properly predict stall behavior, actual aerodynamic loads, and the relationship between wind speed and power in wind turbines led to inefficient designs and costly turbine failures. At the time, there was a significant lack of research and data in this area, Viterna explains, as well as

“three-dimensional effects going on that we had no way of calculating or even measuring.”

In 1981, using data previously collected from an old Danish turbine, coupled with test data gathered by fellow NASA researcher Robert Corrigan from the Plum Brook turbine, Viterna developed a model that took into account three-dimensional effects and predicted stall behavior with far greater accuracy than previous methods.

The model was not well accepted by colleagues in the wind energy field, Viterna remembers. “I almost got laughed off the stage when I presented it,” he says, explaining that the model violated existing theories that used two-dimensional airfoil data. Viterna, however, continued to employ the model for NASA’s purposes, even using it in 1991 to improve Glenn’s Icing Research Tunnel, designed to study the effects of ice buildup on aircraft. Based on the model’s results, Viterna suggested that slightly shaving down the wood fan blades could boost the tunnel’s 299-miles-per-hour (mph) capability. During a nighttime test, the wind tunnel’s pressure release door flew open, sending 400-mph winds ripping through the adjoining work area. (The tunnel’s new upper limit after implementing Viterna’s model: 430 mph.) The surprise Viterna’s coworkers encountered the following morning was on par with what Viterna experienced during a random Internet search nearly 25 years after inventing his model.

## Partnership

In 2005, long after the easing of the energy crisis and shift of the wind energy program to the DOE, Viterna, now in Glenn’s Office of Strategic Management, was searching the Internet when he began to come across multiple references to the “Viterna method” by experts in the wind energy field. He discovered his initially criticized model had, within a decade of its creation, quietly become the established method of modeling the performance of wind turbine airfoils under high angles of attack—stall conditions.

***Viterna has discovered his once-mocked model is now employed for vertical wind turbines, wind tunnels, and even underwater turbines.***

Renewable Energy Laboratory’s National Wind Technology Center (NWTC), located in Boulder, Colorado. In 2005, the center added the Viterna model to its design-code software suite for horizontal-axis wind turbines, the most popular variety of turbines in use today.

“Viterna’s model does a very effective job of estimating stall behavior on inboard sections of the blade and how it varies along the blade’s span,” says Dr. Sandy Butterfield, wind program chief engineer at the NWTC. “Even though it was invented in the 1980s, it remains a model used by engineers predicting performance and loads for wind turbines.”

The NWTC suite—which offers design and analysis software tools for use in achieving worldwide certification of wind turbines—incorporates Viterna’s model in its FoilCheck preprocessor. FoilCheck allows users to generate airfoil tables and compute dynamic stall parameters for use in NWTC’s AeroDyn software library, which enhances the center’s YawDyn, FAST, and ADAMS turbine simulators. The entire suite is available to private industry for free, which has enabled wind turbine manufacturers like Westport, Massachusetts-based [Aerostar Inc.](#) to use Viterna’s method to help craft their products.

“It had become, and still is, the most widely used stall model in the United States,” says Viterna, who along with Corrigan recently received a “Space Act Award” from NASA’s Inventions and Contributions Board, as well as the Agency’s inaugural “Blue Marble Award” at its Environmental and Energy Conference.

Among the many who use the Viterna method is the DOE’s National



Aerostar’s wind turbines are stall regulated, a feature enabled by the Viterna model.

## Product Outcome

Aerostar produces a 6-meter, 10-kW wind turbine, the design for which was developed in the 1980s by company president Paul Gay, as well as a recently added 11-meter, 30-kW model. Aerostar wind turbines are designed to provide electricity to individual homes, farms, and remote locations with limited or no connection to the power grid. As opposed to a rigidly mounted, three-blade design—the three blades commonly seen on wind turbines today are a feature imported from Denmark and Germany, which became the main technology drivers in wind energy following NASA’s major involvement—Aerostar’s turbines feature teetering, two-bladed rotors like NASA’s early models. This design helps lower the weight and cost of the structure by reducing the large, gyroscopic loads typically inflicted on the turbine and its tower.

The company’s turbines belong to a class called fixed pitch turbines. The rotors of fixed pitch turbines turn at a relatively constant speed regardless of the current wind speed. This is in contrast to variable speed turbines (a NASA-developed technology), in which the rotor speed varies with the wind speed. While variable speed turbines have the advantage of producing more power as wind speeds increase, the frequency, voltage, and current of their output also varies, requiring a line commutated inverter to make the output compatible with the power grid. Fixed pitch turbines like Aerostar’s, however, use induction motors to produce electricity. The same kind of motor used in common technologies like water pumps and air conditioners, an induction motor transforms into a generator when its shaft rotates at speeds faster than it turns as a motor. The induction generator is already in phase with the electrical current supplied by the power grid, so the cost and inefficiency of an additional inverter is unnecessary.

Because Aerostar’s turbines are of this variety, the Viterna model plays a major role in the manufacture of its products. The company employs the NWTC suite,



The teetering, two-bladed rotor of Aerostar’s wind turbines is similar to that of NASA’s early designs.

including FoilCheck, when designing its wind turbines. Utilizing the Viterna method through this software has enabled Aerostar to create efficient, effective turbine designs, says Gay.

“The model makes it possible for manufacturers like us to predict and characterize the performance of airfoils for these turbines,” he says. Viterna’s model is highly important to Aerostar’s turbines because, like many fixed pitch turbines, they are actually regulated by stall, the conditions Viterna’s model was the first to accurately predict for wind turbine airfoils.

A constant-speed rotor will only operate effectively in a narrow range of wind speed, Gay explains. Above that range, the airfoils go into stall, and power production tapers off. Aerostar’s turbines and many others utilize stall regulation as an automatic, passive way of managing the turbine at high wind speeds—like a built-in power governor. This eliminates the need for moving parts, which are required for blade pitching, furling, and other active power-limiting devices.

“If you can’t calculate how the rotor performs at these higher wind speeds, you might find it producing way too much power, burning out the generator,” Gay says. Being able to accurately predict stall behavior allowed for this kind of control, says Viterna.

“We were trying to simplify the design of wind turbines early on to get the market going,” Viterna says. “It was very important to get the entire industry off and running with a design capable of operating reliably in a passive control mode.” (The effort worked: Fixed pitch turbines comprised 60 percent of turbines worldwide by 1991.)

The Viterna method is finding applications beyond horizontal wind turbines; Viterna has discovered his once-mocked model is now employed for vertical wind turbines, wind tunnels, and even underwater turbines that make use of tidal energy to produce power. In the meantime, NASA continues to be involved in the advancement of wind energy; Glenn, for example, is supporting the plans of Cuyahoga County, Ohio, to establish on Lake Erie the world’s first freshwater, offshore wind turbine site.

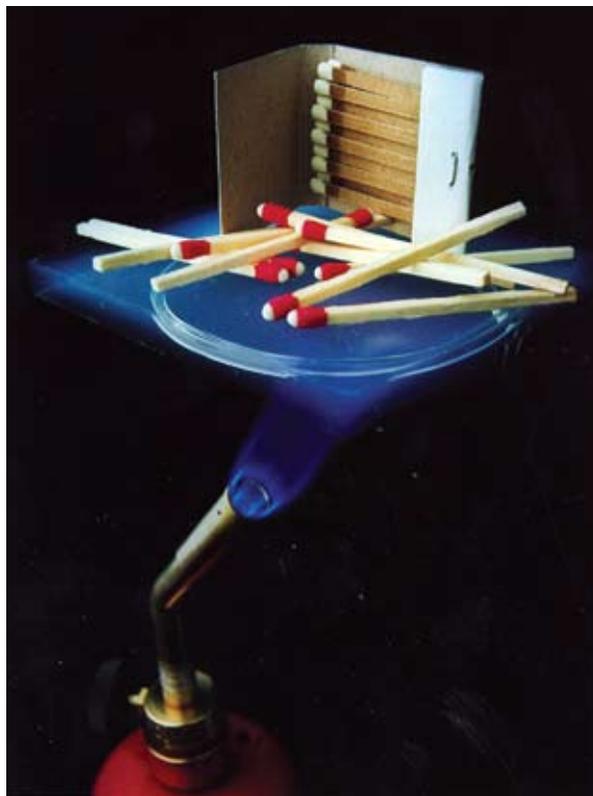
The Agency can also expect to see its early work experience a resurgence, predicts Dr. Butterfield of the NWTC. “As the industry moves forward and becomes more competitive and broad, you will see efforts to explore lower cost, more structurally efficient machines, and that’s when people will begin to capitalize again on that good work NASA did in the early 1970s and 1980s,” he says. It seems likely that Viterna’s and NASA’s pioneering work will continue to play a significant role given the Nation’s ambitious energy goals: The DOE has outlined a plan for generating as much as 20 percent of the country’s energy from wind power by 2030. ❖

# Thermal Insulation Strips Conserve Energy

## Originating Technology/NASA Contribution

Launching the space shuttle involves an interesting paradox: While the temperatures inside the shuttle's main engines climb higher than 6,000 °F—hot enough to boil iron—for fuel, the engines use liquid hydrogen, the second coldest liquid on Earth after liquid helium.

Maintained below 20 K (-423 °F), the liquid hydrogen is contained in the shuttle's rust-colored external tank. The external tank also contains liquid oxygen (kept below a somewhat less chilly 90 K or -297 °F) that



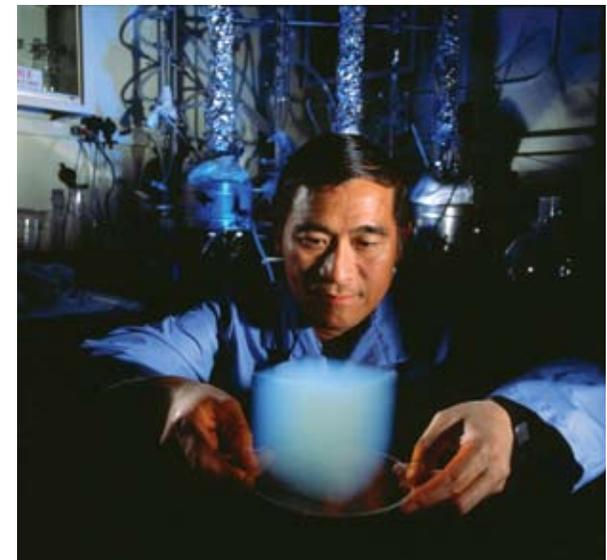
The remarkable insulating properties of aerogels have made them the focus of significant NASA research.

combines with the hydrogen to create an explosive mixture that—along with the shuttle's two, powdered aluminum-fueled solid rocket boosters—allows the shuttle to escape Earth's gravity.

The cryogenic temperatures of the main engines' liquid fuel can cause ice, frost, or liquefied air to build up on the external tank and other parts of the numerous launch fueling systems, posing a possible debris risk when the ice breaks off during launch and causing difficulties in the transfer and control of these cryogenic liquid propellants. Keeping the fuel at the necessary ultra-cold temperatures while minimizing ice buildup and other safety hazards, as well as reducing the operational maintenance costs, has required NASA to explore innovative ways for providing superior thermal insulation systems. To address the challenge, the Agency turned to an insulating technology so effective that, even though it is mostly air, a thin sheet can prevent a blowtorch from igniting a match.

Aerogels were invented in 1931 and demonstrate properties that make them the most extraordinary insulating materials known; a 1-inch-thick piece of aerogel provides the same insulation as layering 15 panes of glass with air pockets in between. Derived from silica, aluminum oxide, or carbon gels using a supercritical drying process—resulting in a composition of almost 99-percent air—aerogels are the world's lightest solid (among 15 other titles they hold in the *Guinness World Records*), can float indefinitely on water if treated to be hydrophobic, and can withstand extremely hot temperatures (from 1,100 °F to 3,000 °F depending on the type of aerogel) down to cryogenic levels, making this “frozen smoke” ideal for use in space. Because of its low weight and ability to withstand temperature extremes, an aerogel was even used as the space-based catcher's mitt to trap comet particles and space dust for NASA's Stardust mission, launched in 1999.

All of this remarkable technology's characteristics were ideal for NASA's purposes except one: The aerogels were extremely brittle. Through a long-term partnership



Despite a ghostly appearance like a hologram, aerogels feel like Styrofoam. A NASA partnership led to flexible aerogels found in commercial applications today.

between Kennedy Space Center and Aspen Aerogels Inc., of Northborough, Massachusetts, researchers developed a flexible, durable form of aerogel that NASA has since used as cryogenic insulation for space shuttle launch systems. Through Aspen Aerogels, the technology has made oil pipeline insulation, extreme weather clothing, and infrared shielding for combat helicopters.

## Partnership

Aspen Aerogels, which developed the “R&D 100” award-winning flexible aerogels under **Small Business Innovation Research (SBIR)** contracts with Kennedy, approached [Acoustiblok Inc.](#), of Tampa, Florida, to perform acoustical testing on its Spaceloft flexible aerogel to explore the potential for enhancing the aerogel's sound-muffling capabilities. Acoustiblok is an industry leader in acoustical insulation (one-eighth of an inch of Acoustiblok, the company's proprietary acoustical

insulation, reduces more sound than 12 inches of concrete when added to a stud wall) and has previously conducted research with NASA on floor resonance—reducing sound from one floor of a building to the next. Impressed by the aerogel’s qualities, Acoustiblok considered aerogel products for enhancing energy efficiency that could take advantage of the company’s expertise in providing sound insulation for buildings and other applications.

While a great deal of energy conservation efforts focus on transportation, “Estimates are that over 50 percent of the energy in the United States is used within buildings,” says Lahnne Johnson, Acoustiblok’s president and founder. He also notes that energy consumption in buildings results in an estimated 46 percent of the Nation’s carbon emissions. Because of this, Acoustiblok saw great potential in engineering a narrow strip of flexible aerogel to be applied to wall studs in buildings to break the thermal transfer (thermal bridging) between the interior and exterior of building walls. The companies arranged for Acoustiblok to take over the production and marketing of this aerogel application.

## Product Outcome

Thermal bridging is an acute problem when it comes to insulating buildings, says Johnson. Over 30 percent of the energy used for temperature control in buildings escapes through walls, more than through the floor, windows, or roof, which is why Johnson foresees a significant impact from his company’s aerogel product: Thermablok.

“We see Thermablok as having incredible market potential and providing a benefit to people all over the world,” he says.

Manufactured by Acoustiblok, Thermablok is a thin, 3/8-inch-thick by 1/2-inch-wide strip of flexible aerogel in a plastic casing with a peel-and-stick adhesive backing. The strips are 100-percent recyclable, comprised of more than 30-percent recycled material, and allow low-cost, low-emissions shipping due to their virtually weightless composition. According to tests conducted



Thermablok strips are easily applied to wall studs, providing an affordable and environmentally friendly boost to a wall’s insulation factor.

by the U.S. Department of Energy, a 1/4-inch-thick strip of Thermablok applied to wall studs before the installation of drywall increases the wall’s insulation factor by 30 percent; a 3/8-inch-thick strip produces an increase of 42 percent. As an example, Acoustiblok notes that a typical 2,400-square-foot Midwest home (16-inch, on-center stud framing; standard insulation; wood siding) outfitted with Thermablok would save over \$700 annually in energy costs with an accompanying 3.9-ton reduction in carbon dioxide emissions. The strips can be easily cut to any length and applied using the adhesive backing or staples.

Johnson says Acoustiblok is currently acquiring numerous construction contracts and getting Thermablok, which is also available in sheet form, specified into public and commercial buildings. Thermablok’s hydrophobic qualities (which also render it age-resistant) make it suitable for marine applications as well. Johnson says Thermablok will see use in industrial and commercial boats and in oil rigs and refineries, where piping that is both extremely loud and extremely hot will benefit from Thermablok and Acoustiblok layered together. Lumber yards and commercial chain stores like Home Depot and Lowes are expressing interest in selling the product, as well.

Acoustiblok also plans to take advantage of the popularity of its acoustical insulation in the Middle East, where privacy is highly valued, to meet the need there for superior thermal insulation. Johnson anticipates developers specifying Thermablok into mega building projects in the region.

“This is a U.S. product, a U.S. patent,” says Johnson. “It will bring significant cash flow into the U.S. while also benefiting people in other countries.”

Johnson traces Thermablok’s potential worldwide impact back to NASA research and development. “NASA is doing things that we just can’t afford to do here in free enterprise,” he says. “It’s important people realize the real benefits of NASA’s work and how it trickles down into many aspects of our world today.” ❖

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***A typical Midwest home outfitted with Thermablok would save over \$700 annually in energy costs.***

# Satellite-Respondent Buoys Identify Ocean Debris

## Originating Technology/NASA Contribution

NASA operates a series of Earth-observing satellites, which help scientists learn more about our home planet. Through partnerships with universities and other government agencies, like the National Oceanic and Atmospheric Administration (NOAA), the Space Agency helps scientists around the world capture precise movements of the Earth's crust to learn more about the underground processes related to earthquakes and volcanic eruptions, create accurate assessments of wind resources for future energy use, and preserve endangered species by generating much-needed data about their environments. This work, done primarily from space with satellites using a variety of complex instruments to take readings of the surface below, generates leagues of valuable data that aid scientists on the ground—or in some cases—on the water.

As much of the Earth is covered in water—liquid, frozen, saltwater, or fresh—much of NASA's remote sensing work focuses on the oceans and their health. This valuable, mammoth (yet fragile) resource provides insight into the overall health of our planet, as water, in addition to being abundant, is a key ingredient to all known life on Earth.

As part of its ocean-observing work, NASA partnered with NOAA and private industry to develop remote sensing technologies for protecting the seas of the North Pacific from a nefarious and pervasive problem: derelict fishing gear.

## Partnership

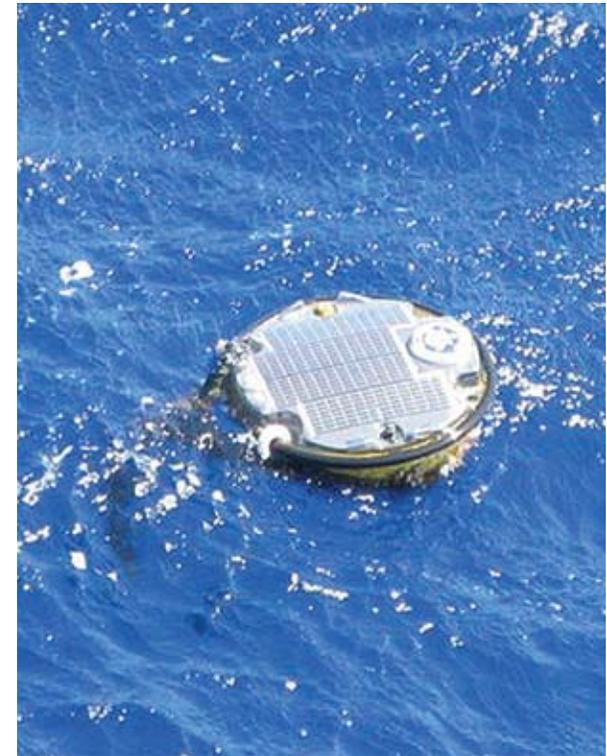
**Airborne Technologies Inc. (ATI)**, of Wasilla, Alaska, is a specialist in airborne marine surveying. Having been in business flying the northernmost state for over 25 years, the small company has developed a history of remote sensing from aircraft, aerial mapping, near-shore ocean aerial surveying for fisheries and oceanographic research, and satellite-based asset tracking and monitoring.

In 2001, company president Tim Veenstra attended a workshop in Anchorage where he learned of a new research opportunity sponsored by NASA and the State of Alaska. His company had already been conducting remote sensing for a number of years on a variety of projects including locating fish for commercial ventures and tracking sea birds and marine mammals for research, so this new opportunity to develop systems to track high seas debris was well within his range of expertise. ATI's proposal was to use satellite and airborne remote sensing to locate lost and abandoned commercial fishing gear: errant drift nets known as ghost nets.

Drift netting is a commercial fishing practice using large (between 75 feet to over 30 miles in length) nets weighted at the bottom edge and with buoys floating the top edge. They create a vertical wall of netting in the ocean sometimes several hundred meters deep. Not anchored or attached to a boat, these huge fishing nets are sometimes inadvertently left behind or lost in storms, becoming ghost nets.

While these floating ghost nets prove to be navigation hazards for unsuspecting ships whose propellers can get entangled, they have an even more devastating impact on the environment. Unattended nets damage coral reefs; suffocate marine mammals, sea turtles, and birds when they wash ashore; and, if left afloat, bunch up and then begin a perpetual cycle of mass fish kills—dense balls of nets heavy with trapped fish sink, are cleaned by bottom-dwelling scavengers, and float back to the surface to start the cycle over. Modern synthetic netting can sustain this cycle indefinitely while drifting over a vast range: Ghost nets from around the Pacific have washed ashore on beaches as far apart as Alaska and the outer Hawaiian Islands.

NASA and NOAA were jointly exploring ways of improving methods of locating and disposing of ghost nets before they could damage vessels and the environment. The effort was also aimed at eliminating labor-intensive manual cleanup of the nets—in the warmer waters of



The satellite-communicating buoys designed by Airborne Technologies Inc. monitor ocean currents to locate areas where floating debris is likely to converge.

Hawaii usually involving divers with knives cutting the nets free of reefs or propellers and then loading them into inflatable boats—an expense estimated in the millions of dollars per year. In the frigid waters of Alaska, cleanup has been greatly restricted to beach cleanup. Finding the nets in the open ocean before they have the opportunity to cause too much harm was the preferred option, but presented another problem: It was like finding a needle in a haystack.

Veenstra and ATI proposed using satellites to monitor the convergence of currents in order to track the paths the nets were likely to take. These spaceborne perspectives

would allow researchers to scan thousands of square miles of water at a time, and ATI would provide a series of satellite-communicating buoys that would allow them to narrow the scope and determine current convergence. Knowing how the waters were naturally collecting debris, the researchers could then use sensor-equipped aircraft to find debris fields. Ships could then be deployed to perform cleanup. NASA agreed to the plan, and the work started.

After completing the work with NASA, ATI formed a new commercial division, Ocean Trek Research Inc., to expand upon the line of satellite communicating ocean buoys, opening up their use to additional markets. The original work has also led to the development of a prototype unmanned aircraft system and unique complementary software designed to process ocean images to detect debris fields.

## Product Outcome

ATI has already built over 900 buoys, each about the size of a laundry basket. As part of the ghost net remediation project through NOAA, it makes the buoys available to vessels of opportunity, including U.S. Coast Guard and research boats—any craft out on the water in the regions where the nets might be spotted and tagged with a buoy. The tagged nets are then easy to locate and recover for crews who can then collect them. The buoys are also finding additional uses, including as makeshift floating mini-ecosystems. Nearly anything in the water will start to grow algae, which attracts small fish that eat the plants. Larger fish are then attracted to the smaller fish. Commercial fishing vessels are deploying fleets of the buoys to tag floating fish-attracting devices to help attract schools of tuna.

In addition to the buoys, another product that came out of this research is video processing software capable of near-real-time, simultaneous processing of up to three video feeds at a rate of 30 frames per second. It receives data from the downward-facing cameras on aircraft



Ghost nets, abandoned or lost fishing nets, are nearly invisible yet devastating to marine ecosystems. A NASA, NOAA, and industry collaboration is using satellites and a system of buoys to locate this debris.

flying over the seas to locate the debris fields. Once set with user-defined parameters, the software is capable of telling an onboard high-resolution camera when to take a picture. It uses an adjustable algorithm and analyzes the video stream, checking for anomalies, then snapping high-resolution pictures and uploading the images to the user's computer for analysis.

The software is designed to complement the small unmanned aircraft system designed and currently being tested by ATI under a Phase I Small Business Innovation

Research (SBIR) contract from NOAA. With the ultimate goal of expanding the visual search area of a vessel at sea, it is an all-electric, autonomous, hand-launched "marinized" aircraft capable of carrying a variety of different sensors. Just under 10 pounds with its payload, the aircraft currently has 90 minutes of battery life and a range of approximately 75 miles. It is capable of landing safely both on hard surfaces and in the water, where it can then be retrieved by the operator's boat. ATI is currently conducting sea trials of the aircraft. ❖

# Mobile Instruments Measure Atmospheric Pollutants

## Originating Technology/NASA Contribution

As a part of NASA's active research of the Earth's atmosphere, which has included missions such as the Atmospheric Laboratory of Applications and Science (ATLAS, launched in 1992) and the Total Ozone Mapping Spectrometer (TOMS, launched on the Earth Probe satellite in 1996), the Agency also performs ground-based air pollution research. The ability to measure trace amounts of airborne pollutants precisely and quickly is important for determining natural patterns and human effects on global warming and air pollution, but until recent advances in field-grade

spectroscopic instrumentation, this rapid, accurate data collection was limited and extremely difficult.

In order to understand causes of climate change and airborne pollution, NASA has supported the development of compact, low power, rapid response instruments operating in the mid-infrared "molecular fingerprint" portion of the electromagnetic spectrum. These instruments, which measure atmospheric trace gasses and airborne particles, can be deployed in mobile laboratories—customized ground vehicles, typically—to map distributions of pollutants in real time. The instruments must be rugged enough to operate rapidly

and accurately, despite frequent jostling that can misalign, damage, or disconnect sensitive components. By measuring quickly while moving through an environment, a mobile laboratory can correlate data and geographic points, revealing patterns in the environment's pollutants. Rapid pollutant measurements also enable direct determination of pollutant sources and sinks (mechanisms that remove greenhouse gasses and pollutants), providing information critical to understanding and managing atmospheric greenhouse gas and air pollutant concentrations.

## Partnership

With a **Small Business Innovation Research (SBIR)** contract from Ames Research Center in 1985, **Aerodyne Research Inc. (ARI)**, based in Billerica, Massachusetts, began developing its Tunable Infrared Laser Differential Absorption Spectrometer (TILDAS) instruments for measuring stratospheric ozone depletion and greenhouse gasses. Additional SBIR contracts followed from both Ames and Glenn Research Center to develop TILDAS for measuring ambient pollutant concentrations and pollutant source fluxes.

ARI has also collaborated with the Agency's Office of Earth Sciences, now part of the Science Mission Directorate, to develop innovative mobile laboratory capabilities to characterize and analyze urban air pollution. TILDAS instruments have been used in ARI's mobile laboratories to map urban greenhouse gas and air pollutant distributions, starting with Agency-sponsored field measurements in Boston and Cambridge, Massachusetts, and in Manchester, New Hampshire in the 1990s. Later, field studies (sponsored in part by Glenn and Langley

Aerodyne Research Inc. (ARI) uses its Tunable Infrared Laser Differential Absorption Spectrometer (TILDAS) instruments in its mobile laboratory to measure pollutant gasses and submicron particles in a DC-8's engine exhaust plumes.



Image courtesy of Dr. W. B. Knighton of Montana State University

Research Center) included mobile studies of exhaust emissions from city buses in New York, traffic in Mexico City, and commercial aircraft during taxi, take-off, and landing operations at airports in Oakland, California, and Atlanta. According to ARI's president, Charles Kolb, these projects enabled ARI to improve the company's advanced instrumentation for mobile laboratories while providing valuable data for air quality managers working to improve urban air pollution.

### Product Outcome

In 2002, ARI introduced a line of thermoelectrically cooled quantum cascade (QC) TILDAS instruments, which are much smaller, more highly automated, and more robust than earlier lead-salt diode laser systems. ARI developed QC-TILDAS to detect a range of more than 15 of the most important greenhouse gasses and air pollutants—including carbon dioxide, nitrogen dioxide, and methane—at sub-parts-per-billion concentrations. Depending on laser selection and tuning range, each laser can quantify one to three trace gasses. The system consists of the tunable laser, infrared detectors, power electronics, a microcomputer with integrated control and data analysis software, and an astigmatic multiple pass absorption cell.

In addition to using QC-TILDAS and TILDAS instruments for mobile measurements from van, aircraft, and ship platforms, ARI and its customers and collaborators use the technology to perform eddy correlation flux measurements, a method of correlating changes in atmospheric composition of trace gasses with wind fluctuations to determine the magnitude of pollutant emission sources and sinks. Kolb explains that with this technique, the ARI team can measure nitrous oxide from fertilizer in nearby fields or can determine which neighborhoods are most affected by emissions from local airports. In the past, meteorologists quantified atmospheric heat fluxes by correlating temperature, water vapor, and wind fluctuations. "Now with rapid response laser sensors available, we can



In 2002, ARI introduced a line of thermoelectrically cooled quantum cascade (QC) TILDAS instruments for use in its mobile laboratories. The QC-TILDAS instruments are incorporated into a system that contains the tunable laser, infrared detectors, power electronics, a microcomputer with integrated control and data analysis software, and an astigmatic multiple pass absorption cell.

measure trace gas emission or deposition fluxes as well," Kolb says.

A key component to this rapid response is the QC-TILDAS astigmatic mirror absorption cell, which makes the system "tens to hundreds of times more sensitive" than most differential absorption infrared spectrometers, says Kolb. These patented cells pass a laser beam through the sample up to 300 times, producing long absorption paths of 75–300 meters, depending on cell length and mirror configuration. In essence, the

longer a path the laser has, the more sensitive the measurement will be, so the long absorption path of the QC-TILDAS, combined with a very small volume sample cell, allows the atmospheric air sample to be changed 20 times per second, providing rapid measurement of changes in pollutant concentration while still providing the measurement sensitivity required. ARI can also adapt QC-TILDAS for open path measurements by replacing the absorption cell with a remote retro-reflecting mirror; the company used this configuration to profile exhaust pollutants from aircraft engines.

QC-TILDAS uses a two-step process to detect concentrations of different airborne gasses. A QC laser (or solid-state diode laser, in the earlier system) is emitted in the molecular absorption band of the gas being measured, and then is tuned over the spectral absorption lines of that same gas. The laser's high-spectral resolution helps isolate spectral lines of the gas with minimal unwanted interference from other molecular absorption lines. The QC-TILDAS analysis software then integrates the measured absorption lines of the sample, and compares them with a theoretical spectral absorption, based on the known spectral line strengths, line broadening coefficients, the ground state energy, and other properties of the absorption lines and the temperature and pressure in the sample cell. This basic measurement and analysis sequence is repeated many thousands of times per second, and the system then averages the results.

Because of ARI's development and commercialization of TILDAS (and QC-TILDAS) and the mobile laboratory, the company's products are currently in use at numerous academic, government, and industrial air quality and climate change laboratories on five continents. Since the first field deployment of TILDAS in the 1990s, ARI continues to enable NASA and commercial customers to study air pollution in detail, and recent SBIR awards to ARI suggest more systems for monitoring air pollutants are on the way. ❖

# Cloud Imagers Offer New Details on Earth's Health

## Originating Technology/NASA Contribution

A stunning red sunset or purple sunrise is an aesthetic treat with a scientific explanation: The colors are a direct result of the absorption or reflectance of solar radiation by atmospheric aerosols, minute particles (either solid or liquid) in the Earth's atmosphere that occur both naturally and because of human activity. At the beginning or end of the day, the Sun's rays travel farther through the atmosphere to reach an observer's eyes and more green and yellow light is scattered, making the Sun appear red. Sunset and sunrise are especially colorful when the concentration of atmospheric particles is high. This ability of aerosols to absorb and reflect sunlight is not just pretty; it also determines the amount of radiation and heat that reaches the Earth's surface, and can profoundly affect climate.



Stratton Park Engineering Company Inc. (SPEC) installed its Cloud Particle Imager (CPI) on NASA's High Altitude Research Program aircraft. Research facilities around the world have since used the commercially available CPI to further atmospheric study.

In the atmosphere, aerosols are also important as nuclei for the condensation of water droplets and ice crystals. Clouds with fewer aerosols cannot form as many water droplets (called cloud particles), and consequently, do not scatter light well. In this case, more sunlight reaches the Earth's surface. When aerosol levels in clouds are high, however, more nucleation points can form small liquid water droplets. These smaller cloud particles can reflect up to 90 percent of visible radiation to space, keeping the heat from ever reaching Earth's surface.

The tendency for these particles to absorb or reflect the Sun's energy—called extinction by astronomers—depends on a number of factors, including chemical composition and the humidity and temperature in the surrounding air; because cloud particles are so small, they are affected quickly by minute changes in the atmosphere. Because of this sensitivity, atmospheric scientists study cloud particles to anticipate patterns and shifts in climate.

Until recently, NASA's study of atmospheric aerosols and cloud particles has been focused primarily on satellite images, which, while granting large-scale atmospheric analysis, limited scientists' ability to acquire detailed information about individual particles. Now, experiments with specialized equipment can be flown on standard jets, making it possible for researchers to monitor and more accurately anticipate changes in Earth's atmosphere and weather patterns.

## Partnership

Boulder, Colorado-based [Stratton Park Engineering Company Inc. \(SPEC\)](#) has won 16 Phase I **Small Business Innovation Research (SBIR)** contracts and 11 Phase II contracts with NASA since 1990. These contracts all related to developing atmospheric instrumentation and included: a Phase II **Small Business Technology Transfer (STTR)** contract in 1996 from Langley Research Center for cloud radiation measurement; a Phase II SBIR in 1999 from Jet Propulsion Laboratory for cloud particle imagers; a Phase I SBIR in 2001 from

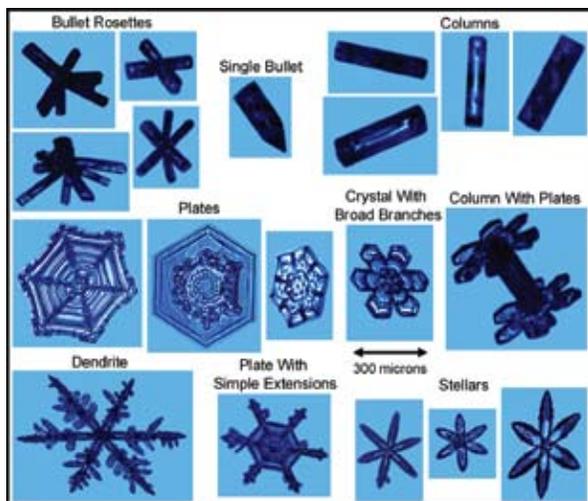
Goddard Space Flight Center for in situ lidar for cloud and aerosol radiation studies; a Phase II SBIR in 2003 for cloud micro-sensors from Goddard; and a Phase I SBIR in 2008 from Wallops Flight Facility and Goddard for advanced cloud particle probes.

Developed with funding from the 1999 SBIR, the SPEC Cloud Particle Imager (CPI) was installed on NASA's High Altitude Research Program aircraft, the two WB-57s based at Ellington Field near Johnson Space Center. Research facilities around the world have since used the commercially available CPI to further atmospheric study. SPEC has sold its CPIs to the National Center for Atmospheric Research, the University of Washington, the University of North Dakota, and Sandia National Laboratories, in addition to other agencies and institutions in the United States, Australia, and Canada.

## Product Outcome

Recognizing the need to analyze cloud particles from close range, SPEC designed its CPI to be mounted to airplane exteriors; this robust design allows the CPI to operate in most airspeeds, altitudes, and air pressures, and to withstand vibrations and extreme temperatures as low as  $-70^{\circ}\text{C}$ . The system can also be adapted for harsh ground studies, and has been used at locations at the South Pole and New Hampshire's Mount Washington.

As a research aircraft flies through clouds, the externally mounted CPI captures digital images of cloud particles. As they enter the CPI's detection subsystem, particles cause light to scatter from two overlapping laser beams. That scattered light hits detectors and triggers the CPI's imaging system to capture a high-resolution digital photograph of the particles using a 1-megapixel charge coupled device camera, which can image between 75 and 500 frames per second, depending on camera upgrades. The CPI captures images of particles that range in size from 15 to 2,500 micrometers, and the high-resolution images have a nominal resolution of 2.3 micrometers, displaying unprecedented detail for researchers. After



As a research aircraft flies through clouds, the externally mounted CPI captures digital images of cloud particles that range in size from 15 to 2,500 micrometers.

capturing a particle's image, the system transmits the information to a computer and SPEC's CPI software, which crops and compresses the images. The system then stores the images and information for further analysis.

SPEC's customized post-processing software, CPIView, performs some analysis automatically, calculating perimeters, areas, lengths, and volumes. It also creates graphical displays to show researchers certain distributions, such as patterns over time and in certain locations.

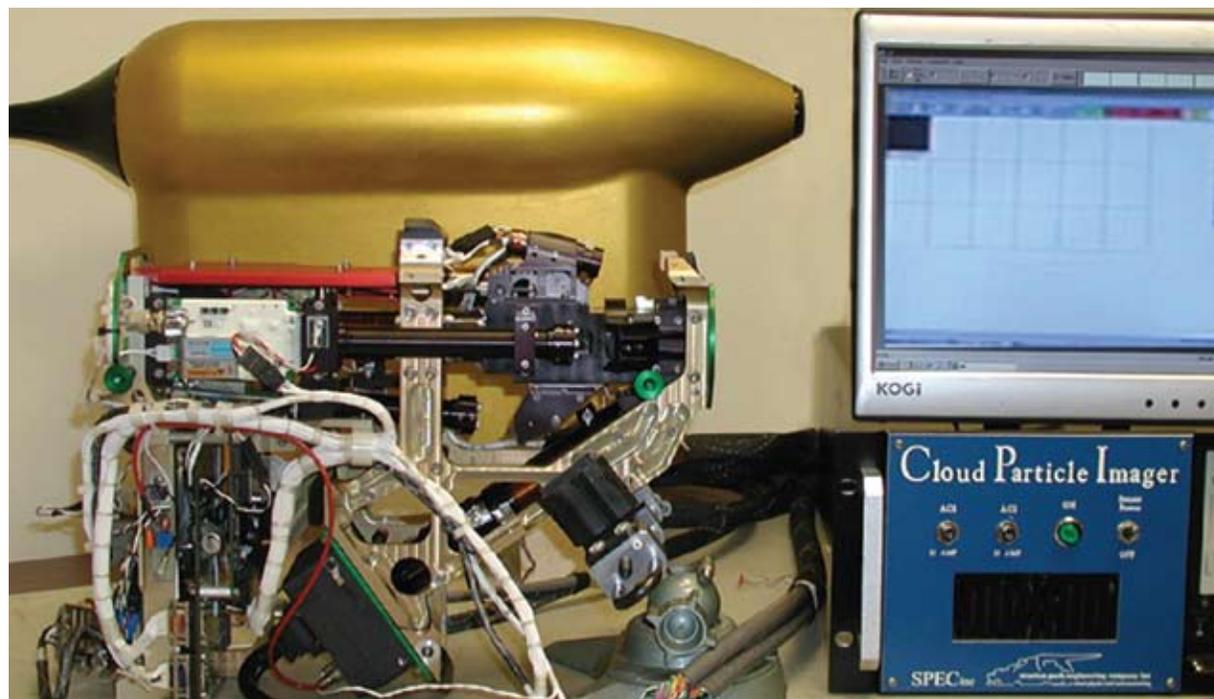
With such long-term studies and histograms of particle sizes, SPEC's CPI system can help alert scientists to how the Earth's climate is changing, and how quickly. SPEC president and CEO, Dr. Paul Lawson, explains that clouds and cloud particles have a major impact on global climate change: "If we change the mean size of cloud particles by a micron, a millionth of a meter, then that's the same as doubling the concentration of carbon dioxide in the atmosphere," thereby drastically increasing the lower atmosphere's tendency to trap heat on Earth's surface.

The company is now developing extremely small instruments that can image cloud particles continuously for up to 24 hours. Under the 2008 Wallops and Goddard SBIR agreement, SPEC has designed a small version of its CPI, the Micro-CPI, for small Uninhabited Aerial Vehicles (UAVs) which span fewer than 6 feet across. NASA and other agencies are using UAVs for atmospheric measurements because, among other reasons, they can fly in extremely cold or oxygen-poor altitudes. Micro-CPI—like the original CPI—measures the properties of ice crystals and water droplets, records the data onboard the UAV, and then sends them back to a computer.

SPEC also continues to develop the other particle imaging products funded by SBIR and STTR contracts,

including the in situ lidar. This instrument can measure the absorption in liquid clouds with sampling volumes of millions of cubic meters. In this technique, a laser sends out pulses of light horizontally from an aircraft inside an optically thick cloud. Meanwhile, wide field-of-view detectors measure the time series of the number of photons returned. The ultimate use of these instruments is to provide a large volume of high-quality data about clouds for climate prediction models.

For its own studies and research using the CPI, the Micro-CPI, and the in situ lidar, SPEC makes the collected data available to the scientific community for analysis and further study, helping promote a better understanding of the Earth's climate. ❖



After SPEC's externally mounted CPI captures a particle's image, the system transmits the information to a computer and SPEC's CPI software, which crops and compresses the images. The system then stores the images and information for further analysis.

# Antennas Lower Cost of Satellite Access

## Originating Technology/NASA Contribution

Whether for scientific inquiry, weather forecasting, or public safety, the world relies upon the data gathered by satellite remote sensing. Some of NASA's most valuable work is in its remote sensing capabilities—the ability to retrieve data acquired at great distances—affording a height and scope not available from the ground. NASA satellites in low Earth orbit (LEO) monitor ocean health by taking large-scale pictures of phytoplankton blooms and measuring surface temperatures; snap photographs of full hurricanes from above, teaching researchers about how these giant storms form; and capture images of cloud formation and air pollution, all allowing researchers to further develop understanding of the planet's health. NASA remote sensing satellites also monitor shifts in the Earth's crust, analyze wind patterns around the world to develop efficient wind energy, help people around the world recover from natural disasters, and monitor diminishing sea ice levels.

Just as researchers are more heavily relying on this data from space to conduct their work, the instruments carried on satellites are getting more sophisticated and capable of capturing increasingly complex and accurate measurements. The satellites are covering larger areas, from farther away, and generating more and more valuable data.

The ground-based receivers for this wealth of satellite data have grown increasingly capable of handling greater bandwidth and higher power levels. They have also become less expensive, through a NASA research partnership, with the creation of a high-rate X-band data receiver system that is now in widespread use around the globe.

## Partnership

**SeaSpace Corporation**, of Poway, California, recognized a need for developing economical systems for receiving, processing, analyzing, and archiving incoming data from X-band remote sensing satellites, as they already provided similar systems for L- and S-band satellites. This



SeaSpace Corporation provides satellite data acquisition for a variety of uses, including weather monitoring and environmental monitoring.

need was one experienced throughout the world, as people became more reliant upon high-resolution satellite data. This was especially true within NASA, where the Space Agency could save millions of dollars by having available commercial providers of low-cost satellite data receivers accommodate its remote sensing program needs.

The company approached NASA's Jet Propulsion Laboratory with proposals for a two-part research project to create such a system and was granted funding under two **Small Business Innovation Research (SBIR)** contracts, a Phase I and follow-on Phase II. SeaSpace proposed that its reception and processing systems could reduce the cost of satellite ground tracking by at least a factor of 10, and that the profits from its commercial sales would lead to even more enhancements to the receiver systems, extending applications to land-use management, marine pollution tracking, polar science operations, and ultimately, widespread commercial adoption of its product.

## Product Outcome

SeaSpace engineers were already pioneers in the field of ground-based direct reception stations, and under the NASA SBIR projects, they developed both new hardware and software to help with the acquisition of satellite data. The company was already working with the nearby San Diego-based Scripps Institution of Oceanography, and so applied its radio frequency equipment to an existing Scripps antenna platform to capture high-rate data from EOS-1 (an Earth-observing satellite). SeaSpace also designed and implemented the software necessary to control the antenna frame and process the data, which was later added to their existing TeraScan software product. This proved the viability of the ground-based antenna for receiving X-band.

Once the company had demonstrated the usability of this ground station, interested parties took note, and



U.S. Coast Guard cutters use the SeaSpace antennas to determine how thick the Arctic ice is. They are then able to cut channels through the ice.

SeaSpace began taking orders. To date, the company has installations in over 35 countries and has sold over 50 X-band systems, adding to an extensive list of customers reaching over 450 TeraScan systems worldwide. Its ground-based receivers are in continuous operation on all seven continents, with customers including aerospace and defense clients, the scientific community, national and local weather services, the research industry, and public safety organizations.

Clearly, these customers appreciate the lower price of the units, but in addition to the cost savings (approximately one-tenth the cost of conventional antennas), SeaSpace ground stations, with sizes ranging from 0.6–6.1 meters, have additional benefits. Able to receive data from multiple platforms, they are available for a variety of applications: tracking LEO satellites for remote sensing; science; communications; and telemetry, tracking, and command applications, providing true full hemispherical coverage.

The units require very little maintenance, are reliable with redundancy motors and drives, and have a high level of remote fault detection and fault isolation. A minimal amount of moving parts, extremely low tracking dynamics, and few components all contribute to the ability of this antenna system to run for long periods without downtime. Their ruggedness combined with the ability to run around the clock make these antennas ideal for unattended, remote-controlled use in severe environments.

The first X-band system sold by SeaSpace was purchased by the University of Wisconsin's Space Science and Engineering Center (SSEC), in Madison. The department receives, manages, and distributes large amounts of geophysical data and develops software to visualize and manipulate these data for use by researchers and operational meteorologists all over the world. To aid in this work, the SSEC hosts a 4.5 meter SeaSpace X-band system.

The U.S. Navy uses SeaSpace systems for operation flight plans and monitoring dust storms in Iraq and



From weather, oceanography, and environmental studies to disaster management and military operations, SeaSpace's ground systems are the complete acquisition and data processing solution for every major polar orbiting X-band satellite.

Afghanistan. While this function saves the engines of F-16s by alerting pilots and ground controllers about the threat of the small but invasive airborne debris, it also saves lives. Ground troops can know in advance not to move into an area when they are not going to be able to receive support from the air. Battlefield planners can use the data to make smarter, safer decisions about where to send troops.

Another customer, Raytheon Polar Services Company, has two of the systems deployed at literally the far end of the Earth: one at McMurdo Station, a large American research center off of Ross Island in the Antarctic, and the much smaller Palmer Station, located on Anvers Island, just north of the Antarctic Circle. Both of these remote research stations are operated by the National Science Foundation, which has a contract with Raytheon for the company to provide this support. At McMurdo, for example, the outdoor ground-based systems experience an

average monthly temperature of -18 °C and average wind speeds of 11 miles per hour. With weather like that, it is important that the systems are rugged so they can endure, but also so that researchers do not often have to slough out into the cold to repair or maintain the equipment.

In a warmer climate, Mexico, the National Commission for the Knowledge and Use of Biodiversity (CONABIO), a government agency dedicated to coordinating, supporting, and executing activities and projects designed to increase regional understanding of biodiversity, uses a 2.4-meter SeaSpace X-band system. CONABIO produces and collates biodiversity data and assessments across Mexico's varied ecosystems. It consolidates this information and guides a range of biological conservation and sustainability projects using the satellite data. ❖

TeraScan® is a registered trademark of SeaSpace Corporation.

# Feature Detection Systems Enhance Satellite Imagery

## Originating Technology/NASA Contribution

In 1963, during the ninth orbit of the Faith 7 capsule, astronaut Gordon Cooper skipped his nap and took some photos of the Earth below using a Hasselblad camera. The sole flier on the Mercury-Atlas 9 mission, Cooper took 24 photos—never-before-seen images including the Tibetan plateau, the crinkled heights of the Himalayas, and the jagged coast of Burma. From his lofty perch over 100 miles above the Earth, Cooper noted villages, roads, rivers, and even, on occasion, individual houses.

In 1965, encouraged by the effectiveness of NASA's orbital photography experiments during the Mercury and subsequent Gemini manned space flight missions, U.S. Geological Survey (USGS) director William Pecora put forward a plan for a remote sensing satellite program that would collect information about the planet never before attainable. By 1972, NASA had built and launched Landsat 1, the first in a series of Landsat sensors that have combined to provide the longest continuous collection of space-based Earth imagery. The archived Landsat data—37 years worth and counting—has provided a vast library of information allowing not only the extensive mapping of Earth's surface but also the study of its environmental changes, from receding glaciers and tropical deforestation to urban growth and crop harvests. Developed and launched by NASA with data collection operated at various times by the Agency, the National Oceanic and Atmospheric Administration (NOAA), Earth Observation Satellite Company (EOSAT, a private sector partnership that became Space Imaging Corporation in 1996), and USGS, Landsat sensors have recorded flooding from Hurricane Katrina, the building boom in Dubai, and the extinction of the Aral Sea, offering scientists invaluable insights into the natural and manmade changes that shape the world.

Of the seven Landsat sensors launched since 1972, Landsat 5 and Landsat 7 are still operational. Though

both are in use well beyond their intended lifespans, the mid-resolution satellites, which provide the benefit of images detailed enough to reveal large features like highways while still broad enough for global coverage, continue to scan the entirety of the Earth's surface. In 2012, NASA plans to launch the Landsat Data Continuity Mission (LDCM), or Landsat 8, to extend the Landsat program's contributions to cartography, water management, natural disaster relief planning, and more.

## Partnership

In 2002, [Geospatial Data Analysis Corporation \(GDA\)](#), of State College, Pennsylvania, received a Phase I **Small Business Innovation Research (SBIR)** contract with Stennis Space Center. (The company also engaged in a follow-on Phase II SBIR with Stennis.) The NASA center was seeking a new method for detecting clouds for future use with Landsat 8. Cloud contamination is a common problem with satellite imagery. For previous Landsat missions, NASA has used its Automated Cloud Cover Assessment (ACCA) algorithm to estimate cloud contamination in Landsat images. ACCA heavily relies on thermal data from the Landsat satellites—thermal signals being the easiest method for cloud detection. Thermal sensors, however, are expensive additions to satellites, and Landsat 8 will not feature any in its array. GDA took on the challenge of developing a new system that could accurately detect clouds without the benefit of thermal data.

“We proposed that, in order to identify clouds automatically and without thermal data, you have to move beyond the spectral signal in the imagery and into spatial feature and pattern recognition,” says Dr. Stephanie Hulina, GDA president and senior scientist. GDA employed its SBIR funding to arrive at the embodiment of this approach: the Cloud and Cloud Shadow Assessment (CASA) software.

CASA is a highly automated feature detection/extraction system. The system contains global libraries of expected spatial, visual, and near-infrared spectral and



Launched in 1999, Landsat 7 continues to provide stunning, detailed images of Earth, like this shot of South Florida. Images like these provide unparalleled views of the impact of natural and manmade factors on the health of the planet.

contextual signatures for the feature of interest (in this case clouds and cloud shadows). For example, depending on the Sun's angle and viewpoint of the sensor, all of the clouds in any particular image should have shadows in similar locations. CASA uses information like this to confirm or reject elements in a given image as clouds. The system goes through an iterative, hierarchical self-learning process, identifying clouds based on a comparison to the characteristics in its global library. Definitive clouds are logged in a local library for additional comparison, helping CASA learn with increasing accuracy how to identify clouds and cloud shadows. The system produces a raster

***“To have the research and development funding and the backing of NASA to go out into the commercial market has been key for us.”***

mask, showing per pixel cloud and cloud shadow contamination of the image. Clouds of different types can be assigned different color shades.

When tested on Landsat 5 and 7 images, CASA comes within 10 percent of the visual cloud estimate for 94 percent of the images tested—comparable to and often exceeding ACCA’s capabilities.

“CASA would be the perfect technology for the next-generation Landsat sensor,” says Hulina.

Department of Agriculture (USDA) and the National Geospatial Intelligence Agency.

“The NASA SBIR contracts allowed us to get our start and develop our intellectual property using sound science,” says Hulina. “To have the research and development funding and the backing of NASA to go out into the commercial market has been key for us.”

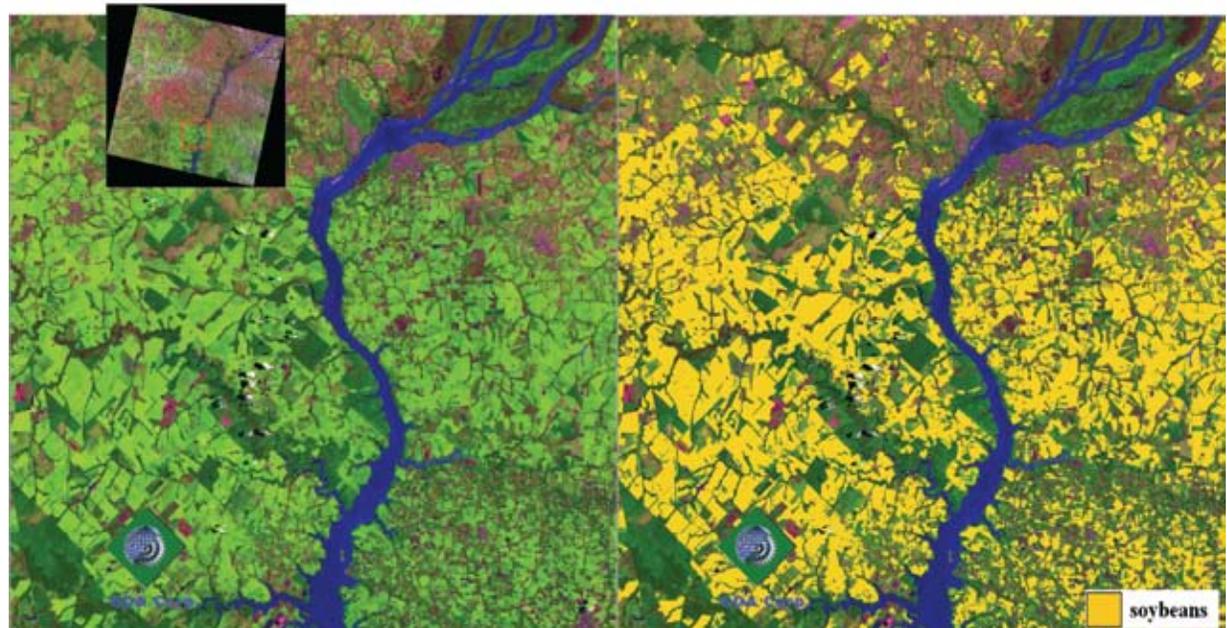
Hulina also notes that GDA has since branched out into other categories of feature detection. Using the same technology it applied for CASA, GDA can provide detection services for virtually any predefined class of features. The company has entered into Phase III SBIRs with the USGS and USDA Forest Service for

the development of feature detection systems for stream networks, riparian buffers (vegetated areas along streams or rivers), and certain land covers. The company also has contracts from the USDA Foreign Agricultural Service for detecting crop fields around the globe. GDA provides these clients with outputs like crop acreage maps or flood maps derived from the satellite imagery, allowing them to accurately evaluate key information about everything from agricultural production to the impact of pollution.

As concerns about the effects of climate change and population growth lead to a greater need for the valuable data acquired through remote sensing, GDA’s NASA SBIR-developed feature detection capabilities will likely be in high demand. ❖

## Product Outcome

Since establishing CASA’s effectiveness with Landsat imagery, GDA has taken advantage of the system’s versatility and high level of automation to provide cloud detection services for a host of space-based sensors. GDA has proven the CASA software effective for cloud and cloud shadow detection in high-resolution imagery from commercial satellites such as QuickBird (owned and operated by DigitalGlobe), SPOT (Spot Image), IKONOS, and OrbView (both GeoEye). The company also completed a NASA Dual-Use Technology Development contract with Stennis to adapt the CASA algorithms to the Indian Remote Sensing-P6 Advanced Wide Field Sensor, or AWiFS, data. CASA’s automation enables it to process large data sets in short periods of time, allowing GDA to guarantee return of cloud masks within minutes of receiving the raw data on its servers. Using the CASA output, GDA can also remove identified clouds and cloud shadows on a per pixel basis, backfill them, and radiometrically normalize the changes from one image to another—all without the lengthy and expensive process of removing them by hand. The company counts a number of private remote sensing imagery firms among its CASA clients, as well as the U.S.



From a satellite image of a South American river valley (left), GDA’s feature detection system produced a detailed map of soybean crop fields (right), revealed in yellow. Capabilities like this can provide useful information on agricultural production.

# Chlorophyll Meters Aid Plant Nutrient Management

## Originating Technology/NASA Contribution

On December 7, 1972, roughly 5 hours and 6 minutes after launch, the crew of Apollo 17 took one of history's most famous photographs. The brilliant image of the fully illuminated Earth, the African and Antarctic continents peering out from behind swirling clouds, came to be known as the "Blue Marble." Today, Earth still sometimes goes by the Blue Marble nickname, but as the satellites comprising NASA's Earth Observing System (EOS) scan the planet daily in ever greater resolutions, it is often the amount of green on the planet that is a focus of researchers' attention.

Earth's over 400,000 known plant species play essential roles in the planet's health: They absorb carbon dioxide and release the oxygen we breathe, help manage the Earth's temperature by absorbing and reflecting sunlight, provide food and habitats for animals, and offer building materials, medication, and sustenance for humans. As part of NASA's efforts to study our own planet along with the universe around it, the Agency's EOS satellites have been accumulating years of valuable data about Earth's vegetation (not to mention its land features, oceans, and atmosphere) since the first EOS satellite launched in 1997. Among the powerful sensors used is the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the NASA Terra and Aqua satellites. MODIS sweeps the entire Earth every few days, beaming back information gathered across 36 bands of visible and infrared light, yielding images that let scientists track how much of Earth is green over the course of seasons and years.

Monitoring the density and distribution of vegetation on Earth provides a means of determining everything from the impact of natural and human-induced climate change to the potential outbreak of disease. (Goddard Space Flight Center and U.S. Department of Defense researchers have determined, for example, that vegetation density can be used to pinpoint regions of heavy rainfall



NASA satellites offer insight on topics like climate change and disease outbreaks through data like this Normalized Difference Vegetation Index image showing vegetation in Africa in August 1994.

in Africa—regions ripe for outbreaks of rainfall-correlated diseases like mosquito-borne Rift Valley fever.)

While the Space Agency is continually seeking to upgrade the power and scope of its satellite sensors, it is also finding ways to bring that potent information-gathering capacity down to Earth. Scientists at Stennis Space Center developed one such tool that is placing some of those sensor capabilities in the hands of farmers and agricultural researchers on the ground.

## Partnership

In 1998, Mike Thurow, president of Plainfield, Illinois-based [Spectrum Technologies Inc.](#), met with Stennis scientists and learned about a new technology

the Center had recently patented: a hand-held plant chlorophyll meter developed from Stennis work on satellite sensors. The meter measures two wavelengths of light—700 nanometers (nm) and 840 nm—to determine a plant's chlorophyll content. Chlorophyll, the pigment found in green plants and algae that allows for the production of energy from light (photosynthesis), comes in two varieties: a and b. Chlorophyll a absorbs 700-nm light, while 840-nm light is unaffected by the chlorophyll but helps indicate the reflectiveness of a leaf's physical surface. The NASA meter compares the ratio of 700-nm and 840-nm available light to the ratio of the same wavelengths of reflected light, arriving at a chlorophyll index value. Chlorophyll levels are strong indicators of health in green plants; the meter's Stennis inventors demonstrated that, by detecting chlorophyll amounts, their technology could reveal plant stress caused by factors like heat, insects, disease, and lack of water or nutrients—up to 16 days before visible signs emerged.

The following year, Spectrum—a leading provider of agricultural measurement instruments in the areas of weather monitoring, nutrient management, integrated pest management, and soil properties—licensed the meter from NASA. Initially marketed as the Observer (featured in *Spinoff* 2001), Spectrum's commercial chlorophyll meter featured enhancements to the NASA invention, such as a built-in ambient light sensor, dual high-power targeting lasers, a data logger, and a hardware encasement with a pistol grip for easy use.

## Product Outcome

Spectrum now offers its NASA-derived technology as the FieldScout CM 1000 meter, which the company views as a powerful nutrient management tool.

"In the world of nutrient management, nitrogen is one of the key elements for growers to manage," says Thurow. Nitrogen is a main component of chlorophyll; plants with low chlorophyll levels are thus indicators of poor nitrogen



The NASA-derived, point-and-shoot FieldScout meter can take chlorophyll measurements from individual leaves or across a canopy, providing valuable information for nutrient management of crops and turf grass.

levels in the ground. Growers can respond by providing health-boosting doses of nitrogen fertilizer.

Whereas some chlorophyll meters attach to individual leaves like a clothespin, the FieldScout meter is a point-and-shoot tool that can take measurements from individual leaves or across a plant canopy, making it a fast and accurate way to survey chlorophyll levels not only for crops like cotton or corn, but also for turf (like

athletic fields and golf courses) and long grasses like wheat and rice.

“With the NASA-developed meter, from 5 to 6 feet away, you can look at a canopy of close to 7 inches in diameter,” says Thurow. “It integrates a larger sample than other meters, making it faster and easier to use.”

The FieldScout meter takes individual readings with the click of the trigger and also supplies a running

average. To provide an extra level of value to the meter’s readings, the user can also log the latitude and longitude of each reading with an optional GPS device and upload this information into Spectrum’s SpecMaps Web-based software utility. SpecMaps then produces a map showing the spatial variability of chlorophyll levels based on the meter’s readings. This helps the user more accurately determine the cause of less-than-ideal readings—perhaps poor soil quality in certain areas—and employ a targeted solution, such as providing fertilizer to only those areas low in nitrogen, allowing for maximum economic yield.

Spectrum also now offers a FieldScout CM 1000 NDVI meter, which measures red (660 nm) and near-infrared (840 nm) light reflectance to calculate a Normalized Difference Vegetation Index (NDVI) for an enhanced analysis of the meter’s spectral data. NDVI was originally developed by Goddard for use measuring the health of plant life from space-based sensors.

Currently, Thurow says the meters’ main users are researchers working with small grains, turf, and rice, and Spectrum is aiming to grow a larger market base among agricultural consultants and growers. Since the NASA-derived meter was introduced by Spectrum in 2001, the company has sold 350 units, resulting in \$700,000 of revenue—good numbers for a specialty product, Thurow says. He credits the product’s success to the benefits of partnership.

“I have a strong belief in partnering,” he says. “In our case, NASA had a basic, validated technology that we were able to finish developing. It gave us the opportunity to offer a product that we would never have created on our own. It’s a win-win deal.” ❖

FieldScout® is a registered trademark of Spectrum Technologies Inc. SpecMaps™ is a trademark of Spectrum Technologies Inc.

***The company has sold 350 units, resulting in \$700,000 of revenue.***

# Computer Technology



NASA's computer scientists provide engineers with the computing resources and simulation tools to carry out critical NASA missions, but these same abilities translate into terrestrial benefits. The technologies featured in this section:

- Interpret Rocket, Airplane Engine Data
- Automate Complex Operations Monitoring
- Streamline Project Management
- Refine Vehicle Design
- Improve Wireless Products





# Telemetry Boards Interpret Rocket, Airplane Engine Data

## Originating Technology/NASA Contribution

For all the data gathered by the space shuttle while in orbit, NASA engineers are just as concerned about the information it generates on the ground. From the moment the shuttle's wheels touch the runway to the break of its electrical umbilical cord at 0.4 seconds before its next launch, sensors feed streams of data about the status of the vehicle and its various systems to Kennedy Space Center's shuttle crews. Even while the shuttle orbiter is refitted in Kennedy's orbiter processing facility, engineers constantly monitor everything from power levels to the testing of the mechanical arm in the orbiter's payload bay. On the launch pad and up until liftoff, the Launch Control Center, attached to the large Vehicle Assembly Building, screens all of the shuttle's vital data. (Once the shuttle clears its launch tower, this responsibility shifts to Mission Control at Johnson Space Center, with Kennedy in a backup role.)

Ground systems for satellite launches also generate significant amounts of data. At Cape Canaveral Air Force Station, across the Banana River from Kennedy's location on Merritt Island, Florida, NASA rockets carrying precious satellite payloads into space flood the Launch Vehicle Data Center with sensor information on temperature, speed, trajectory, and vibration.

The remote measurement and transmission of systems data—called telemetry—is essential to ensuring the safe and successful launch of the Agency's space missions. When a launch is unsuccessful, as it was for this year's Orbiting Carbon Observatory satellite, telemetry data also provides valuable clues as to what went wrong and how to remedy any problems for future attempts.

All of this information is streamed from sensors in the form of binary code: strings of ones and zeros. One small company has partnered with NASA to provide technology that renders raw telemetry data intelligible not only for Agency engineers, but also for those in the private sector.

## Partnership

[Ulyssix Technologies Inc.](#), of Frederick, Maryland, has a long-standing and comprehensive relationship with NASA beginning with the company's founding in 2000. A woman-owned small business focused on supporting the telemetry ground-based market, Ulyssix provides a range of telemetry processing solutions. "Pretty much all of our products are in use at different NASA facilities,"



Ulyssix telemetry products support NASA rocket launches from Wallops Flight Facility and Cape Canaveral Air Force Station—the site of this Atlas IIA rocket launch, carrying a satellite into space.

says Glenn Rosenthal, the company's president and CEO. Beyond shuttle and rocket telemetry at Kennedy and Cape Canaveral, Ulyssix products are used for monitoring sounding rocket launches at NASA's Wallops Flight Facility and for Glenn Research Center simulations for the Constellation Program. The company is also exploring collaboration with Langley Research Center to provide support for wind tunnel testing of the Orion crew exploration vehicle.

In 2007, Ulyssix entered into a Space Act Agreement with Kennedy. The ongoing partnership allows NASA and the company to share resources to further the development of Ulyssix's pulse code modulation (PCM) processor board—the TarsusPCM, currently in use by the Center for space shuttle and rocket launches—and related software for the benefit of both parties. Ulyssix's highly versatile TarsusPCM processing board can perform a range of data acquisition and telemetry processing functions, allowing it to bit synchronize (recover the speed of the data transmission), frame synchronize (group the ones and zeros), and decommutate (separate the frame block into individual words that correspond to measurement values) binary code telemetry data. In simple terms, the technology translates the data into understandable measurements to be fed into display systems for engineer analysis. The TarsusPCM is also outfitted with a full PCM simulator that allows engineers to run tests using past data. The device can additionally record live data and then feed that data through the board's simulator as though it were real-time information. Under the agreement, Ulyssix has also been working with Dryden Flight Research Center, which utilizes these latter capabilities for aeronautical testing involving drone aircraft.

Ulyssix has been quick to modify their products to support the needs of the space shuttle program. Many of the suggestions made in conjunction with the shuttle program have been permanently incorporated in the company's products and made available to other users, governmental and non-governmental alike.

## Product Outcome

Beyond its extensive role in NASA missions, the company's Tarsus line provides support to a host of military and aerospace applications. Eglin Air Force Base has employed Linux code created under the NASA Space Act Agreement to use the TarsusPCM card for remote-controlled drone testing. Pratt & Whitney (a division of United Technologies Corporation) and Embraer S.A. are utilizing Ulyssix Tarsus hardware for jet engine and airplane testing and development. ATK Space Systems incorporated the company's technology into the ground-support equipment for the satellites it built for NASA's Time History of Events and Macroscale Interactions during Substorms—otherwise known as THEMIS—mission to study the activities of Earth's magnetosphere that lead to spectacular events like the Northern Lights. Ulyssix is also providing satellite launch support for the United Launch Alliance, a joint venture between Lockheed Martin Corporation and Boeing that offers launch services for the U.S. Government. In addition, Rosenthal notes that Ulyssix products are ideal for the private space industry and is looking forward to expanding the company's reach into this developing field. "Our products are 100-percent compatible with these efforts," he says.

The Tarsus line is one of several offered by the company, each named for anatomical parts of the company's symbol, the bald eagle. (The tarsus is part of the eagle's leg; the company's Syrinx line is named for the eagle's vocal cords, the Hallux line for the eagle's opposing toe, and the Talon line for the eagle's claws.) Ulyssix's products have not only benefitted from NASA's technical assistance, but from their association with the Agency.

"Having the credentials of NASA behind my products has been a great reference," says Rosenthal.

Ulyssix's partnership with NASA promises to encourage future evolution of its products and capabilities: The company's processing hardware is supporting special



The TarsusPCM board—enhanced through Ulyssix's partnership with NASA—translates raw telemetry data into understandable measurements for engineer analysis, playing an essential role in satellite launch and ground support, as well as the testing of remote-controlled drones and jet engines.

testing of the space shuttles to help with the progress of the Constellation Program. This includes interpreting data from seat sensors to determine the different forces impacting the astronauts during launch—data that will help with the development of the Orion capsule, the space shuttle's eventual successor. Rosenthal expects Ulyssix will continue to advance its telemetry expertise in support of the Constellation Program.

"Rather than just supporting space shuttle launches, our equipment is helping enable this research going forward," he says. "Our hardware is helping build a bridge between the shuttle and Constellation." As more aerospace companies incorporate the TarsusPCM into their efforts, it seems likely that Ulyssix's technology will provide a bridge to future commercial aerospace endeavors, as well. ❖

# Programs Automate Complex Operations Monitoring

## Originating Technology/NASA Contribution

**K**ennedy Space Center, just off the east coast of Florida on Merritt Island, has been the starting place of every human space flight in NASA's history. It is where the first Americans left Earth during Project Mercury, the terrestrial departure point of the lunar-bound Apollo astronauts, as well as the last solid ground many astronauts step foot on before beginning their long stays aboard the International Space Station. It will also be the starting point for future NASA missions to the Moon and Mars and temporary host of the new Ares series rockets designed to take us there.

Since the first days of the early NASA missions, in order to keep up with the demands of the intricate and critical Space Program, the launch complex—host to the large Vehicle Assembly Building, two launch pads, and myriad support facilities—has grown increasingly complex to accommodate the sophisticated technologies needed to manage today's space missions. To handle the complicated launch coordination safely, NASA found ways to automate mission-critical applications, resulting in streamlined decision-making. One of these methods, management software called the Control Monitor Unit (CMU), created in conjunction with McDonnell Douglas Space & Defense Systems, has since left NASA, and is finding its way into additional applications.

## Partnership

**Command and Control Technologies Corporation (CCT)**, of Titusville, Florida, was founded in 1997 with the express purpose of commercializing technologies developed by NASA. A team of McDonnell Douglas contractors at Kennedy had helped develop CMU to manage NASA's complex space station checkout. Realizing that this software had applications outside of the NASA realm, they formed CCT and licensed the software usage rights from NASA (*Spinoff* 1999). Two years after its founding, CCT was named Kennedy's "Small Business Contractor



Kennedy Space Center's launch complex—host to the large Vehicle Assembly Building, two launch pads, and myriad support facilities—has grown to accommodate the sophisticated technologies needed to manage today's space missions.

of the Year," and the company has continued supporting the Space Agency with cutting-edge software.

As CCT's founders realized, a lot of the same management technologies created for NASA launches apply to other complex yet critical operations. CCT has therefore found applications outside of its NASA work helping the military at weapons test ranges, protecting the borders,

and it has the potential to work with large industrial processes, like monitoring and managing power plants.

## Product Outcome

CCT delivers products, engineering expertise, and support for aerospace, industrial, security, and defense applications. At the core of its capabilities is the software

initially developed with NASA and significantly improved over the last 12 years by CCT, marketed commercially as Command and Control Toolkit (CCTK). A turnkey system, the software is customizable to a wide array of intricate situations and capable of handling complex data in real time.

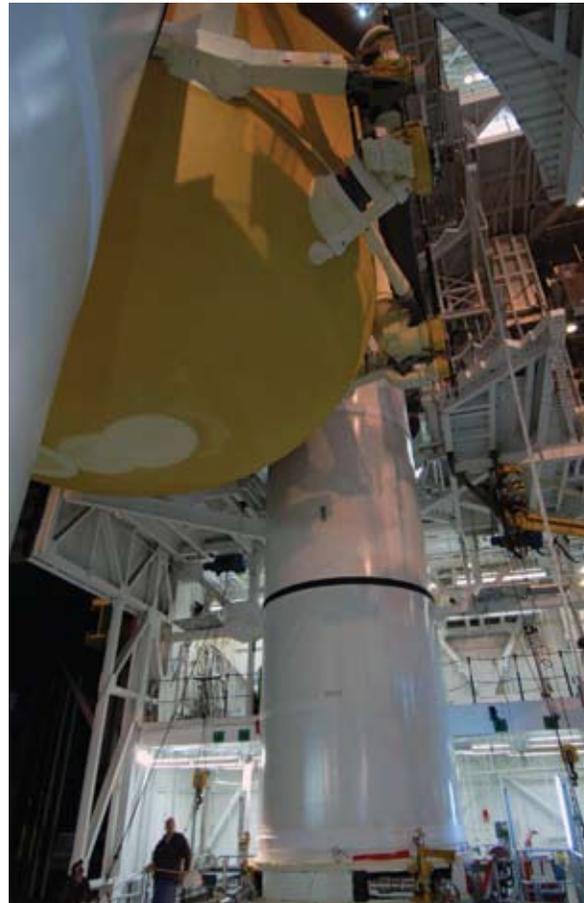
CCTK is robust and easy to use. It has a graphical interface and is flexible, easily configurable for real-time situational awareness, and capable of handling millions of data, command, event, and message transactions. It runs on any standard personal computer platform and can be customized by the company or directly by each user, depending on need.

CCT's software is capable of simultaneously handling incoming information from varied sources, while still calculating for a variety of additional factors, including safety and engineering aspects. A prime example of this flexibility is the work CCT is conducting at NASA's Wallops Flight Facility on Virginia's Eastern Shore. Managed by Goddard Space Flight Center, Wallops is a launch site used by not only NASA, but by the military and the research community. While the launch facility already offers the capacity and expertise needed to enable frequent flight opportunities for a diverse customer base, it expects that in the coming years, it will become increasingly called upon for commercial space launches.

CCT was contracted by Goddard to provide range safety decision support systems for the test facility at Wallops, as well as process telemetry and radar acquisition data and assist with early analysis for a redesign of the range control center. At Wallops, CCTK also monitors U.S. Navy launches at the site conducted by the nearby Naval Air Systems Command along the Patuxent River in Maryland.

The Virginia Space Flight Facility, also located at Wallops, has been using CCTK to automate its remote control rocket cryogenic fueling systems. Adding this capability is one of the first steps in gearing the facility for more commercial launches, as it greatly increases the

safety of launches by minimizing human exposure to hazardous conditions. CCT was recently contracted by the Virginia Commercial Space Flight Authority to design and develop a new launch vehicle fueling control system that will support the newly designed Orbital Sciences Taurus II launch vehicle, as well as other launch vehicles using the commercial pads at Wallops.



To handle the complicated launch coordination safely, NASA found ways to automate mission-critical applications, resulting in streamlined decision-making.

CCT also received Small Business Innovation Research (SBIR) funding from the Air Force Research Laboratory to create gateways from various weapons systems to surveillance platforms. It collects information, integrates it into a common data format, and then presents the information so that military decision makers have access to all of the critical information. Additional government projects have included designing command and control systems for border protection that integrate radar, seismic, infrared, and proximity sensor data with auto-tracking cameras and automatic dispatch systems. These systems provide the U.S. Department of Homeland Security with accurate, real-time border security information. With an area as large as a border equipped with a wide variety of sensors, collecting and analyzing data to determine threats can be a daunting task. CCTK helps integrate the data and improve the quality of information that border patrol agents use to make interdiction decisions.

Having demonstrated success with its government clients, CCT has entered the commercial markets. Potential industrial avenues include energy generation, process control, and manufacturing.

For all of the technical support that NASA has shown CCT, the company has been able to reciprocate in turn by providing the Space Agency with valuable launch services and range safety research and development support. ❖

CCTK™ is a trademark of Command and Control Technologies Corporation.

# Software Tools Streamline Project Management

## Originating Technology/NASA Contribution

Three innovative software inventions from Ames Research Center (NETMARK, Program Management Tool, and Query-Based Document Management) are finding their way into NASA missions as well as industry applications.

The first, NETMARK, is a program that enables integrated searching of data stored in a variety of databases and documents, meaning that users no longer have to look in several places for related information. NETMARK allows users to search and query information across all of these sources in one step. This cross-cutting capability in information analysis has exponentially reduced the amount of time needed to mine data from days or weeks to mere seconds.

NETMARK has been used widely throughout NASA, enabling this automatic integration of information across many documents and databases. NASA projects that use NETMARK include the internal reporting system and project performance dashboard, Erasmus, NASA's enterprise management tool, which enhances organizational collaboration and information sharing through document routing and review; the Integrated Financial Management Program; International Space Station Knowledge Management; Mishap and Anomaly Information Reporting System; and management of the Mars Exploration Rovers.

Approximately \$1 billion worth of NASA's projects are currently managed using Program Management Tool (PMT), which is based on NETMARK. PMT is a comprehensive, Web-enabled application tool used to assist program and project managers within NASA enterprises in monitoring, disseminating, and tracking the progress of program and project milestones and other relevant resources. The PMT consists of an integrated knowledge repository built upon advanced enterprise-wide database integration techniques and the latest Web-enabled technologies. The current system is in a

ACTY	ACTY	ACTY	
.82	\$ 33.61	\$ 7,701.16	\$ 985.00
		299.89	
\$2.79	27.11	1,842.26	995.90

PanOptica software incorporates three NASA-developed programs.

pilot operational mode allowing users to automatically manage, track, define, update, and view customizable milestone objectives and goals.

The third software invention, Query-Based Document Management (QBDM) is a tool that enables content or context searches, either simple or hierarchical, across a variety of databases. The system enables users to specify notification subscriptions where they associate "contexts

of interest" and "events of interest" to one or more documents or collection(s) of documents. Based on these subscriptions, users receive notification when the events of interest occur within the contexts of interest for associated document or collection(s) of documents. Users can also associate at least one notification time as part of the notification subscription, with at least one option for the time period of notifications.

## Partnership

The three software tools have been bundled together for the purpose of executing a nonexclusive patent license, and in June 2006, [JumpStart Solutions LLC \(JSS\)](#), of Cave Creek, Arizona, licensed NETMARK, PMT, and QBDM for use in its PanOptica product suite.

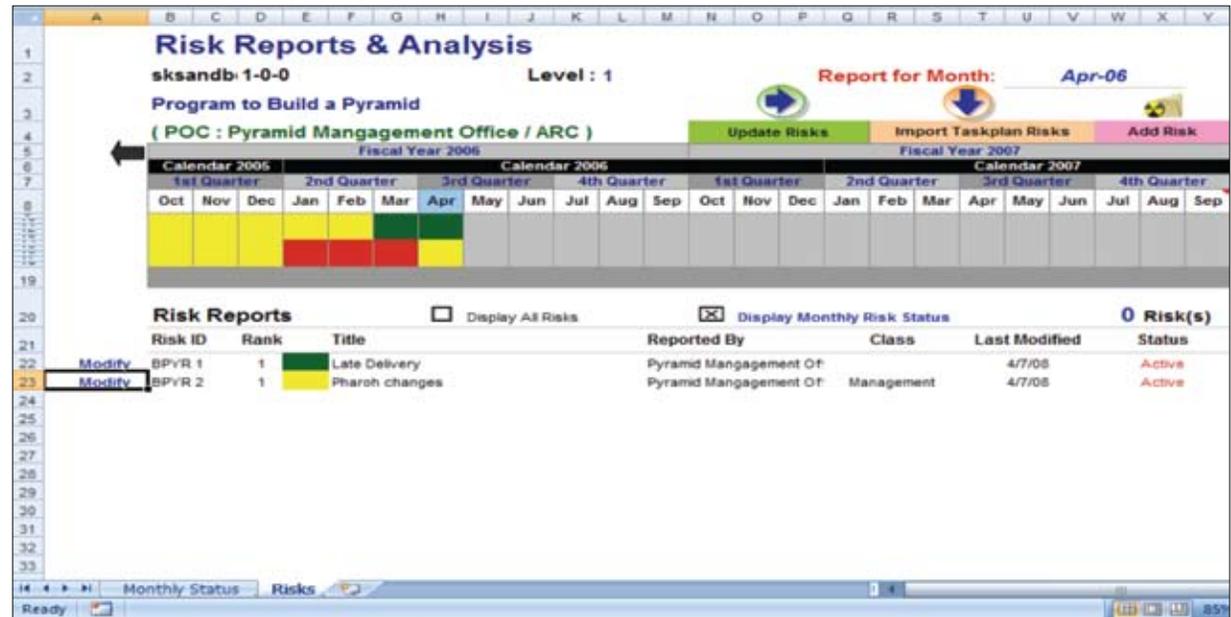
This license also allows JSS to re-license the three programs individually to targeted commercial companies, venture capital firms, and other government agencies.

## Product Outcome

In September 2006, JSS announced the availability of PanOptica, its new suite of business intelligence and knowledge management tools. PanOptica was built using NETMARK, PMT, and QBDM and offers customers a cost-effective, scalable, easy-to-use suite of tools to manage projects, portfolios, and knowledge bases and documents.

The PanOptica product suite can be understood as a set of collaboration tools, enabling implementers and managers across functionalities, responsibilities, and geographies to communicate with each other, share knowledge, and update their decision-making to evolve action to fit strategic objectives in a changing environment.

PanOptica applies the technologies to enable customer project, portfolio, and program managers to integrate the information from their project plans—work breakdown structures, milestones, budgets—with their financial, operating, and other systems—and to create reports that are useful and intelligible to their varied constituents. In other words, anyone, from principal investigators to senior management, to multiple funding sources and partnering organizations, can know “how are we doing?” on each of the project elements and how they roll up to larger views (portfolios and programs). Earned Value Management tools are applied. PanOptica is particularly useful in complex organizations, where different constituents, such as multiple funding sources for actual work, have



PanOptica is a comprehensive, Web-enabled tool set, which provides intuitive and enhanced Web interfaces to automate the tedious process of monitoring, disseminating and tracking the progress of individual projects and project portfolios.

their own objectives, and, consequently, have different perspectives on the work being done.

One of the goals of PanOptica is simplicity of use. This starts with assisting the customer to enable data to be entered only once, rather than the multiple iterations often required for different uses. It continues with intuitive Web-based interfaces, using widely understood Microsoft Office applications for reports. It enables straightforward approvals by authorized users of actions, such as releasing funds, to follow and, then, seamlessly, provides information to update the various systems.

This product suite provides users a comprehensive set of Web-based tools for project and portfolio management. JSS also plans to integrate other technologies with NETMARK/PMT/QBDM to provide project portfolio management and knowledge document management capabilities for its industry, university, and other customers.

Many companies are reluctant to license technology from the U.S. Government. The primary reason is the length of time required to investigate the technologies, determine the technical applications, negotiate the license agreement, and learn the government licensing process. It is JSS's secondary strategy to shorten the licensing process time and become a clearing house for technologies that it has licensed from Federal agencies and universities that have commercial viability. JSS will prepare the licensed technologies for re-licensing, and re-license them to the private sector or other government entities. ❖

PanOptica® is a registered trademark of JumpStart Solutions LLC.

# Modeling Languages Refine Vehicle Design

## Originating Technology/NASA Contribution

When we watch a space shuttle launch on television, we have only the vaguest sense of the extraordinary amount of work required to make such a complex operation successful. Even with the most highly trained engineers in the world, designing a space vehicle requires many thousands of hours of labor—and that is just in the early concept phases. With new partnerships and developments in software, however, a design task that formerly took 1,000 hours may take fewer than 100 hours.

The Vehicle Analysis Branch (VAB) at Langley Research Center is responsible for a variety of important tasks in support of the Agency's space and planetary exploration missions, including performing preliminary design and analysis of space transportation system concepts. Recent industry collaboration with this advanced analysis branch resulted in a novel software platform that is assisting both NASA's missions and the aerospace industry in general.

## Partnership

Cincinnati, Ohio's [TechnoSoft Inc.](#) is a leading provider of object-oriented modeling and simulation technology used for commercial and defense applications. The company designed its Adaptive Modeling Language (AML) software for the U.S. Air Force to assist the military with saving time and costs during new vehicle development. This software has since evolved through NASA involvement and is applicable to a wide variety of industries.

AML is an object-oriented, knowledge-based engineering modeling framework upon which other applications can be built. It enables multidisciplinary modeling and integration of the entire product and process development cycle.

TechnoSoft's president, Adel Chemaly, believes the AML product is unique for two reasons: "One aspect



Artist's concept of the air-breathing X-43A Hypersonic Experimental Vehicle, or "Hyper-X." NASA is using software by companies such as TechnoSoft Inc. to design these supersonic combustion ram-air compression jets (scramjets).

is doing modeling—capturing model requirements for different disciplines, like multianalysis design environments. The other aspect is computing—collaboration, distributed computing, object computing, and web-enabled capabilities."

Because the Air Force had such success with the AML framework, TechnoSoft knew that it would also be useful to others who had similar research initiatives, such as NASA. The Air Force helped pave the way for the firm to meet with NASA researchers at Langley: A researcher from the Air Force Research Laboratory was collaborating with Langley engineers on different projects to learn best practices in vehicle design. The researcher recommended using TechnoSoft's AML program.

According to John Martin at Langley's VAB, the team there had invested "quite a bit of time into developing code for collaborative applications, but it didn't perform that well."

"The AML software also came with extensive corporate knowledge, and that was a real plus for us," says Shelly Ferlemann, another VAB researcher. With the vote of confidence from VAB, TechnoSoft eventually received a **Small Business Innovation Research (SBIR)** contract from Langley to develop the software further.

TechnoSoft built the Collaborative Hypersonic Air-breathing Vehicle Design Environment (CoHAVE) on

its AML framework. According to Chemaly, the partnership ended up benefiting everyone: TechnoSoft tapped into NASA expertise, and eventually, the company took a leadership role, customizing CoHAVE to help NASA engineers analyze scramjet/ramjet vehicles for two-stage-to-orbit and hypersonic cruise missions.

NASA aerospace partners became interested in the capabilities of the enhanced software. Because it provided a mechanism for different disciplines like structural analysis and optimization to work together, CoHAVE improved the product and process design, saving time and money. "If analysis can be performed at an earlier stage," Chemaly says, "it will help prevent a lot of problems. In the past, you had to choose one or two concepts to pursue and hope the gamble paid off." Now, designers who utilize TechnoSoft's AML framework can perform analysis at earlier stages, with higher or lower fidelity as needed. "NASA provided us the methodologies for automation at the various levels, enabling people to introduce higher fidelity earlier in the design process," says Chemaly.

TechnoSoft was ahead of schedule on the software's development, and by the time they were in an SBIR Phase II contract, the product was already being used in design processes. The success of CoHAVE led to a Phase III contract from Langley. "NASA's investing in TechnoSoft has helped prove that this technology is valid and that it reduces risk," Chemaly says. "Once we proved it within certain programs in NASA, we were able to leverage these successes with the Air Force and commercial sectors."

NASA found that CoHAVE is applicable to the Reusable Space Transportation System's product area for evaluating the architectures of the Space Transportation Architecture Study and second-generation reusable launch vehicle studies. Recently, CoHAVE has been extended to incorporate models for other applications such as reentry vehicles. Since the environment now includes vehicles other than traditional hypersonic air-breathing vehicles, the name has morphed into the Integrated Design and Engineering Analysis Environment, or IDEA.

## Product Outcome

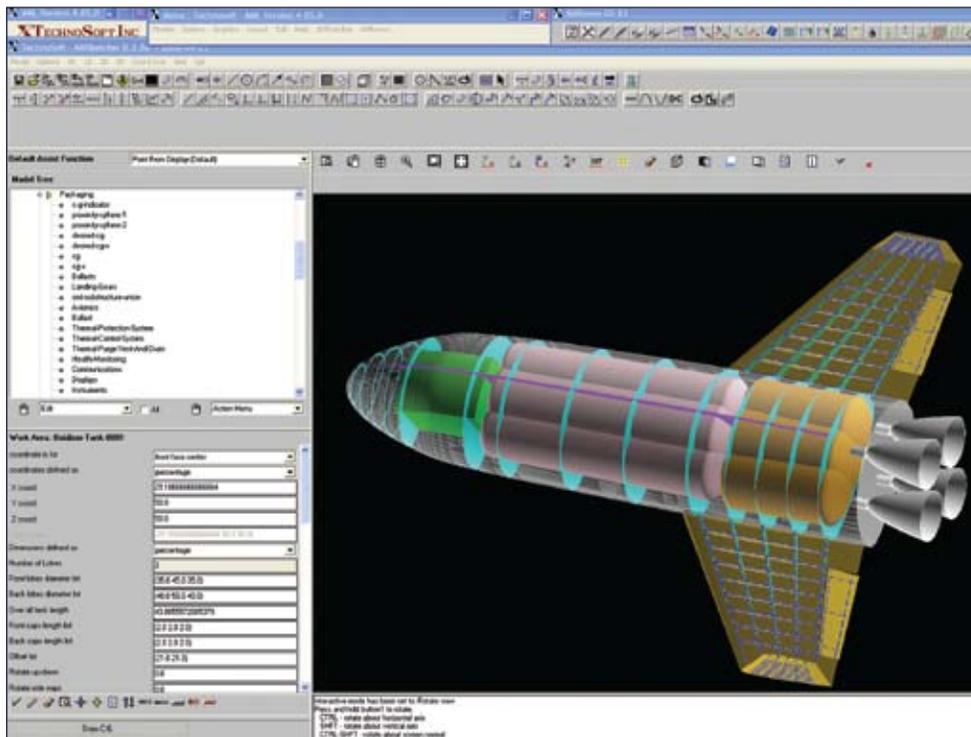
Engineers can use IDEA and the enhanced AML platform early in the design process to analyze a variety of customized models for different designs including fluid dynamics, aerodynamics, structural design, and plenary models. AML offers an advanced modeling paradigm with an open architecture, enabling the automation of an entire product development cycle, integrating product configuration, design, analysis, visualization, production planning, inspection, and cost estimation.

AML enables generative modeling, which leaps beyond present approaches to integrated design and analysis processes. In a generative modeling environment, knowledge of the engineer's tools and the intricacies associated with executing them is captured within a

modeling language. This empowers the engineer to search a broader set of product design configurations, rather than being limited to simple parameter changes. "These can be built to switch back and forth and allow a lot of iterations early on, making the process affordable and fast," Chemaly explains.

The software also greatly improves efficiency, says Chemaly. "We have reduced the design time by at least 50 percent, and some of our customers are quoting 90 percent improvement or better." Since "physics is physics," he says, the TechnoSoft AML can easily be adapted to different vehicle designs, whether the vehicles are traveling in space, the sea, or on Earth.

Current advancements in AML also allow engineers to incorporate changes in cost in a product's life cycle.



Engineers use the enhanced Adaptive Modeling Language platform to analyze a variety of customized models for different designs, including fluid dynamics, aerodynamics, structural design, and plenary models.

This could once again benefit NASA engineers and commercial designers, enabling ongoing cost analysis for everything from surface ships and automobiles to the space shuttles. With AML, Chemaly says, "We can look at the cost of sustaining the design in the long-run," taking into account such factors as ongoing maintenance and repair costs. "If the technology evolves or if costs change, we need to be able to insert that into a design," he says.

The program encourages integration with third-party applications through a number of standard methodologies, including shared memory, pipes, TCP/IP sockets, file transfer, and foreign functions. Built-in XML export capability enables a state model of the AML object hierarchy and geometry to be exported automatically to an XML file, which is viewable using TechnoSoft's AML Viewer. The available "Net Conference" mode enables real-time collaboration among team members across local and global computer networks. A suite of graphical user interface (GUI) classes is provided to allow developers to create customized front-ends to their AML applications. In addition, a visual GUI-builder can be used, making it easier to layout forms and controls, and to assign their associated methods and properties.

TechnoSoft is now customizing AML for clients in green industries, which includes designers for power plant exhaust filtration systems and for wind turbines. TechnoSoft's focus on making the technology more affordable and deployable by the end of 2009, says Chemaly, has opened the doors to smaller commercial customers. With a platform that can reduce 10,000 work hours to 1,000, it is clear there will be ongoing demand for TechnoSoft's Adaptive Modeling Language. ❖

Adaptive Modeling Language™ is a trademark of TechnoSoft Inc.

***The Adaptive Modeling Language platform can reduce 10,000 work hours to 1,000.***

# Radio Relays Improve Wireless Products

## Originating Technology/NASA Contribution

In order to transmit communications through Earth's atmosphere, satellites and space vehicles need radio equipment that can operate at higher frequencies than on Earth. These higher frequencies, until recently, have demanded mechanical switches in radio relays. Unfortunately, the mechanical switches had some problems with frequency routing, which inspired NASA to seek more rugged, reliable solutions.

NASA began to design new, lightweight, microelectromechanical systems, or MEMS. MEMS are extremely small devices (a fraction of a millimeter long) with moving parts, already used in sensors for airbag accelerometers and video game controllers, as well as radio electronics for cell phones, digital mirror displays, and hand-held radios. Switching to MEMS relays for actuators (and not just sensors) from older mechanical switches offered the Agency improved performance in higher frequencies. A California company helped NASA create new MEMS relays that offer some new benefits as well.

## Partnership

After developing a radio frequency (RF) MEMS relay under U.S. Department of Defense contracts, Signal Hill, California-based [XCOM Wireless Inc.](#) continued its research with a Phase II **Small Business Innovation Research (SBIR)** contract in 2003 through NASA's Jet Propulsion Laboratory (JPL). In order to improve satellite communication systems, XCOM produced wireless RF MEMS relays and tunable capacitors that use metal-to-metal contact—moving microscopic metal beams into contact with special electrodes—operating much like a light switch small enough to fit on the cross section of a human hair. They have the high speed of solid-state switches, but with mechanical contacts that outperform semiconductor technology. Also, by introducing a MEMS relay with electrostatic—and not electromechanical—actuation, XCOM was able to produce a MEMS relay



NASA's Lunar Reconnaissance Orbiter, or LRO, and NASA's Lunar Crater Observation and Sensing Satellite, known as LCROSS, shown at top, launched aboard an Atlas V/Centaur rocket in 2009. LCROSS will communicate using radio frequency signals, between antennas on the spacecraft and large dish antennas on Earth, such as the one in Canberra, Australia, shown at bottom. This communication depends on distance, spacecraft orientation, and the physical characteristics of the transmitting and receiving antennas and electronics. Companies such as XCOM Wireless Inc. are working with the Agency to improve these electronics.

that consumed less power and was easier to manufacture than earlier relays.

These MEMS relays are used for signal tuning, routing, and phase-shifting circuitry, thus enabling wireless systems to adapt to changing operating conditions, radar or communications waveforms, and other mission needs. For its work with NASA, XCOM Wireless concentrated on frequencies in the range of 70 GHz–100 GHz, while most commercial radio frequencies use the range from 0.1 GHz–6 GHz. Despite the difference in bandwidth, XCOM's president, Dr. Daniel Hyman, says that the NASA technology is a “fundamental switching device” now incorporated into all of XCOM's products.

## Product Outcome

After designing these improved devices, XCOM entered into a partnership with MEMS manufacturer, Innovative Micro Technology Inc. (IMT), based in Santa Barbara, California. With its NASA-derived design improvements and IMT's manufacturing abilities, XCOM automated its relay manufacturing and testing, and reduced costs to one-tenth the previous amount. This, Hyman says, gave the new relays potential to be “a mainstream product with thousands of solid industrial customers in a stable and growing market.”

XCOM has two products made possible by the MEMS technology the company developed under the SBIR from JPL. The first is an industrial relay used for high-frequency test equipment and instrumentation, the XW3100 single pole double throw relay. The second, an RF MEMS tuning circuit, is in development for the wireless communications industry.

The XW3100 relays offer faster performance for automated test equipment, with frequency switching as high as 20 GHz—much more efficient than large electromagnetic relays. Typically the size of sugar cubes, electromagnetic relays consume a lot of power, and because of their large size, they are very slow. Conversely, the XW3100s incorporate gold contacts to offer speed

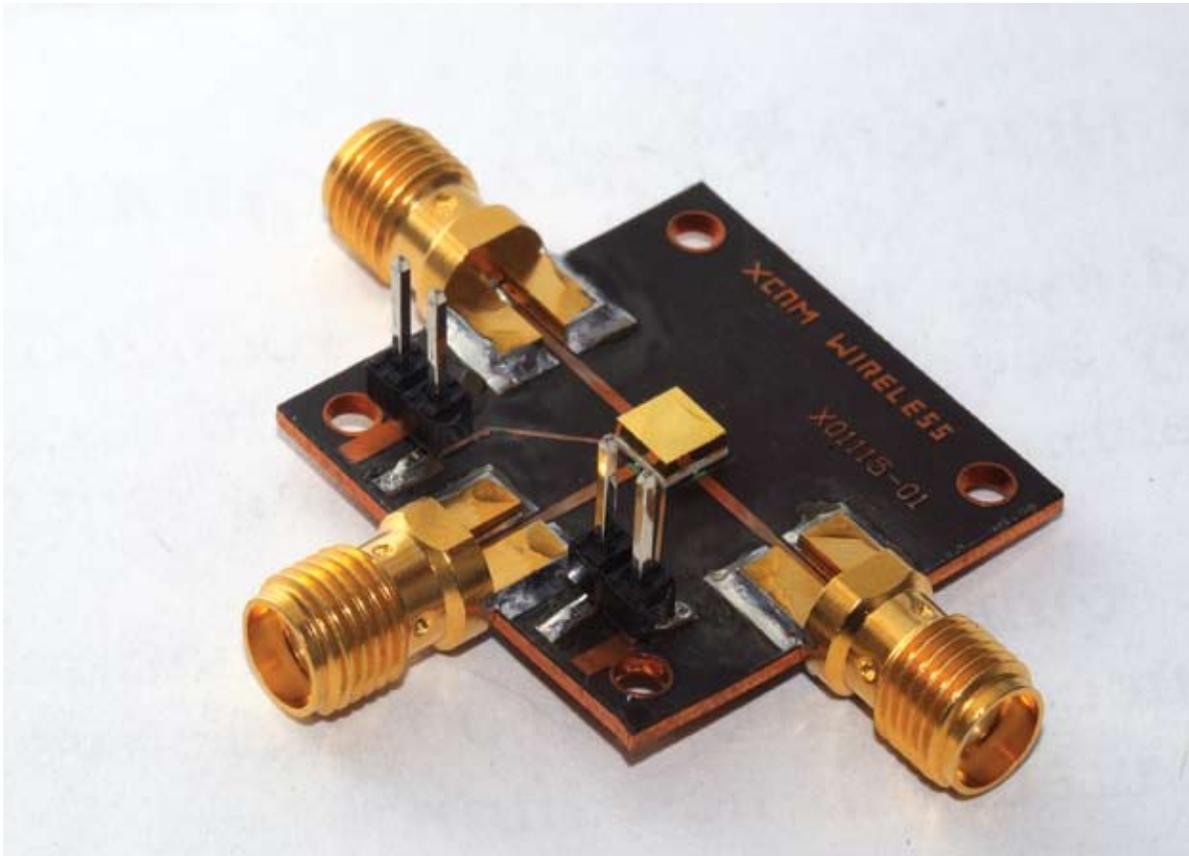


Image courtesy of XCOM Wireless Inc.

The XCOM Wireless XW3100 microelectromechanical single pole double throw relay, mounted on a radio frequency test coupon. According to the company, the XW3100 relays offer faster performance for automated test equipment, with frequency switching as high as 20 gigahertz.

in a small footprint. Industrial systems that reconfigure different testing for computer chips or cell phones, for instance, depend on the speed of these relays. Reconfiguration speed can account for half of the total cost of testing final products, so companies are able to cut costs by having faster, smaller relays. "Fifty percent improvement in profits to the chipset makers is our compelling value and why our parts are so desirable," Hyman says. The XW3100 relays also offer other

advantages, such as linearity, lifetime, and bandwidth, but Hyman suggests that the most attractive features are the reduced power consumption and significantly higher switching speed, especially when contrasted with electromagnetic relays. The relays offer a continuous RF current of 400 milliamps.

Although early interest for the RF MEMS technology was primarily for instrumentation for aerospace and defense industries, the opportunities are now far more

varied. Newer applications include fixed and wireless broadband data link equipment, wireless network hardware, cell phones, laptop computers, and personal digital assistants.

The second product, which will be available in 2010, is an RF MEMS tuning circuit for use in hand-held radios and cell phones. These circuits use the low-loss switch technology developed with the NASA funding, and Hyman expects the technology will greatly improve interoperability and power consumption in tactical radios. Miniaturizing the circuits and integrating them with filter and antenna subsystems allow older and newer radios to communicate seamlessly, making multi-agency operations more efficient. Hyman also expects XCOM's relays will be incorporated into multiband third generation (3G) cellular systems because they enable cell phones to have better worldwide service, improved simultaneous data and voice use, and better wireless local network service. American cell phones typically do not work in Europe, for example, but the relays can make the numerous waveforms all compatible, thus enabling seamless global coverage. The relays can also switch a phone call from a cellular network to an available broadband wireless network automatically, thereby reducing the use of cell phone minutes and reducing dependence on overloaded cellular infrastructure. Lastly, the technology can also extend battery life and reduce dropped calls.

Hyman expects more commercial broadband companies will take advantage of the technology soon. The applications are still growing today as consumer wireless companies continue to reduce cost while increasing functionality in each new model. "These are the technologies and opportunities that will shape the next generation of wireless," Hyman concludes. ❖

# Industrial Productivity



The engineering lessons from NASA missions and research help to build and make things other than space vehicles. The technologies featured in this section:

- Boost Optical Communication, Imaging
- Enhance Architecture Around the World
- Support Powerful Imaging Devices
- Cool, Power Electronics
- Advance Revolutionary Weld Technique
- Reduce Cost, Enhance Quality of Nanotubes
- Monitor Cryogenic Liquids
- Monitor Harmful Static
- Measure Heat Potential





# Advanced Sensors Boost Optical Communication, Imaging

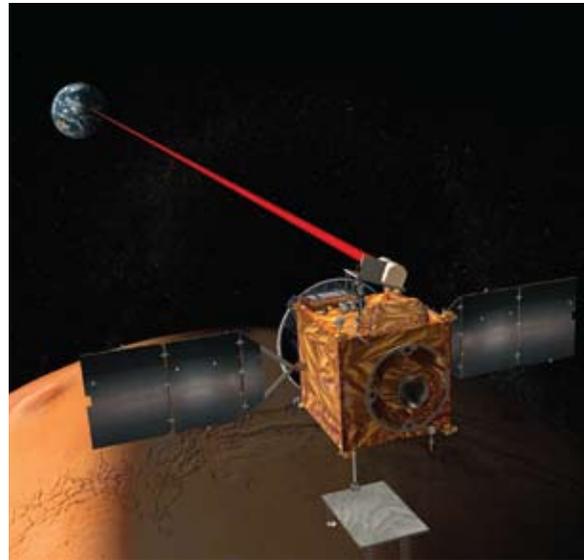
## Originating Technology/NASA Contribution

In 1992, on a gravity assist flyby of Earth that would help propel it along its mission to Jupiter, NASA's Galileo probe detected a line of light pulses emerging from Earth's night-darkened hemisphere. Over the next few days, Galileo's camera imaged similar signals—even though the probe was hurtling through space nearly 4 million miles from the planet.

The pulses Galileo detected were powerful laser bursts from telescopes at NASA's Table Mountain Observatory in Wrightwood, California, and the U.S. Air Force Phillips Laboratory Starfire Optical Range near Albuquerque. The lasers, firing bursts in the range of tens of megawatts, were part of the Jet Propulsion Laboratory (JPL) Galileo Optical Experiment (GOPEX) that gave a glimpse into the future of communications—and how a Mars colonist might one day phone home.

As the scope of NASA's missions have expanded in reach, unprecedented levels of data have flooded in from increasingly powerful sensors, and as manned missions and possible colonies on the Moon and Mars have inched closer to becoming viable realities, the Agency has seen the need for more efficient and effective means of communicating across the expanses of space. In addition, the practical demands of space exploration require further reductions in spacecraft size and weight, making smaller, lighter, more energy-efficient communications equipment a priority. GOPEX demonstrated the potential of free space (no physical connection) optical communications.

JPL's Optical Communications Group has been tackling the challenge of enabling space missions to return 10–100 times more data while reducing antenna area to 1 percent of its current size—all while also employing less mass and power. Optical laser communication presents a host of benefits in these regards. It offers high-bandwidth, low mass, and low power consumption, allowing missions to communicate deeper into space. Optical communications are to radio frequency communications as a dart is



Lasers may one day facilitate interplanetary communications networks and high data-rate transmissions from powerful space-based sensors.

to a shotgun blast; a radio signal from Mars spreads out to about 100 times Earth's diameter by the time it reaches the planet, while an optical signal pinpoints a spot about one-tenth of the Earth's diameter. This kind of precision enhances the security of the communicated data, but there are significant difficulties in acquiring, tracking, and pointing optical signals accurately over such incredible distances. As such, JPL continues to explore increasingly powerful sensor technologies that can help detect even the faintest light signals, helping enable NASA's effort to establish interplanetary communications networks and a virtual presence throughout the solar system. One company has assisted JPL in this mission by developing a light sensor that has multiple applications on Earth, as well.

## Partnership

Brooklyn, New York-based [Amplification Technologies Inc. \(ATI\)](#), a subsidiary of PowerSafe Technology, received

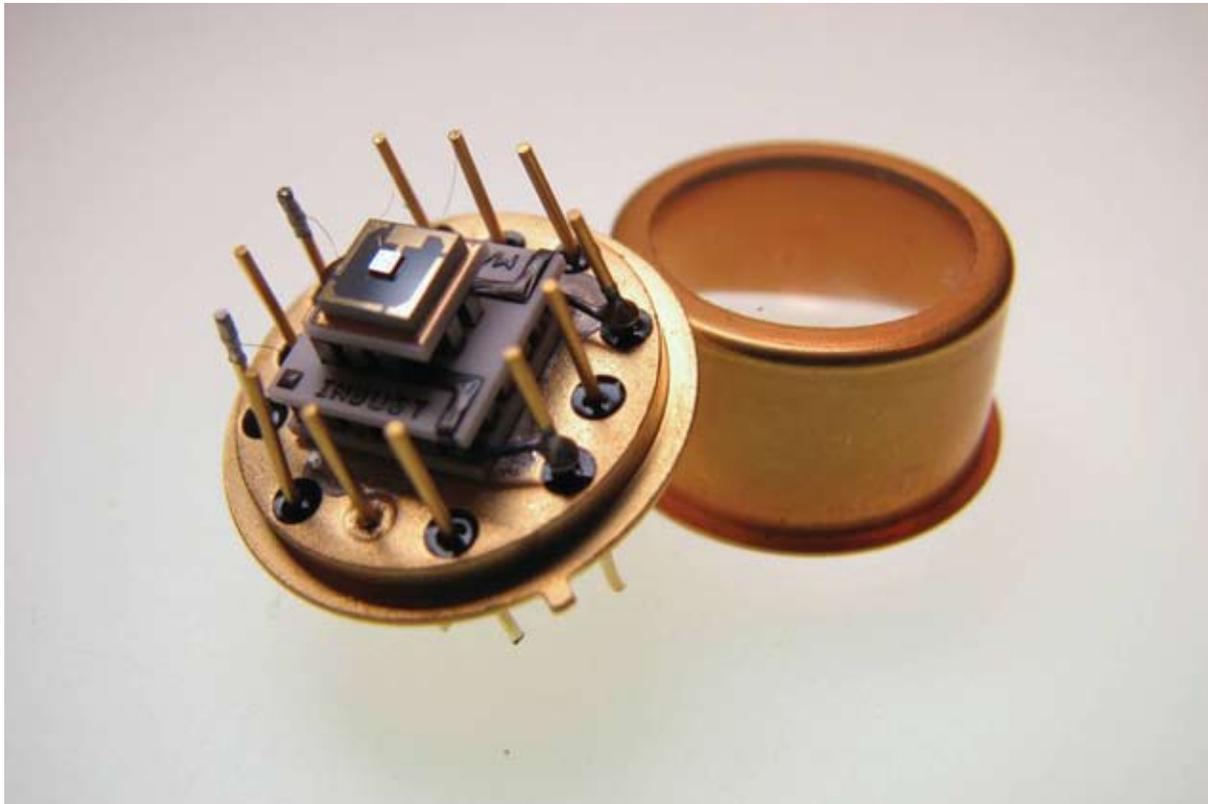
Phase I and II **Small Business Innovation Research (SBIR)** contracts with JPL to pursue the development of a solid-state photomultiplier capable of detecting light down to its most reduced form—particles called photons. Photomultipliers are highly sensitive light sensors that boost the signals of even the faintest light to detectable levels. ATI, an advanced developer of photon detection technology, had already developed its patented Discrete Amplification Photon Detector (DAPD), a solid-state, silicon-based photomultiplier that can detect visible light wavelengths down to a single photon. JPL was looking for photomultipliers that could detect individual photons in the near infrared (NIR) light wavelengths, specifically in the bands of 1060 and 1550 nanometers (nm) that the Center is exploring for use in free space optical communications. ATI employed its SBIR funding to implement a new indium-gallium-arsenide base for its DAPD technology, leading to a photomultiplier that detects single photon levels in the NIR range of 950 nm to 1700 nm. JPL used the device in its laser communications module, and it is now emerging as a commercial product with a variety of terrestrial uses.

"We looked at the NASA requirements and jumped on the project," says ATI consultant Dr. Krishna Linga. "We came up with a unique product that no one else has on the market today."

## Product Outcome

ATI commercialized its SBIR-developed photomultiplier as the company's NIRDAPD series. The extremely high-gain NIRDAPD sensor takes advantage of ATI's patented discrete amplification method, which uses multichannel amplification to boost the low-level electrical signal produced when the sensor encounters individual photons.

"If you take a simple photodetector, it can only yield one electron from one photon," says Linga, meaning the sensor will not be very sensitive to the lowest levels of light. "ATI's detector is able to sense a single photon and



yield a million electrons.” Those million electrons, Linga explains, can then be transferred in some form of a current to a resistor, and the significant voltage drop in the resistor can be detected by any general electronic meter. Featuring many tiny cells, each capable of detecting a single photon, the NIRDAPD sensor does not require any additional amplifiers or external circuitry to render the current from the circuit detectable. “You just plug the sensor into any electronic media that can record these signals,” Linga says. The sensor has a fast response time, high voltage and thermal stability, and a low noise factor (intrusion from undesired ambient light has a minimal impact), in addition to being small (less than 5 millimeters), light

in weight (less than one-tenth of a pound), and energy efficient. These qualities all amount to a solid-state photomultiplier that ATI says outperforms other solid-state photodetectors in the NIR wavelength range.

“This device can be applied for any NIR optical sensing that requires single photon detection,” says Linga, citing communications, the military, and imaging as main markets for the sensor. The NIRDAPD photomultiplier can be used for free space optical communications applications closer to Earth, like satellite communications and data transmission from unmanned aerial vehicles used for military purposes or forest fire detection. Additional military applications include lidar and ladar range-finding



Amplification Technologies's NIRDAPD photomultiplier can sense infrared light down to individual photons, without the cooling required by other infrared sensors.

used to target munitions with pinpoint accuracy (the sensor detects the faint light from the targeting beam reflected off the target), and night vision goggles, which can take advantage of the sensor's portability and ability to operate efficiently at room temperature. (Other infrared sensors often require liquid nitrogen cooling to operate effectively.) NIR cameras can also benefit from these qualities.

While the company has not yet explored medical applications, says Linga, he notes the sensor can be used as part of a laser-based glucose monitoring system. He also points to quantum cryptography, which employs elements of quantum mechanics—including photons—to secure encrypted information, as a future application for ATI's NASA SBIR-funded sensor, meaning this technology could one day be used for protecting secrets on Earth and among the stars. ❖

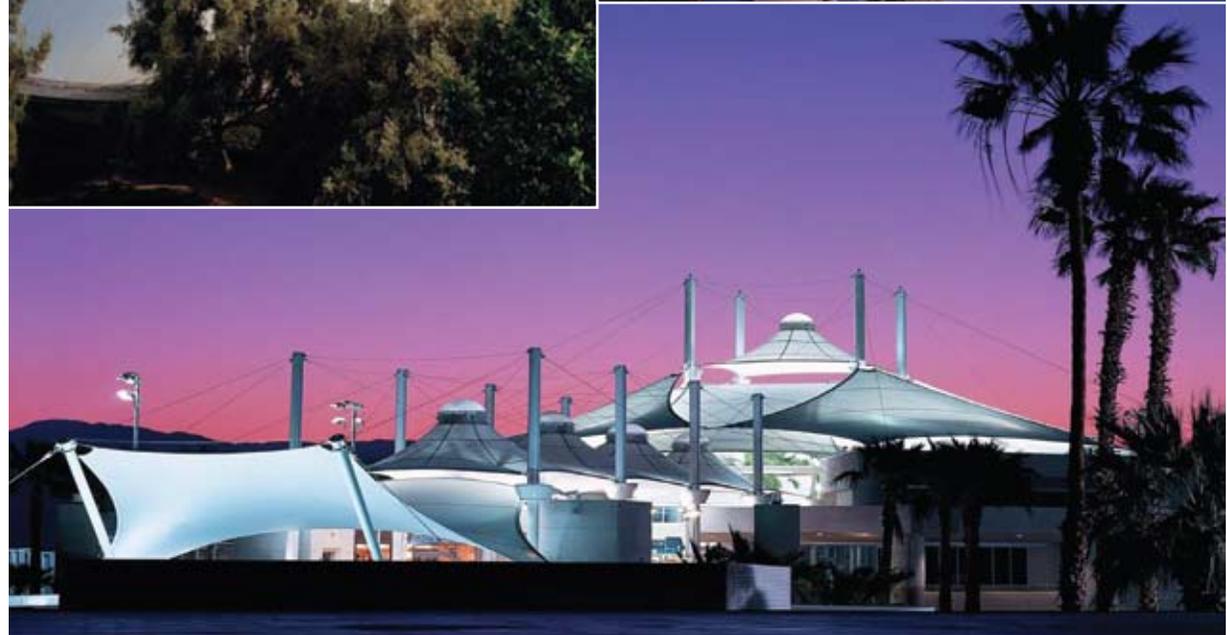
# Tensile Fabrics Enhance Architecture Around the World

## Originating Technology/NASA Contribution

On a Friday night in March 2008, fans at a college basketball game at Atlanta's Georgia Dome noticed the stadium's scoreboard begin to sway. Outside, winds howled through the city. Unknown to those in the stadium, a tornado was ripping through downtown. The safety of the more than 18,000 people would depend in large part on the integrity of the stadium's domed roof—built using a material originally developed to protect NASA astronauts.

Over 40 years earlier, NASA's effort to achieve the first manned Moon landing nearly derailed when a fire broke out on the Apollo 1 command module during a test exercise, resulting in the destruction of the module and the deaths of the three astronauts onboard. In the wake of the tragedy, NASA engineers redesigned the Apollo module and searched for ways to enhance the safety performance of the nylon space suits. The suits required an outer layer component that would be durable, strong, lightweight, flexible, and noncombustible. Owens-Corning Fiberglass, of Toledo, Ohio—working with DuPont, of Wilmington, Delaware—proposed a fabric known as "Beta cloth." The primary component of this fabric was ultrafine glass filaments, which were twisted into yarns and then woven into the fabric. The manufacturers then coated it with polytetrafluoroethylene (PTFE, more commonly known as Teflon), a DuPont invention. The fabric proved noncombustible (with a melting point over 650 °F) and durable enough for NASA's needs. The Agency incorporated the PTFE fiberglass fabric into the outer protective layers of the Integrated Thermal Micrometeoroid Garment (ITMG) of the A7L space suit worn for the Apollo missions and Skylab program. The PTFE fiberglass fabric layer provided both thermal protection as well as shielding from abrasive lunar dust during Moon landings.

While the current NASA space suit used on the space shuttle and International Space Station employs Ortho-



Fabric (a blend of GORE-TEX, Kevlar, and Nomex—all private industry inventions) in its ITMG instead of the PTFE fiberglass fabric, that original innovation has gone on to become a unique component of an unrelated, terrestrial field: architecture.

Birdair's roof structures, using fabric originally developed for the Apollo space suits, now adorn buildings such as (clockwise from top left) the original Birdair "Super Tents" structure at the University of La Verne in La Verne, California; Navy Pier in Chicago, and Palm Springs International Airport in Palm Springs, California.

## Partnership

In 1956, aeronautical engineer Walter Bird founded [Birdair Structures Inc.](#) in the kitchen of his home in Buffalo, New York. Birdair initially focused on air-supported, neoprene-coated nylon fabric structures, building upon its founder's experience crafting such structures for use by the U.S. military.

Birdair's work developing the air-supported, vinyl-coated fiberglass fabric roof (the first of its kind) of the U.S. Pavilion at Expo 1970 in Osaka, Japan, led the company to explore improved fiberglass fabric options for architectural use. The company collaborated with Owens-Corning, DuPont, and Chemical Fabrics Corporation (Chemfab), of Merrimack, New Hampshire on a modified, stronger version of the PTFE glass fiber fabric developed for NASA. The resulting fabric (later called Sheerfill Architectural Membrane, manufactured by Chemfab), expanded the market for Birdair in the field of lightweight, tensile membrane roof structures for roofs, skylights, and canopies.

## Product Outcome

"When there are so many architectural materials out there, fabric is not something architects usually think of offhand," says William Barden, Birdair's director of architectural development. "Walter Bird's pioneering role in the tensile structure industry was to take a technology that was perceived by people as 'pie in the sky' and create a market for it."

In 1973, Birdair engineered, fabricated, and installed the world's first permanent tensile membrane roof system utilizing PTFE fiberglass membrane for the Sports Science and Athletics Pavilion at the University of La Verne in La Verne, California. Thirty-six years later, that original structure remains in excellent condition. Birdair, now a specialty contractor based in Amherst, New York, has grown into a multimillion-dollar company with nearly 900 landmark tensile structures to its name, most of which

employ the original PTFE fiberglass fabric developed for NASA. Major transportation hubs, sports facilities, and convention centers are among the buildings around the world that feature Birdair's signature PTFE fiberglass membrane roofing. These include Denver International Airport's Jeppesen Terminal; the 105-acre Hajj Terminal in Saudi Arabia; Reliant Stadium in Houston (the first retractable roof in the NFL); the O2/Millennium Dome in London, England (22 acres of fabric roof); the Sony Center in Berlin, Germany; and many others. Barden estimates the company has fabricated and installed over 30 million square feet of the PTFE fiberglass membrane in its various projects.

The same qualities that made the PTFE fiberglass fabric appealing to NASA also make it ideal for large-scale, permanent tensile membrane roofs. The material is pound-for-pound stronger than steel while weighing less than 5 ounces per square foot. It offers up to 24 percent solar translucency while providing as much as 75 percent solar reflectance, meaning the fabric lets in natural light while keeping out heat, making it an energy-efficient roofing alternative. It is also cost-effective due to its durability and low maintenance characteristics. Barden estimates a properly maintained Birdair roof could provide 30–35 years or more of useful service life, as opposed



Houston's Reliant Stadium features a retractable, PTFE fiberglass fabric roof crafted by Birdair.

to the 20–25 years offered by conventional roofing materials like asphalt shingles or single-ply rubber. As a non-flammable fabric, the PTFE fiberglass material is safer than many roofing options, as well, and allows for the creation of swooping, eye-catching architectural forms.

Birdair's PTFE fiberglass membrane, still manufactured for Birdair by Chemfab (now called Saint-Gobain Performance Plastics), entered the Space Foundation's Space Technology Hall of Fame in 1989. The material's capabilities—and possibilities—have yet to be exhausted, however. In 2008, Sheerfill Architectural Membrane was approved by the U.S. Environmental Protection Agency as an ENERGY STAR qualified roof product and recognized by the Cool Roof Rating Council, based on the fabric's high solar reflectance and thermal emittance. Birdair also introduced its Tensotherm insulated fabric roofing product, which allows natural light to pass through while providing enhanced thermal resistance and acoustical qualities.

The company continues to work on new structures—including three out of the four primary stadiums for the 2010 World Cup in South Africa and the new Dallas Cowboys Stadium—while celebrating the enduring quality of its existing creations. Among those is the Georgia Dome, which came out of the March 2008 Atlanta tornado with only slight damage to its roof and not a single injury to its occupants, though winds ranged up to 135 miles per hour and caused significant destruction in the city. The stadium roof's PTFE fiberglass membrane, the same material that once protected astronauts in the harsh environs of the Moon, required only minor repairs. ❖

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# Robust Light Filters Support Powerful Imaging Devices

## Originating Technology/NASA Contribution

Consider the anatomy of a rainbow: From the inner arch, violet shifts to blue, then green, yellow, and red. Contained in the rainbow is the spectrum of light that our eyes take in and translate into images of the world around us. But the human eye only registers a minute percentage of the electromagnetic spectrum, which theoretically stretches into infinity beyond the wavelengths (between 0.38 and 0.76 micrometers) of visible light. Past violet, the wavelengths of ultraviolet, X-rays, and gamma rays cramp closer and closer together. Going in the other direction, past red, stretch the expanding wavelengths of infrared, terahertz, microwaves, and radio waves. It is within these invisible ranges that many of the secrets of our universe remain.

Much of the universe is not observable using visible light. Clouds of cosmic gas and dust obscure the gaze of traditional telescopes, and the ongoing expansion of the universe following the Big Bang further complicates observation of distant galaxies. As the galaxies race away from our position, the visible light they emit is redshifted, or stretched, transforming it into infrared (IR) light—thermal, or heat radiation—which is able to pass unimpeded through cosmic dust clouds. Telescopes that detect IR light are therefore capable of unveiling vastly greater views of our universe and even peering into its very beginnings.

NASA has been at the forefront of IR astronomy since 1974, when its Kuiper Airborne Observatory (KAO), an IR telescope mounted on a transport jet, made astonishing observations on a series of flights that lasted until 1995. (The Earth's atmosphere absorbs much of the IR radiation from space, making high-altitude telescopes far more effective than ground-based versions. Space-based telescopes are more sensitive yet, since they can be cooled to very low temperatures, limiting interference from their own heat radiation.) The Agency has developed many IR observatories, from the 1979 construction of the Infrared



These Orion nebula images compare an infrared view taken by the Spitzer Space Telescope (left), revealing bright clouds and developing stars, with a darker, dust-obscured, visible light view.

Telescope Facility 14,000 feet up the slope of Mauna Kea in Hawaii to the 1983 launch of the Infrared Astronomical Satellite, the first IR satellite telescope, to the Cosmic Background Explorer (COBE), to the near-infrared camera multiobject spectrometer (NICMOS) operating onboard the Hubble Space Telescope since 1997. In 2003, the Spitzer Space Telescope combined sensitive modern infrared detectors with a cooled telescope to produce a remarkably powerful observatory. NASA plans to come full circle in its IR observatory efforts in 2010 with the first operational flight of KAO's next-generation cousin, the Stratospheric Observatory for Infrared Astronomy (SOFIA), a large, airplane-mounted IR telescope. Four years later, the Agency expects to launch the infrared James Webb Space Telescope, which will allow us to see deeper into the universe than ever before.

## Partnership

[Lake Shore Cryotronics Inc.](#), of Westerville, Ohio, entered into 2002 Phase I and Phase II **Small Business Innovation Research (SBIR)** contracts with NASA's Jet Propulsion Laboratory (JPL) and similar contracts in 2004 with Langley Research Center. The NASA centers wanted robust and high performance optical filters for IR astronomy to select the wavelengths of light that reach the detector. Since warm objects emit IR radiation, steps must be taken to reduce the amount of local thermal noise that



The infrared (IR) telescope of the Stratospheric Observatory for Infrared Astronomy (SOFIA) peers through the opening in the fuselage of its Boeing 747 mothership.

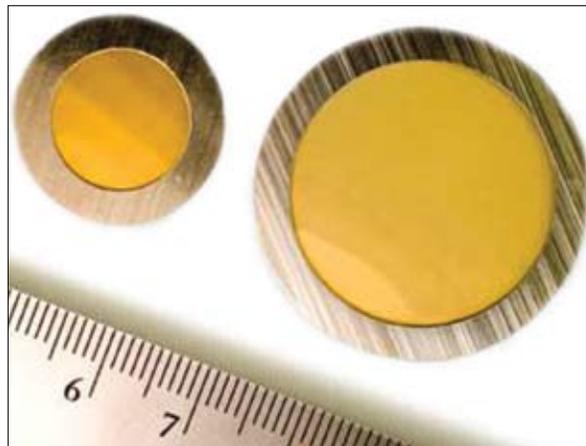
interferes with the desired signal, typically by cooling the detector and its filters to a near-absolute-zero temperature. Existing IR filters, composed of multiple layers of different materials with different mechanical properties, tend to delaminate (separate from one another) at such extreme temperatures. They are also extremely expensive and often comprised of mechanically and chemically fragile materials. Lake Shore, a leading supplier of cryogenic temperature sensors and instrumentation, magnetic test equipment, metrology systems, and probe stations for the characterization of magnetic and transport properties of material, was intrigued by the problem and used the SBIR funding to investigate porous silicon technology, and subsequently, metal-mesh technology, as possible elements of a new filter technology for the IR. The company invested significant internal funds in the project; Lake Shore prides itself in a research and development budget that is typically double the national average for instrumentation companies.

The effort resulted in a more affordable long wave pass IR filter composed of mesoporous silicon. The filter, composed of a lattice of electrochemically etched, porous layers of monocrystalline silicon, maintains its properties and does not delaminate at extreme temperatures. Its high transparency for the far IR range (most removed from visible light) also makes it more desirable than conventional filter technology, which cannot perform using the long wavelengths employed for deep space imaging. This research program also resulted in the development of metal-mesh constructed filters (also referred to as frequency selective surfaces) specifically for IR band pass filters.

“The SBIR funding jumpstarted this program internally for us,” says David Klein, Lake Shore’s lead on new business development programs. “As we confirmed interest from NASA and other aerospace organizations, it further justified our decision to pursue the technology’s development and push toward commercialization.”

## Product Outcome

Lake Shore now features two standard IR filter products: mesoporous silicon long pass filters and a line of metal-mesh band pass and narrow band pass filters. (Long pass filters allow transmission of wavelengths above a certain minimum; a 10 micron long pass filter, for example, allows all wavelengths longer than 10 microns to pass. Band pass filters allow a transmission like a bell curve; a 10 micron band pass filter allows maximum transmission at 10 microns with decreasing transmission at neighboring wavelengths.) During development, Lake Shore determined the mesoporous silicon technology worked well for long pass filters but was not ideal for band pass filters. At the suggestion of Dr. Harvey Moseley, senior astrophysicist at Goddard Space Flight Center, Lake Shore created band pass filters composed of thin metal mesh with varied geometrical openings to allow the transmission of desired wavelengths. The metal-mesh filters—a frequency selective surface (FSS) technology—are also fully functional at ultra-low temperatures, and easily fit into existing filter assemblies. Lake Shore recently delivered a number of the SBIR-



Lake Shore’s SBIR-developed IR filters are ideal for astronomy applications, as well as for technologies like terahertz imaging.

developed filters to Cornell University for use with its Faint Object Infrared Camera (FORCAST), designed for NASA’s SOFIA program.

Lake Shore’s main customers for its filter products are within the astronomy community, but there are other promising applications on the horizon. One such opportunity is in the burgeoning field of terahertz imaging. Terahertz radiation—the range of wavelengths between IR and microwaves—is blocked by water or metal but passes through a range of other materials, including wood, cardboard, clothing, ceramics, and plastic. This makes terahertz radiation a highly appealing option for everything from medical imaging to examining artwork. Because certain materials, like plastic explosives, have special spectral signatures when imaged with terahertz radiation, the potential is great for developing highly specific security measures using terahertz. Klein notes that Lake Shore’s filter technology could be useful for this developing field.

“Our partnership with NASA has provided us with cross-cutting technology that we can use for other applications in different markets,” says Klein. The company is also investigating ways of using its SBIR-developed macroporous silicon technology in the development of other types of optical and electronic devices. “We wouldn’t have this porous silicon technology if it wasn’t for the NASA SBIR program.”

“The relationship between NASA and the private sector results in a cross-pollination of ideas and technologies, some with readymade applications and customers,” says Klein. “The U.S. government’s multi agency SBIR and STTR programs and their focus on supporting the small, technically rich business community provides an incentive for companies like Lake Shore Cryotronics to further invest in these technologies and bring them to market.” ❖

# Thermoelectric Devices Cool, Power Electronics

## Originating Technology/NASA Contribution

**M**ore than 10 billion miles away from Earth, a NASA spacecraft continues a journey that began in 1977. Having long since accomplished its original mission to Jupiter and Saturn, Voyager 1 is the farthest human-made object from Earth, hurtling at more than 38,000 miles per hour toward the heliopause—the very edge of the solar system.

At these extraordinary distances, the Sun's light is too faint to power a solar panel-equipped spacecraft. In fact, the Sun does not provide a viable source of power for many NASA missions. To accommodate this need, NASA employs thermoelectric (TE) devices, which can generate electricity from temperature differentials and vice versa. In a power-generating capacity, TE devices work via the Seebeck effect, in which a circuit made from dissimilar metals creates a voltage if a temperature difference exists between its two sides. When a voltage is applied to a TE device and a current flows through it, the reverse action occurs: The electrical input creates a temperature difference, moving heat from one side of the device to the other in what is called the Peltier effect. When functioning this way, TE devices become temperature management tools, cooling or heating a surface depending on the direction of the electrical flow.

For 25 missions so far—including Apollo missions to the Moon, the Viking and Pathfinder missions to Mars, and the Voyager, Pioneer, Ulysses, Galileo, and Cassini solar system missions—radioisotope thermoelectric generators (RTGs) have powered NASA spacecraft. A solid-state technology featuring no moving parts and thus significantly reducing the possibility of failure, these TE devices provide steady, reliable supplies of power for as long as their fuel emits enough heat; powered by three RTGs each, both Voyager 1 and its sister Voyager 2 (launched the same year) are expected to continue operation until 2025, a nearly 50-year lifespan.

Engineers at NASA's Jet Propulsion Laboratory (JPL), who built and operate the Voyager spacecraft among other deep-space missions, continue to explore the potential of thermoelectrics for providing energy and thermal management solutions for use in space. Thermoelectrics have a host of applications on Earth as well, among them semiconductor electronics, lasers, infrared sensors, air conditioners, and communication systems. In keeping with the Agency's mission to facilitate the transfer of space technology for public benefit, JPL has partnered with a North Carolina company to share the fruits of its research.

## Partnership

In 2005, Dr. Jesko von Windheim and his team founded [Nextreme Thermal Solutions Inc.](#), based in Research Triangle Park, North Carolina, to commercialize thermoelectric technology acquired from RTI International, also headquartered in Research Triangle Park. Having previously licensed technology from the California Institute of Technology (Caltech) with microelectromechanical systems startup Cronos Integrated Microsystems, von Windheim was aware of JPL's thermoelectric expertise and its expansive patent portfolio (Caltech manages JPL for NASA). He discovered a broad JPL thermoelectrics patent that complemented Nextreme's RTI technology. In 2006, the company exclusively licensed the Caltech/JPL patent, which covers thermoelectric devices containing thermoelectric material less than 40 microns thick. The licensed technology enabled Nextreme's development as a pioneer in solid-state thermal management for electronics and semiconductors.

"This license puts us in a strong position competitively in thin film thermoelectrics," says Dr. Paul Magill, Nextreme's vice president of marketing and business development.

## Product Outcome

As electronics advance, becoming faster and more powerful while at the same time smaller and more densely built, engineers are running up against a significant challenge: heat. The lack of corresponding advances in cooling techniques has become a barrier to further development in integrated circuit technologies like microprocessors, where heat buildup can affect performance and lead to device failure. The heat generated by microchips is focused in hotspots rather than uniformly distributed, making conventional thermoelectric coolers (TECs)—also referred to as bulk modules and assembled from tiny pillars of thermoelectric material—impractical options due to their relatively large size. According to Nextreme, using system cooling options like fans, heat sinks, and refrigeration to address microchip hotspots is like air conditioning an entire house just to cool an overheated element on a kitchen stove. Nextreme's licensed NASA technology is enabling the ideal solution for this problem: thin film thermoelectrics.

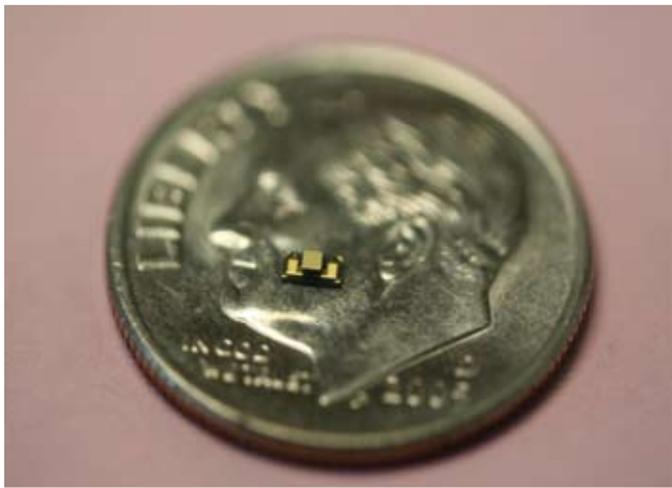
"We believe that the JPL technology is fundamental to thin film thermoelectric devices," says von Windheim, Nextreme's CEO. "We currently implement it in all of our products."

Thin film thermoelectrics is exactly what it sounds like: ultra-thin thermoelectric technology. Using a process called metal-organic chemical vapor deposition, Nextreme engineers grow films of bismuth telluride which are then used to create the company's breakthrough thermoelectric application: the thermal copper pillar bump.

Copper pillar bumps (CPBs) are solder bumps used to create mechanical and electrical connections as part of the flip chip method for joining semiconductor devices like integrated circuits to external circuitry. Nextreme adds thermal management capabilities to these bumps by integrating a thin film layer of thermoelectric material into each bump, converting them into TECs. As electricity is passed through the thermal bump, heat is moved through

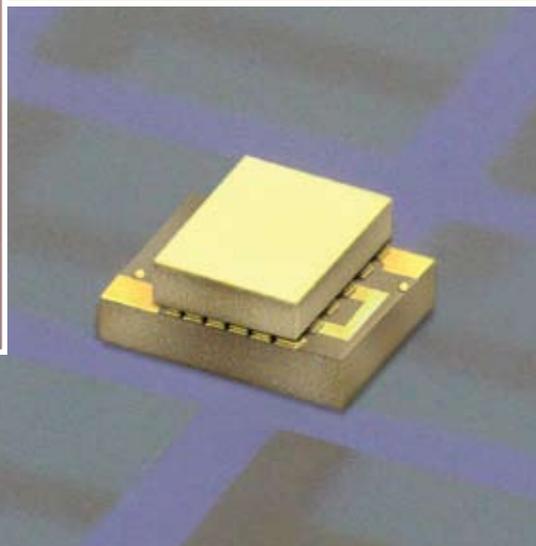
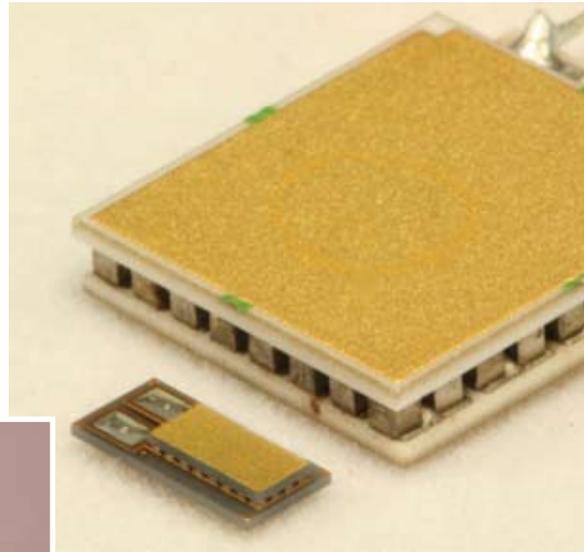
the Peltier effect from one side of the bump to the other, shifting it out of the chip and resulting in 5–15 °C of spot cooling per bump.

Using a modified CPB flip chip manufacturing process employed by major producers like Intel, Amkor, and Casio, designers can either uniformly distribute these thermal bumps (each 238 microns in diameter and 60 microns high) on a chip or locate them at specific hotspots for targeted thermal control. Nextreme notes that this implementation of thin film thermoelectrics is ideal considering that the flip chip market is one of the largest, fastest-growing semiconductor industry segments, and that as much as 40 percent of flip chip devices have significant thermal challenges. By reversing the current flow in a thermal bump, the device can switch between cooling and heating, providing precise, integrated thermal control.



The small size of Nextreme's thermoelectric coolers (shown above and in comparison to a conventional bulk module at top right) is part of what makes them effective solutions for microchip hotspot cooling. The company's OptoCooler products, including the HV14 module at bottom right, are enabled by thin film thermoelectric technology licensed from NASA.

“Now you can design new kinds of circuits that cool themselves, temperature stabilize themselves as a function of the circuit, not as an external cooling or refrigeration function,” says von Windheim. In a separate capacity,



through the Seebeck effect, heat applied to one side of the thermal bump results in an electrical output—up to 10 milliwatts (mW) per bump, transforming the device into an embedded thermoelectric generator (eTEG).

The NASA-enabled thermal bump technology also forms the core of its discrete thermoelectric products, each of which is no larger than a piece of confetti. The OptoCooler product line is ideal for applications including photonics, optoelectronics like laser diodes and high-brightness light-emitting diodes (LEDs), and biomedical devices. On the energy generation side, Nextreme's eTEG can produce up to 260 mW of power, providing a scalable and cost-effective technology for applications like medical implants and wireless sensor networks, the company says.

Nextreme continues to develop and improve its thin film thermoelectrics while expanding the technology's possible uses to applications beyond electronics—such as cooling the human body. “The beauty of these products being so small,” says Magill, “is that they can be easily integrated into clothing and military body armor at places where the blood comes close to the skin” like the wrists or temples. As the body's entire supply of blood is continuously cycled, the micro-TECs remove small amounts of heat, supplementing the body's existing thermal management system and helping it cool.

The NASA technology developed to help power unprecedented journeys to the stars could also one day help people travel more effectively on Earth. The future could see Nextreme's thermoelectric devices producing energy by harvesting normally wasted heat from engines, thus improving automobile fuel efficiency. ❖

OptoCooler™ and eTEG™ are trademarks of Nextreme Thermal Solutions Inc.

# Innovative Tools Advance Revolutionary Weld Technique

## Originating Technology/NASA Contribution

The iconic, orange external tank of the space shuttle launch system not only contains the fuel used by the shuttle's main engines during liftoff but also comprises the shuttle's "backbone," supporting the space shuttle orbiter and solid rocket boosters. Given the tank's structural importance and the extreme forces (7.8 million pounds of thrust load) and temperatures it encounters during launch, the welds used to construct the tank must be highly reliable.

Variable polarity plasma arc welding, developed for manufacturing the external tank and later employed for building the International Space Station, was until 1994 the best process for joining the aluminum alloys used during construction. That year, Marshall Space Flight Center engineers began experimenting with a relatively new welding technique called friction stir welding (FSW), developed in 1991 by The Welding Institute, of Cambridge, England. FSW differs from traditional fusion welding in that it is a solid-state welding technique, using frictional heat and motion to join structural components without actually melting any of the material. The weld is created by a shouldered pin tool that is plunged into the seam of the materials to be joined. The tool traverses the line while rotating at high speeds, generating friction that heats and softens—but does not melt—the metal. (The heat produced approaches about 80 percent of the metal's melting temperature.) The pin tool's rotation crushes and stirs the "plasticized" metal, extruding it along the seam as the tool moves forward. The material cools and consolidates, resulting in a weld with superior mechanical properties as compared to those weld properties of fusion welds.

The innovative FSW technology promises a number of attractive benefits. Because the welded materials are not melted, many of the undesirables associated with fusion welding—porosity, cracking, shrinkage, and distortion of the weld—are minimized or avoided. The process is

more energy efficient, safe (no toxic smoke or shielding gas, liquid metal splatter, arcing, dangerous voltage, or radiation), and environmentally sound (no consumables, fumes, or noise) than fusion welding. Under computer control, an automated FSW machine can create welds with high reproducibility, improving efficiency and overall quality of manufactured materials. The process also allows for welding dissimilar metals as well as those metals considered to be "unweldable" such as the 7xxx series aluminum alloys. Its effectiveness and versatility makes FSW useful for aerospace, rail, automotive, marine, and military applications.

A downside to FSW, however, is the keyhole opening left in the weld when the FSW pin tool exits the weld joint. This is a significant problem when using the FSW process to join circumferential structures such as pipes and storage containers. Furthermore, weld joints that taper in material thickness also present problems when using the conventional FSW pin tool, because the threaded pin rotating within the weld joint material is a fixed length. There must be capability for the rotating pin to both increase and decrease in length in real time while welding the tapered material. (Both circumferential and tapered thickness weldments are found in the space shuttle external tank.) Marshall engineers addressed both the keyhole and tapered material thickness problems by developing the auto-adjustable pin tool. This unique piece of equipment automatically withdraws the pin into the tool's shoulder for keyhole closeout. In addition, the auto-adjustable pin tool retracts, or shortens, the rotating pin while welding a weld joint that tapers from one thickness to a thinner thickness. This year, the impact of the Marshall innovation was recognized with an "Excellence in Technology Transfer Award" from the Federal Laboratory Consortium.

## Partnership

In the late 1990s, [Nova-Tech Engineering LLC](#), a machine design, aerospace tooling, and manufacturing



The retractable pin tool developed at Marshall Space Flight Center fully enables friction stir welding (FSW) for circumferential and tapered thickness welds, like those needed to assemble the space shuttle's external tank.

systems company, based in Lynnwood, Washington, provided Marshall with stir welding machine retrofits that employed the retractable pin tool, for use during the center's FSW research on longitudinal and circumferential welds for the space shuttle's external tank. In 2003, Nova-Tech acquired the FSW equipment and process capabilities of Seattle, Washington firm MCE Technologies Inc., which was co-licensee of the 2001 NASA license for the Marshall FSW technology. After acquiring MCE, Nova-Tech applied for and received a co-exclusive license for the auto-adjustable pin tool for friction stir welding.

## Product Outcome

The Marshall adjustable pin tool technology is featured on nearly all of Nova-Tech Engineering's stir

welding systems, including the first three FSW weld heads delivered to the Marshall Space Flight Center in the late 1990s. Nova-Tech supplies a wide range of stir welding machine configurations including circumferential and vertical stir welders for rocket tank assembly; large, five-axis horizontal and vertical stir welders for combat vehicle construction; and multi-axis stir welders for research and development use.

“There are some distinct advantages to the retractable pin,” says Don Holman, FSW product manager for Nova-

Tech. He explains that the pin provides an integrated solution to the keyhole problem on circumferential welds, and though the technology is not necessary for longitudinal welds, it can still be applied to eliminate the keyhole rather than using run-off tabs (additional lengths of metal that can be trimmed off to eliminate keyholes). Holman also notes that the adjustable pin can sustain uninterrupted full penetration welds on plates of varying thicknesses, without requiring multiple pin tools of varying lengths. A computer-controlled servo motor positions the adjustable pin precisely—within 0.001 inch—to ensure the proper pin penetration in the material. “The retractable pin tool increases the

capabilities of our machines,” Holman says, making them more efficient at creating more precise, stronger FSW welds.

The appeal of Nova-Tech’s adjustable pin-equipped FSW systems has extended across a wide range of industries. Concurrent Technologies Corporation, a nonprofit research and development organization with offices across the country, uses a Nova-Tech five-axis stir welder at its Johnstown, Pennsylvania, location for welding of armor plate for the U.S. Army’s Expeditionary Fighting Vehicle program. Nova-Tech also built a production FSW machine for Noble Drilling Services of Houston, Texas, a leading offshore drilling contractor that uses the machine to weld aluminum riser piping for offshore drilling rigs; the Nova-Tech machine was the first FSW system developed for the oil and gas industry.

Nova-Tech FSW systems are also employed by a number of research institutions exploring ways to improve welding processes for manufacturing. These include the Edison Welding Institute in Columbus, Ohio, and the Missouri University of Science and Technology in Rolla, Missouri. Nova-Tech is additionally a partner of an integrated project team that last year developed and delivered a low-cost FSW system prototype to the U.S. Navy Metalworking Center, which plans to use the machine as an efficient, cost-effective production tool for its Littoral Combat Ship (LCS) program. The LCS program is developing next-generation combat ships for use in littoral, or close to shore, zones.

Just as the demands of space exploration led to the adjustable pin technology Nova-Tech now incorporates in its FSW machines, the company is also contributing back to the space industry. Space Exploration Technologies Corporation (SpaceX), of Hawthorne, California, performs circumferential welds on its rockets using a Nova-Tech FSW system. A private launch company, SpaceX is working in close cooperation with NASA to develop, among other things, a cargo launch system for transporting supplies to the International Space Station. ❖



Nova-Tech’s FSW machines, like this G10K/Large Plate Gantry Friction Stir Welder, achieve increased capabilities with the incorporation of NASA’s auto-adjustable pin tool technology.

# Methods Reduce Cost, Enhance Quality of Nanotubes

## Originating Technology/NASA Contribution

For all the challenges posed by the microgravity conditions of space, weight is actually one of the more significant problems NASA faces in the development of the next generation of U.S. space vehicles. For the Agency's Constellation Program, engineers at NASA centers are designing and testing new vessels as safe, practical, and cost-effective means of space travel following the eventual retirement of the space shuttle. Program components like the Orion Crew Exploration Vehicle, intended to carry astronauts to the International Space Station and the Moon, must be designed to specific weight requirements to manage fuel consumption and match launch rocket capabilities; Orion's gross liftoff weight target is about 63,789 pounds. Future space vehicles will require even greater attention to lightweight construction to help conserve fuel for long-range missions to Mars and beyond.

In order to reduce spacecraft weight without sacrificing structural integrity, NASA is pursuing the development of materials that promise to revolutionize not only spacecraft construction, but also a host of potential applications on Earth. Single-walled carbon nanotubes are one material of particular interest. These tubular, single-layer carbon molecules—100,000 of them braided together would be no thicker than a human hair—display a range of remarkable characteristics. Possessing greater tensile strength than steel at a fraction of the weight, the nanotubes are efficient heat conductors with metallic or semiconductor electrical properties depending on their diameter and chirality (the pattern of each nanotube's hexagonal lattice structure). All of these properties make the nanotubes an appealing material for spacecraft construction, with the potential for nanotube composites to reduce spacecraft weight by 50 percent or more. The nanotubes may also feature in a number of other space exploration applications, including life support, energy storage, and sensor technologies.



By increasing the size of its fluidized bed reactors, seen here, SouthWest NanoTechnologies Inc. (SWeNT) increased its carbon nanotube production capacity while at the same time lowering cost.

NASA's various efforts with carbon nanotubes have made it a global leader in this field. Among the many examples are Johnson Space Center's Carbon Nanotube Project, which focuses on bulk nanotube production, purification, and application, and Goddard Space Flight Center's improved arc discharge method of nanotube production, developed under the direction of Jeannette Benavides (featured in *Spinoff* 2007 and 2008). While the Agency continues its own research, it partners with private companies to advance this unique technology for use on Earth as well as among the stars.

## Partnership

One of the significant challenges involved with taking advantage of single-walled nanotube technology lies in how the nanotubes are made. Typical manufacturing methods are expensive, are not amenable to large scale production, and can be inefficient, resulting in samples containing as low as 10–15 percent nanotubes. Costly and time-consuming separation procedures are needed to sort out nanotubes of the desired diameter, length, and chirality. In addition, nanotube samples can be tainted with residual catalyst impurities and common byproducts like amorphous carbon and graphite nanofibers. Thus, affordable, largely pure nanotube supplies with tailored properties for research and commercial efforts have been lacking.

To address these issues, Johnson awarded Phase I and II **Small Business Innovation Research (SBIR)** contracts to [SouthWest NanoTechnologies Inc. \(SWeNT\)](#), of Norman, Oklahoma, to pursue the development of a new nanotube production method. Founded in 2001, SWeNT is the offshoot of landmark research conducted by Daniel Resasco at the University of Oklahoma. Resasco pioneered a controlled catalytic method for creating nanotubes that is inherently scalable for mass production. During Resasco's cobalt-molybdenum catalytic procedure—known as the CoMoCAT process—pure carbon monoxide (CO) flows through suspended cobalt and molybdenum catalyst particles in a device called a tubular fluidized bed reactor. At certain temperatures and pressure, the nanotubes are grown as the CO decomposes into carbon and carbon dioxide. By controlling the conditions and catalyst within the reactor, Resasco was able to grow significant, highly selective amounts of high-quality nanotubes within a couple of hours.

Using the NASA SBIR funding, SWeNT demonstrated that increasing the size of the fluidized bed reactor platform increased production capacity while decreasing

cost. The SBIR support also provided another welcome outcome: higher quality nanotubes.

“When we invested in larger scale equipment, we also invested in more automation, instrumentation, and process controls,” says SWeNT CEO David Arthur. “That resulted in significant improvement in quality at the same time that we were expanding capacity and reducing cost.”

### Product Outcome

In 2008, SWeNT opened a commercial-scale nanotube manufacturing plant. Since beginning operations at the 18,000-square-foot facility, Arthur says, the company has experienced a hundredfold increase in production coupled with a tenfold reduction in cost. SWeNT now offers two single-walled carbon nanotube product lines, as well as customized orders for the company’s hundreds of customers.

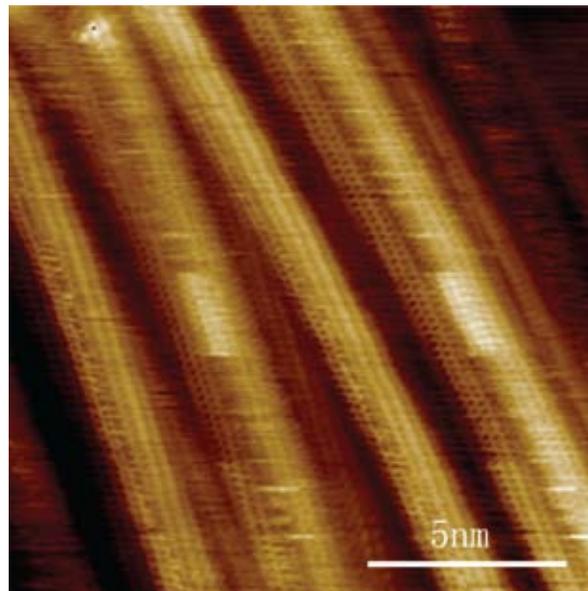
“We are one of the only companies that is able to supply these materials in commercial quantities in North America,” says Arthur. “None of this would have happened without the original NASA SBIR funds to prove our production methods.”

Those production methods are the key to increasing output while lowering cost, Arthur notes. By controlling nanotube synthesis, SWeNT can selectively grow the nanotubes its clients want while avoiding an expensive, wasteful, time-consuming, and non-scalable sorting process. Using the CoMoCAT process, the company delivers nanotube orders that are routinely 95 percent carbon in composition, with more than 90 percent of that carbon in the form of nanotubes—all above typical industry outcomes.

SWeNT’s controlled synthesis capabilities have allowed it to provide customers with customized nanotubes for a wide range of new and developing technologies. The company has supplied diameter-specific nanotubes for use in reinforcing carbon fibers, with the potential to yield a material 17 times stronger than Kevlar for use in

bulletproof body and vehicle armor. It is working with aerospace and nanomaterials clients to produce chirality-specific nanotubes—the goal, Arthur says, is to create the most electrically conductive carbon nanotubes in the world—for nanocomposite cable wiring to replace standard metal wiring in commercial aircraft. The company is exploring the use of its semiconducting nanotubes in the form of an ink, enabling the production of low-cost, printable electronics; applications include radio frequency identification, biological and chemical sensors, and electronic displays. Arthur foresees SWeNT nanotubes also enabling more affordable solar photovoltaic panels and solid-state lighting products that could have a dramatic impact on energy consumption.

SWeNT has set its sights on expanding its capabilities to also produce small-diameter, multiwalled carbon



This image of SWeNT’s single-walled carbon nanotubes reveals the hexagonal lattice sidewall structure of the nanotubes. The pattern of this structure plays a role in determining the nanotubes’ properties.

nanotubes for niche electrical applications, as well as building on its current single-walled nanotube success.

“Our vision is to once again increase our production scale a hundredfold and enjoy another tenfold reduction in cost,” says Arthur. At that point, he says, the company can even further reduce costs by recycling the CO feed gas used in the synthesis process—its most expensive production material.

SWeNT’s NASA SBIR-enabled CoMoCAT process is receiving notice from beyond its customer base. The company received a 2007 “Tibbets Award” for excellence in SBIR achievement, and last year the National Institute of Standards and Technology designated SWeNT’s SG65 single-walled carbon nanotubes as a starting material for developing a carbon nanotube Standard Reference Material. These reference materials are employed by industry, academia, and government as standards for commerce, trade, and research and development. ❖

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*The company has experienced a hundredfold increase in production with a tenfold reduction in cost.*

# Gauging Systems Monitor Cryogenic Liquids

## Originating Technology/NASA Contribution

Rocket fuel needs to stay cool—super cool, in fact. The ability to store gas propellants like liquid hydrogen and oxygen at cryogenic temperatures (below  $-243^{\circ}\text{F}$ ) is crucial for space missions in order to reduce their volumes and allow their storage in smaller (and therefore, less costly) tanks. The Agency has used these cryogenic fluids for vehicle propellants, reactants, and life support systems since 1962 with the Centaur upper stage rocket, which was powered with liquid oxygen and liquid hydrogen.



The Saturn V was a liquid-fueled expendable rocket used for Apollo and Skylab missions. Apollo 15, shown here, used over three-quarters of a million gallons of liquid oxygen and liquid hydrogen.

During proposed long-duration missions, super-cooled fluids will also be used in space power systems, spaceports, and lunar habitation systems. In the next generation of launch vehicles, gaseous propellants will be cooled to and stored for extended periods at even colder temperatures than currently employed via a process called densification. Densification sub-cools liquids to temperatures even closer to absolute zero ( $-459^{\circ}\text{F}$ ), increasing the fluid's density and shrinking its volume beyond common cryogenics. Sub-cooling cryogenic liquid hydrogen, for instance, from 20 K ( $-423^{\circ}\text{F}$ ) to 15 K ( $-432.4^{\circ}\text{F}$ ) reduces its mass by 10 percent. These densified liquid gasses can provide more cost savings from reduced payload volume.

In order to benefit from this cost savings, the Agency is working with private industry to prevent evaporation, leakage, and other inadvertent loss of liquids and gasses in payloads—requiring new cryogenic systems to prevent 98 percent (or more) of boil-off loss. Boil-off occurs when cryogenic or densified liquids evaporate, and is a concern during launch pad holds. Accurate sensing of propellants aboard space vehicles is also critical for proper engine shutdown and re-ignition after launch, and zero boil-off fuel systems are also in development for the Altair lunar lander.

## Partnership

One company, in partnership with NASA, has developed a liquid-sensing system that monitors cryogenics and densified propellants. Fremont, Ohio's [Sierra Lobo Inc. \(SLI\)](#) specializes in cryogenics and propulsion, and, in particular, produces propellant storage systems. The Hispanic-American-owned company that began with only 9 employees in 1993 now has an ISO 9001:2008 registration and currently employs over 370 people in its Ohio, Florida, Texas, Alabama, Virginia, and California facilities.

In 2006, SLI developed the Cryo-Tracker Mass Gauging System (Cryo-Tracker MGS) with funding from a Phase III **Small Business Innovation Research (SBIR)**

contract from Kennedy Space Center, after receiving Phase I and Phase II funding from the U.S. Department of Defense. The Cryo-Tracker (CT) probe—the key component of the Cryo-Tracker MGS—works in conjunction with the system's other two components: electronics that provide power and signal management for each sensing element, and software that displays data received from the probe. Since winning the initial SBIR contract, SLI has successfully tested Cryo-Tracker MGS on parabolic flights, which simulate the reduced gravity of space flight without the high costs. On these flights, SLI researchers validated wicking technology used in the system's sensors by capturing numerous images of the system's CT probe operating in water during 90 reduced-gravity parabolas lasting 25 seconds each. Sierra Lobo also successfully tested a 33-foot CT probe and the Cryo-Tracker MGS in a simulation of typical pre-launch and flight operations in a large-scale expendable launch vehicle liquid oxygen tank.

SLI has also received funding from NASA's Innovative Partnerships Program Seed Fund in order to advance its system's flight readiness for use on NASA and commercial launch vehicles. The NASA Launch Services Program, which certifies launch vehicles and manages payloads for the Agency, rated the Cryo-Tracker MGS at technology readiness level (TRL) 6, which indicates successful testing of a prototype in a relevant environment. The next level, TRL 7, requires successful operation in space. Cryo-Tracker MGS has been successfully tested with the liquid forms of nitrogen, oxygen, methane, and hydrogen, and the system proved robust in extensive vibration testing.

## Product Outcome

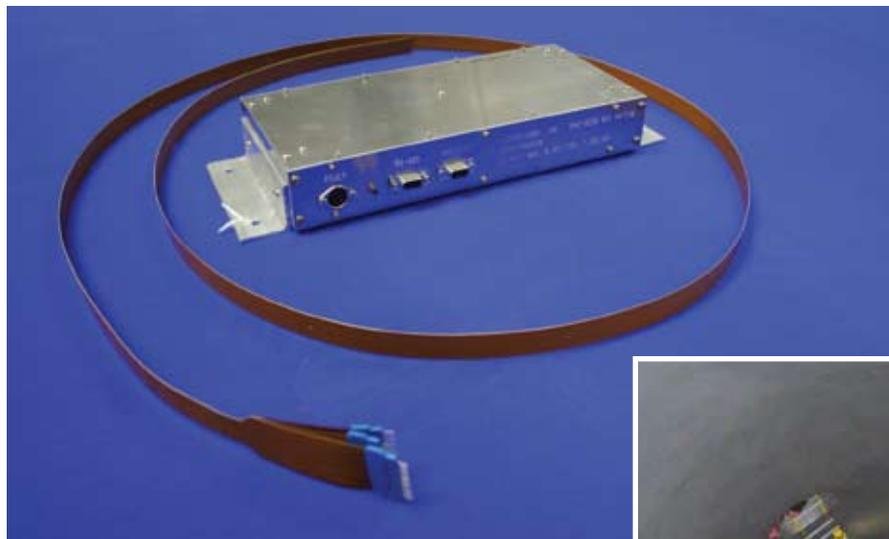
SLI is marketing the Cryo-Tracker MGS as a commercial product to testing facilities that use and store cryogenics. Various industries routinely use cryogenic Dewar flasks (vacuum flasks) to store or transport super-cooled liquids, including the medical industry, metals processing, and semiconductor manufacturing. The

Cryo-Tracker MGS is used in these industries to monitor mass, liquid levels, temperature, and pressure for stored liquid helium, hydrogen, nitrogen, or oxygen.

The Cryo-Tracker MGS is a three-part system that integrates the use of software, electronics, and the “R&D 100” award-winning CT probe. The probe offers increased reliability and adaptability over other cryogenic probes, according to Mark Haberbusch, director of research and technology at SLI. The patented probe has low mass for quick thermal response and flexible, one-piece construction, which reduces potential problems from vibration or breakage. It can also be adapted to different applications that may have size restrictions; Haberbusch explains that the CT probe can be manufactured to virtually any length and width, and has a nominal thickness of 0.030 inches (0.76 millimeters). Flexible material allows the CT probe to be installed along non-uniform tank walls, allowing it to gauge mass, tank pressure, liquid temperature profiles, and liquid levels in tight spaces.

In addition, the probe offers a flexible design configuration; each of the probe’s silicon diode sensors can be independently operated to detect liquid level or sense temperatures ranging from 1.4 K (-457 °F) to 325 K (125 °F) in the liquid as well as the unfilled container space (called ullage). Each diode’s sensing mode can then be toggled on the fly or by a preprogrammed logic of operations. A 1-millimeter-thick layer of polyimide insulates the diodes inside the probe from the fluids, enabling the probe to respond accurately to temperature and liquid-level changes in less than 1 second. The sensing elements can detect the difference between liquid and vapor (even when they are at the same temperature) through the difference in voltage output. This quick response adds a level of safety to cryogenic operations and storage by providing the ability to detect dangerous heat levels inside a tank that could lead to rapid over-pressurization.

An electrical enclosure houses the Cryo-Tracker MGS electronics, which include a circuit board and electrical connections. These electronics power the CT probe’s



The Cryo-Tracker probe (at left) can monitor mass, levels, temperature, and pressure of stored cryogenic liquids. Below, the Cryo-Tracker probe descends into a large tank where a worker checks conditions.

sensors and relay data from the sensors to the Cryo-Tracker MGS software. A microcontroller in the electronics regulates the diode currents, which convey data from the sensors.

***Sierra Lobo Inc.  
won the  
“R&D 100”  
award for its  
Cryo-Tracker  
probe in 2001.***

The third component in the system, the Cryo-Tracker MGS software, determines the mass of fluid in a tank by monitoring liquid temperature, level, and ullage pressure. The software calculates mass and mass uncertainty, identifying the components needing the most monitoring. The software can monitor liquid mass for a variety of fluids in different types of Dewar flasks or tanks. In addition, the software uses computational fluid dynamics to determine the optimum number of sensors and their ideal locations for mass measurements.

Although SLI is currently marketing the Cryo-Tracker MGS primarily to customers interested in medical or industrial storage, it may only be a few years before



this “super cool” gauging system appears in consumer products. SLI soon expects that manufacturers will begin using SLI’s Cryo-Tracker MGS to monitor tanks for gas grills and no-vent fuel tanks in liquid hydrogen-powered automobiles. ❖

Cryo-Tracker® is a registered trademark of Sierra Lobo Inc.

# Voltage Sensors Monitor Harmful Static

## Originating Technology/NASA Contribution

Anyone who has ever experienced an unpleasant jolt from a doorknob after shuffling across the carpet on a dry morning knows that static electricity—also known as triboelectric charging—can be a nuisance. However, many computer enthusiasts are too familiar with how built-up triboelectricity can actually cause major problems when building a home computer; a simple spark from a finger can damage sensitive components and render them unusable. Under certain conditions, built-up triboelectricity discharges in these seemingly minor jolts, called electrostatic discharge (ESD), which can also cause major problems for NASA, as well as the computer industry. ESD can create sparks that ignite fuel in launch operations, and ESD can also damage delicate electronics and avionics, for operations on Earth as well as on space missions.

This concern over static electricity damaging mission-critical components led scientists to add grounding wires to the base of antennas for Spirit and Opportunity, which continuously discharge up to a few hundred volts, accumulated as they make their way across the dry surface of Mars. Without some sort of grounding or protection, the Mars rovers might have been incapacitated by a single electric shock.

Kennedy Space Center's Electrostatics and Surface Physics Laboratory scientist, Dr. Carlos Calle, proposed developing static sensors for future missions, in which larger vehicles would be at greater risk from accumulating more dangerous levels of triboelectricity. These static sensors would not just be useful on other planets for roving robots, however; they could also help protect sensitive components here on Earth.

In addition to causing problems for personal computers, ESD can also cause problems in the manufacture of hard disk drives, semiconductors, flat panel displays, and avionics. These problems include electrostatic attraction drawing contaminants onto the product, the ESD itself

causing defects, and electromagnetic interference causing consequent malfunction in the products and production equipment.

## Partnership

In 2004, San Diego's [QUASAR Federal Systems Inc.](#) (QFS) completed Phase I of a **Small Business Innovation Research (SBIR)** contract for Kennedy's Electrostatics



Concern over static electricity damaging components on Mars rovers Spirit and Opportunity led scientists to add grounding wires to the base of the rovers' antennas.

and Surface Physics Laboratory, after Calle provided NASA's requirements for a wearable electrostatic sensor. QFS focuses on electromagnetic sensor products for relatively low frequencies, from near-DC through the megahertz range. Led by the company's vice-president of research and development, Dr. Yongming Zhang, QFS completed a prototype of an electrostatic hazard detection sensor in Phase II of the contract in 2006. The company now calls the product its Remote Voltage Sensor (RVS).

QFS formed a partnership with Novx Corporation, which was then acquired by MKS Instruments Inc. (MKS). A creator of ionization and monitoring products for many electronics and industrial markets, MKS now distributes the QFS RVS sensor as part of its ION Systems product line.

## Product Outcome

The RVS is a dime-sized electrometer designed to measure triboelectric changes in the environment. Eric Duff, vice president of business development at QFS, explains how the sensor works: "The RVS is an extremely sensitive measure of the electric potential in free space," he says. "Any voltage on anything in front of the sensor will shift that potential. It's essentially a sensor that is sensitive to any voltage changes in the environment." The sensor only responds to stationary objects acquiring a charge from various sources, or to time-varying fields, which are caused by charged objects moving into the sensor's range. The sensor does not respond to static DC fields, but will sense potential changes down to 0.2 Hz, so equipment that is operating normally near the RVS will not trigger it.

One of the unique qualities of the RVS is that, because of its sensitivity, it can detect static at greater distances than previous devices. According to Zhang, earlier sensors had to be within 2.5 centimeters of the subject in order to detect potential ESD, but the RVS can now measure voltage changes from a few centimeters to a few meters away, due to its much-improved sensitivity.

This “work station protection,” as Duff calls it, monitors electrostatic fields in real time, and is rugged, low power, and low cost. Because the RVS does not have moving parts, it cannot be a source of ESD itself, which was a major problem with prior devices. Additional features include fast response time, reduction of DC drift issues, variable voltage range settings, and ultra-low circuit noise, which makes the sensor up to 1,000 times more sensitive than traditional electric field mills (devices which measure the strength of electric fields).

Because of its small size, this sensor can be worn on clothing to monitor the triboelectric energy a worker accumulates, or can be affixed to laboratory entrances or specific equipment to monitor voltage changes near sensitive instruments. The sensor’s very small footprint also allows it to be easily integrated into existing equipment and applications.

MKS Instruments markets the RVS as part of its Novx Series 7000 Monitoring System for single-sensor uses, and offers the Novx Series 3370 for applications requiring multiple sensors. These systems take data transmitted by the sensor and allow the customer to set the instrument sensitivity “filtering,” thus tailoring the instrument’s output to specific need.

QFS, which has a patent pending for the sensor, is finding success in sensitive-manufacturing facilities, including those that produce semiconductor wafers and flat-panel displays. For semiconductor applications, the RVS offers 300-millimeter wafer diagnostics, continuous wafer charge monitoring, pre-cursor identification for electrostatic chuck failures, and external monitoring of vacuum chamber wafer charges. By allowing manufacturers to avoid static-related product defects, the RVS contributes to the overall productivity of the electronics industry, which also includes medical device manufacturing and aerospace electronics manufacturing.

Duff says the company looks forward to infusing its commercialized technology back into NASA, but in the meantime, the company is selling the RVS and developing

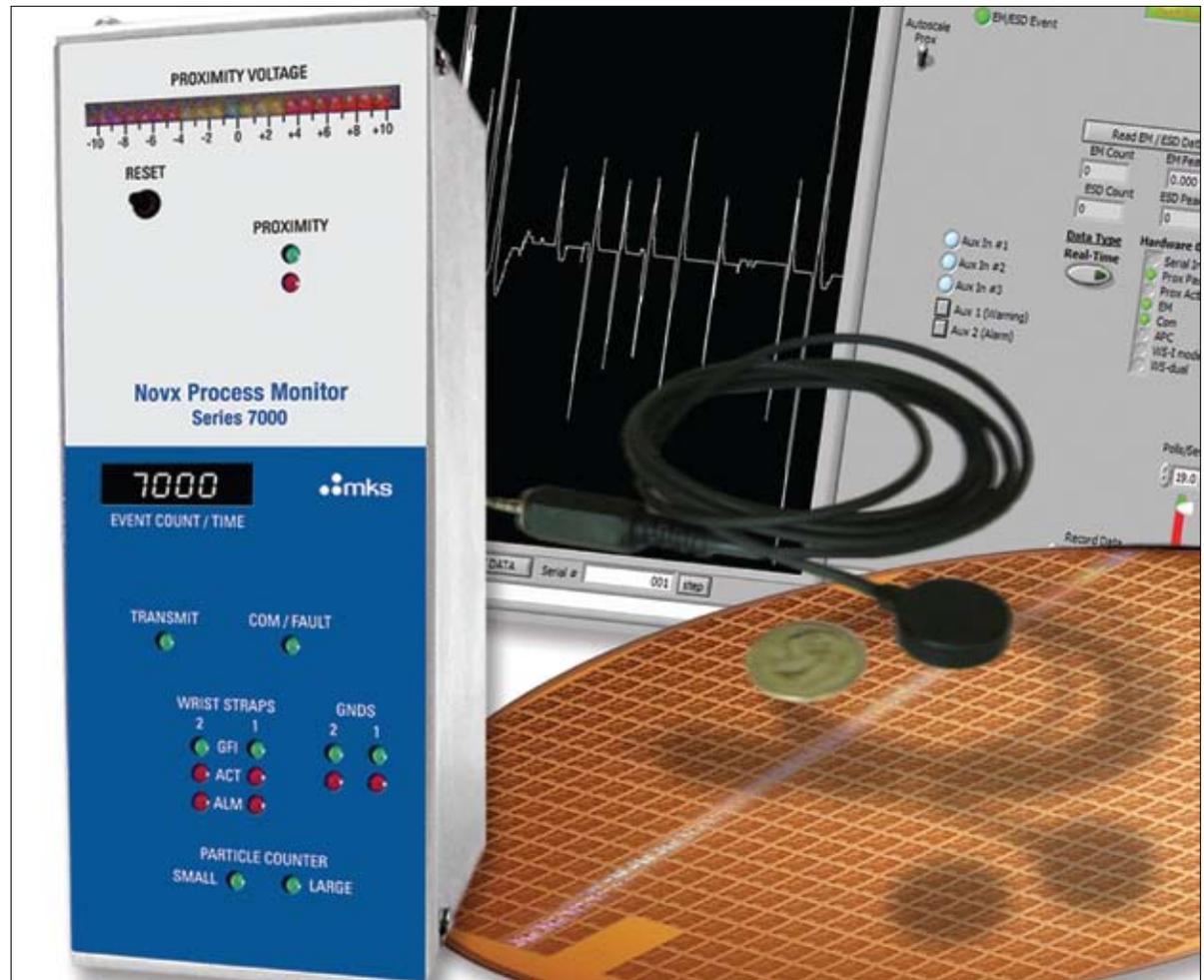


Image courtesy of MKS Ion Systems

MKS Instruments markets the RVS as part of its Novx Series 7000 and Novx Series 3370 monitoring systems. These systems allow the customer to set the instrument sensitivity, thus tailoring the instrument’s output to a specific need.

related sensors for a variety of customers. Although sales of the RVS have been limited in 2009, the company believes there will be more demand as the market recovers from the economic slowdown and market production increases, particularly in the semiconductor industry. Meanwhile, the company continues to pursue SBIRs with

several government agencies, and found working with NASA, according to Duff, a productive collaboration QFS would like to re-experience. ❖

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# Compact Instruments Measure Heat Potential

## Originating Technology/NASA Contribution

Without the insulating protection of Earth's atmosphere, orbiting space shuttles, space stations, and satellites are subject to thermal damage from radiation. This damage varies with different orbital parameters, solar activity, and the vehicle's angle to the Sun, so these external surfaces must be designed to resist degradation and protect payloads (and crew) in these varying conditions.

When designing space vehicles and structures, it is important to know how effectively materials will heat or cool a system, and how much they change while in use. Spectral reflectometers, which measure these thermal properties, determine how well a surface absorbs, reflects, emits, or radiates heat. When measuring the surface properties of a material that will be used in space, scientists have traditionally used reflectometers with integrating spheres (also called Ulbricht spheres), which are best suited for the solar spectrum where radiation is hemispherical and the heat sink is all-encompassing, as is the case in space.

In the 1980s, NASA sought an instrument that astronauts could carry on extravehicular activities (EVAs) to assess conditions of external surfaces on space shuttles and space stations. NASA has also used these devices to assess spacecraft instruments and coatings prior to launch to ensure proper thermal properties.

## Partnership

A woman- and veteran-owned small business with 35 employees, [AZ Technology Inc.](#) offers expertise in electromechanical-optical design and advanced coatings. It sells several portable instruments for measuring different optical properties, including solar absorptance, reflectance, transmittance, and emittance. Based in Huntsville, Alabama, AZ Technology has received eight **Small Business Innovation Research (SBIR)** contracts with Marshall Space Flight Center for the development

of spectral reflectometers and the measurement of surface thermal properties.

Marshall awarded AZ Technology its first NASA contract in 1989 to develop a space-portable spectral reflectometer (SPSR), a hand-held instrument for measuring the thermal properties of surfaces in space. The SPSR was transported to the Mir space station on STS-86, and then used in EVAs to assess the optical performance of external spacecraft radiation tiles.



During training exercises, an astronaut uses a mockup of a space-portable spectral reflectometer, an instrument for measuring the thermal properties of surfaces in space.

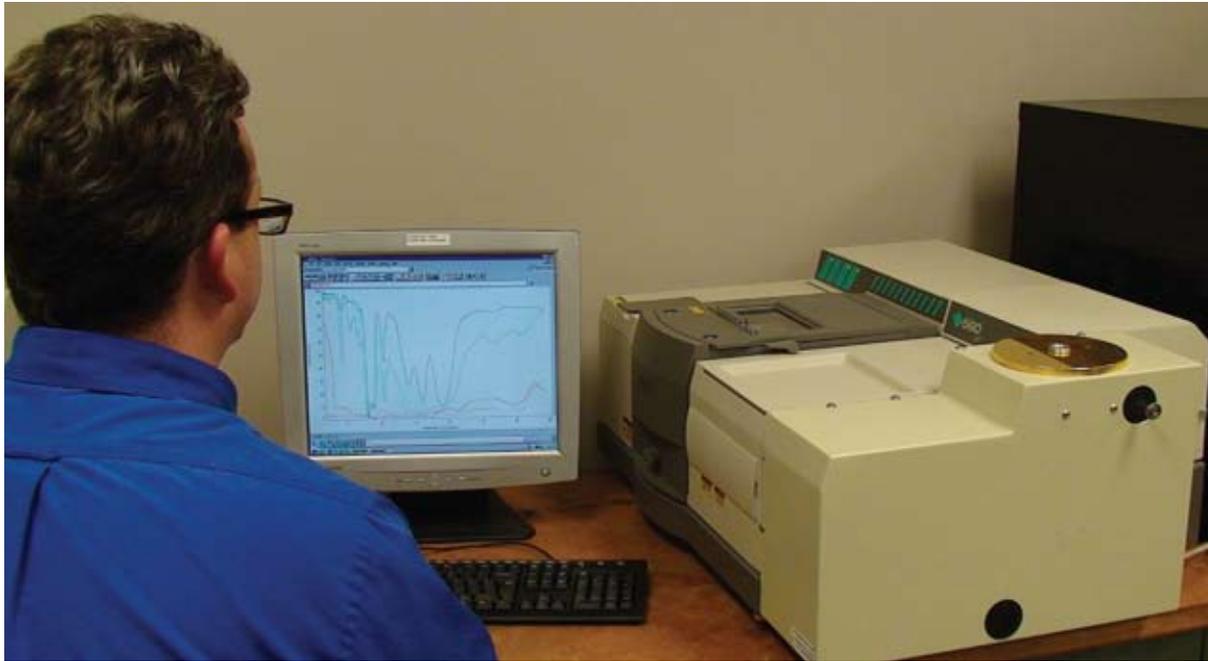
Based on its experience with the SPSR, AZ Technology then entered into a dual-use agreement with Kennedy Space Center for the development of another portable reflectometer, the Total Emittance and Solar Absorption (TESA) instrument, featured in *Spinoff* 1999.

AZ Technology has also received funding from a Phase III SBIR to develop its Spectrafire laboratory-based spectral emissometer. Recently, the company adapted the Spectrafire into a high-temperature spectral emissometer for Marshall, where it is being used to evaluate ablative materials and emittance characterizations of rocket nozzle designs. The company has also been awarded several SBIRs relating to thermal coatings, which continue to develop concurrently with the company's expertise in thermal design and instrumentation.

## Product Outcome

At ambient conditions, typically near room temperature, most energy transfer is in the infrared spectrum. The materials used to make good integrating spheres—useful for the solar spectrum—do not work well for the infrared spectrum on Earth. To work around bandpass limitations and the need for special calibrations, among other issues, AZ Technology engineers created the Spectrafire with an ellipsoidal collector. This type of collector allows several advantages over an integrating sphere.

David Crandall, AZ Technology's executive vice president in instruments and engineering services, explains that the ellipsoidal collector allows the Spectrafire to take full advantage of extended spectral ranges. When the Spectrafire is used with a Fourier transform interferometer, spectral total hemispherical reflectance can be measured and, from that, optical properties from the ultraviolet range through far infrared can be calculated. In this configuration, the Spectrafire can predict emittance at temperatures outside of ambient range: "On a regular basis, we see good projections up to 600 °C," Crandall says.



Shown attached to a personal computer for processing, the Spectrafire is an emissometer that uses an ellipsoidal collector, which allows this bench unit to be smaller than its predecessors.

Another advantage, Crandall explains, is that the measurement is absolute, and not relative, so there is no operator calibration required for normal emittance. Traditional emittance measurement systems required calibration, often multiple times a day.

In the infrared region there is a loss of energy, which presents a limitation for integrating sphere-based systems. By design, energy that is collected in an integrating sphere is reflected many times before it reaches the detector, causing loss. If a sphere liner is 95-percent reflective, after two reflections, only 90 percent of the energy would remain, and after 14 reflections, more than half of the energy would be absorbed. With an ellipsoidal collector, as is used in the Spectrafire, this is not a problem. There is only one reflection off the collector wall, so the energy throughput is far better. Also, the collector is considerably

smaller than an equivalent integrating sphere, which enables the Spectrafire to be even smaller than its predecessors.

Using the Spectrafire, AZ Technology is also able to determine the transmittance of thin materials, such as frosted glass and translucent polymer films. Typically, conventional instruments measure specular transmissions and can measure the transmittance of clear glass, but translucent materials are problematic because they scatter energy; this results in erroneous measurements. The Spectrafire is able to account for that scattering and provide accurate information about the optical properties of translucent materials.

The development of Spectrafire and AZ Technology's ability to generate spectral reflectance and emittance measurements, Crandall says, enabled the company to

begin offering unique services to industry. In 2007, the company used Spectrafire when providing measurement services to General Electric Company (GE) for the design of its Giraffe Warmer for newborns in neonatal intensive care units. "We made suggestions on how they could tailor the emittance with changes in materials and surface finishes," Crandall says. The device incorporates a heat source that shines onto a reflector. "And that reflector has to emit properly to maintain that baby's temperature," explains Crandall. "They had a thermal designer, but he had to know the emittance, and we were able to provide that." The Giraffe Warmer won the 2008 "Medical Design Excellence Award."

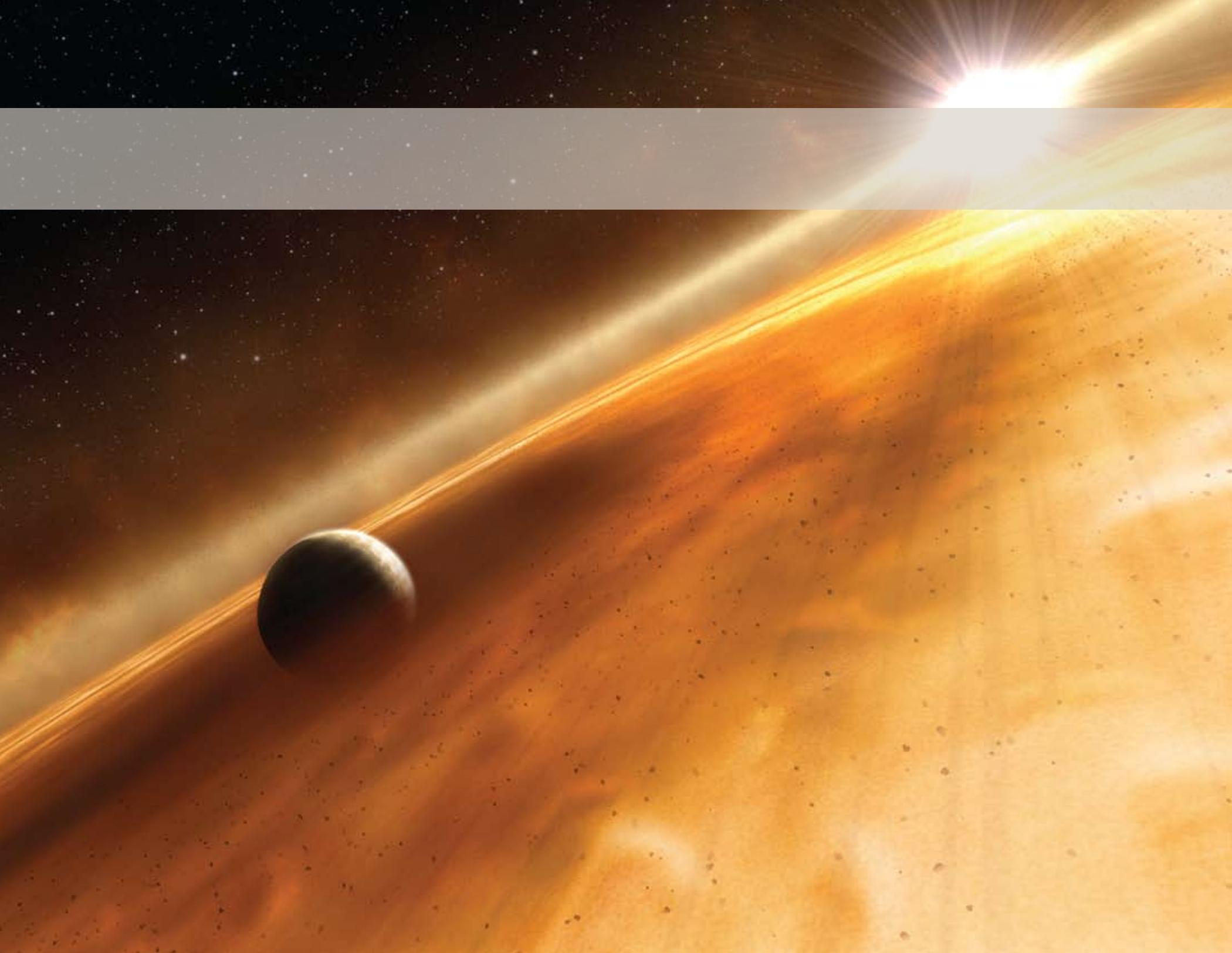
Thanks to the core competencies developed through its long line of contracts with NASA, AZ Technology sells several other optical measurement tools for field and laboratory use. The TEMP 2000A, for which the company also received NASA funding, has been used to qualify heat exchanger pipe coatings in solar collectors and roofing materials for ENERGY STAR designation. Additionally, the company also qualifies reflectors for infrared camera systems and black baffle coatings for infrared optical systems. Lastly, because of its unique expertise, AZ Technology develops calibration standards for instrumentation, including emissometers and scatterometers. In addition to its optical measurement tools and services, AZ Technology sells thermal control coatings, which have also been developed with NASA funding. ❖

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# Aeronautics and Space Activities

NASA's four Mission Directorates—Exploration Systems, Aeronautics Research, Science, and Space Operations—lead ongoing research and operations that are expanding space exploration capabilities, advancing aviation and space flight, improving our understanding of Earth and the universe, and extending human presence beyond our home planet. These efforts, conducted at each of NASA's 10 field centers, continue to broaden the horizons of human accomplishment while providing foundations that may lead to future spinoffs benefiting life on Earth.



# Aeronautics and Space Activities

NASA's mission is to pioneer the future in space exploration, scientific discovery, and aeronautics research. To carry out this mission, the Agency relies upon the ongoing research activities and operational support of its four Mission Directorates: Exploration Systems, Aeronautics Research, Science, and Space Operations. These efforts are conducted at each of NASA's 10 field centers.

## Exploration Systems Mission Directorate

NASA's Exploration Systems Mission Directorate (ESMD) develops capabilities and supporting research and technology that will make human and robotic exploration possible. It also makes sure that astronaut explorers are safe, healthy, and can perform their work during long-duration space exploration. In the near-term, ESMD does this by developing robotic precursor missions, human transportation elements, and life-support systems.

## Electric Vehicle Technologies Designed for Lunar Exploration

As part of its mission to return to the Moon, NASA has identified the need for a long-range electric vehicle to carry astronauts great distances from the lunar outpost.

***The LER needs technologies similar to those required for electric vehicles that the U.S. needs to reduce its dependency on fossil fuels***

This Lunar Electric Rover (LER) is about the size of a pickup truck (with 12 wheels) and can house 2 astronauts for up to 14 days with sleeping and sanitary facilities. It is designed to require little or no maintenance and be able to travel thousands of miles climbing over rocks and up 40-degree slopes during its 10-year life exploring the harsh surface of the Moon.



The Lunar Electric Rover may assist in the exploration of the Moon while inspiring advanced electric vehicle technologies on Earth.

The view from the cockpit and the LER's ability to "kneel" make it easy for astronauts to get close to objects they want to examine without having to leave the cabin. Its wheels can move sideways in a "crabbing" motion, one of many features that make it skilled at scrambling over rough terrain. The crab-style steering allows the vehicle to turn on a dime with a zero turning radius and drive in any combination of forward and sideways. Astronauts can work in shirtsleeves in the safety of the rover's cabin, and in emergencies or for exploration missions, they can quickly enter and exit their space suits through suitports.

These suitports on the rover's aft bulkhead keep the astronauts' suits outside, allowing a spacewalk to start in 10 minutes and keeping Moon dust out of the cabin.

The LER requires similar new technologies as those required for electric vehicles such as cars, tractors, and heavy equipment that the United States needs to reduce its dependency on fossil fuels. These technologies include new batteries and fuel cells, advanced regenerative brakes, and new tire technologies.

A prototype LER was developed in conjunction with an off-road race truck team and was field tested at Black Point Lava Flow in Arizona with 140 kilometers of driving on rough terrain. This prototype rover is a plug-in electric vehicle built using today's most advanced technologies, with a cutting-edge, lithium-ion battery with a 125 Wh/kg specific energy (including cells, packaging and battery management electronics). As more advanced electric vehicle technologies are developed, they will be incorporated into the design. The development of these more advanced technologies will not be easy, so NASA has its best engineers and scientists working with the U.S. auto and heavy equipment industries, universities, other government agencies, and international partners to make the program succeed. For each advancement NASA makes in the LER's capabilities, the world will be one step (and 12 wheels) closer to returning to the Moon and one step closer to having highly reliable and efficient electric vehicles on Earth.

## Constellation Program Yields Early Benefits

The Constellation Program has moved beyond just drawings and into real hardware fabrication and testing, with new, advanced manufacturing techniques being tested, developed, and improved. For example, NASA is using friction stir welding (*Spinoff* 2008 and 2009) to manufacture and assemble the upper stage of the next-generation human launch vehicle, the Ares I rocket.

Friction stir welding is a solid-state welding process where metal parts to be joined are not melted during the joining process, thus retaining the metal's original characteristics. Friction stir welding uses a small, pin-like tool that rotates at high speed. Friction generated between the rotating tool and the metal plates being joined causes the metal to flow together, forming a weld. Friction stir welding produces fewer defects than conventional welding, and it can be done much faster, as the rotating tool passes rapidly along the weld line. The friction stir weld-

ing machine at Marshall Space Flight Center is being used to demonstrate the fabrication of large propellant tanks for the Ares I upper stage.

NASA is also developing methods to manufacture 10-meter-diameter composite structures for the Ares V launch vehicle. Composites will be used for the payload fairing, the barrel structure between the first and second stages, and the solid rocket motor cases. These structures will be at least two times larger in diameter than the composite structures that have been fabricated for commercial

airplanes; however, autoclave facilities used to cure the composites do not exist at this size, and they would be too expensive to build. NASA is working with industry to develop out-of-autoclave processing methods for large composite structures, which could significantly lower their cost.

Contributing to the advanced manufacturing techniques developed for the Constellation Program, the Thermal Protection System (TPS) Materials project has developed two new materials for the heat shield of the Orion Crew Exploration Vehicle (CEV). These materials will protect the spacecraft when it reenters the Earth's atmosphere on its return journey from the Moon. The TPS materials ablate, or vaporize, carrying away the intense heat during reentry. The Orion heat shield will experience about five times greater heating rate than the ceramic tiles used on the space shuttle. The two new materials are Avcoat, developed by Textron Inc., of Providence, Rhode Island, and Phenolic Impregnated Carbon Ablator (PICA), developed by Ames Research Center and The Boeing Company. After extensive testing of the two materials in arcjets that simulate the high temperatures encountered during reentry, Avcoat, which was used for the Apollo command module heat shield, was selected as the baseline material for the Orion heat shield. PICA will be used on the Mars Science Laboratory mission. The main technical challenge was fabricating a 5-meter-diameter heat shield from these materials. The Thermal Protection System Materials project delivered two full-scale manufacturing development unit heat shields to Lockheed Martin Corporation for testing.

### **NASA Initiates Human Testing for Simulated Orion Launch Conditions**

Orion is the Constellation Program's new CEV, set to carry as many as four crewmembers to the International Space Station (ISS) and lunar orbit and return its crew safely to Earth after missions to the Moon's surface. Understanding the crew's performance during the various



To fabricate the Ares I rocket for the Constellation Program, NASA employs friction stir welding (FSW) techniques. FSW has been enhanced by the invention of an auto-retractable pin tool by Marshall Space Flight Center engineers.

phases of the mission is of paramount importance. Since the launch environment the astronauts experience from the new Ares I rocket may produce crew vibration significantly greater than was experienced during the Mercury, Gemini, and Apollo launches, the Orion Project initiated human tests in the 20-G centrifuge at Ames to assess visual performance for modern display technologies under the combined 12-Hz whole-body vibration and elevated 3.8-G loading expected during Ares I launch. Several studies were completed using test subjects from the general population and astronaut crew office. Test subjects were seated in a vibrating chair while also experiencing elevated gravitational forces induced by the centrifuge and were asked to read Orion-inspired numerical computer display formats. The results of this study have potential application to the design of displays for other domains where human subjects are subjected to vibration and G-load stresses, such as commercial and military aviation.

### Future Space Suit Designs Are Underway

The Extravehicular Activity (EVA) Systems Project will provide the suits, tools, and equipment necessary to protect astronauts as they explore the surface of the Moon. In many ways, the Apollo space suits were a remarkable design; however, since NASA left the Moon, advances in technology will enable future lunar explorers to be more comfortable and more productive than their Apollo brethren. Two areas of improvement that the EVA Systems Project is pursuing, in conjunction with the Exploration Technology Development Program, are the development of a Space Suit Water Membrane Evaporator (SWME) and the Rapid Cycle Amine (RCA) swingbed.

The SWME is being developed as an alternative to the current sublimator used to provide cooling capabilities on the space shuttle/ISS Extravehicular Mobility Unit (EMU) Portable Life Support System (PLSS). The SWME will provide increased robustness and capacity for lunar operations, decreased costs, and multimission

usage (extensible to Mars exploration). The SWME has advantages over the space shuttle EMU sublimator, as it will operate above the triple point of water for use in both lunar and Martian environments. The EVA Systems Project has been developing the SWME to increase the performance life and decrease sensitivity to water quality over the state-of-the-art sublimators. Also, the SWME is more of a Mars-forward design than the sublimator because it can operate at higher atmospheric pressures. Two membrane configurations are currently being evaluated, and a down selection will be made after another round of testing.

The RCA swingbed will be used to control carbon dioxide and humidity in space suit applications. This application is already being considered for the Environmental Control and Life Support System for the Orion CEV. The RCA that will be developed for the space suit will be driven by carbon dioxide removal requirements, whereas the design for Orion is driven by humidity control. The EVA Systems Project has been focusing to date on developing innovative designs for the canister and the valve that cycles between the beds. This design decreases mass and improves the ability to package the RCA into the PLSS. The project has been building subscale test articles to evaluate the manufacturing risks associated with the design and will begin to work on unique EVA performance issues that primarily stem from the small control volume.

### Device Manufactures IV Fluid During Space Missions

NASA developed the Intravenous Fluid Generation (IVGEN) device to allow flight surgeons more options to treat ill or injured crewmembers during future long-duration exploration missions. It was designed following a trade study examining various technologies that might be used to meet the fluid purity and composition requirements of the United States Pharmacopeia (USP)—the official public standards-setting authority for medication

and health care products manufactured or sold in the country. These technologies included forward osmosis, reverse osmosis, distillation, resin beds, and sterilizing-grade membrane filters. As part of that review, NASA fluid physics experts analyzed the ability of the devices to operate in the microgravity and partial gravity environments present during space missions.

Based on analysis and test results, NASA designed a filtration system using technologies developed by PRISMedical Corporation and a Kennedy Space Center system designed for use in developing countries.

Independent panels reviewed the preliminary IVGEN design. After passing that review, NASA tested the specific design elements in a laboratory setting. Following that testing, the research team demonstrated in a second review that the design was sufficiently mature to warrant flight hardware fabrication. The IVGEN team is currently fabricating both ground test and flight hardware.

In operation, the crew will fill a bag contained within a vessel (known as the accumulator) with ISS potable water. The interior of the accumulator will be pressurized, thus pressurizing the bag, using compressed nitrogen available onboard the ISS. Compressed gas is projected to be onboard exploration vehicles as well as in habitable exploration environments. Avoiding a pump reduces hardware mass, volume, complexity, and cost.

Once a crewmember opens the accumulator outlet valve, water will enter the purification assembly, where it initially flows through a bank of membrane filters designed to bleed off any air that may have been trapped

***IVGEN  
could be  
commercialized  
for applications  
where resources  
are few and  
medical  
treatment is  
constrained,  
such as  
wilderness  
outposts,  
developing  
countries,  
and frontline  
battlefield  
hospitals.***

in the accumulator. Following that, the water will pass through a sensor designed to measure the water's conductivity. Not only is conductivity part of the USP requirements, but the measurement is also an excellent global indicator of water quality.

The water will next enter the resin bed, which removes impurities and most of the bacterial load. A second conductivity sensor at the output of the resin bed will quantify the resin bed lifetime because the conductivity will rise as the resin bed's filtering capacity is exhausted. A second set of membrane filters will remove any air bubbles that may have been liberated from the resin bed. These filters will also remove any residual bacteria that may have passed through the resin filter.

Following that bank of filters, the water will pass out of the purification assembly and into the mixing assembly. Water will enter what is known as the mixing bag, where the correct amount of sodium chloride required to produce 0.9-percent Normal Saline, USP, will be present. The purified water will be mixed with the sodium chloride using a laboratory stir bar. NASA conducted extensive microgravity mixing tests and determined that this technology performed the best in microgravity conditions.

After the mixing bag, the final product will pass through another tube into the collection bag. Along the way, the IV fluid will pass through another conductivity sensor to verify mixture uniformity, as well as a final membrane filter. The operator will transfer fluid between the two bags by placing the mixing bag in what is essentially a large blood pressure cuff and pumping air into the cuff bladder, which in turn will pressurize the mixing bag, causing the fluid to flow. Once the collection bag is full, it will be disconnected, sealed, and returned to Earth for testing to validate that the fluid complies with USP standards.

Operationally, a device for exploration use will feature fewer sensors, and capacity can be scaled up or down by changing the size of the resin bed filter. Operational

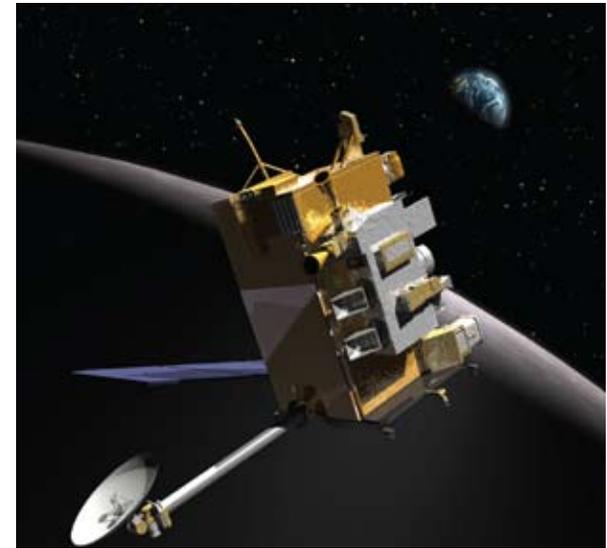
testing is currently scheduled onboard the ISS in the Microgravity Sciences Glovebox in March 2010.

IVGEN could be commercialized for normal gravity applications in locations where resources are few and medical treatment is constrained. Examples include wilderness outposts, developing countries, and frontline battlefield hospitals. In those applications, manual-mixing techniques could be employed, and the accumulator could be pressurized with a manual pump.

### **Preparing for Human Return with Robotic Precursors**

It will take many years of significant effort to build a lunar outpost where humans can live and work on a continuous basis. Considerable planning based on the best information NASA can obtain followed by much work remains to be done before humans can again return to the surface of the Moon. The Lunar Reconnaissance Orbiter (LRO) and the Lunar Crater Observation and Sensing Satellite (LCROSS) will collect essential information about potential sites for the outpost. The LRO and the LCROSS launched together from Kennedy in June 2009. The LRO will orbit the Moon for at least 1 year, creating high-resolution maps of the lunar terrain and potential lunar resources, seeking ideal landing sites by identifying hazards, and characterizing the thermal, lighting, and radiation environments that the outpost systems must be designed to endure.

Previous lunar missions have identified excess hydrogen near the lunar poles, suggesting that permanently shadowed craters near the poles may have water frozen beneath the surface. Mission planners intend for the LCROSS to impact the Moon in one of these permanently shadowed regions in an attempt to measure any water that may be present. The LCROSS shepherding satellite and the LRO's Earth-departure stage booster will strike the Moon's South Pole in fall 2009. As LCROSS approaches the Moon, the Earth-departure stage will separate and impact a crater, creating a 770,000-pound



NASA's Lunar Reconnaissance Orbiter will map the Moon in preparation for future landings and the establishment of lunar outposts.

plume. The shepherding spacecraft will fly through the plume, using instrumentation to examine the cloud for signs of water and other compounds. After sending these data to Earth, this satellite itself will become an impactor, creating a second plume. The plumes are expected to be visible to lunar-orbiting spacecraft and Earth-based observatories.

### **Inflatable Habitat Deployed in Antarctica**

NASA is developing lightweight inflatable habitats for the lunar outpost. An inflatable habitat is constructed from fabric materials, and it can be packaged into a small volume for launch. Internal pressure is used to deploy the habitat and to maintain its shape. Inflatable habitats could provide much greater living space for the crew than rigid habitats fabricated from metal.

In partnership with the National Science Foundation, a prototype inflatable shelter manufactured by ILC Dover LP,



The prototype inflatable shelter tested at McMurdo Station in Antarctica demonstrated the promise of similar structures for use on the Moon. Such structures could also be ideal for mobile field hospitals in challenging environments on Earth.

of Frederica, Delaware, was deployed at McMurdo Station in Antarctica. McMurdo, a research station operated by the United States, is the largest community in Antarctica, having over 100 buildings.

The fabric walls of the shelter were instrumented with sensors to measure the stresses caused by the wind and snow. The inflatable shelter held its shape for over a year in the extreme Antarctic environment, where the annual temperature average is 0 °F.

Inflatable shelters are portable and can be deployed rapidly. They have terrestrial applications for mobile field hospitals and equipment shelters.

### Flash Lidar Aids Autonomous Landing and Hazard Avoidance

When astronauts land on the Moon, they will need to touch down safely at a precise location close to the



The flash lidar technology mounted on the nose of this helicopter may one day enable automated space docking and precise lunar landings.

lunar outpost. Unpiloted landers will also bring cargo to the outpost. Dust and shadows could obscure rocks and craters in the landing zone, so the landers must be able to operate in any lighting conditions without navigational aids. To allow lunar landers to autonomously detect and avoid hazards, NASA is developing flash lidar sensors.

A flash lidar consists of a laser, a small telescope, and a photodetector. The lidar sends out a pulse of laser light that is scattered by distant objects. The telescope collects the backscattered light and directs it to the photodetector. By measuring how long it takes the laser pulse to return to the photodetector, the flash lidar builds up a three-dimensional image of the terrain. The Autonomous Landing and Hazard Avoidance Technology project tested a flash lidar on a helicopter. The helicopter flew over simulated hazards in the desert, and the lidar generated a map of the terrain. Flash lidar sensors can also be used for rover navigation on the lunar surface and for automated rendezvous and docking.

## Stirling Converters for Fission Surface Power Systems

The Fission Surface Power Project is developing power conversion and thermal management technologies for a 40-kilowatt nuclear reactor that could provide power for the lunar outpost. The reactor would be cooled with a mixture of liquid sodium and liquid potassium metal circulating through its core. The liquid metal coolant would transfer its heat to eight Stirling converters, each generating about 6 kilowatts. A Stirling converter is a small heat engine that drives an oscillating piston connected to an alternator to generate electricity.

NASA is working with Sunpower Inc., of Athens, Ohio, to develop the Stirling converters. Stirling converters could also be coupled with a radioisotope power source to generate electricity for driving a lunar rover.

Stirling converters are being used on Earth to generate power from concentrated sunlight or waste heat from furnaces, and they could be a key technology for enabling new sources of renewable energy.



With the ability to generate electricity from heat, Stirling converters could provide new possibilities for sustainable energy.

## Aeronautics Research Mission Directorate

NASA's Aeronautics Research Mission Directorate conducts cutting-edge, fundamental research in traditional and emerging disciplines to help transform the Nation's air transportation system and to support future air and space vehicles. Its goals are to improve airspace capacity and mobility, improve aviation safety, and improve aircraft performance while reducing noise, emissions, and fuel burn.

### Vision Technologies for Safe All-Weather Capability

Reduced visibility affects the safety and efficiency of nearly all flight operations. As a result, researchers have been seeking methods of improving or providing vision capabilities for those who command and control air and space vehicles that are independent of the actual visibility or other weather conditions. In recent years, research has focused on two technologies to help pilots see in all conditions—Synthetic Vision Systems (SVS) and Enhanced Vision Systems (EVS). SVS technology provides pilots with a virtual, visual depiction of features in the external environment superimposed with relevant aircraft state, guidance, and navigation information. These SVS displays are created using worldwide terrain models, locations, and dimensions of cultural features (such as roads, buildings, towers, and airport layouts), and a precision navigation system (typically Global Positioning System and Inertial Navigation System data). In contrast, EVS technology uses imaging sensors (e.g., Forward-Looking Infrared) that attempt to “see through” obscurations such as those produced by darkness, clouds, or fog.

A third concept—integrated SVS/EVS—takes advantage of the complementary characteristics of these systems. Weather does not affect synthetic vision, so it can always offer a clear picture. However, it may not

always be accurate due to navigation system limitations or geographic map/model deficiencies. In contrast, navigation system and mapping errors do not affect EVS, but its sensors will have limited field-of-view and will perform differently depending on weather conditions or visibilities. Although the methods, architectures, and operational issues associated with SVS and EVS are significantly different, integrating the two approaches can provide a more robust, comprehensive capability.

One goal of these technologies is to provide an electronic means by which pilots can visually, and more intuitively, operate a vehicle without actually being able to see outside through their windows with natural vision.

Engineers at NASA's Langley Research Center tested an integrated system concept in a 2008 experiment in the Integrated Flight Deck simulator. The simulator looks and flies exactly like a modern airliner. The objective of the experiment was to determine to what extent advanced cockpit display technologies could provide pilots an all-weather, all-visibility capability.

Twenty-four pilots, many of them airline captains, evaluated various display concepts as part of a rigorously defined and controlled experiment. They “flew” the simulator through a number of approach, landing, taxi, and take-off scenarios. Instruments in the flight deck offered them a variety of display sizes, visibility options, and guidance. Researchers also threw in some potential accident scenarios to gauge pilot awareness and reactions to unexpected events. How they react to failure scenarios is critical in determining safety.

Results showed that such innovative display concepts can make up for an inability to see

*One of the goals of these technologies is to provide an electronic means by which pilots can operate a vehicle without actually being able to see outside.*

the outside world. In fact, the pilots' abilities to land the aircraft improved, since the pilots did not have to shift their attention from their instruments to the outside view as they do today. The experiment also showed that larger field-of-view displays can improve pilot performance and awareness of surroundings, while reducing pilot workload. Finally, results indicated that the use of graphical displays that looked like the real outside world enhance situational awareness and reduce workload also. These findings support and advance long-term research objectives for both more integrated and intelligent flight deck systems and more environmentally friendly supersonic aircraft designs involving a no-boom or low-boom characteristic (i.e., "window-less" cockpits).

The ultimate goal of the NASA aeronautics work is to give pilots a "better than visual" capability that acknowledges that accidents and inefficiencies happen even while flying in pristine weather conditions when pilots can see everything clearly. To provide that capability, cockpit technologies need to give pilots information that confirms visual observations, fills in gaps of what can be seen, and does so in a way that assures awareness of surroundings without increasing workload, flight technical errors, or affecting other aspects of performance. The guiding principle behind the work is to keep displays intuitive and easily understood.

Based on analyses and a series of human-in-the-loop experiments, the research continues to explore the extent to which "better than visual" can be achieved. Among the questions that still need to be answered are: How much information is too much information? How much is sufficient? How should it be displayed? What are the technological performance requirements? Through additional experiments and analyses, NASA researchers continue working with its industry and academic partners to answer these questions and give flight crews an extra set of eyes, ears, and smart technologies that can help improve flight safety and efficiency.

These concepts and technologies are also applicable to operator stations for remotely operated vehicles and to other modes of transportation where external visibility is diminished or unavailable. These include rotorcraft operations in fog; dusty conditions brought about due to rotor wash or smoke from forest fires; planetary/lunar descent, landing, and roving vehicles; shipping operations in or near shallow or narrow channels; and undersea vehicle operations.

### **Instrumented Crimping Tool for Critical Wiring Applications**

Modern commercial aircraft rely on thousands of crimped wire connections for critical communication, navigation, control, and electrical power distribution systems. Failed crimp connections can be a significant threat to aircraft safety, leading to such events as a loss of critical functions or even an onboard fire. Additionally, a large maintenance cost is associated with the diagnosis and repair of faulty crimp connections. Present practices for assuring good crimps are based on following detailed crimping procedures and using specialized tools. Periodically, verification of the tools and procedures is performed by destructively testing representative crimps. However, there are no independent methods to verify individual crimp quality.

By adapting traditional, ultrasonic, nondestructive inspection methods, NASA researchers have developed a new technique to enhance a crimp tool's capability and provide real-time verification of wire-crimp integrity while the crimp is being formed. The quality of the contact between the connector and wire is determined by sending an acoustic wave through the crimp assembly. As the applied pressure increases and the crimp terminal deforms around the wire, the ultrasonic signature passing through the crimp is altered. The change in signal amplitude and frequency content is analyzed to provide an indication of the quality of both the electrical and mechanical connection between the wire and terminal. Various crimp



NASA's newly developed technique for assessing wire-crimp integrity has applications in aerospace, marine, automotive, and medical industries.

quality issues such as undercrimping, missing wire strands, incomplete wire insertion, partial insulation removal, and incorrect wire gauge have been tested using this technique and results show that the instrumented crimp tool consistently discriminates between good and poor crimps for all of these potential quality issues. This information can be used to provide a "pass" or "fail" indication to the technician for instant verification of the crimp quality and gives a better prediction for the service life of the crimp.

This technology may have broad application to other industries with critical wire terminations such as marine, automotive, and medical. In many cases, this new crimp validation capability may be accomplished by modification of existing tooling. The next step in development involves miniaturizing the electronics from the current laptop computer-sized system to a battery powered, hand-held unit that could be mounted on a tool belt or incorporated directly into the crimp tool. Additionally, research is being conducted for this technology to be used in diagnostic tools for preexisting crimps.

## Aging and Durability of Engine Hot Section Components

A critical aspect of NASA's Aviation Safety Program's goal to address aging aircraft issues is the ability to sense conditions in the hot section of an aircraft engine, including the turbine. Such sensors must operate in an extremely harsh environment, yet are critical to safety as the degradation and damage that develops over time in hot section components can lead to catastrophic failure. At present, the degradation processes that occur in the harsh hot section environment are poorly characterized, which hinders development of more durable components and requires extensive inspection and maintenance. Since it is so difficult to model turbine blade temperatures and strains, actual measurements are needed to better assess the condition of the engine.

NASA research seeks to develop high-temperature, thin film ceramic sensors capable of measuring static strain, temperature, and heat flux in turbine engine applications. NASA researchers are investigating the use of thin film ceramic sensors instead of platinum metals, which are only usable to 1,000 °C, more expensive (approximately \$2,000 per troy ounce), and tend to have signals that decrease over time. Unlike currently available wire or foil sensors, thin film sensors do not require special machining of the components on which they are mounted, and, with thicknesses less than 10 microns, they are considerably thinner than wire or foils. Thin film sensors are thus less disruptive to the operating environment and have a minimal impact on the physical characteristics of the engine components under the sensors.

The conductive ceramic sensors in this research area are being developed for use by turbine engine manufacturers during test instrumentation, but are also possibly applicable to ground-based turbines such as electrical power generators. In addition, advances in the development of high-temperature, thin film sensors may enable other applications such as heat flux measurement on the

heat shield of NASA's Orion Crew Exploration Vehicle under development, or for devices used for power harvesting, converting heat energy into electrical power to power wireless sensors in extreme-temperature environment applications.

## Integrated Resilient Aircraft Control Flight Test

Adaptive flight control technology is being developed under NASA's Aviation Safety Program to enable control of aircraft in all conditions, including those where the aircraft is degraded, where ice disrupts its controllability, or where the aircraft is upset by turbulence. The project's primary goal is to develop adaptive and fault-tolerant flight control systems, tackling the primary cause of accidents in commercial jet aviation. In the summer of 2008, a series of flights were flown on NASA's NF-15B Intelligent Flight Control System (IFCS) airplane to provide validation of two specific adaptive controls designs. The information obtained from these flight tests provides validation of the concepts and points out aspects needing further improvement. This is an ongoing effort with a long-term goal of promoting adaptive control technology as a viable design solution for increased aircraft safety and resilience.

Current control system technology is based on a model of how an undamaged, unperturbed aircraft will behave in normal flight conditions and thus may not be able to control the aircraft well in abnormal conditions. The adaptive systems "learn" about the new flight condition as it is experienced, and thus can account for much larger and more drastic changes. These new state-of-the-art control algorithms can correctly identify and respond to changes in aircraft stability and control characteristics, enabling the system to adjust immediately in order to maintain the best possible flight performance in a wide range of abnormal conditions. While benefits have been shown in simulations, NASA's flight tests provide unique

validation of these benefits in a more realistic environment.

NASA's NF-15B IFCS airplane provided a research test bed platform uniquely suited to test the adaptive control, with an unprecedented combination of control power and onboard computational capability. The vehicle started as a robust F-15 fighter aircraft with high structural strength in case the experimental control algorithm does not respond as predicted. Large canard control surfaces were added to the vehicle. The excess control capability allows for in-flight simulation of

*The project's primary goal is to develop adaptive and fault-tolerant flight control systems, tackling the primary cause of accidents in commercial jet aviation.*



Originally an F-15 fighter, NASA's NF-15B Intelligent Flight Control System aircraft has validated adaptive control concepts that may improve commercial aviation safety.

the effects of significant vehicle damage. The flight control computer was augmented with additional processors that allow for testing of very complex adaptive control schemes.

During the flights in the summer of 2008, the adaptive systems were subjected to a destabilizing flight condition in which, without the adaptive system engaged, the vehicle was almost impossible to pilot. When the adaptive system was engaged, most of the good flying characteristics of the vehicle were restored. In another test, a flight control surface was “stuck.” Unlike normal flight conditions, in which some control surfaces control pitch and others control roll, in this condition, the remaining pitch control surfaces created an asymmetric command that also created roll, and thus the control of pitch and roll was cross-coupled. With normal control systems, this type of behavior can be very disorienting to a pilot, but the adaptive control system regained control, provided maneuvering capability, and eventually provided the ability to land the damaged vehicle safely.

The flight results demonstrated the potential of control systems to adapt to failures and adverse conditions. The information collected from these flights will lead to improvements in future adaptive systems and smooth their implementation in many vehicle classes, including commercial, fighter, transport aircraft, unmanned air vehicles, and spacecraft.

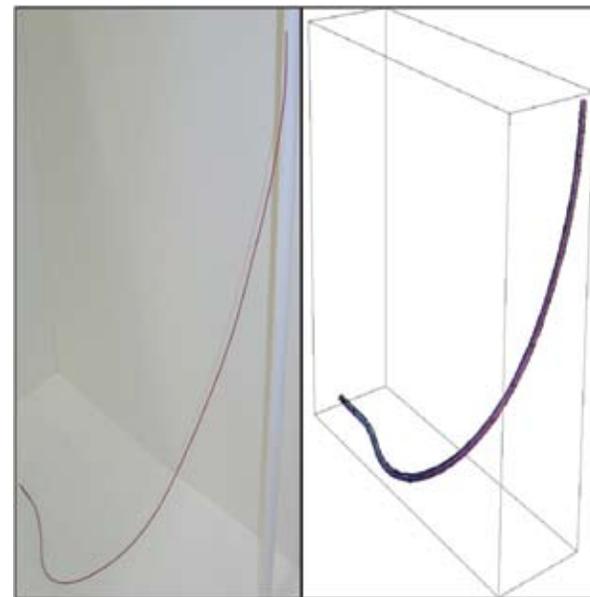
### Multicore Fiber Optic Shape Sensing

Researchers at NASA have developed a novel method for accurately determining the shape of multicore optical fibers in three dimensions; this method can help improve the safety of future aircraft and spacecraft and could be a key component in an Integrated Vehicle Health Management System. In recent years, attention has been given to the development of multicore optical fibers for use as fiber optic shape sensors. Optical fibers are often referred to as light pipes, because they hold and guide light from one end to the other in much the same

way as water pipes hold and guide water. The light pipes, however, are not hollow; they are solid glass and the light is held and guided along the core. The core is surrounded by another glass region known as the cladding. A traditional single-core optical fiber transmits one channel of light information; a multicore optical fiber, in contrast, contains three or more light-guiding cores symmetrically arranged in the cladding, enabling the transmission of three or more individual channels in a single fiber.

A multicore fiber applied to an airframe surface or interior, however, would experience bending along the fiber as a result of shape changes if the airframe experienced deflection. The bending along the fiber causes the sections of fiber on the insides of bends to compress and the sections of the fiber on the outsides of bends to stretch. This compressing and stretching of the fiber sections is generally called strain and is measureable using sensors like fiber Bragg gratings (FBGs) embedded in the fiber. FBGs are just millimeters long and are etched into the fiber as it is produced. They work by reflecting a certain wavelength of light, depending on the amount of fiber stretch or compression, back to an interrogation system that tracks the wavelengths each FBG is reflecting. If an FBG experiences stretching, or positive strain, its reflection wavelength will increase; if an FBG experiences compression, or negative strain, its reflection wavelength will decrease. Using the reflections from FBGs in each core of a multicore optical fiber, a measurement system can track the strain along the entire fiber length. Because the strain imposed in each core depends on the radius of the bend and the direction of the bend along the fiber, strain information from the FBG sensors embedded within the multicore fiber can be used to estimate the bending at each FBG location along the fiber.

In the past, shape-sensing measurements using such an optical fiber were performed by using only the estimated bending parameters to calculate the location of each small section of fiber based on the location of the previous section; the resulting measured fiber shape was many little



Aircraft and spacecraft safety may soon be enhanced by new NASA algorithms that significantly improve the accuracy of multicore fiber optic shape sensors.

bends added together to form one curve, the shape of which had many discontinuities and errors. Because the overall fiber shape and end position measurement resulted from appending several measurements serially along the fiber, the shape error at each measurement section along the fiber was propagated into the final measurement.

NASA’s new patent-pending algorithms take into account both the natural elastic behavior of the shape-sensing multicore optical fiber and the measured bending parameters in determining fiber shape. Moreover, point-to-point measurement errors are not summed into the final measurement. The new methods have significantly improved the accuracy of multicore fiber optic shape sensors. This new technology will be useful in the monitoring of airframe deflections during high load situations such as turbulence and hard landings and could prove useful in controlling wing and stabilizer flutter.

Multicore fiber optic shape sensing research can also be applied to minimally invasive surgical end-effector tracking. Steerable surgical tools provide a means to navigate and position a surgical end-effector (the end of a robotic arm or mechanism) to a desired location in the body. Once in position, the end-effector is used to perform a specific medical procedure, such as excise tissue for a biopsy or deposit a pharmaceutical drug. A major limitation, however, is in the accuracy of guiding the end-effector to the target. Cables (which act like tendons) are typically used to steer an end-effector, but its location is not known precisely. Multicore fiber technology embedded in a steerable surgical tool would provide the means to locate the end-effector precisely, relative to the target. Other non-aerospace applications include cabled remote-vehicle tracking (such as in collapsed buildings or mineshaft search and rescue), 3-D underground drilling direction monitoring, and towed sonar array position tracking.

### Onboard Engine Performance Diagnostics

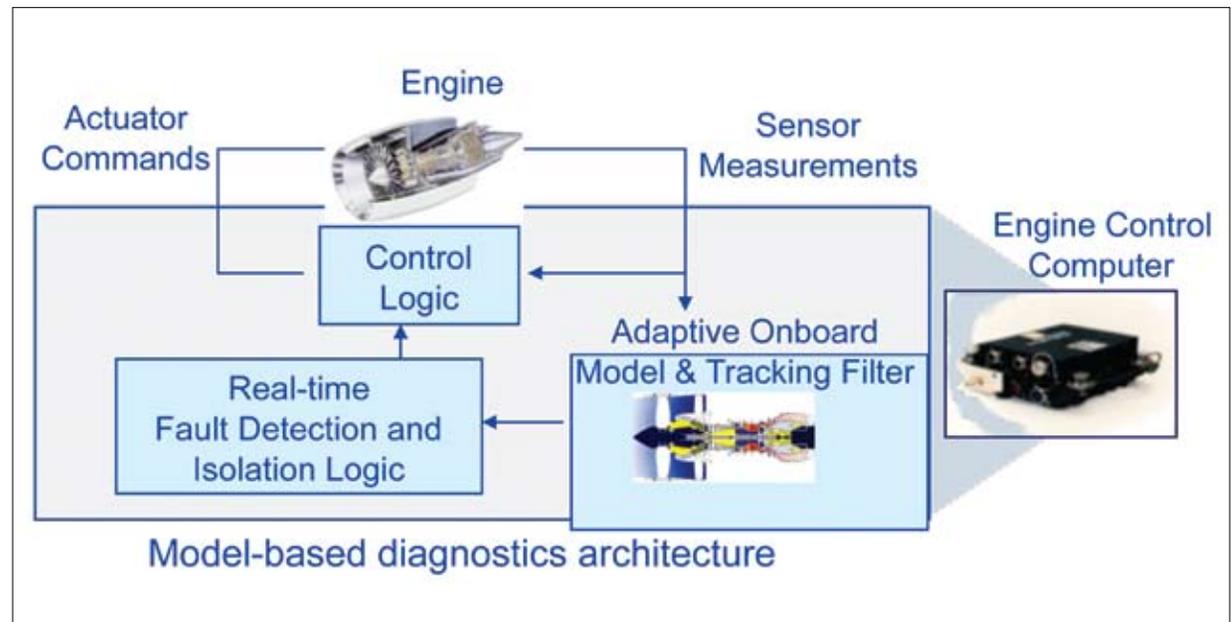
Under the Aviation Safety Program’s Integrated Vehicle Health Management Project, NASA researchers are developing technologies to enhance the safety of aircraft propulsion systems. Included are techniques to provide a continuous real-time assessment of engine health such as onboard model-based performance diagnostics. Model-based performance diagnostics incorporate an onboard adaptive engine model embedded within the engine control computer; the onboard model is automatically updated to trend the performance condition of the physical engine based on sensed measurements. This technology has been enabled by increases in onboard processing capability and allows onboard diagnostic functionality to be tailored to the specific condition of an individual engine. Tailoring is particularly relevant for gas turbine engines, which naturally undergo performance deterioration over their lifetime of use due to turbomachinery degradation. An accurate onboard model provides

a continuous assessment of current engine condition and establishes a baseline of recent engine performance that can be used to diagnose rapid or abrupt engine events including turbomachinery, control actuator, and control sensor faults. Adaptive model-based performance diagnostics can help reduce onboard diagnostic system false alarms and missed detections and can also enable the early detection of small magnitude incipient faults, such as icing conditions in propulsion systems or faults in power electronics.

A key component of onboard adaptive engine model technology is the tracking filter that provides automated tuning, or updating, of the model; the effects of engine performance deterioration are captured, permitting the onboard model to match the performance of the actual physical engine. A challenge facing the adaptive model update is that a relatively limited number of sensors are

typically available, resulting in an underdetermined estimation problem. NASA recently developed a systematic strategy for optimally selecting model tuning parameters to minimize the estimation error within the model parameters of interest. Initial results based on simulation studies indicate that this new approach reduces the degradation-induced error in onboard engine models by over 50 percent, relative to the conventional ad hoc approach of selecting onboard model tuning parameters.

In addition to diagnostics, onboard adaptive engine models also hold great potential benefit for aircraft engine controls and structural life usage monitoring applications, which require an estimate of unmeasured engine outputs. It is not practical to instrument the engine to sense every parameter of interest due to cost, weight, and harsh high-temperature environment constraints. Therefore, conservative worst-case parameter estimates



Sensor data fed into an aircraft’s engine control computer can be used to constantly update an onboard adaptive engine model, which offers a continuous assessment of engine condition and performance, a key safety enhancement.

are often applied. Improving the accuracy of these synthesized parameter estimates through onboard adaptive models can help reduce uncertainty and directly improve applications such as model-based controls and calculating life consumption based on usage. NASA will collaborate with industry for further developments, which is of current interest within the aviation community.

### Smart Materials Improve Helicopter Noise and Vibration

NASA research into helicopter rotors made with shape-changing smart materials could change the way commuters view helicopters in the future. Twenty years from now, large rotorcraft could be making short hops between cities such as New York and Washington, carrying as many as 100 passengers at a time in comfort and safety. Routine transportation by rotorcraft could help ease air traffic congestion around the Nation's airports, but noise and vibration must be reduced significantly before the public can embrace the idea.

There has been substantial research in smart materials for many years. The general characteristic of a smart material is the ability to change in shape, texture, color, or other property in a controlled response to a user-provided stimulus, such as electric field or temperature. Piezoelectric materials are a class of smart material that can produce deflection when subjected to an electric field or can produce an electric field when subjected to motion. One of the most widely recognized first uses of piezoelectric materials was in sonar to produce an ultrasonic submarine detector during World War I.

The solution for future rotorcraft and helicopters could lie in rotor blades made with piezoelectric materials that flex when subjected to electrical fields. NASA and the Defense Advanced Research Projects Agency (DARPA), the U.S. Army, and Boeing have spent the past decade experimenting with smart material actuated rotor technology (SMART) using piezoelectric devices. In the SMART rotor application, the material is used to drive



Engineers prepare the SMART rotor hub for wind tunnel testing. The rotor's piezoelectric enhancements help control noise and vibration.

an extra flap on each rotor blade. The flap deployment changes the lift of the individual rotor blade, and that

affects the way the blade creates noise and vibration. Controlling the amplitude and phase of the flap deployment controls the noise and vibration. The potential for substantial noise and vibration reduction using this approach has been predicted using advanced computer simulations.

The only full-scale SMART Rotor ever constructed in the United States was run through a series of wind tunnel tests between February and April 2008 in the National Full-Scale Aerodynamics Complex at Ames Research Center. The SMART Rotor partners joined with the U.S. Air Force, which operates the tunnel, to complete the demonstration.

A SMART Rotor with piezoelectric actuators driving trailing edge flaps was tested in the 40- by 80-foot tunnel in 155-knot wind to simulate conditions the rotor design would experience in high-speed forward flight. The rotor also was tested at cruise speed conditions of 124 knots to determine which of three trailing edge flap patterns produced the least vibration and noise. One descent condition also was tested.

The test results showed that the SMART Rotor reduced by half the amount of noise generated within the controlled environment of the wind tunnel. SMART also demonstrated reduced vibration of the rotor system. These improvements can be translated into benefits for helicopter operations and maintenance that will reduce the cost and improve the comfort of rotary wing flight for future passenger transport rotorcraft.

These same smart piezoelectric materials are currently used in other applications such as cigarette lighters, spark plugs, microphones, inkjet printers, and small motors, such as the auto-focus in reflex cameras.

*Twenty years from now, large rotorcraft could be making short hops between cities, carrying as many as 100 passengers at a time.*

## Science Mission Directorate

The Science Mission Directorate engages the Nation's science community, sponsors scientific research, and develops and deploys satellites and probes in collaboration with NASA's partners around the world to answer fundamental questions requiring the view from and into space. The directorate seeks to understand the origins, evolution, and destiny of the universe and to understand the nature of the strange phenomena that shape it.

### Phoenix Wraps Up Successful Mission to Mars

NASA's Phoenix Mars Lander returned unprecedented science data to Earth prior to terminating communications November 2, 2008. Launched August 4, 2007, Phoenix safely touched down on Mars on May 25, 2008, at a site farther north than where any previous spacecraft had landed. Phoenix's soft landing on Mars was the first in 32 years and only the third in history. The lander dug, scooped, baked, sniffed, and tasted the Red Planet's soil, and cameras on Phoenix sent more than 25,000 images back to Earth. Preliminary science data shed light on whether the Martian arctic environment ever has been favorable for microbes; documented a mildly alkaline soil environment unlike any found by earlier missions; discovered small concentrations of salts that could be nutrients for life; located calcium carbonate; and detected perchlorate salt. Phoenix exceeded its planned operational life of 3 to 5 months, and analysis of data from its instruments continues.

"Phoenix has given us some surprises, and I'm confident we will be pulling more gems from this trove of data for years to come," said Peter Smith, Phoenix principal investigator at the University of Arizona in Tucson.

"Phoenix not only met the tremendous challenge of landing safely, it accomplished scientific investigations on 149 of its 152 Martian days as a result of dedicated work



NASA's Phoenix Mars Lander took this composite self-portrait with its Surface Stereo Imager camera. The black circle is where the camera itself is mounted on the lander.

by a talented team," said Barry Goldstein, Phoenix project manager at NASA's Jet Propulsion Laboratory (JPL).

Phoenix findings also support the goal of documenting the history of water on Mars. These findings include excavating soil above the ice table, revealing at least two distinct types of ice deposits; observing snow descending from clouds; providing a mission-long weather record, with data on temperature, pressure, humidity, and wind; observations of haze, clouds, frost, and whirlwinds; and coordinating with NASA's Mars Reconnaissance Orbiter to perform simultaneous ground and orbital observations of Martian weather.

"Phoenix provided an important step to spur the hope that we can show Mars was once habitable and possibly supported life," said Doug McCuistion, director of the Mars Exploration Program at NASA Headquarters. "Phoenix was supported by orbiting NASA spacecraft providing communications relay while producing their own fascinating science. With the upcoming launch of the Mars Science Laboratory, the Mars Program never sleeps."

The University of Arizona leads the Phoenix mission with project management at JPL and development partnership at Lockheed Martin Corporation in Denver. International contributions came from the Canadian Space Agency; the Université de Neuchâtel, Switzerland; the universities of Copenhagen and Aarhus in Denmark; the Max Planck Institute in Germany; the Finnish Meteorological Institute; and Imperial College of London.

### Arctic Sea Ice Decline Continues

Arctic sea ice coverage appears to have reached its lowest extent for the year and the second-lowest amount recorded since the dawn of the satellite era, according to observations from the NASA-supported National Snow and Ice Data Center at the University of Colorado in Boulder.

While slightly above the record-low minimum set in September 2007, the data from September 2008 further reinforces the marked reduction in summer sea ice observed during the past 30 years. The previous record low for September was set in 2005.

In March 2008, when the Arctic reached its annual maximum sea ice coverage during the winter, scientists from NASA and the data center reported that thick, older sea ice was continuing to decline. According to NASA-processed satellite microwave data, this perennial ice used to cover 50–60 percent of the Arctic, but this winter it covered less than 30 percent. Perennial sea ice is the long-lived layer of ice that remains even when the surrounding

short-lived seasonal sea ice melts to its minimum extent during the summer.

NASA scientists have been observing Arctic sea ice cover since 1979. NASA developed the capability to observe the extent and concentration of sea ice from space using passive microwave sensors.

### **THEMIS Satellites Discover What Triggers Eruptions of the Northern Lights**

What causes the shimmering, ethereal aurora borealis to suddenly brighten and dance in a spectacular burst of colorful light and rapid movement? To find out, NASA launched a fleet of five satellites on a mission called the Time History of Events and Macroscale Interactions during Substorms (THEMIS). Using THEMIS findings, researchers have discovered that an explosion of magnetic energy a third of the way to the Moon powers substorms, sudden brightenings and rapid movements of the aurora borealis, also known as the Northern Lights.

The culprit turns out to be magnetic reconnection, a common process that occurs throughout the universe when stressed magnetic field lines suddenly “snap” to a new shape, like a rubber band that has been stretched too far.

“We discovered what makes the Northern Lights dance,” said Dr. Vassilis Angelopoulos of the University of California, Los Angeles. Angelopoulos is the principal investigator for the THEMIS mission. Substorms produce dynamic changes in the auroral displays seen near Earth’s Northern and Southern magnetic poles, causing a burst of light and movement in the Northern and Southern Lights. These changes transform auroral displays into auroral eruptions.

“As they capture and store energy from the solar wind, the Earth’s magnetic field lines stretch far out into space. Magnetic reconnection releases the energy stored within these stretched magnetic field lines, flinging charged particles back toward the Earth’s atmosphere,” said David Sibeck, THEMIS project scientist at Goddard Space

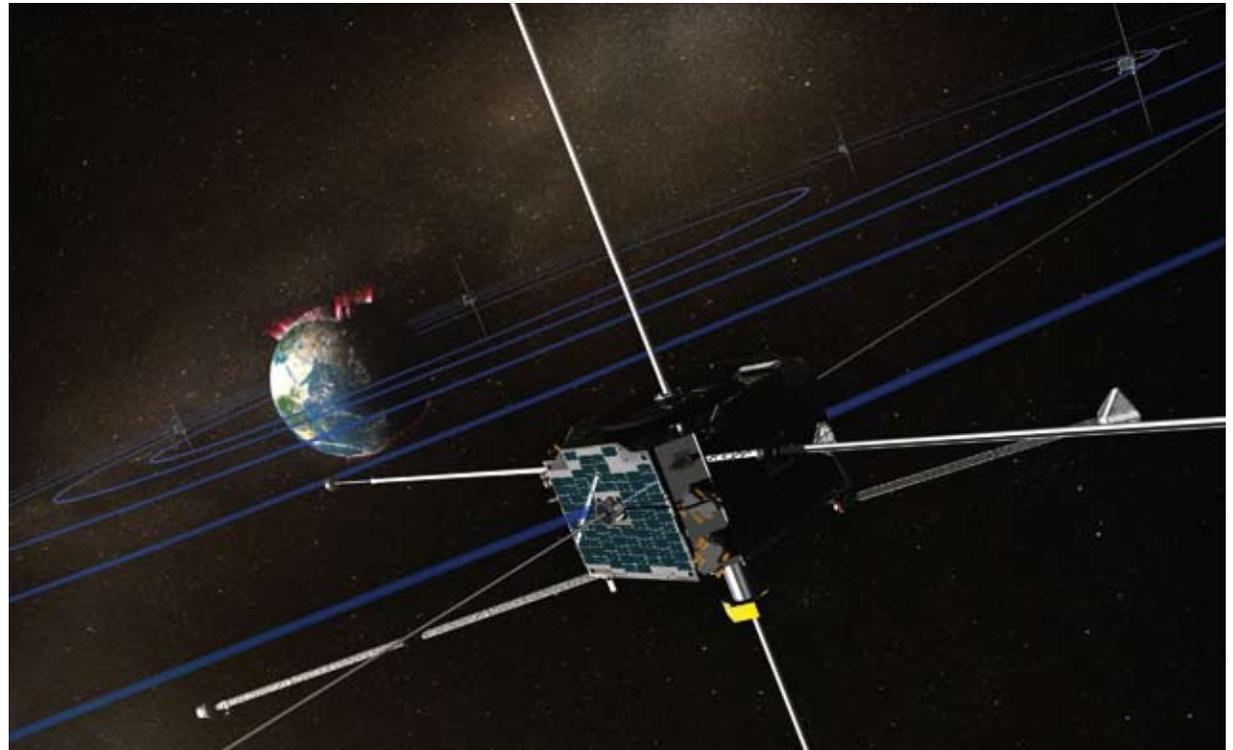
Flight Center. “They create halos of shimmering aurora circling the Northern and Southern poles.”

Substorms often accompany intense space storms that can disrupt radio communications and global positioning system signals and cause power outages. Solving the mystery of where, when, and how substorms occur will allow scientists to construct more realistic substorm models and better predict a magnetic storm’s intensity and effects.

Scientists directly observe the beginning of substorms using the 5 THEMIS satellites and a network of 20 ground observatories located throughout Canada and Alaska. Launched in February 2007, the five identical sat-

ellites line up once every 4 days along the equator and take observations synchronized with the ground observatories. Each ground station uses a magnetometer and a camera pointed upward to determine where and when an auroral substorm will begin. Instruments measure the auroral light from particles flowing along Earth’s magnetic field and the electrical currents these particles generate.

During each alignment, the satellites capture data that allow scientists to pinpoint where, when, and how substorms measured on the ground develop in space. On February 26, 2008, during one such THEMIS lineup, the satellites observed an isolated substorm beginning in



The five THEMIS satellites have unveiled the magnetic secrets of the aurora borealis—the Northern Lights. The satellites line up along the equator once every 4 days, capturing data that scientists have used to determine the cause of the famous atmospheric displays.

space, while the ground-based observatories recorded the intense auroral brightening and space currents over North America.

These observations confirm for the first time that magnetic reconnection triggers the onset of substorms. The discovery supports the reconnection model of substorms, which asserts that when a substorm starts, it follows a particular pattern. This pattern consists of a period of reconnection, followed by rapid auroral brightening and rapid expansion of the aurora toward the poles. This culminates in a redistribution of the electrical currents flowing in space around Earth.

THEMIS is the fifth medium-class mission under NASA's Explorer Program. The program, managed by the Explorers Program Office at Goddard, provides frequent flight opportunities for world-class space investigations in heliophysics and astrophysics. The University of California at Berkeley's Space Sciences Laboratory managed the project development and is currently operating the THEMIS mission. ATK Space Systems (formerly Swales Aerospace), of Beltsville, Maryland, built the THEMIS satellites.

## Hubble Observes a Planet Orbiting Another Star

NASA's Hubble Space Telescope has taken the first visible-light snapshot of a planet circling another star. Estimated to be no more than three times Jupiter's mass, the planet, called Fomalhaut b, orbits the bright Southern star Fomalhaut, located 25 light-years away in the constellation Piscis Australis, or the "Southern Fish." Fomalhaut has been a candidate for planet hunting ever since an excess of dust was discovered around the star in the early 1980s by NASA's Infrared Astronomy Satellite (IRAS).

In 2004, the coronagraph in the High Resolution Camera on Hubble's Advanced Camera for Surveys produced the first-ever resolved visible-light image of the region around Fomalhaut. It clearly showed a ring of protoplanetary debris approximately 21.5 billion miles



The planet Fomalhaut b, the first planet outside the solar system to be imaged using visible light, basks in the glow of its namesake star in this artist's rendering. The planet was photographed by NASA's Hubble Space Telescope.

across with a sharp inner edge. This large debris disk is similar to the Kuiper Belt, which encircles the solar system and contains a range of icy bodies from dust grains to objects the size of dwarf planets, such as Pluto. Hubble astronomer Paul Kalas, of the University of California at Berkeley, and team members proposed in 2005 that the ring was being gravitationally modified by a planet lying between the star and the ring's inner edge. Circumstantial evidence came from Hubble's confirmation that the ring is offset from the center of the star. The sharp inner edge of the ring is also consistent with the presence of a planet that gravitationally "shepherds" ring particles.

Independent researchers have subsequently reached similar conclusions.

Now, Hubble has actually photographed a point source of light lying 1.8 billion miles inside the ring's inner edge.

"Our Hubble observations were incredibly demanding. Fomalhaut b is 1 billion times fainter than the star. We began this program in 2001, and our persistence finally paid off," Kalas says.

"Fomalhaut is the gift that keeps on giving. Following the unexpected discovery of its dust ring, we have now found an exoplanet at a location suggested by analysis

***The planet is 10.7 billion miles from the star, or about 10 times the distance of the planet Saturn from our Sun.***

of the dust ring's shape. The lesson for exoplanet hunters is 'follow the dust,'" said team member Mark Clampin of Goddard.

Observations taken 21 months apart by Hubble's Advanced Camera for Surveys coronagraph show that the object is moving along a path around the star, and is, therefore, gravitationally bound

to it. The planet is 10.7 billion miles from the star, or about 10 times the distance of the planet Saturn from our Sun.

The planet is brighter than expected for an object of three Jupiter masses. One possibility is that it has a Saturn-like ring of ice and dust reflecting starlight. The ring might eventually coalesce to form moons. The ring's estimated size is comparable to the region around Jupiter and its four largest orbiting satellites.

Kalas and his team first used Hubble to photograph Fomalhaut in 2004 and made the unexpected discovery of its debris disk, which scatters Fomalhaut's starlight. At the time, they noted a few bright sources in the image as planet candidates. A follow-up image in 2006 showed that one of the objects is moving through space with Fomalhaut but changed position relative to the ring since the 2004 exposure. The amount of displacement between the two exposures corresponds to an 872-year-long orbit as calculated from Kepler's laws of planetary motion.

Future observations will attempt to see the planet in infrared light and will look for evidence of water vapor clouds in the atmosphere. This would yield clues to the evolution of a comparatively newborn 100-million-year-old planet. Astrometric measurements of the planet's orbit will provide enough precision to yield an accurate mass.

NASA's James Webb Space Telescope, scheduled to launch in 2013, will be able to make coronagraphic

observations of Fomalhaut in the near- and mid-infrared. Webb will be able to hunt for other planets in the system and probe the region interior to the dust ring for structures such as an inner asteroid belt.

### **Space Operations Mission Directorate**

The Space Operations Mission Directorate provides NASA with leadership and management of the Agency's space operations related to human exploration in and beyond low-Earth orbit. Space Operations also oversees low-level requirements development, policy, and programmatic oversight. Current exploration activities in low-Earth orbit include the space shuttle and International Space Station (ISS) programs. The directorate is similarly responsible for Agency leadership and management of NASA space operations related to launch services, space transportation, and space communications in support of both human and robotic exploration programs. Its main challenges include: completing assembly of the ISS; utilizing, operating, and sustaining the ISS; commercial space launch acquisition; future space communications architecture; and transition from the space shuttle to future launch vehicles.

### **Space Station Research Could Help Prevent, Treat Food Poisoning**

Germs are virtually everywhere on Earth and it is natural that they would stow away for the ride into space. New NASA research shows some of those germs, or microbes, are more infectious after spending time in reduced gravity.

While that may sound like a bad thing—and certainly it is a challenge that needs to be met to keep astronauts healthy—there is a silver lining. Using space flight studies to understand the mechanism for this increased virulence could help scientists develop new strategies for fighting



Astronaut Heidemarie M. Stefanyshyn-Piper, STS-126 mission specialist, works with the Microbe Group Activation Pack on the mid-deck of Space Shuttle Endeavour while docked with the International Space Station (ISS).

the spread of such illness-causing microbes here on Earth.

"This research opens up new areas for investigations that may improve food treatment, develop new therapies and vaccines to combat food poisoning in humans here on Earth, and protect astronauts on orbit from infectious disease," said Julie Robinson, program scientist for the ISS.

Experiments with *Salmonella* were flown on space shuttle missions to the ISS in September 2006 and March

2008. The 2006 experiment surprisingly showed that the space flight environment causes a short-term alteration in *Salmonella* virulence. The 2008 experiment demonstrated that a change in growth media controls the virulence effect. There is no evidence that the space-grown bacteria sustain these effects long-term upon return to Earth.

*Salmonella* is a leading cause of food poisoning and related illnesses, and their unpleasant effects on our digestive systems are well documented. Bacteria like *Salmonella* use an amazing array of techniques to outwit the human body's defense mechanisms and cause illness. By changing their gene expression, they adapt to different environments to alter their disease-causing potential or virulence. In the United States alone, according to the Centers for Disease Control and Prevention, 1.4 million non-typhoidal *Salmonella* infections resulted in 168,000 doctor's office visits annually from 1996–1999. *Salmonella* infections caused 15,000 hospitalizations and 400 deaths in each of those years. Recently, *Salmonella* has been in the news as the agent responsible for infectious disease outbreaks in the United States linked to contaminated food products like peanut butter that have sickened thousands of individuals and caused several fatalities.

Although the study of factors related to microbial virulence is now well advanced, many key pieces of the puzzle still are missing. Cheryl Nickerson, a researcher in the Center for Infectious Diseases and Vaccinology at Arizona State University's Biodesign Institute, led the team that investigated the effect of space flight on *Salmonella* on the 2006 and 2008 missions. The 2006 experiment was the first to identify the molecular "switch" that activates the increased virulence of *Salmonella* caused by space flight. The follow-up experiment in 2008 showed that adjusting the ion content of the bacteria's growth medium can be used to turn off the increase in *Salmonella* virulence observed in space. Nickerson's initial findings, published in the Proceedings of the National Academy of Sciences, and her collective findings, published in the journal

PLoS ONE, hold promise for new strategies to combat *Salmonella* foodborne infections.

These space experiments helped researchers show that a mechanical force known as fluid shear, which is the motion of fluid that cells sense as they pass over a surface, could have a dramatic effect on *Salmonella*'s disease-causing potential. Lower fluid shear conditions, it turns out, are found both in microgravity and in our intestines. The bacteria cultured in space are more virulent, and Nickerson's work showed that by modifying the medium in which the cells are grown, the virulence could be reduced or turned off. In other words, space travel may trick the bacteria into behaving as though they were in the low fluid shear environment of the intestine, essentially turning on a switch inside the microbe that increases virulence. Changing the chemistry of the medium in which the bacteria are cultured reverses this effect.

This research opens up new opportunities to improve food treatment methods, develop new therapies and vaccines to combat food poisoning in humans here on Earth, and help better protect astronauts in space from infectious disease.

## International Space Station Turns 10

Nations around the world marked a milestone in space exploration on November 20, 2008, celebrating the 10th birthday of the ISS.

Now the largest spacecraft ever built, the orbital assembly of the space station began with the launch from Kazakhstan of its first bus-sized component, Zarya, on November 20, 1998. The launch began an international construction project of unprecedented complexity and sophistication. The station is a venture of international cooperation among NASA, the Russian Federal Space Agency, Canadian Space Agency, Japan Aerospace Exploration Agency (JAXA), and the European Space Agency (ESA). More than 100,000 people in space agencies and contractor facilities in 37 American states and throughout the world are involved in this endeavor.

"The station's capability and sheer size today are truly amazing," said Mike Suffredini, NASA's ISS program manager. "The tremendous technological achievement in orbit is matched only by the cooperation and perseverance of its partners on the ground. We have overcome differences in language, geography, and engineering philosophies to succeed."

Only a few weeks after the U.S.-funded, Russian-built Zarya module was launched from Kazakhstan, the space shuttle carried aloft the Unity connector module in December 1998. Constructed on opposite sides of Earth, Unity and Zarya met for the first time in space and were joined to begin the orbital station's assembly and a decade of peaceful cooperation. Today the ISS has expanded to more than 650,000 pounds, and its interior volume is more than 26,000 cubic feet, comparable to the size of a five-bedroom house.

"Sixty years ago, people in Europe were fighting one another," said Alan Thirkettle, ISS program manager for ESA. "Now, they're working together, working on spacecraft and space stations. Two decades ago, the Cold War was still going on, and here we are working with the Russians, the Americans, the Japanese, the Europeans, everyone working together. It seems a far better thing to be doing than what we were doing 60 years ago." Cooperation among international teams of humans and robots is expected to become a mainstay of space exploration throughout our solar system.

As of the first element 10-year launch anniversary, the ISS had completed 57,309 orbits of the Earth, a distance of 1,432,725,000 miles. If the station had been traveling in a straight line instead of in orbit, it would have passed the orbit of Pluto and would now be in the outer reaches of our solar system.

***"Everything we're learning only 240 miles away from the planet, we can apply to the Moon—240,000 miles away."***

The ISS has been continuously human occupied since November 2, 2000—over 8 years and counting. “With the International Space Station, we have learned so many things—and we’re going to take that knowledge and

apply it to flying to the Moon and Mars,” said Expedition 18 commander Mike Fincke. “Everything we’re learning so close to home, only 240 miles away from the planet, we can apply to the Moon, 240,000 miles away.”



The ISS is backdropped by the blackness of space and Earth’s horizon, as seen from Space Shuttle Discovery. Earlier the STS-119 and Expedition 18 crews concluded over 9 days of cooperative work onboard the shuttle and station.

## New Space Station Module Name Honors Apollo 11 Anniversary

The ISS module formerly known as Node 3 has a new name. After more than a million online responses, the node will be called Tranquility.

The name Tranquility was chosen from thousands of suggestions submitted by participants on NASA’s Web site. The “Help Name Node 3” poll asked people to vote for the module’s name by either choosing one of four options listed by NASA or offering their own suggestion. Tranquility was one of the top 10 suggestions submitted by respondents to the poll, which ended March 20, 2009.

“The public did a fantastic job and surprised us with the quality and volume of the suggestions,” said Bill Gerstenmaier, associate administrator for Space Operations.

“Apollo 11 landed on the Moon at the Sea of Tranquility 40 years ago this July. We selected Tranquility because it ties it to exploration and the Moon and symbolizes the spirit of international cooperation embodied by the space station.”

Tranquility arrived at Kennedy Space Center in May 2009. It will be prepared for Space Shuttle Endeavour’s flight, designated STS-130, which is targeted for launch in February 2010. Tranquility will join four other named U.S. modules on the station: the Destiny laboratory, the Quest airlock, the Unity node, and the Harmony node.

Tranquility is a pressurized module that will provide room for many of the station’s life support systems. Attached to the node is a cupola, which is a unique workstation with six windows on the sides and one on top.

NASA also named another piece of equipment as a result of public interest generated by the poll. Appearing on the popular television show “The Colbert Report,” Astronaut Sunita Williams announced a new ISS treadmill will be named after the show’s host, Stephen Colbert.

“We don’t typically name U.S. space station hardware after living people, and this is no exception,”



In the Space Station Processing Facility at Kennedy Space Center, astronauts Terry Virts (left) and Charles Hobaugh familiarize themselves with the ISS Cupola module. The cupola will provide unprecedented views of activities outside the station and spectacular views of the Earth.

Gerstenmaier joked. “However, NASA is naming its new space station treadmill the ‘Combined Operational Load Bearing External Resistance Treadmill,’ or COLBERT. We have invited Stephen [Colbert] to Florida for the launch of COLBERT and to Houston to try out a version of the treadmill that astronauts train on.”

The treadmill is targeted to launch to the station on STS-128 Discovery in August. It will be installed in Tranquility after the node arrives at the station next year. A newly created patch will depict the acronym and an illustration of the treadmill. Williams made the announce-

ment 2 years after running the Boston Marathon in space on a station treadmill similar to COLBERT.

### **New Water Reclamation System on International Space Station**

ISS crews now have a new water reclamation system that recycles wastewater, allowing up to six crewmembers to live aboard the orbiting laboratory.

The new Water Recovery System, or WRS, is the second part of a comprehensive life support system for the station. It was delivered aboard Space Shuttle Endeavour



NASA engineers prepare one of the two ISS Water Recovery System racks for transport. The system will help the station accommodate six crewmembers.

on STS-126, November 2008. The first part of the system, the Oxygen Generation System, was launched on Space Shuttle Discovery in July 2006. The two systems

are part of NASA's Regenerative Environmental Control and Life Support System, or ECLSS, for the station.

"Recycling will be an essential part of daily life for future astronauts, whether onboard the space station or living on the Moon," said NASA ISS program manager Suffredini. "Delivering this hardware is an important step in achieving the station's full potential, allowing for additional crewmembers and more scientific research."

By recycling, the system reduces the dependence on Earth resupply by cutting the amount of water and consumables by about 15,000 pounds, or 6,800 kilograms, a year.

"As early as the late 1960s, we knew sustaining life in space would require recycling water and oxygen," said Bob Bagdigian, ECLSS project manager. "A number of us have experienced the entire lifecycle of this technology, all the way from early ideas to implementation. Knowing that we will soon see this system completed gives us great pride."

Through a series of chemical treatment processes and filters, the Water Recovery System creates water clean enough to drink. In fact, part of the same process has been used in developing countries to produce drinkable water (*Spinoff* 2006).

A distillation process is used to recover water from urine. The process occurs within a rotating distillation assembly that compensates for the absence of gravity, aiding in the separation of liquids and gasses in space. Once distilled, the water from the urine processor is combined with other wastewaters and delivered to the water processor for treatment.

The water processor removes free gas and solid materials such as hair and lint before the water goes through a series of filtration beds for further purification. Any remaining organic contaminants and microorganisms are removed by a high-temperature catalytic reaction. These rigorous treatment processes create water that meets stringent purity standards for human consumption.

Engineers at Marshall Space Flight Center and at Hamilton Sundstrand Space Systems International Inc., of Windsor Locks, Connecticut, led the design and development of the Water Recovery System.

### **NASA's STS-119 Mission: Boosting the Station Power**

The ISS is able to host three additional space dwellers thanks to the combined efforts of NASA's STS-119 astronauts and the Expedition 18 crew.

At 7:43 p.m. on March 15, 2009, Space Shuttle Discovery lifted off into a cloudless twilight sky over Kennedy. Secured in Discovery's payload bay were the S6 truss, a final set of U.S. solar arrays, and a distillation assembly to get the station's water recycling system up to full operation.

Veteran astronaut Lee Archambault commanded the crew of seven, which included pilot Tony Antonelli; mission specialists Joseph Acaba, Steve Swanson, Richard Arnold, and John Phillips; and JAXA astronaut Koichi Wakata.

Although technical issues delayed liftoff for more than a month, the March 15 launch countdown proceeded smoothly. After reaching orbit, the crewmembers removed their orange flight suits and began the first of many tasks.

The shuttle's orbiter boom sensor system was used to examine the spacecraft's thermal protection system. Data from the heat shield inspection was transmitted to Earth where technicians combed the images for any debris damage that could have occurred during launch.

As the crew prepared the orbiter docking system for rendezvous with the ISS, space suits were inspected for the mission's three spacewalks. Archambault deftly guided the spacecraft through a back flip maneuver, allowing the station's Expedition 18 Commander Michael Fincke and Flight Engineer Sandra Magnus to take photos of Discovery's heat shield.

Once docked with the station, the hatches opened between the two spacecraft. After a hearty greeting from the station crew, Wakata officially replaced Magnus as flight engineer aboard the orbital scientific complex.

Then, preparations for the first spacewalk went into high gear. Phillips and Magnus used the station's robotic Canadarm2 to grapple the 31,000-pound, 45-foot-long S6 truss segment carefully out of the shuttle's payload bay and over to the shuttle's robotic arm operated by Antonelli and Acaba.

Swanson and Arnold were first to set foot out in space to install the final segment of the station's backbone and solar arrays. Their task was completed successfully in about 6½ hours.

With the unfurling of two, 1-acre-sized "wings," the orbiting outpost now is able to draw on 84 kilowatts of usable electricity, and its capacity to perform science experiments has doubled. The solar arrays provide about 708,000 kW-hours, enough to power about 50 homes.

After the successful deployment of the new solar arrays, Fincke and Magnus replaced a failed distillation unit on the complex's urine processor and water purification recycling system.

The newly activated system was put through its paces, and 15 pounds of reclaimed drinking water was collected and returned to Earth aboard Discovery. It will be analyzed before station crewmembers are given the go-ahead to drink the recycled water.

The second spacewalk performed by Swanson and Acaba took about 6½ hours. The space outing was dedicated to preparing a work site for new batteries that will be delivered on Space Shuttle Endeavour's STS-127 mission, and installation of a Global Positioning System

*With the unfurling of two, 1-acre-sized solar arrays, the orbiting outpost's capacity to perform science experiments has doubled.*

antenna on Japan's Kibo laboratory. This was Acaba's first venture into the expanse of space.

The third and final spacewalk of the STS-119 mission had Acaba and Arnold relocating one of two crew equipment carts from one side of the mobile transporter to the other. This move provided clearance for assembly tasks

on Endeavour's upcoming STS-127 mission, including attachment of the Japanese Exposed Facility onto its science laboratory.

On the final day at the outpost, the shuttle and station crews gathered in the Harmony module for a long distance phone call from President Barack Obama. The

president, schoolchildren, and congressional members quizzed the 10 crewmembers about their mission and life in space. Later, the crewmembers turned their attention to last-minute checklist items.

With the complex mission behind them, it was time to say farewell to the Expedition 18 crewmembers. After 129 days aboard the station, Magnus boarded Discovery for a ride home.

After undocking, the astronauts performed one last inspection of Discovery's thermal protection system and began their journey back to Earth.

The first landing opportunity at Kennedy was waved off because of high wind. With one more spin around the planet, the wind lessened, and mission control gave Discovery the "go" for deorbit burn. The shuttle glided to a perfect landing at Kennedy's Shuttle Landing Facility at 3:14 p.m. on March 28, successfully completing NASA's 13-day STS-119 mission.

The crewmembers returned to Kennedy's crew quarters for a family reunion and medical checkup. The next day, the crew flew back to Johnson Space Center in Houston where they were honored with a homecoming celebration at nearby Ellington Field.

With the ISS now operating at full power, the stage is set for future assembly tasks, scientific experiments, and NASA's upcoming space shuttle missions. ❖



The seven STS-119 crewmembers. From the right (front row) are NASA astronauts Lee Archambault, and Tony Antonelli. From the left (back row) are NASA astronauts Joseph Acaba, John Phillips, Steve Swanson, Richard Arnold, and Japan Aerospace Exploration Agency astronaut Koichi Wakata.

# Education News

Using the inspirational pursuit of space exploration to spark the imagination of our youth is critical to creating a scientifically literate populace and keeping this Nation competitive in an ever more technologically advanced world. Toward that end, NASA has a tradition of investing in programs and activities that engage students, educators, families, and communities in exploration and discovery—helping support the Agency’s missions and cultivate its future leaders and innovators.





# Education News

NASA is using its quest for space exploration and scientific discovery to spark the public imagination. Through NASA's Office of Education, the Agency is inspiring, engaging, educating, and employing the next generation of explorers, leaders, and innovators. In 2009, NASA is creating compelling education activities in support of its mission and future workforce needs.

## Drawing Inspiration from Spacewalking Educators and Hubble Images

True to the spirit of its founding legislation, NASA has actively endeavored to engage the public through its compelling scientific and exploration missions. One such mission, Space Shuttle Discovery's STS-119 flight to the International Space Station (ISS) in March 2009, delivered the fourth and final set of solar array wings



Space Shuttle Discovery and its seven-member STS-119 crew lift off from Kennedy Space Center, leaving Earth to link-up with the International Space Station (ISS).



Artist's illustration of the giant planet HR 8799b. It is slightly larger than Jupiter, may be at least seven times more massive, and was discovered in archived Hubble imagery.

to complete the station's truss, or backbone. NASA Education focused on highlighting this important mission and its crew, which included two NASA astronauts who are also educators.

Mission Specialists Joe Acaba and Richard Arnold are science teachers who are now fully trained NASA astronauts and made their first journey into orbit on STS-119. During the mission, Acaba and Arnold stepped outside the station to conduct critical spacewalking tasks. NASA Education planned a variety of activities that leveraged the excitement of the flight, showcased the Agency's education resources, and provided direct opportunities to get involved with the STS-119 mission.

On March 11, NASA held a forum at Kennedy Space Center titled "New Opportunities for NASA and STEM Education" that included 40 higher education and K-12 leaders, experts, educators, and students. Forum participants discussed current and future STEM (science, technology, engineering, and mathematics) initiatives; relevant student and educator experiences, leveraging NASA content for education; and partnerships between organizations serving diverse audiences and grade levels.

To complement the spacewalks scheduled for Acaba and Arnold, the Agency unveiled a new NASA Education Spacesuits and Spacewalks Web site for educators. NASA's Digital Learning Network produced a live webcast of the STS-119 launch, with student questions that were submitted electronically and answered on the air. Channel One News invited over 6 million middle and high school students to its Web site to submit text and

*The astronauts on the ISS received a phone call from the White House and fielded questions from President Obama, members of Congress including former astronaut Senator Bill Nelson, and a group of students from local Washington, DC schools.*



Mission Specialists Joe Acaba and Richard Arnold, both fully trained NASA astronauts and science teachers, take part in a spacewalk outside the ISS during STS-119.



President Barack Obama, members of Congress, and Washington, DC-area school children communicate with astronauts aboard the ISS.

video questions for the STS-119 crew. After the crew arrived at the ISS, via Discovery, for the 13-day mission, they answered questions during a downlink broadcast nationally in schools and online through Channel One Network. The astronauts on the ISS later received a phone call from the White House and fielded questions from President Obama, members of Congress including former astronaut Senator Bill Nelson, and a group of students from local Washington, DC schools. On March 27, students from the Punahou School in Honolulu, Hawaii,

participated in the final educational downlink, which occurred the day before Space Shuttle Discovery returned to Earth.

Another significant NASA mission took place in May 2009: the final Hubble Space Telescope servicing flight. The STS-125 Space Shuttle Atlantis mission aimed to push the boundaries of how deep in space and far back in time humanity can see. The crew of seven astronauts upgraded what already may be the most significant satellite yet launched, and NASA excited students, educators,

and the informal education community with the mission's key breakthroughs and the awe-inspiring Hubble images currently available.

Through a pre-launch education forum titled "Using the Power of Hubble to Inspire the Next Generation of Explorers," NASA engaged informal education leaders in discussing collaboration between the Agency and community programs for learning beyond the classroom, strategies to improve STEM awareness, and best practices for inspiring audiences with Hubble imagery. Participants were also invited to tour Kennedy and view the launch of STS-125. The Office of Education highlighted the increased capability of the tremendous telescope that will result in untold new knowledge and opportunities to motivate future explorers. Through activities for students and teachers before, during, and after its compelling missions, NASA continues its ongoing efforts to deliver content and experiences that involve Americans in the Agency's mission and strengthen the Nation's education programs.

***NASA aims to engage every American in its mission and open the minds of the entire next generation to the limitless possibilities of education and exploration.***

### **NASA Partners with National Federation of the Blind**

The mission to service the Hubble Space Telescope will enhance the Agency's ability to immerse the public in the excitement of space science. NASA aims to engage every American in its mission and open the minds of the entire next generation to the limitless possibilities of education and exploration. Toward that end, NASA is using its longstanding relationship with the National Federation of the Blind (NFB) to make the stunning images received from its space telescopes available to students of all sight



NASA's Assistant Administrator for Education, Joyce Winterton, with Marc Maurer, president of the National Federation of the Blind at the unveiling of the 2009 Louis Braille Bicentennial Silver Dollar.

abilities. In 2008, the Agency released a NASA-sponsored book, *Touch the Invisible Sky*, which uses Braille, large type, and tactile diagrams of celestial images observed by space telescopes Hubble, Chandra, and Spitzer. *Touch the Invisible Sky* is among several outstanding products and activities that connect the blind and seeing-impaired with NASA's work.

On March 25, 2009, the NFB and the U.S. Mint presented the new 2009 Louis Braille Bicentennial Silver Dollar, honoring the life and work of the man who invented the Braille method of reading and writing that has made literacy possible for millions of blind citizens. Dr. Joyce Winterton, NASA assistant administrator for education, participated in the ceremony. Winterton

informed the audience of NASA's plans to carry the Braille coin into space on the STS-125 mission to Hubble. "NASA believes strongly in the importance of educational opportunities for everyone, and that is why we have partnered with the National Federation of the Blind to help create programs that enhance scientific study for blind youth. Launching the first coin ever to contain tactile, readable Braille into space symbolizes NASA's commitment to the spread of knowledge by every means and to every individual," Winterton said.

Dr. Marc Maurer, president of the NFB, added, "The Louis Braille Bicentennial Silver Dollar symbolizes the power of knowledge and future opportunities for blind children across America. It is therefore fitting that this historic coin will be part of a mission to uncover the secrets of the universe. Perhaps someday a Braille reader will also be part of such a mission."

NFB leaders were invited to participate in the NASA STS-125 pre-launch education forum, which culminated with a viewing of the Braille coin's liftoff aboard Space Shuttle Atlantis. A portion of the proceeds from the coin sales will further NFB programs to promote Braille literacy.

Since 2004, NFB and NASA have collaborated to produce many products and activities, including the Rocket On! science camps for blind high school students. The camps challenge students from across the country to develop, build, and launch a 12-foot rocket from NASA's Wallops Flight Facility on Virginia's Eastern Shore. During the summer of 2009, the Agency again worked with the NFB on its second Youth Slam, a 5-day experiential academy focusing on STEM subjects and careers. The partnership between NASA and the NFB will continue to pioneer new frontiers of accessible science that make exploration possible for all.

## NASA Offers New Science Teaching Certificate

Among the participants in the Office of Education's STS-119 pre-launch education forum in March 2009 were members of a new group of NASA teacher fellows. NASA unveiled the Endeavor Science Teaching Certificate Project in late 2008, which will award more than 200 fellowships to educators during a 5-year period. The goal of the project is to ensure that teachers across the country can use NASA's ongoing discoveries to inspire the next generation of explorers, scientists, engineers, astronauts, and innovators.

The Endeavor Science Teaching Certificate Project provides workshops, online and onsite graduate courses, and NASA content and materials to teachers and students in K-12 classrooms. Educators accepted as fellows are exposed to current NASA science and engineering and supported in translating the information for use in classrooms. NASA will collaborate with state departments of education to ensure that participants can apply credit from project courses toward state certification requirements.

"Through this opportunity, educators will receive tools that will help them deliver cutting-edge science into the classroom, promoting science, technology, engineering, and mathematics education," says Winterton. "This will include proven NASA and NASA-sponsored educational resources to meet specific learning goals."

Fellows can earn a certificate of completion in Applied Science

***"Through this opportunity, educators will receive tools that will help them deliver cutting-edge science into the classroom, promoting science, technology, engineering, and mathematics education."***

Education from Teachers College Innovations at Columbia University's Teachers College in New York City, as well as graduate credit from other institutional partners.

Additional efforts by the project include assisting and training pre-service science teachers to help improve science instruction in U.S. schools. The project is administered by U.S. Satellite Laboratory Inc., of Rye, New York. Funding for the program is provided through the NASA Endeavor Teacher Fellowship Trust Fund, in tribute to the dedicated crew of Space Shuttle Challenger mission STS-51L.

### **Student-Designed Camera Provides New 'Global View' from Space**

An event in November 2008 exemplified NASA's goal to leverage its education and exploration missions. Among the 32,000 pounds of cargo launched into space on Space Shuttle Endeavor mission STS-126 was a camera that will help U.S. agriculture and provide unique educational opportunities for students.

Students and faculty at the University of North Dakota (UND), Grand Forks, built the agricultural camera, known as AgCam, which was installed on the ISS. The students will operate the camera from their campus and work closely with NASA engineers and station astronauts.

AgCam will take images in visible and infrared light of growing crops, rangeland, grasslands, forests, and wetlands in the northern Great Plains and Rocky Mountain regions. "AgCam provides students with the opportunity to do real engineering that will protect our environment now and in the future," said George Seielstad, the director of AgCam and the Northern Great Plains Center for People and the Environment at UND.

AgCam is an example of a space-related research project that delivers direct benefits to the public. AgCam will relay useful data to agricultural producers in North Dakota and neighboring states, helping farmers, ranch-

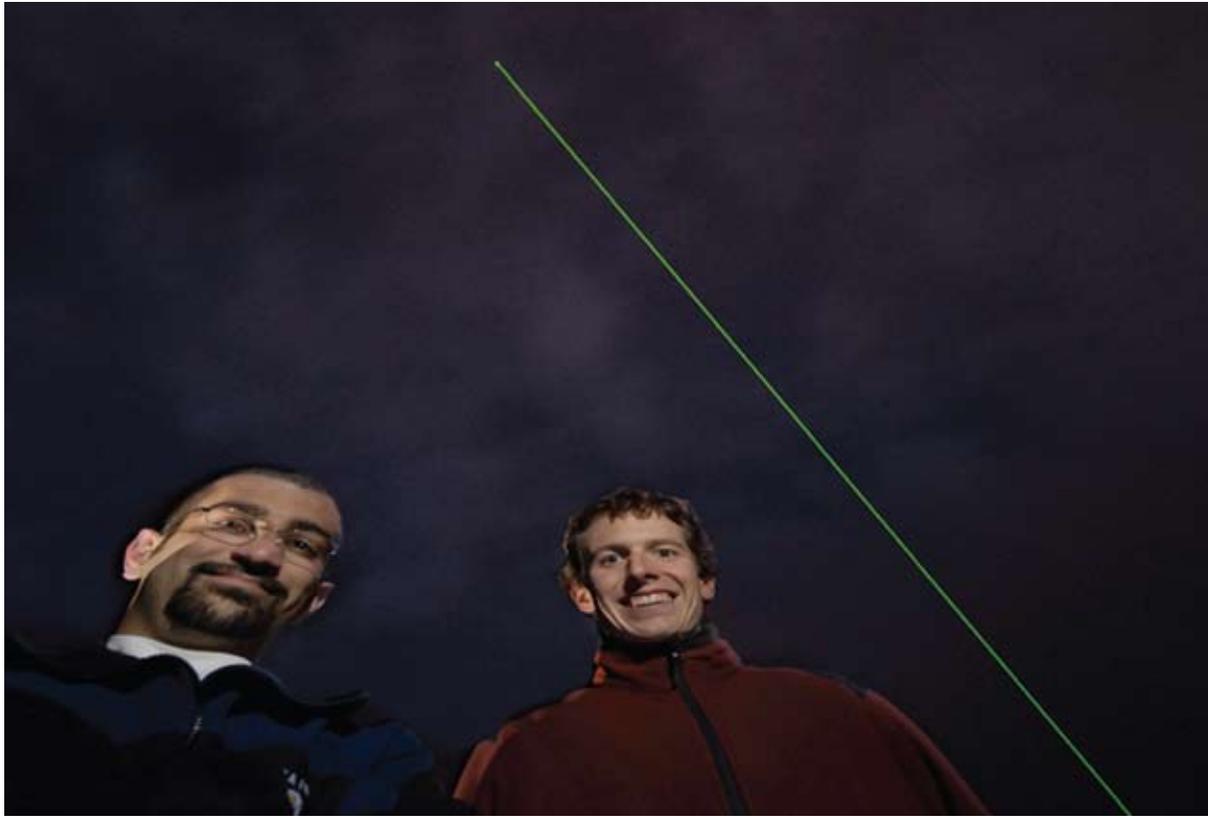


Engineering students assemble the AgCam power data controller in a clean room facility at the University of North Dakota.

ers, tribal resource managers, and researchers. AgCam data will improve decision-making regarding fertilizer and chemical inputs as well as livestock capacity of rangelands, which can reduce negative environmental effects and ecosystem damage from overgrazing and erosion. AgCam imagery also may assist in disaster management, such as flood monitoring and wildfire mapping. Images from the camera will be shared with educators throughout the country for use in their classrooms.

### **GSRP Paves Way for International Recognition**

Through opportunities to directly support NASA missions and research, the Office of Education is increasing the number of highly trained scientists and engineers in aerospace-related disciplines and broadening the base of students pursuing advanced degrees in science, mathematics, and engineering.



Amin Nehrir and David Hoffman are both students in the Langley Research Center Graduate Student Researcher's Program. They stand near a green laser beam they are using to study the composition of the Earth's atmosphere.

First year graduate student Amin Nehrir is involved in one such NASA opportunity, the Graduate Student Researchers Program (GSRP) at Langley Research Center. GSRP builds research ties to the academic community to help meet the continuing needs of the Nation's aeronautics and space effort. Fellowships are awarded for graduate study leading to master's or doctoral degrees in fields related to NASA research and development.

Nehrir, who studies electrical and computer engineering at Montana State University, recently won the "Best Poster" award at the 24th International Laser Radar

Conference (ILRC). The 2008 ILRC was held during July in Boulder, Colorado, as a part of the International Coordination-Group on Laser Atmospheric Studies. The biennial conference brings together an interdisciplinary group of scientists working in the field of laser remote sensing as applied to the atmosphere, earth, and oceans. Selected from approximately 290 entries, Nehrir's poster also received a monetary prize. The award was given for his outstanding paper titled: "Water Vapor Profiling using a Compact Widely Tunable Diode Laser Differential Absorption Lidar."

In early 2009, Nehrir was also nominated by GSRP to become part of the new NASA Student Ambassadors Virtual Community. "There are many new and exciting technologies being developed in the field of applied electrical and computer engineering. The Graduate Student Researchers Program has allowed me to extend my knowledge of electrical engineering into the field of atmospheric optical remote sensing," Nehrir said. "It has given me the opportunity and freedom to conduct and lead my own research under the guidance of scientists that are pioneering cutting-edge technology in atmospheric laser remote sensing."

### **NASA Awards \$11.5 Million in K-12 Competitive Grants**

In March 2009, NASA awarded \$11.5 million in cooperative agreement awards to public school districts, state-based education leadership, and nonprofit education organizations nationwide. The K-12 Competitive Grants Opportunity was unveiled in 2008 for secondary school level teaching and learning, with grants being awarded to U.S. public schools and nonprofit organizations. The selected proposals illustrate innovative approaches to using NASA-themed content in support of secondary-level STEM teaching and learning, with a particular emphasis on high school education.

Nine proposals selected for funding included schools from the District of Columbia and eight states: California, Florida, Georgia, Illinois, Louisiana, Maryland, Massachusetts, and Virginia. Winning proposals were selected through a merit-based, peer-reviewed competition. The awards have a 2-year period of performance and range in value from \$300,000 to \$1.4 million.

The K-12 Competitive Grants Opportunity is one of three competitive funding opportunities NASA announced in July 2008 in response to congressional direction. NASA also provided the Global Climate Change Education Opportunity, which aims to improve the quality of global climate change and Earth science

education at the elementary, secondary, and undergraduate levels. In addition, NASA launched a competitive project for science museums, science-technology centers, and planetariums to enhance programs related to space exploration, aeronautics, space science, Earth science, or microgravity. These two funding opportunities are in the selection phase of their award processes, and the Agency looks forward to the implementation of innovative education activities resulting from these awards to informal, elementary, secondary, and higher education institutions.

### Students Help Name the Next NASA Mars Rover

More than 9,000 students in kindergarten through 12th grade had the opportunity to get directly involved with a NASA mission in early 2009. The students submitted essays proposing names for the Mars Science Laboratory rover in a nationwide contest that ended January 25. Entries were received from all 50 states, Puerto Rico, and the families of American service personnel overseas. In late March, NASA posted nine names online and invited the public to vote for its favorite. NASA selected the winning name, "Curiosity," based on review of student essays and results of the public poll, and announced the selected name in May.

Clara Ma, from Sunflower Elementary School in Lenexa, Kansas, submitted the winning name and will be invited to NASA's Jet Propulsion Laboratory to sign the rover. Additionally, all 30 semifinalists in the naming contest will have an opportunity to place an individually tailored message on a chip.

The naming contest was part of a Space Act Agreement between NASA and Walt Disney Studios Motion Pictures, the prize provider for the contest. This collaboration made it possible for WALL-E, the animated robotic hero from the 2008 movie of the same name, to appear in online content inviting students to participate.

Scheduled to launch in 2011 and land on Mars in 2012, the rover will use a set of advanced scientific instruments to analyze whether the environment in a selected landing region has been favorable for supporting microbial life and preserving evidence of such life. The

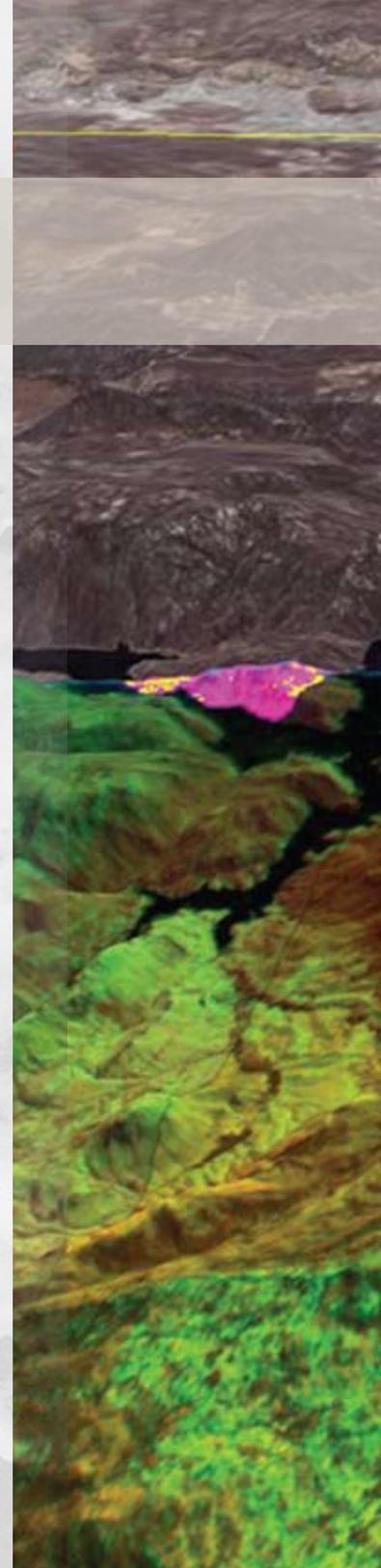
rover also will search for minerals that formed in the presence of water and will look for chemical building blocks of life. ❖

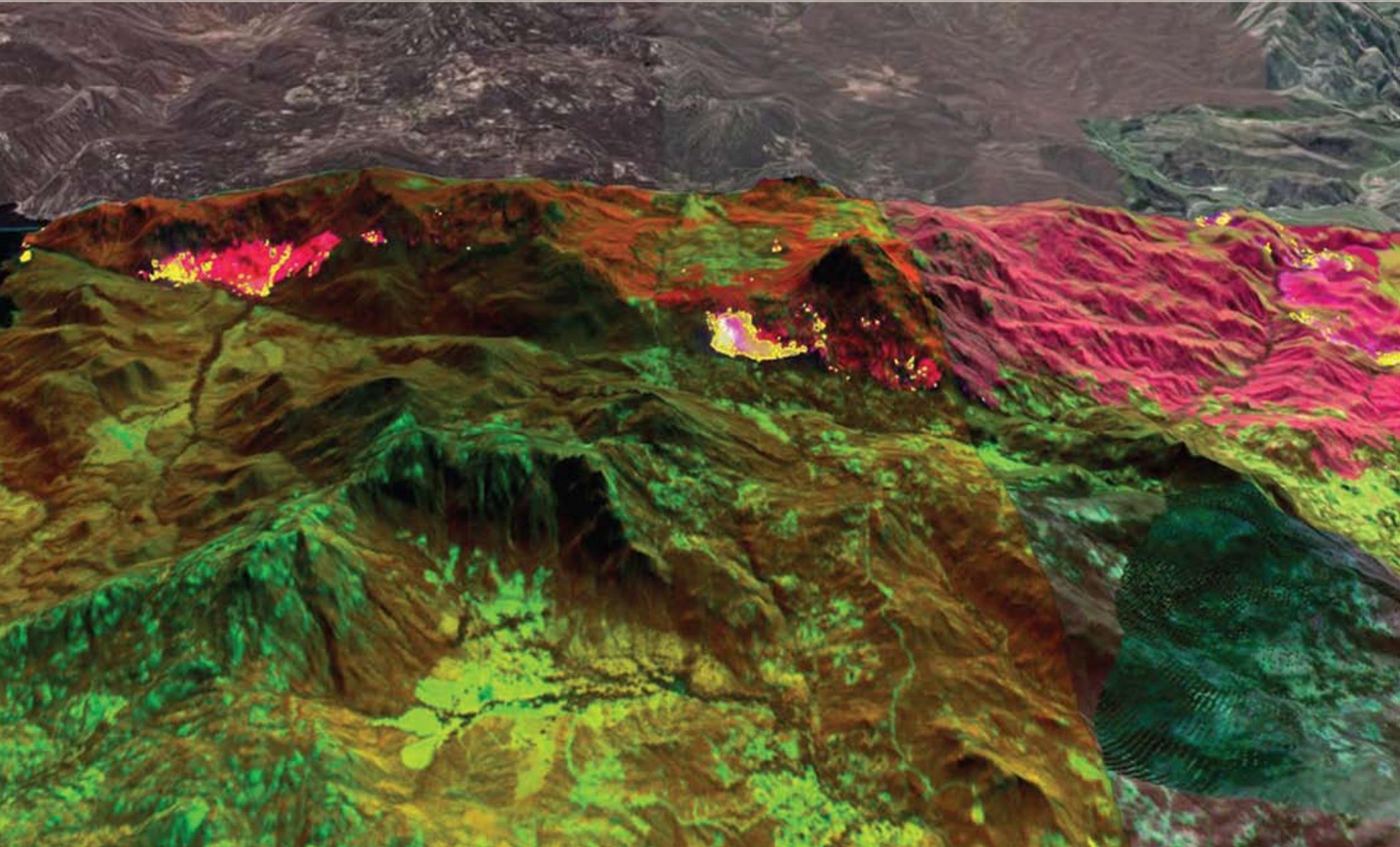


JPL Mars Science Laboratory engineer Suparna Mukherjee presents a certificate to Clara Ma, who won the Mars Science Laboratory naming contest with her entry, "Curiosity."

# Partnership News

NASA enriches the lives of people everywhere through partnerships with private industry, academia, and other government agencies. Employing NASA's advanced facilities, technologies, and wealth of technical expertise, these successful partnerships are helping combat wildfires and floods, prevent disease, encourage technological development, and provide many other benefits—bringing space-inspired science back to Earth.





# Partnership News

The Innovative Partnerships Program (IPP) aims to provide leveraged technology for NASA's mission directorates, programs, and projects through investments and technology partnerships with industry, academia, government agencies, and national laboratories. The following stories highlight some of the exceptional results of these many partnerships.

## New Cataract Early Detection Technique Benefits Astronauts and the Public

A compact fiber optic probe developed for the Space Program has proven valuable as the first noninvasive early detection device for cataracts, the leading cause of vision loss worldwide.

Researchers from NASA and the National Eye Institute (NEI), part of the National Institutes of Health located in Bethesda, Maryland, partnered to develop a testing device for measuring a protein related to cataract formation. Several proteins are involved in cataract formation, but one known as alpha-crystallin serves as the eye's own anti-cataract molecule. Alpha-crystallin binds to other proteins when they become damaged, preventing them from bunching together to form a cataract. Humans are born with a fixed amount of alpha-crystallin, so if the supply becomes depleted due to radiation exposure, smoking, diabetes, or other causes, a cataract can result. By detecting subtle protein changes before a cataract develops, people may be able to reduce their risk by making simple lifestyle changes, such as decreasing sun exposure, quitting smoking, stopping certain medications, and controlling diabetes.

The new device is based on a laser light technique called dynamic light scattering (DLS). It was initially developed to analyze the growth of protein crystals in a zero-gravity space environment. Dr. Rafat Ansari, senior scientist at Glenn Research Center, brought the technology's possible clinical applications to the attention of NEI vision researchers when he learned that his father's cataracts were caused by changes in lens proteins.

During the recent NASA-NEI clinical trial, researchers used the DLS device to shine a low-power laser light into the eyes of people ages 7 to 86 who had lenses ranging from clear to severely cloudy from cataracts. They had previously determined alpha-crystallin's light-scattering ability, which was then used to detect and measure the amount of alpha-crystallin in the lenses. They found that as cloudiness increased, alpha-crystallin in the lenses decreased. Alpha-crystallin amounts also decreased as the participants' ages increased, even when the lenses were still transparent. These age-related, pre-cataract changes would remain undetected by currently available imaging tools.

"This research is a prime example of two government agencies sharing scientific information for the benefit of the American people," says Paul Sieving, NEI's director.

NASA researchers will use the device to study the impact of long-term space travel on the visual system; the increased radiation exposure astronauts would receive during long-term space missions—such as a 3-year mission to Mars—could lead to cataracts and other problems. In the meantime, the DLS technique will assist vision scientists in looking at long-term lens changes due to aging, smoking, diabetes, LASIK surgery, eye drops for treating

glaucoma, and surgical removal of the vitreous gel within the eye, a procedure known to cause cataracts within 6 months to 1 year. It may also help in the early diagnosis of Alzheimer's disease, in which an abnormal protein may be found in the lens.

"By understanding the role of protein changes in cataract formation, we can use the lens not just to look at eye disease, but also as a window into the whole body," says Ansari.

## NASA-Developed Technologies Receive Awards for Excellence in Technology Transfer

A welding innovation and a glucose monitoring advancement have been selected as winners of 2009 Awards for Excellence in Technology Transfer from the Federal Laboratory Consortium for Technology Transfer (FLC). The annual awards recognize laboratory employees who have accomplished outstanding work in the process of transferring a technology developed by a Federal laboratory to the commercial marketplace. A distinguished panel of technology transfer experts from industry, state and local government, academia, and the Federal laboratory system evaluated the nominations.

The auto-retractable pin tools developed at Marshall Space Flight Center improve the use of friction stir welding for both NASA and industry.



Marshall Space Flight Center's auto-adjustable pin tool has vastly improved the process of friction stir welding (FSW), a superior welding technique that uses frictional heat and motion from a rotating pin tool to join structural components without actually melting any of the material (*Spinoff* 2008 and 2009). The Marshall technology eliminates the main problem with FSW: the keyhole left by the pin tool at the end of the weld. The auto-adjustable pin tool automatically withdraws the pin into the tool's shoulder when the weld is complete; the shoulder then smooths the end of the weld, eliminating the keyhole. The technology was developed to improve FSW for use on circumferential welds for NASA applications like the space shuttle external tank and has since been employed in commercial FSW machines.

Glenn's award-winning glucose monitoring advancement is a result of research on low-Earth orbital atomic oxygen interactions with spacecraft materials (*Spinoff* 2008). The contribution consists of a practical and effective method of constructing microscopic cones on the surface of optical fibers that are necessary for a fiber optic blood glucose monitoring device to function. The technology has resulted in a new glucose monitoring system that requires much smaller quantities of blood than conventional lance and absorbent strip devices, which, coupled with the enhanced affordability of the fiber sensor, invites more frequent monitoring and thus better blood glucose control. The system is currently in the process of commercialization—good news for the almost 24 million diabetics in the United States.

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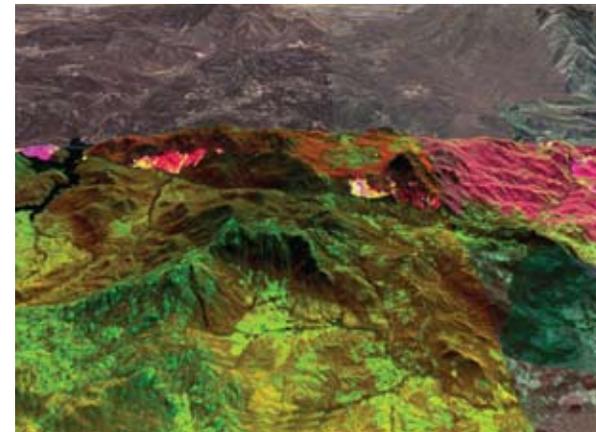
## **NASA Aircraft Monitors Wildfires, Saves Lives**

When the request came in from the California Department of Forestry and Fire Protection to help battle the 2008 wildfires, Ames Research Center equipped a remote-controlled, \$6 million Ikhana aircraft with an Autonomous Modular Scanner (AMS) and sent it out from NASA's Dryden Flight Research Center. The Federal Aviation Administration (FAA) allowed NASA unprecedented flexibility to fly the missions in support of the firefighting effort.

Ames had obtained the Ikhana, based on the same airframe as the military's Predator drones and manufactured by General Atomics Aeronautical Systems Inc., to use as a test bed for advanced sensor projects. (Ikhana is a Native American Choctaw word meaning "intelligent," "conscious," or "aware.") The AMS operates like a digital camera, with specialized filters to detect light energy at visible and thermal infrared wavelengths. The scanner uses an advanced mercury-cadmium-telluride detector that can be tuned to any desired infrared wavelength and is calibrated to register discrete temperature changes of 33 °F to over 1,800 °F, superior to typical thermal systems that do not accurately measure high-temperature target ranges. To more easily detect hot spots, Ames researchers crafted an algorithm to call out the hot pixels in the images that indicate the hottest parts of a fire.

"The AMS basically lets us look right through the smoke and essentially create a discrete thermal profile of the fire, with complete geospatial awareness," says Steve Hipskind, chief of the Earth Science Division at Ames.

The AMS sensor can save more than 20 hours of image scans in its on-board data storage, or it can stream its data in real time while flying over fire areas. At Ames, the data is autonomously integrated with Google Earth and Microsoft Virtual Earth maps to see the location and scope of the fires. Within about 10 minutes, those images are received and the fire information is distributed to



Thermal-infrared sensors on the Ikhana aircraft recorded this 3-D processed image of a fire in the mountains of California.

the field. For the 2008 flights, the National Interagency Fire Center directed Ikhana's flight sequence to incidents deemed of the highest priority. The aircraft-vectoring process relied heavily on the use of NASA's MODIS Rapid Response System data, compiled at the U.S. Forest Service Remote Sensing Applications Center, to derive fire locations and incident priority.

Ikhana's efforts brought praise from California Governor Arnold Schwarzenegger, who visited Ames to learn how NASA helps the Nation deal with natural disasters. Schwarzenegger called the Ikhana "one of the most exciting new weapons in our firefighting arsenal" and "a true lifesaver." During one flight in 2008, the Ikhana and its sensors detected a hot spot on the eastern edge of the town of Paradise. That information played a key role in the order for a mandatory evacuation of 10,000 people at risk.

Ames and Dryden were among the organizations that received the Federal Laboratory Consortium's "Interagency Partnership Award" involving NASA, USDA Forest Service, FAA, and the National Interagency Fire Center in the development and operational use of the Ikhana aircraft to monitor and track fires.

## NASA Honors Inventions, Software of the Year

Hand-held instruments, a high-temperature resin, and a mission optimization program have won “Invention of the Year” and “Software of the Year” awards for 2008.

A high-speed three-dimensional laser scanner, developed by Ames, has been named “NASA Government Invention of the Year.” The scanner is used in a Mold Impression Laser Tool (MILT), a hand-held instrument used to scan space shuttle tiles to detect and measure the amount of any damage. The MILT unit wirelessly transmits flaw dimensions and location information to a laptop computer several meters away. Several MILT instruments are currently in use at Kennedy Space Center for space shuttle missions and are planned for use in future missions.

“We are honored in receiving this award and wish to thank all of the people who have contributed to the success of this invention, and especially to its meaningful application to critical NASA applications,” said Joe Lavelle, manager and lead engineer, 3D Vision Systems Laboratory at Ames.

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. This resin 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. The resin is well-suited for aerospace applications, particularly products that need to be at high temperatures for thousands of hours, because it is extremely lightweight and remains durable at high temperatures typical in high altitudes.

Invented by Langley Research Center senior scientists John Connell, Paul Hergenrother, and Joseph G. Smith, Jr., PETI-330 is now licensed to Ube Industries, based in Japan with its American headquarters in New York



Developers of OTIS4 and winners of the prestigious 2008 “NASA Software of the Year” (seated from left) are Glenn Research Center engineers Waldy Sjauw, Robert Falck, and John Riehl, and Boeing engineer Stephen Paris on the monitor.

(*Spinoff* 2009). In addition to being durable and lightweight, the resin is also nontoxic, which makes it safer for workers to handle. Its nontoxic composition may help cut expenses for manufacturers because it does not require special facilities or handling.

The Optimal Trajectories by Implicit Simulation, version 4 (OTIS4) program is the 2008 NASA “Software of the Year.” OTIS4, developed by John Riehl, Robert Falck, and Waldy Sjauw of Glenn and Stephen Paris of Boeing Phantom Works, is a general trajectory and mission optimization program. It has broad applications within space exploration and aeronautics research. OTIS4 is used at Glenn and Marshall in support of the Constellation Program, at Kennedy for highly detailed expendable launch vehicle performance verification and validation (for the Mars Phoenix lander, Kepler spacecraft, and others) and at Dryden in support of that Center’s missions.

Similarly, OTIS4 is, in brief, widely used throughout the U.S. aerospace industry; Boeing, Lockheed Martin Skunk Works, Northrup Grumman, Johns Hopkins University’s Applied Physics Laboratory, Rocketplane Global Inc., Blue Origin, and many consultants to the aerospace industry all employ the software. Additionally,

OTIS4 can be used for applications outside of the aerospace industry, such as underwater autonomous vehicles, with a few, very simple modifications to the source code.

All award winners were honored during the NASA Project Management Challenge Conference in early 2009.

## Pipeline-Monitoring Partnership Aids Safety and Homeland Security

With the increase in security risks in our Nation’s energy infrastructure—refineries, chemical plants, and pipelines—in this post-9/11 era, monitoring liquid pipelines and pipeline rights-of-way (ROW) has become more and more critical. Pipeline operators are looking to improve monitoring instruments and systems and to migrate from piloted to unpiloted aerial systems (UAS) and satellites for more frequent, consistent, and accurate surveillance.

Ames and the Pipeline Research Council International Inc. (PRCI) have initiated a new public-private collaboration to identify and demonstrate technologies for autonomously monitoring pipeline ROW. The Rights-of-Way Autonomous Monitoring project evolved from an earlier project with BP Pipelines and Logistics North America and is partnered with the U.S. Department of

Transportation's Pipeline and Hazardous Materials Safety Administration. Broader industry interest in the project resulted in PRCI allocating resources and coordinating the project on behalf of its membership. This multi-phase, multi-year program will focus on remotely detecting three types of issues along the ROW: encroachment and intrusions, ground disturbances and movements, and leaks of hydrocarbon gasses and liquids.

A key goal of the project is near-real-time detection and reporting. Building on past research funded by PRCI and current work in progress by its member companies, as well as work by NASA, independent researchers, institutions, and commercial resources—a new generation of surveillance and encroachment management systems promises to deliver a significant improvement in the proactive prevention of third-party damage. Imagery acquisition, change-detection analysis, subsequent automated hazard assessment, and alert notification processes may be scalable for security surveillance for airborne vehicles, ground patrol vehicles, or for mounting on stationary structures. The deployment of UAS in addition to weekly piloted flights can increase ROW surveillance capability and capacity. As optimization of routes, technology, and other factors come into play, the cost per mile for UAS will be equivalent to or lower than costs for current piloted flights.

This project supports the active remote sensing program at the Ames Earth Science Division, which has utilized space-based, piloted, and unpiloted aerial platforms for more than 26 years. Further development of remote sensing capabilities for piloted and unpiloted aerial systems under this project will enhance both rapid data collection efforts in the early phases of science missions and methane detection capabilities for improved environmental monitoring. Other potential applications for this technology within the oil and gas industry, as well as for the power transmission/distribution and railroad transportation industries, are also being explored.

## Zero-Gravity Flights Pave Way for Small Business Technologies

Small businesses are seeing their developing technologies make a great leap forward thanks to a new NASA program that is taking the gravity out of costly testing requirements.

NASA's IPP provides needed technology and capabilities for NASA's Mission Directorates, programs, and projects through investments and partnerships with industry, academia, government agencies, and national laboratories. A key goal of IPP is technology infusion—

providing technical solutions to challenges being faced by the Agency. To meet this goal, IPP works to enable cost avoidance and technology maturation.

The biggest obstacle to technology infusion is the perceived risk by program/project managers of adopting a new technology. They like to have technologies that are flight-tested and demonstrated effective in their relevant environments—from microgravity to lunar or Martian gravity levels. Unfortunately, many small business technologies stall in their development due to the high costs of testing and a lack of opportunities to test prototypes

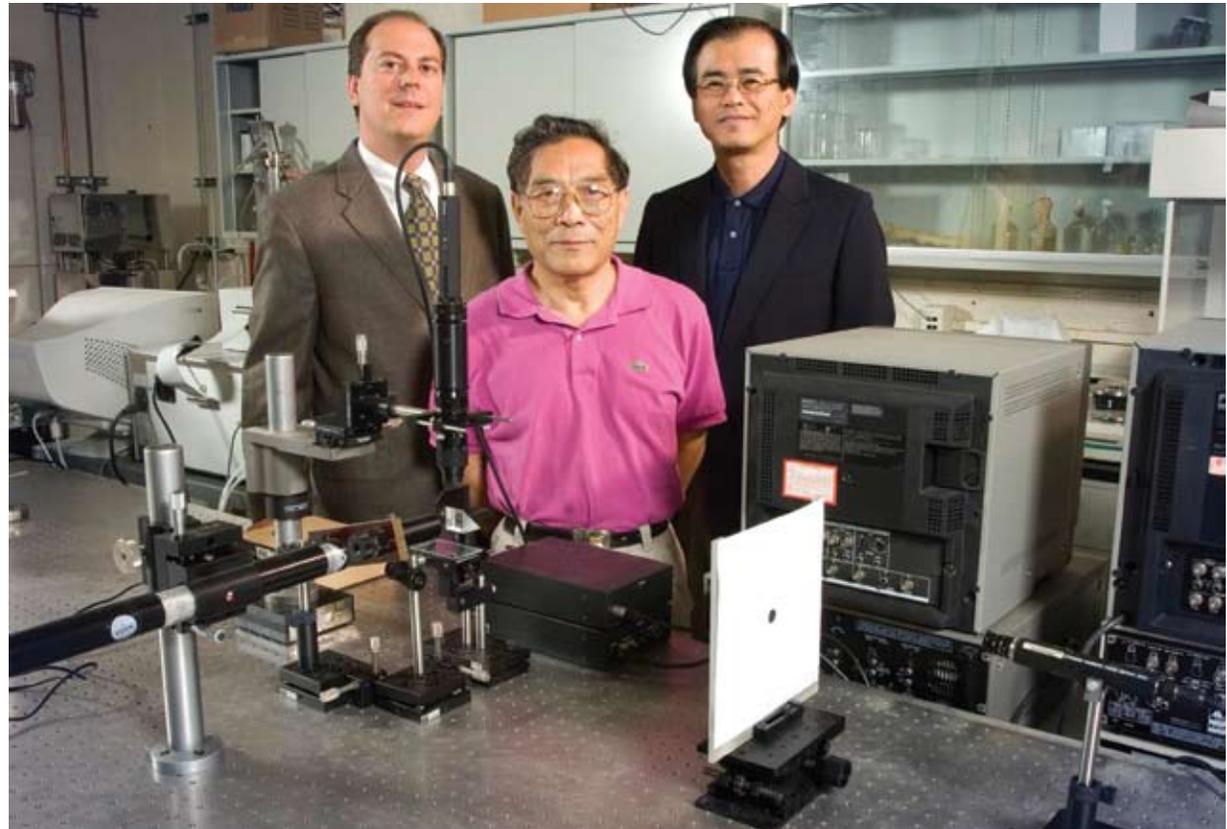


IPP's Facilitated Access to the Space Environment for Technology Development and Training (FAST) program provides opportunities for companies, research institutions, universities, and government agencies to test hardware in the space environment. Researchers fly experiments on parabolic aircraft flights, which simulate microgravity, reduced gravity, and variable-gravity conditions.

in relevant environments. To create more opportunities to advance the maturity of key technologies, reduce the perceived risk of adopting those technologies, and increase the likelihood of more technology infusion, IPP has established the Facilitated Access to the Space Environment for Technology Development and Training (FAST) program.

FAST helps emerging technologies mature by providing free testing capabilities in a reduced gravity environment. This unique testing environment can be provided in an aircraft flying repeated parabolic trajectories. The aircraft can provide about 25 seconds of near-zero-gravity conditions during each parabolic maneuver and can simulate reduced-gravity levels similar to those found on the surface of the Moon or Mars. NASA has been flying parabolic flights on NASA-owned aircraft for decades out of Ellington Field in Houston under the management of the Johnson Space Center's Reduced Gravity Office. Those flights have made numerous contributions to scientific advancement and technology development.

There are now commercial providers who offer microgravity flight capabilities on a routine basis. The Zero-Gravity Corporation, headquartered in Las Vegas, has been contracted to conduct flights for the FAST program out of Ellington Field, demonstrating the effectiveness of employing the emerging commercial space sector to advance technology maturity. Initial reduced-gravity tests with small businesses developing technologies for NASA were conducted last year, with seven companies already funded by NASA Small Business Innovation Research (SBIR) contracts participating in FAST's initial flights. Those tests validated the FAST concept and have paved the way to offer this opportunity for all U.S. organizations developing technology NASA may need. In the future, the FAST program expects to provide more extensive technology testing with suborbital and orbital flights, when such commercial services become available.



Drs. David Chao and John Sankovic of Glenn and Negli Zhang of the Ohio Aerospace Institute received an “R&D 100” award for their invention, the Multidimensional Contact Angle Measurement Device.

### **NASA Researchers Receive “R&D 100” Awards**

NASA researchers and contractor personnel are among the 100 winners to receive the prestigious “R&D 100” awards. An “R&D 100” award is a mark of excellence known to industry, government, and academia as proof that the product is one of the most innovative of the year. The awards were presented at a ceremony at Chicago’s Navy Pier Grand Ballroom and Lakeview Terrace on Thursday, October 16, 2008.

NASA’s awards this year were for the following technologies: Multidimensional Contact Angle Measurement Device (MCAMD), Simultaneous Non-Contact Precision Imaging of Microstructural and Thickness Variation in Dielectric Materials, Sensor Web 2.0, and SansEC Sensors.

MCAMD is a breakthrough in measurement technology which enables a vast number of industries to measure transparent liquid drops on a solid surface. It collects a host of crucial information simultaneously in

a 360-degree view and allows scientists to see how those liquid droplets interact with different surfaces.

Because of the advancement in technology, scientists will be able to study the contact angles in a way that is superior to any currently available contact angle meters. The previous method only measured a contact angle from a single side view.

Although MCAMD's direct application involves NASA space missions, it impacts many other things, such as industrial applications like coating, painting, lubricating, gluing, film cooling, biological cell adhesion, and boiling heat transfer.

With Simultaneous Non-Contact Precision Imaging of Microstructural and Thickness Variation in Dielectric Materials, scientists use terahertz imaging to analyze the quality, compactness, and dimensions of non-conducting materials or products, including materials such as foams, over a large continuous region, without having to cut out sections.

When it comes to space travel, foams play a major role in thermal protection systems. With the new technology, NASA now has the option of performing process and quality control of foams and other thermal protection system materials without destructively cutting and using laborious conventional quality control methods.

Using revolutionary methods and software, the Terahertz Density Thickness Imager extends the ability of conventional terahertz imaging. It allows NASA scientists and engineers to measure foam spray quality in terms of thickness and density variations over a large area that might occur as a result of hail damage, improper processing, or worker handling.

The density-thickness imager technology is currently used exclusively by NASA, but in the future, it may have application not just for foam but plastics, wood, paper, ceramics, and pharmaceutical materials.

Goddard Space Flight Center's Sensor Web 2.0 was also given the prestigious award. A Web services-based software, Sensor Web 2.0 gathers and assimilates data

from a network of sensors—seismic and GPS ground sensors, fire tower sensors, weather radar devices, and satellite sensors—enabling them to operate as a cohesive whole. By employing Workflow Management Coalition workflows and taking advantage of emerging “mashup” capabilities, Sensor Web 2.0 enables users to set up such sensor webs through easy point-and-click interfaces. Because the sensor-integration path is not tied to a particular system, it strengthens the U.S. contribution to GEOSS, the Global Earth Observation System of Systems that stems from about 60 countries to form a network of Earth-observing systems. The result is a complete, real-time picture of Earth via shared global resources.

Dan Mandl, the innovation team leader, noted that while all sensor web initiatives work toward early detection of natural disasters, the Sensor Web 2.0 has the advantages of being particularly user friendly and cost effective. “Scientists or emergency workers typically spent months or years working with a team of programmers to assemble sensors and data processing algorithms into workflows to accomplish an application,” Mandl said. “Sensor Web 2.0 enables even students to assemble customized sensor web applications in a matter of hours or minutes, with no staff. Like the Internet, the usability will increase exponentially as the library of available workflows grows.”

The technology can be applied to all manner of natural and manmade disasters, including giving advance warning of a tsunami approaching land; precisely determining hurricane strength, location, and trajectory; and detecting oil spills soon after the spill occurs. The development of such customized new applications is accomplished via “mashups,” which involves creating a single, integrated tool by “mashing” together data from multiple sources. So, Sensor Web 2.0 transforms the operations of space-based, airborne, and remote ground sensors from a complicated, manpower intensive, costly effort into a user-driven mashup activity.

Sensor Web 2.0 can be used to quickly and easily make sensors accessible and controllable over the Internet. Users can select an area of interest (either geographic or event-specific) via a standard Web portal and receive notifications of events via instant message or short message service. The technology easily plugs in new sensors, which could pop up in a Google search, growing the network without additional expenditure of resources.

An “R&D 100” award also went to NASA for its SansEC Geometric Sensing Patterns, the simplest completely functional circuit that can be manufactured today. NASA scientists originally developed SansEC as a method of having thermal insulation serve as a damage detection system for inflatable space structures and discovered its additional unique qualities as a new way of creating electrical systems.

Offering several improvements over traditional closed-circuit sensors, each open-circuit SansEC sensor uses a single geometric pattern that eliminates the need for electrical connections and needs no solder or other types of mechanical connections such as pressure or screws. Developed by Langley's Stanley Woodard and Bryant Taylor of ATK Space, it has no “Achilles” point (a point that, when damaged, renders the circuit inoperable) and continues to function even when ripped, punctured, or badly torn.

Unlike other sensors, a SansEC sensor can be designed for measurements unrelated to each other—like temperature and fluid level—and easily switch from one to another or do both simultaneously.

It can be configured to measure some physical quantities or changes without exposing electrical components to harsh environments, like gaseous ammonia or chlorine, and a SansEC sensor can be deposited directly onto any smooth, non-conductive material such as fiberglass. Each sensor can be placed on an adhesive backing and made into a sensing decal or an adhesive roll and used as sensor tape.

Traditional closed-circuit sensors use electrical connections that can be degraded or damaged and have the potential for electrical arcing, but the SansEC open-circuit sensor has no conventional electrical connections, making it highly resilient to damage. It operates as a single component and not only weighs less than its closed-circuit counterparts but can be manufactured at a lower cost. It uses fewer materials, requires less time and labor, produces less waste, and has a wide range of commercial applications.

Because the electrical connections are eliminated, the choice and combination of conductive material can be used to design sensor arrays in an artistic pattern. Designs could be made for individual sensors, as well.

## NASA and Ocean Tomo Sell Government Patent Licenses

NASA and Ocean Tomo Federal Services LLC, a wholly-owned subsidiary of Ocean Tomo LLC, entered into a relationship to commercialize NASA-funded technologies. The arrangement, which resulted in the sale of several licenses for Goddard-developed technologies, was the first of its kind for a government agency.

The live auction, Ocean Tomo's eighth, took place on October 30, 2008, in Chicago. The auction was the largest to date, with over 500 in attendance. The NASA lot licensed at the auction was comprised of a portfolio of 10 U.S. patents and 1 domestic patent application for a method and system used to analyze nonlinear, non-stationary signals, known as the Hilbert-Huang Transform.

"This has been a great day for NASA," said Nona Cheeks, chief of the IPP office at Goddard, which administers these NASA patents. "Today we demonstrated that the Federal Government can be innovative in how it commercializes federally funded technology for the benefit of the American public."

"By being the first Federal agency to participate in a live, public auction of exclusive patent licenses and

demonstrating success, NASA has blazed a trail for others," said Connie Chang, director of Ocean Tomo Federal Services. "We are thrilled with this outcome and look forward to helping others in the government accelerate innovation and contribute to our Nation's economic prosperity."

"The IPP office works diligently to make the most of all opportunities for Goddard technologies to be utilized beyond NASA's needs, and some innovations are better transferred through nontraditional channels," said Darryl Mitchell, a technology transfer manager in Goddard's IPP

office. "That's why we welcome this opportunity to partner with Ocean Tomo. They have unique expertise and tools as well as the motivation to make this innovative pathway to the commercial sector successful."

"While both NASA and Ocean Tomo stand to benefit from the agreement, the ultimate beneficiary," said Cheeks, "is the taxpayer. This groundbreaking collaboration between Goddard and Ocean Tomo accelerates the commercialization of NASA technologies into new and advanced products that help improve quality of life. A successful partnership between Goddard and Ocean



In October 2008, licenses for several Goddard Space Flight Center technologies went on the auction block, representing an innovative first for a Federal agency's technology transfer program attempt to move technologies from the laboratory to the commercial sector.

Tomo is just the beginning of an important way for all of NASA, as well as other Federal labs, to maximize the value to the Nation of Federal technological research and development for unique scientific applications.”

### NASA and USAID Bring Earth-Observation Benefits to Africa

NASA, the U.S. Agency for International Development (USAID), and international partners met in Nairobi, Kenya, to unveil SERVIR-Africa, a system that integrates the satellite resources of the United States and other countries into a Web-based Earth information system.

This effort puts previously inaccessible information into the hands of local scientists, government leaders, and communities to help address concerns related to natural disasters, disease outbreaks, biodiversity, and climate change.

SERVIR, Spanish for “to serve,” has been in operation in Central America, the Caribbean, and southern Mexico since 2005. Now, through the support of multiple government agencies and other organizations, NASA and USAID are expanding the system to Africa in partnership with the Regional Center for Mapping of Resources for Development in Nairobi. The center,

an intergovernmental organization with 15 member states in eastern and southern Africa, is a leader in geospatial mapping in the region.

“A satellite birds-eye view can provide an overall picture of a natural disaster, such as a flood, and its consequences,” said Tesfaye Korme, director of

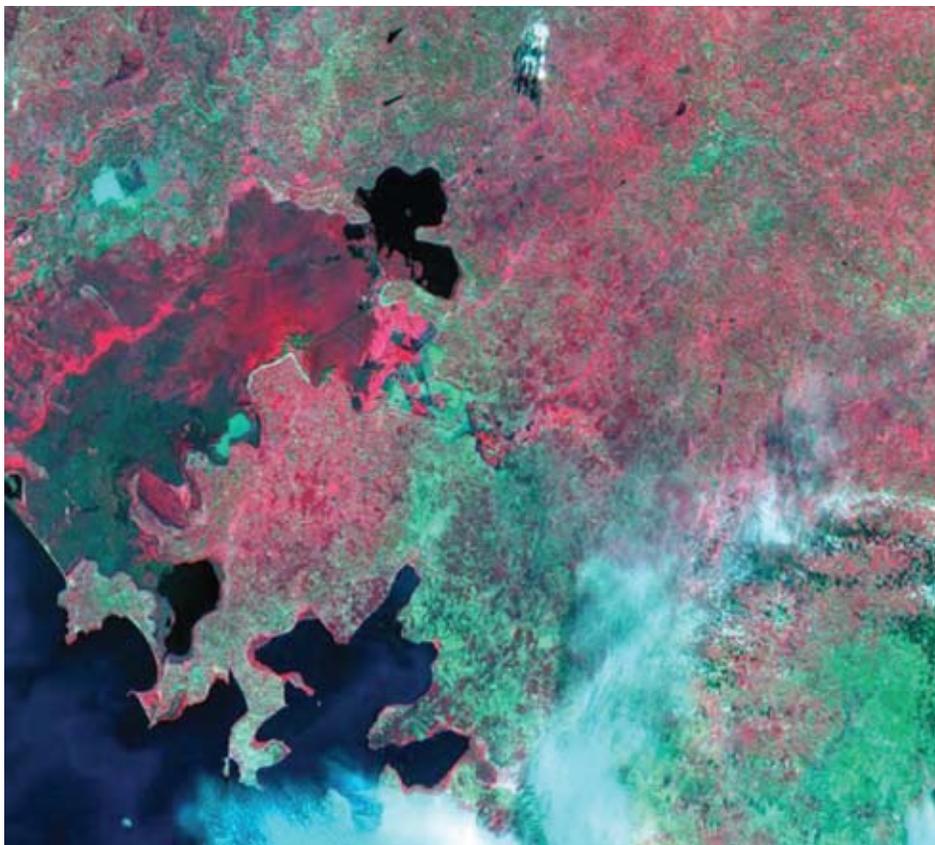
remote sensing and geographic information systems at the center. “Using the SERVIR-Africa platform, we will be able to develop near-real-time maps of flood-affected areas to estimate the number of displaced people and locate potential transportation disruptions.”

SERVIR-Africa will use Earth science satellite data from many of NASA’s missions and other information to better predict areas at risk for severe flooding and map regions hit by floods. It also will develop an early-warning tool to predict the distribution of vector-borne diseases such as Rift Valley fever. By mapping the location of climate change projections, the system will allow people to see impacts on such things as Africa’s diverse ecosystems.

SERVIR-Africa’s information technology team will use the Internet to acquire and distribute satellite and ground-based Earth observations, map data, and geospatial analyses that target issues such as urbanization, biodiversity threats, and management of natural resources.

“SERVIR-Africa will benefit from the breadth and depth of valuable NASA Earth science satellite and model analyses,” said Dan Irwin, SERVIR project director at Marshall. “Science and technology are key, but ultimately it is the combination of local knowledge along with space-based observations that makes real-time monitoring of Africa’s environment effective.”

***“Using the SERVIR-Africa platform, we will be able to develop near-real-time maps of flood-affected areas to estimate the number of displaced people and locate potential transportation disruptions.”***



The Nzoia River basin lies entirely within the Lake Victoria basin in Kenya. The SERVIR-Africa team captured multispectral imagery of the Nzoia River basin from NASA’s EO-1 satellite on August 23, 2008, to provide baseline imagery of this frequently flooded area for future analysis.

The strength of the SERVIR system is in its diverse international team of scientists, developers, and researchers. SERVIR-Africa builds on existing capacity at the mapping center in Nairobi. The center, together with SERVIR's lead partner in Central America, the Water Center for the Humid Tropics of Latin America and the Caribbean, are jointly developing an integrated system. These two regional organizations are standardizing database management and evaluating common methods for predicting severe weather events, analyzing impacts from climate change, and working to understand health and ecosystem interactions.

SERVIR also has been building relationships with industry.

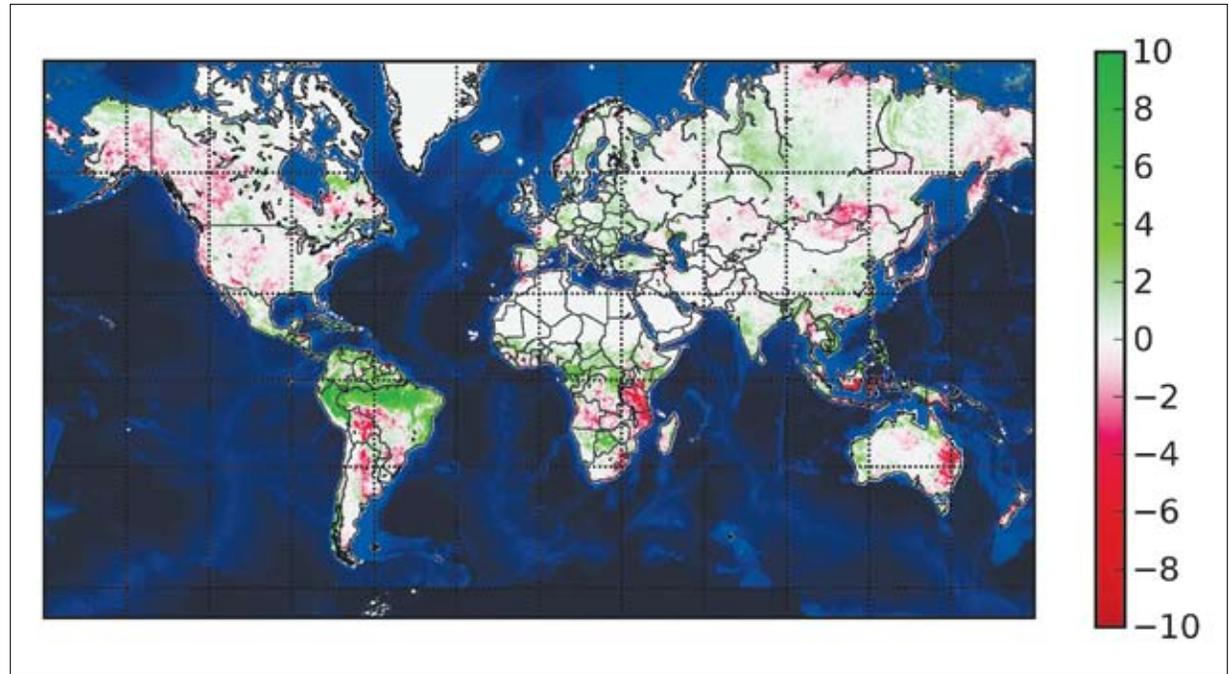
“Public-private partnerships are critical to the success of the SERVIR system,” said Jacqueline E. Schafer of USAID. “Bringing together the expertise and resources of geospatial information systems software and cell phone companies, university researchers, conservation organizations, and governments, SERVIR puts science and technology into the hands of local decision-makers.”

The SERVIR system was developed with USAID by researchers at a global coordination office and rapid prototyping facility at Marshall. Three other NASA centers—Goddard, Ames, and the Jet Propulsion Laboratory (JPL) partnered with Marshall on the system. Also participating in the implementation of SERVIR-Africa is the Institute for the Application of Geospatial Technology at Cayuga Community College Inc., in Auburn, New York.

### **NASA Technology Advances Resource Management with Ecological Forecasts**

NASA's Terrestrial Observation and Prediction System (TOPS) is helping farmers, ranchers, park managers, public health officials, and others to understand current and future environmental conditions to optimize resource management decisions.

Researchers at Ames have created a new capability for ecological forecasting (predicting the effects of changes in



Scientists at NASA, the California State University in Monterey Bay, and Niruthi LLC are currently applying the Terrestrial Observation and Prediction System (TOPS) to track over 30 different environmental parameters from local to global scales. TOPS includes capabilities for identifying both short term changes and long term trends in environmental conditions, including trends in global carbon flux as measured by the Net Ecosystem Exchange (NEE) of carbon between land and the atmosphere. The units for the figure are NEE (grams of carbon per meter squared per year) change per year.

the physical, chemical, and biological environments on ecosystem state and activity) that has the potential to support major advances in management of natural resources in the United States and globally.

Farmers trying to allocate increasingly scarce water resources for irrigation, land managers assessing seasonal fire risk or carbon sequestration potential, or park managers evaluating potential climate change impacts on parks all need forecasts of ecological conditions. Though the latest generation of NASA Earth Observing System (EOS) satellites has brought a new dimension to monitoring the biosphere, use of EOS data to support many applications with significant economic benefits also

requires a capability for forecasting biospheric conditions that cannot be provided by current satellite and other monitoring systems. Such a predictive ability facilitates advanced decision-making tools that can be used in the mitigation of natural hazards or in the exploitation of economically advantageous trends. Forecasting of key ecological parameters can support accurate prediction of agricultural shortfalls or bumper crops, agricultural irrigation demand, epidemics of vector-borne diseases such as malaria and West Nile virus, or wildfire danger as much as 3 to 6 months in advance, providing adequate lead time to alter management decisions.

Led by Dr. Rama Nemani, the Ecological Forecasting Laboratory at Ames, in collaboration with California State University, Monterey Bay, and Niruthi LLC, developed TOPS, the modeling software system designed to produce ecological forecasts. TOPS brings together advances in information technology, weather/climate forecasting, ecosystem modeling, and satellite remote sensing to enhance management decisions related to floods, droughts, forest fires, human health, and crop, range, and forest production. TOPS provides a suite of ecosystem “nowcasts” (measures of current conditions) and forecasts known as the TOPS-30. These data products include measures of vegetation condition and productivity, snow dynamics, soil moisture, and meteorological conditions.

A key feature of TOPS is the ability to integrate surface, satellite, and climate data using ecosystem simulation models. Within the TOPS software architecture, the Distributed Application Framework (DAF) facilitates this integration, and provides a capability to operate multiple-component biogeochemical cycle models. These models simulate the movement of water, energy, and nutrients through terrestrial ecosystems (including agricultural ecosystems), and outputs from these models can be used to produce forecasts of drought conditions, vegetation water stress, crop yields, or streamflow. TOPS component models can be used together or independently to support modeling at multiple spatial and temporal scales ranging from hourly or daily irrigation forecasts for individual agricultural fields to global monthly estimates of ecosystem productivity. As TOPS ingests data from multiple sources, it ensures that inputs are spatially and temporally consistent. The TOPS architecture includes software modules that pre-process data inputs to identify and fill gaps, screen data for quality and consistency, re-project, and mosaic inputs. These capabilities are critical to the operationally reliable production of ecological nowcasts and forecasts. The DAF middleware also includes an applications programming interface to facilitate the rapid integration of new models and data processing libraries,

allowing adaptation of TOPS to address new scientific questions or resource management issues. Daily generation of nowcasts and short-term forecasts relies on a 64-node computer cluster housed in the Ecological Forecasting Laboratory, while continental and global simulations can require the use of the Columbia supercomputer at Ames.

Another key feature of TOPS that is critical to real-time monitoring and forecasting is an automated system for ingesting climate observations from local, regional, and global networks of meteorological stations in real time to produce spatially continuous gridded meteorological fields. This capability allows TOPS to provide continuous estimates of ecosystem conditions for any location in the world, even regions that are remote or sparsely instrumented. In addition to the gridded meteorological surfaces, multiple mesoscale weather models have been integrated into TOPS to provide short-term forecasts. TOPS also incorporates scenarios from global climate models, such as those used in the Intergovernmental Panel on Climate Change assessments, to produce long-term simulations of ecosystem conditions and to assess potential climate change impacts on patterns in snow melt, soil moisture, streamflow, phenological cycles, and vegetation growth.

### **NASA Selects 380 Small Business Research and Technology Projects**

NASA has awarded contracts to 380 small business proposals that address critical research and technology needs for Agency programs and projects. The awards are part of NASA’s Small Business Innovation Research program (SBIR), and the Small Business Technology Transfer program (STTR).

The SBIR program selected 348 proposals for negotiation of Phase I contracts, and the STTR program chose 32 proposals for negotiation of Phase I contract awards. The selected SBIR projects have a combined value of approximately \$34.8 million. The selected STTR projects have a combined value of approximately \$3.2 million.

The SBIR contracts will be awarded to 241 small, high-technology firms in 38 states. The STTR contracts will be awarded to 29 small, high-technology firms in 14 states. As part of the STTR program, the firms will partner with 24 universities and research institutions in 16 states.

The SBIR and STTR programs are managed through the Innovative Partnerships Program Office at NASA Headquarters in Washington, which works with U.S. industry to infuse pioneering technologies into NASA missions and transition them into commercially available products and services.

Results from the programs have benefited several NASA efforts, including air traffic control systems, Earth observing spacecraft, the International Space Station (ISS), and the development of spacecraft for exploring the solar system.

A few of the exciting research areas among this group of selected proposals include:

- Innovative technologies to improve noise prediction, measurement methods, and control for subsonic and supersonic vehicles
- Development of higher performance Thermal Protection System (TPS) materials and integrated entry systems architectures for future exploration missions
- Development of reusable flight software with common-core components and library modules that can be used repeatedly for multiple small satellite missions
- Technologies and analysis to support the navigation capabilities for planetary spacewalks, manned rovers, and lunar surface space suits

The SBIR program is a highly competitive, three-phase award system. It provides qualified small businesses—including women-owned and disadvantaged firms—with opportunities to propose unique ideas that meet specific research and development needs of the Federal Government.

The criteria used to choose these winning proposals included technical merit and feasibility; experience, qualifications, and facilities; effectiveness of the work plan; and commercial potential and feasibility.

### **Centennial Challenge Winner Creates Lunar Lander Prototype**

The Centennial Challenges are NASA-sponsored prize competitions that seek to drive progress in aerospace technology and find innovative solutions to NASA's technical challenges. In 2008, teams won some of the purses available for developing technology to aid future NASA missions to the Moon.

As part of the 2008 Lunar Lander Challenge, sponsored by Northrop Grumman, nine teams with rocket-powered vehicles competed for \$2 million in NASA prize money, October 24–25, at Las Cruces International Airport in New Mexico. The challenge is designed to accelerate technological developments for a new generation of lunar landers capable of ferrying payloads or humans back and forth between lunar orbit and the lunar surface.

Armadillo Aerospace won the first portion of the Northrop Grumman Lunar Lander Challenge, earning \$350,000 in prize money. This first stage of the contest requires a rocket to take off from a designated launch area, shoot up 150 feet, hover for 90 seconds, and then land precisely on a landing pad. The flight must then be repeated in reverse. The next stage, which has not yet been won, requires the rocket to hover for twice as long as before, and then land on a simulated lunar surface.

In August 2008, NASA also awarded a total of \$97,000 in prizes at the 2008 General Aviation Technology Challenge in an event managed by the Comparative Aircraft Flight Efficiency (CAFE) Foundation in Santa Rosa, California. The largest prize awarded was \$50,000 for overall best safety features in an aircraft from Vance Turner of El Dorado Hills, California.

The other challenge categories in 2008 generated spirited competition, but no cash awards. Twenty-five teams

competed in the Lunar Regolith Excavation Challenge in August at California Polytechnic State University, attempting to build a roving excavator that could navigate, excavate, and transfer 150 kg of simulated lunar soil into a collector bin within 30 minutes, without large amounts of power or excessively heavy equipment.

At the Space Elevator Games in 2008, in a demonstration of wireless power transmission, teams in the Power Beaming Challenge attempted to drive their laser-powered devices up a cable 1 kilometer high. Also, in the 2008 Tether Challenge, competitors tried to win the \$2 million prize that requires a team's tether to exceed the strength of the best available commercial tether by 50 percent with no increase in mass.

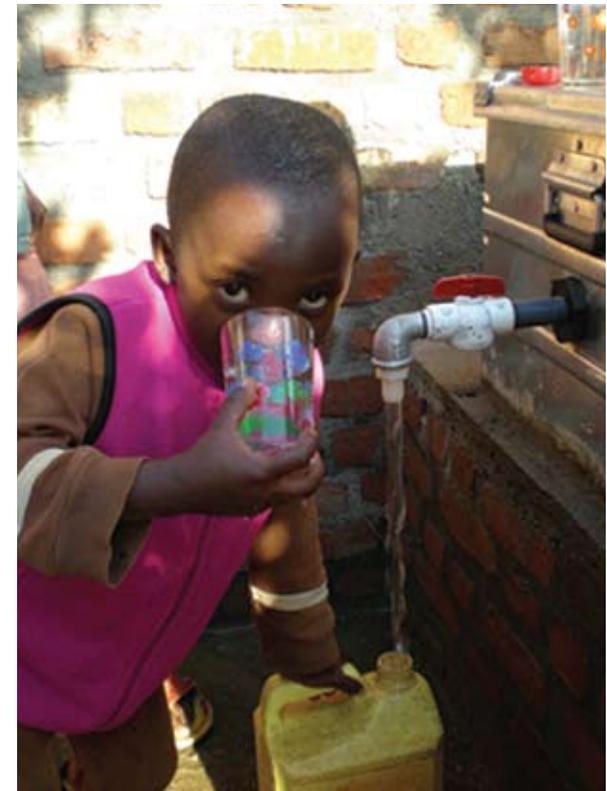
Similarly, in the Lunar Oxygen Challenge in San Luis Obispo, California, no team succeeded in creating a system that could generate breathable oxygen from simulated lunar soil.

Finally, the Astronaut Glove Challenge, last held in 2007, will be in fall 2009 with a \$400,000 purse.

### **Johnson Space Center Engineers Bring Clean Water to Needy Communities**

Volunteers from Johnson Space Center and the surrounding community in Houston are bringing clean water, energy, and food to rural communities in Rwanda and Mexico through Engineers Without Borders (EWB). The EWB-JSC chapter became involved in humanitarian efforts in Rwanda in 2005, and through this project, volunteers have installed several surface water treatment systems for rural communities.

Based on these efforts, the Manna Energy Foundation, a Houston-based nonprofit, is negotiating an agreement with the government of Rwanda to install water treatment systems at every secondary school in Rwanda over the next several years. EWB-JSC has been asked to take the technical lead in this venture, installing the first treatment system.



Johnson Space Center employees, working with Engineers Without Borders, helped bring clean drinking water to Rwanda.

The team is now in the process of developing, testing, and producing an improved surface water treatment system for Puerta de Aguilar in Mexico. This project takes the Rwanda water treatment concepts and accommodates the Mexican community's request for a flat-land or pump-based system.

These are only a few of the projects in which the EWB-JSC members volunteer their time and expertise to help communities and individuals who lack access to safe drinking water, reliable sources of energy, and sustainable sources of food and revenue.

## NASA's New Online Game Educates and Entertains

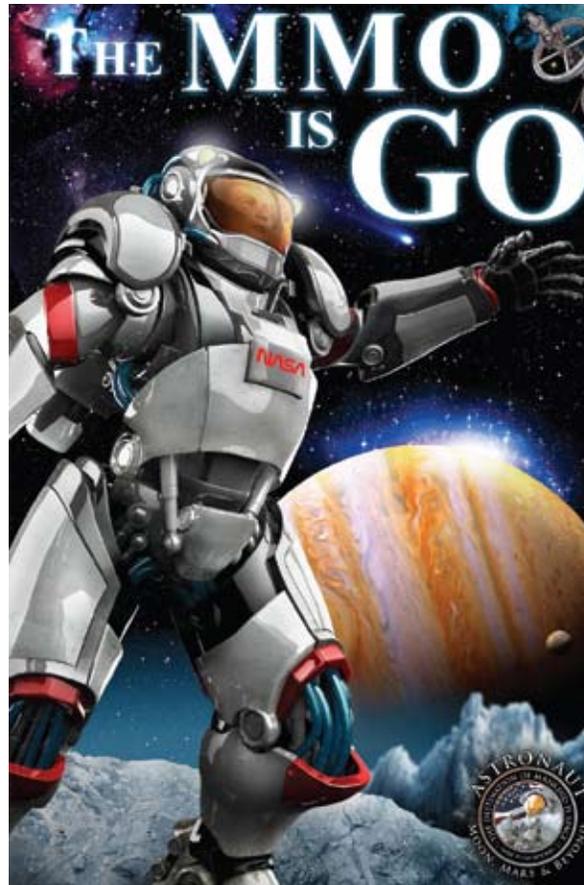
NASA has partnered with Virtual Heroes Inc., Project Whitecard Inc., and Information in Place Inc. to develop a new massively multiplayer online role-playing game in which players will play the roles of roboticists, space geologists, astrobiologists, or mechanical engineers while creating space outposts or exploring the solar system.

"We want to create a fun, compelling gaming experience that will give players the chance to learn about science and engineering careers while they play the game," explains NASA Learning Technologies (LT) research scientist Daniel Laughlin. The LT project supports the development of projects that deliver NASA content through innovative applications of technologies to enhance education in the areas of science, technology, engineering, and mathematics.

One of the main goals of this project, however, is simply to have fun. Upon receiving overwhelming feedback from the public, who said the key element of an online game was "fun," Laughlin and the NASA team realized that professional game developers needed to be in charge of their *Astronaut: Moon, Mars, and Beyond* game.

"We've had to create a new genre of game play, creating what we call first person exploration," the founder and CEO of Virtual Heroes, Jerry Heneghan, explained. Unlike popular "shoot 'em up" varieties of online games, the NASA project is focused on exploration and player cooperation. There will still be an educational quality to the game, however, as players (both individually and as teams) will be required to solve problems in math, science, and engineering in order to unlock different features and options, such as creating new vehicles or space suits.

Virtual Heroes was behind the design of the U.S. Army's free online game, *America's Army*, and the programming is based on Epic's Unreal Engine 3. A playable beta version of the game will be available by the end of



Goddard is developing the Agency's first massively multiplayer online game, a cutting-edge educational tool that also happens to be fun.

2009. The full subscription-based game is expected to be released in 2010.

### NASA and Cisco Collaborate for Climate Change Monitoring Platform

In March 2009, NASA and Cisco Systems Inc. announced a partnership to develop an online collaborative global monitoring platform called the Planetary Skin

to capture, collect, analyze, and report data on environmental conditions worldwide.

Under the terms of a Space Act Agreement, NASA and Cisco will work together to develop the Planetary Skin as an online collaborative platform to capture and analyze data from satellite, airborne, sea- and land-based sensors around

the globe. This data will be made available for the public, governments, and businesses to measure, report, and verify environmental data in near-real-time to help detect and adapt to global climate change.

"In the past 50 years, NASA's expertise has been applied to solving humanity's challenges, including playing a part in discovering global climate change," said S. Pete Worden, director of Ames. "The NASA-Cisco partnership brings together two world-class organizations that are well equipped with the technologies and skills to develop and prototype the Planetary Skin infrastructure."

Cisco and NASA will kick off Planetary Skin with a series of pilot projects, including Rainforest Skin, which will be prototyped during the next year. Rainforest Skin will focus on the deforestation of rainforests around the world and explore how to integrate a comprehensive sensor network. It will also examine how to capture, analyze, and present information about the changes in rainforest carbon in a transparent and useable way. According to scientists, the destruction of rainforests causes more carbon to be added to the atmosphere and remain there. That contributes significantly to global warming.

*"In the past 50 years, NASA's expertise has been applied to solving humanity's challenges, including playing a part in discovering global climate change."*

“Mitigating the impacts of climate change is critical to the world’s economic and social stability,” said John Chambers, Cisco CEO. “This unique partnership taps the power and innovation of the market and harnesses it for the public good. Cisco is proud to work with NASA on this initiative and hopes others from the public and private sectors will join us in this exciting endeavor.”

NASA provides continuous global observations of our home planet using a constellation of spacecraft, as well as airborne and in situ ground observations to monitor the health and well-being of Earth.

Cisco will bring its experience and expertise in networking technologies and advanced innovation to the project. Cisco’s Internet Business Solutions Group has a unique combination of business acumen, scientific, economics, and policy understanding. Its experts will conduct complex data analysis and modeling, and share an in-depth knowledge of the next-generation Internet Protocol architectures to determine how to best prototype, replicate, and scale a Planetary Skin to millions of participants.

Cisco is also working on the Planetary Skin program with the United Nations, multilateral development banks, businesses, international government agencies, universities, think tanks, nongovernmental agencies, and foundations. Planetary Skin participants will pool their unique skills, assets, and technologies to develop the decision support capabilities to effectively manage natural resources such as biomass, water, land, and energy; climate change-related risks such as a rise in sea level, droughts, and disease proliferation; and new environmental markets for carbon, water, and biodiversity.

## Space Technology Hall of Fame Inducts NASA Spinoff Technologies

At the National Space Symposium in Colorado Springs in April 2009, the Space Foundation inducted two NASA-developed technologies into the Space Technology Hall of Fame: drag reduction for semi-trucks, based on research

done at Dryden, and a common nutritional supplement that spun out of work done at Ames as part of the Closed Environment Life Support System (CELSS).

The drag-reduction work dates back several decades but continues to have lasting results. Vehicles push the air as they move, and large trucks move huge quantities of air, creating high-pressure zones. The compressed air spills around the cab in swirling vortices. At the back end, the opposite occurs, with the air unable to negotiate the abrupt turn, creating a low-pressure zone. These effects produce significant aerodynamic drag. In the early 1970s, Edwin J. Saltzman, a Dryden aerospace engineer, felt these turbulent effects first-hand while cycling to work. As trucks overtook him, the air waves pushed him away from the road; as the trucks swept past, their wake drew him toward the road.

Saltzman and other Dryden engineers—already studying drag and wind resistance on aircraft and space shuttle designs—applied their knowledge to improving truck design.

Using a retired delivery van, they used aluminum sheeting to create a “shoe box” similar in design to many period vehicles. After measuring baseline drag, modifications began, rounding edges to reduce drag by more than 52 percent, resulting in an estimated highway fuel economy gain of 20 percent.

Further research determined which adjustments best reduced drag and improved efficiency. The team next modified a cab over engine tractor trailer, the dominant design at the time. These included rounding the corners and edges of the box-shaped cab and reducing drag at those points by as much as 54 percent with a negligible loss of internal volume. Other modifications included placing a smooth fairing on its roof, and extending the sides back to the trailer to produce additional significant drag reduction and fuel savings. Assuming annual mileage of 100,000, these modifications translated to fuel savings of more than 6,000 gallons per year.

In keeping with the Space Act of 1958 to disseminate newfound technologies to the public, NASA shared its research and expertise through a variety of means. The modifications tested at Dryden have been widely adopted. Streamlined cabs and fairings are now a common sight around the world with the once-prominent cab-over design virtually abandoned.

The other technology inducted this year is just as far-reaching. Millions of infants and adults around the world benefit from nutrition technology that began with space research.



Studying space shuttle aerodynamics, engineers at Dryden Flight Research Center discovered specific ways that standard semi-trucks could benefit from design modifications.

In the early 1980s, NASA's CELSS program explored the use of microalgae as a food supply, oxygen source, and waste disposal catalyst on long duration interplanetary missions.

Scientists continued work independently after the program was suspended, founding what would become Martek Biosciences, of Columbia, Maryland, a leader in microalgae research and development.

Martek research soon identified *Cryptocodinium cohnii*, algae that produce high levels of docosahexaenoic acid, known as DHA omega-3 fatty acid, and a fungus, *Mortierella alpina*, that yields arachidonic acid, or ARA, another essential fatty acid.

Both of these essential fatty acids occur naturally in human milk and are important to healthy infant development. However, neither was found in infant formulas until the development of Martek's algae-based Formulaid supplement. DHA- and ARA-rich dietary supplementation can be particularly vital for premature and low-birth-weight infants who may not get their full allotment in utero.

The British Nutrition Foundation and the United Nations Food and Agriculture Organization/World Health Organization Expert Committee on Human Nutrition recognize DHA and ARA as beneficial additives in pre- and full-term infant formulas and as nutrients for women during pregnancy and lactation. The supplement is now found in nearly all U.S. infant formulas and in infant formulas in more than 75 other countries, and is consumed by more than 33 million babies worldwide.

DHA is found throughout the body and is critical for healthy brain and eye development and function and has been shown to support heart health through adulthood. Just as calcium is essential for building strong bones, DHA ensures that the cells in the brain, retina, heart, and other parts of the nervous system develop and function properly. Martek and the National Institutes of Health continue to study the potential benefits of DHA such as

improved cognitive function, and reduced risk of diseases including Alzheimer's.

Today a growing range of products containing DHA for children and adults are found around the world through household names such as Minute Maid, Horizon Organic, Kellogg's, and Yoplait.

### **NASA and NRP Tenants Collaborate in Intellectual Environment**

In 2002, Ames began creating strategic partnerships with academic, nonprofit, and industry partners dedicated to advancing the goals of the NASA Research Park (NRP). NRP's industry partners position themselves for extraordinary opportunities to engage in mutually beneficial cutting-edge research with NASA scientists and engineers. These small, high-tech businesses, now leasing at NRP, conduct research in biotechnology, environmental technology, nanotechnology, communication, and homeland security.

A few of the over two dozen industry tenants at NRP include well-known names such as Tesla Motors Inc. and Google Inc., but also many small businesses with products ranging from the medical—Changene Lab's bone loss therapy or Tibion Corporation's bionic knee—to the environmental—KleenSpeed Technologies Inc.'s electric propulsion systems. Other companies at NRP are creating user-friendly digital photography tools, applying nanoparticles to inkjet technology, and making strides in wireless emergency communications. One small business thriving at the NASA campus is Pragati Synergetic Research Inc., a tenant since June 2005.

Pragati's flagship product, Expozé, analyzes large semi-structured information systems, ferreting out data patterns and revealing key information. In 2004, under a Phase I SBIR contract, Pragati developed Expozé into a cluster-based information extraction tool that creates structured representations from natural language text, rendering anecdotal or qualitative content more usable for quantitative analysis. The basic philosophy behind what the

company calls its "multi-viewpoint clustering analysis" is that any large system has to be understood from different perspectives before it can be analyzed meaningfully.

With this SBIR from Ames, Pragati then used Expozé to analyze safety-related reports written by airline pilots. The conceptual clusters discovered by Expozé revealed regular patterns of preventive measures pilots took when conditions such as turbulence, ice, or birds flying into the blade fans occurred in flight. A laundry list of preventive measures for how to avoid similar accidents in the future could be developed from Pragati's analysis.

Pragati currently has a Phase II SBIR with the Office of Naval Research, and the company is looking forward to the commercialization of an Expozé tool suite with the Army and the intelligence community. With wider exposure in mind, Pragati is also pursuing potential collaborations at Ames' Information Technology directorate.

Whether the companies at NRP have formal partnerships, awards, or informal collaborations with NASA, both industry and the Agency are benefiting; this thriving intellectual culture is sure to produce more technological advancements and useful products for the public as well.

### **Essay Competition Winner Takes in Space Shuttle Launch**

"Since NASA's inception fifty years ago, the technology it has developed has changed everyday life dramatically," writes Jackson Warley in his submission to NASA's 50th Anniversary Essay Competition, held during the 2007-2008 academic year. Warley's own life has changed thanks to his interest in NASA: His essay won first prize. Warley, 14, traveled to Kennedy this past May, where he received a \$5,000 college scholarship savings bond and witnessed the spectacular liftoff of the Space Shuttle Atlantis, on the STS-125 mission to perform the final maintenance operations on the Hubble Space Telescope.

The international essay competition challenged middle school and junior high students to discuss, in an essay of 500 words or less, one of two topics: how they



Innovative Partnerships Program (IPP) Director Doug Comstock and IPP Communications Manager Janelle Turner present essay contest winner Jackson Warley with his \$5,000 savings bond in front of the Vehicle Assembly Building at Kennedy Space Center.

have benefitted in their everyday lives from aerospace technologies built by NASA during the past 50 years, or how their lives may be different 50 years in the future because of NASA technology. Sponsored by IPP at NASA Headquarters, in conjunction with the Office of Education, the competition was designed to inspire and encourage students to continue with science, engineering, and math in high school, college, and beyond, becoming future contributors who will carry on humanity's

expansion into space while bettering life on Earth, as well.

Second prize in the competition and a \$2,500 college scholarship went to Grace Nowadly, a student at Berkeley Middle School in Williamsburg, Virginia. Megha Subramanian of Hershey Middle School in Hershey, Pennsylvania won third prize and a \$1,000 college scholarship. NASA astronauts will visit both students' schools.

## NASA Gains Recognition for Web Presence

NASA has received two Webby Awards for excellence on the Internet. NASA's main Web site, [www.nasa.gov](http://www.nasa.gov), won the "People's Voice" award in the best government site category. The Cassini mission Web site, [saturn.jpl.nasa.gov](http://saturn.jpl.nasa.gov), received the "Webby" award for best science site.

The "People's Voice" award is the second for NASA's Web site, which also won in 2003. More than 500,000 people cast votes this year.

"We're extremely happy to be honored by the Internet community this way," says Brian Dunbar, the content manager for NASA's main Web site. "We've always tried to focus the site on giving the public what they're looking for in an engaging and compelling way. Combined with some of the highest customer satisfaction ratings in the government, this award tells us we're on the right track."

NASA's Web site, which received 120 million visits in 2008, offers the public the latest news, mission coverage, and multimedia from the Agency's scientific research, technology development, and exploration efforts. Visitors can surf thousands of images from throughout the universe, watch live video from the ISS, or read more than a dozen blogs written by Agency employees.

Judges from the International Academy of Digital Arts and Sciences, which sponsors the Webbys, selected the Cassini site for the top honor in the science category.

"The Cassini Web site is the door to the science and technology of the mission to Saturn," says Alice Wessen, manager of Cassini public engagement at JPL. "The site houses all the latest news, science findings, and images Cassini returns as it orbits Saturn. The public can see every picture within eight hours after it's beamed down from the spacecraft."

In the last year, the NASA Web team has expanded its presence into social media, creating an official NASA channel on YouTube at [www.youtube.com/nasatelevi-](http://www.youtube.com/nasatelevi-)

sion, multiple Twitter feeds led by @NASA, and mission and center pages on Facebook and MySpace. NASA was recognized in February with a “Shorty” award in the science category for its @marsphoenix Twitter presence, which was written in the “voice” of the spacecraft. The Shorty Awards were created to honor the best producers of short content on Twitter. The Mars Phoenix Twitter delivered more than 600 “tweets,” or updates limited to 140 characters or less, during the 152 days the lander operated in the north polar region of Mars. By the end of the lander’s mission in early November 2008, more than 38,000 people were following its reports. The account is still used to provide updates on the mission’s science results and has more than 41,000 followers.



Mission specialist Mike Massimino Twittered from space under the name Astro\_Mike, keeping the public informed about the status of STS-125.

***STS-125 astronaut Mike Massimino used Twitter to provide a unique, behind-the-scenes peek at the last weeks of his training and his time on board the Space Shuttle Atlantis.***

“The response was incredible,” says Veronica McGregor, manager of the news office at JPL and originator of the updates. “Very quickly it became a way not only to deliver news of the mission, but to interact with the public and respond to their questions about space exploration.”

The Agency continues to employ social networking tools for just such

purposes. Beginning in April, STS-125 astronaut Mike Massimino used Twitter to provide a unique, behind-the-scenes peek at the last weeks of his training and his time on board the Space Shuttle Atlantis on the fifth and final shuttle servicing mission to the Hubble Space Telescope.

For a list of NASA missions providing updates on social media Web sites, visit [www.nasa.gov/collaborate](http://www.nasa.gov/collaborate).

### **High School Team Wins Pete Conrad ‘Spirit of Innovation’ Award**

On April 4, 2009, at Ames, winners of the Pete Conrad “Spirit of Innovation” award were recognized as a part of the 3-day Innovation Generation Summit.

High school teams from across the country competed for more than \$120,000 in grants. During the summit, 21 finalists presented their concepts and participated in workshops with members of the scientific community. All of the student-led teams were challenged to create an entrepreneurial enterprise and develop a concept in one of three categories: Personal Spaceflight, Lunar Exploration, or Renewable Energy.

Final Frontier Apparel, a group of juniors from Milken Community High School in Los Angeles, won first place in Personal Spaceflight for its mechanical counter pres-

sure space suit. The Lunar Exploration category was won by ALGAE from Eagle’s View Academy in Jacksonville, Florida, for its proposal on using algae to provide oxygen on the Moon. Harwell Asturias Labs, from Cinco Ranch High School in Katy, Texas, won its category for designing a device to convert thermal energy into electrical energy. First place teams won grants of \$10,000, and second and third place teams won \$6,000 and \$4,000.

The “Spirit of Innovation” award is named for the late Charles “Pete” Conrad, a highly decorated naval aviator and astronaut who, as commander of Apollo XII in 1969, was the third person to walk on the Moon. The winning team received a grant for its school and a trophy presented by Nancy Conrad, wife of the late Pete Conrad and creator of the prize. ❖

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# NASA Technology Award Winners

Since its inception in 1976, *Spinoff* has featured myriad award-winning technologies that have been recognized by NASA and industry as forerunners in innovation. Here is a chronology of these winners, including the year(s) they were featured in *Spinoff* and the year they were awarded one (or more) of the following:



## R&D 100

The R&D 100 Awards were established in 1963 to pick the 100 most technologically significant new products invented each year. For 46 years, the prestigious R&D 100 Awards have been helping provide new products with the needed recognition for success in the marketplace.



## NASA Invention of the Year

Since 1990, to recognize inventors of exceptional, cutting-edge NASA technologies, the NASA Inventions and Contributions Board has rewarded outstanding scientific and technical contributions through the NASA Invention of the Year Award.



## Space Technology Hall of Fame

The Space Foundation and NASA created the Space Technology Hall of Fame in 1988. The award recognizes the life-changing technologies emerging from America's space programs; honors the scientists, engineers, and innovators responsible; and communicates to the American public the significance of these technologies as a return on investment in their Space Program.



## NASA Software of the Year

Established in 1994, the NASA Software of the Year Award is given to those programmers and developers who have created outstanding software for the Agency.

Spinoff Year(s)	Technology	R&D 100	Space Technology Hall of Fame	NASA Invention of the Year	NASA Software of the Year
1976, 1977, 1981, 2002, 2005	Memory Foam		1998 		
1976	Improved Firefighter's Breathing System		1988 		
1977, 1979, 1983, 1989, 2004	Liquid-Cooled Garments		1993 		
1978, 1990, 2009	Fabric Roof Structures		1989 		
1978, 1981, 1983, 2005	Phase-Insensitive Ultrasonic Transducer	1978 			
1981	Cordless Tools		1989 		
1983, 1986	PMR-15 Polyimide Resin	1977 	1991 		
1984, 1996	Scratch Resistant Lenses		1989 		

Spinoff Year(s)	Technology	R&D 100	Space Technology Hall of Fame	NASA Invention of the Year	NASA Software of the Year
1985, 2008	Redox Energy Storage System	1979 			
1985	Safety Grooving		1990 		
1985, 1986, 1987, 1991, 1993, 2003, 2008	Earth Resources Laboratory Applications Software (ELAS)		1992 		
1987, 2008	VisiScreen (Ocular Screening System)	1987 	2003 		
1988	Sewage Treatment With Water Hyacinths		1988 		
1989	Data Acquisition and Control System Model 9450/CAMAC	1986 			
1990	NASA Structural Analysis (NASTRAN) Computer Software		1988 		
1991	Heart Defibrillator Energy Source		1999 		
1992	Dexterous Hand Master (DHM)	1989 			
1994	Ballistic Electron Emission Microscope (BEEM)	1990 			
1994, 2008	Omniview Motionless Camera	1993 			
1994	Stereotactic Breast Biopsy Technology		1997 		
1995	1100C Virtual Window	1994 			
1995, 2006, 2008	Microbial Check Valve		2007 		
1996, 2004	Tetrahedral Unstructured Software System (TetrUSS)				1996, 2004 
1996	Anti-Shock Trousers		1996 		

Spinoff Year(s)	Technology	R&D 100	Space Technology Hall of Fame	NASA Invention of the Year	NASA Software of the Year
1996	Automated Hydrogen Gas Leak Detector	1995 			
1996	Ceramics Analysis and Reliability Evaluation of Structures/ Life (CARES/Life)	1995 			1994 
1996	Memory Short Stack Semiconductor	1994 			
1997, 2004, 2009	Outlast Smart Fabric Technology		2005 		
1997	Foster-Miller Fiber Optic Polymer Reaction Monitor	1990 			
1997, 2007	Power Factor Controller		1988 		
1997	Reaction/Momentum Wheel: Apparatus for Providing Torque and for Storing Momentum Energy			1998 	
1998	Data Matrix Symbology		2001 		
1999	Active Pixel Sensor		1999 		
1999	DeltaTherm 1000	1994 			
1999	Superex Tube Extrusion Process	1995 			
1999	Precision GPS Software System		1998, 2004 		2000 
1999	Process for Preparing Transparent Aromatic Polyimide Film			1999 	
1999	Tempest Server	1999 			1998 
2000	Genoa: A Progressive Failure Analysis Software System	2000 			1999 
2000	Humanitarian Demining Device		2003 		
2001	Composite Matrix Resins and Adhesives (PETI-5)			1998 	

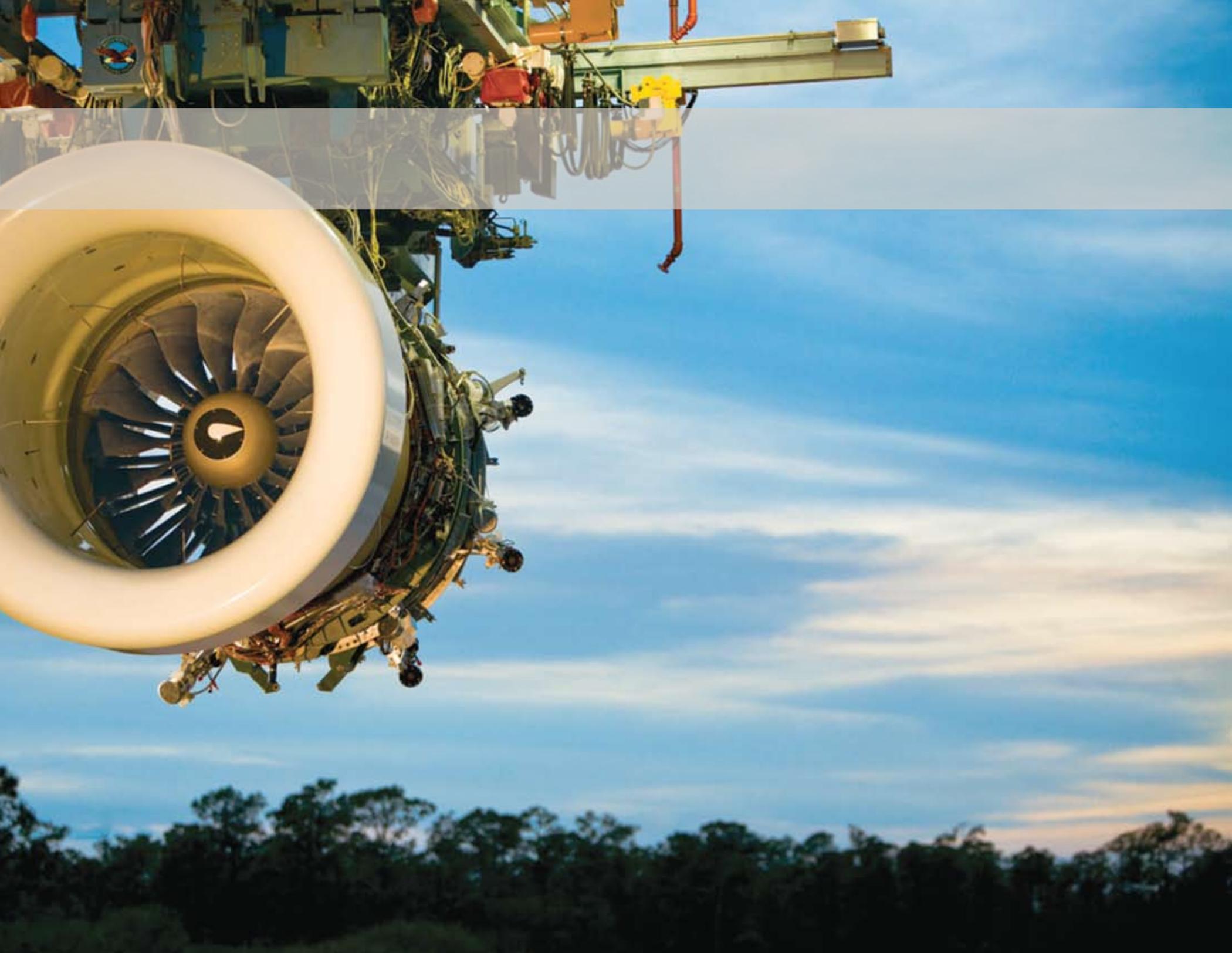
Spinoff Year(s)	Technology	R&D 100	Space Technology Hall of Fame	NASA Invention of the Year	NASA Software of the Year
2001, 2008, 2009	Flexible Aerogel Superinsulation	2003 			
2001	LARC PETI-5 Polyimide Resin	1997 		1998 	
2001	The SeaWiFS Data Analysis System (SeaDAS)				2003 
2001	TOR Polymers	2000 			
2001	Video Image Stabilization and Registration (VISAR)		2001 	2002 	
2002	Automatic Implantable Cardioverter Defibrillator		1991 		
2002	DeBaakey Rotary Blood Pump (Ventricular Assist Device-VAD)		1999 	2001 	
2002	Hybrid Ice Protection System	2003 			
2002	Quantum Well Infrared Photodetector (QWIP)		2001 		
2002	Virtual Window		2003 		
2003	Cart3D				2002 
2003	Cochlear Implant		2003 		
2003	Generalized Fluid System Simulation Program				2001 
2003	LADARVision 4000		2004 		
2003	MedStar Monitoring System		2004 		
2003	Personal Cabin Pressure Altitude Monitor and Warning System			2003 	
2004	InnerVue Diagnostic Scope System		2005 		

Spinoff Year(s)	Technology	R&D 100	Space Technology Hall of Fame	NASA Invention of the Year	NASA Software of the Year
2004	Land Information System (LIS) v. 4.0				2005 
2004, 2009	NanoCeram Superfilters	2002 	2005 		
2004	Numerical Propulsion System Simulation (NPSS)				2001 
2004	Photrodes for Electrophysiological Monitoring	2002 			
2005	PS/PM300 High-Temperature Solid Lubricant Coatings	2003 			
2005	iROBOT PackBOT Tactical Mobile Robot		2006 		
2005, 2008	Light-Emitting Diodes for Medical Applications		2000 		
2005	Numerical Evaluation of Stochastic Structures Under Stress (NESSUS)	2005 			
2005	THUNDER Actuators	1996 			
2005	Zero-Valent Metal Emulsion for Reductive Dehalogenation of DNAPL-Phase Environmental Contaminants		2007 	2005 	
2006	Novariant RTK AutoFarm AutoSteer		2006 		
2006	Radiant Barrier		1996 		
2006	Petroleum Remediation Product		2008 		
2007	Advanced Lubricants		2000 		
2007	Atomic Oxygen System for Art Restoration	2002 			
2007	Future Air Traffic Management Concepts Evaluation Tool (FACET)				2006 
2007	Macro-Fiber Composite Actuator	2000 		2007 	

Spinoff Year(s)	Technology	R&D 100	Space Technology Hall of Fame	NASA Invention of the Year	NASA Software of the Year
2007	Portable-Hyperspectral Imaging Systems		2005 		
2007	ResQPOD: Circulation-Enhancing Device		2008 		
2007	ArterioVision: Noninvasive Cardiovascular Disease Detection		2008 		
2008	DMBZ-15 High-Temperature Polyimide	2003 			
2008	LaRC-SI: Soluble Imide	1995 			
2008	Wireless Measurement Acquisition System	2006 			
2008	Optical Backscatter Reflectometer	2007 			
2009	Cryo-Tracker Probe	2001 			
2009	PETI-330 Resin			2008 	
2009	FPF-44 Polyimide Foam			2007 	
2009	RP-46 Polyimide Resin	1992 		2004 	

# Innovative Partnerships Program

The Innovative Partnerships Program collaborates with industry, academia, and other sources, forming productive partnerships that develop and transfer technology in support of national priorities and NASA's missions. The programs and activities resulting from these partnerships engage innovators and enterprises to fulfill NASA's mission needs while generating advancements that improve daily life.



# Innovative Partnerships Program

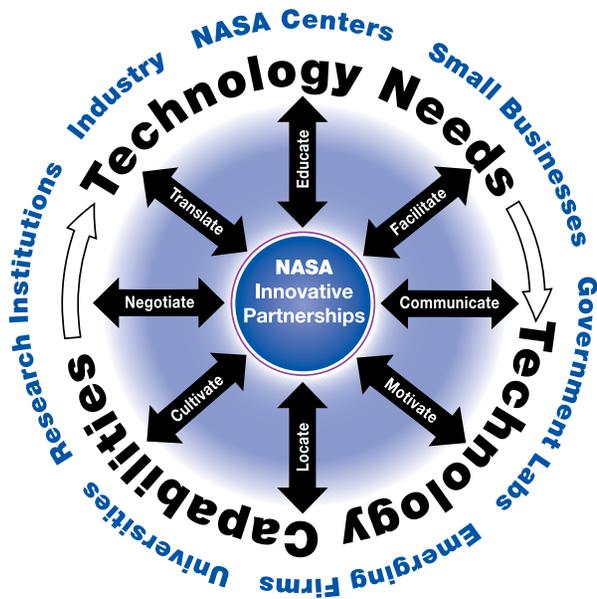
The Innovative Partnerships Program (IPP) provides needed technology and capabilities to NASA's mission directorates, programs, and projects through investments and partnerships with industry, academia, government agencies, and national laboratories.

IPP has offices at each of NASA's 10 field centers and elements that include: Technology Infusion, which manages the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs and the IPP Seed Fund; the Innovation Incubator, which includes the Centennial Challenges and new efforts with the emerging commercial space sector; and Partnership Development, which includes intellectual property management and technology transfer. In 2008:

- IPP facilitated the Agency's entering into about 160 Space Act Agreements with private and other external



Ted Mecum, technology manager with Goddard Space Flight Center's Innovative Partnerships Program (IPP) Office, explains ways that companies can work with NASA.



- entities for development of dual-use technology targeted to Mission Directorate technology needs.
- IPP provided \$3.34 million in funding for 16 Seed Fund partnerships for development of a broad spectrum of technologies addressing specific Mission Directorate technology gaps. Partner and field center contributions of cash and in-kind resources will leverage these funds by a factor of about 2.5. Over the past 3 years, IPP has provided a total of \$19 mil-

- lion in funding for 82 Seed Fund projects involving 94 partners in 35 states and Canada; IPP's aggregated funding will have been leveraged by a factor of about 3.8 at the completion of these projects.
- IPP facilitated the signing of 26 license agreements and about 800 Software Use Agreements.
- IPP facilitated the reporting of about 1,100 new invention disclosures. As a result of IPP's efforts, over

110 NASA patent applications were filed and 112 patents awarded in 2008. Revenues realized from licenses of NASA-sponsored technologies exceeded \$4 million in 2008.

- IPP completed three Centennial Challenge events and awarded \$447,000 in combined prize money at two of them.

To complement the specialized centers and programs sponsored by the IPP, affiliated organizations and services have been formed to strengthen NASA's commitment to U.S. businesses and build upon NASA's experience in technology transfer.

*Technology infusion is the process of strategically binding technical needs and potential solutions.*

## Technology Infusion

Much of what we gain from our space exploration is in the scientific and technological progress that comes from the process of doing it. Many of those technologies are the direct result of NASA-supported funding for both internal research and development (R&D) projects performed at NASA centers and external research from the small business community. As a result of these expanding needs for new capabilities to explore space, NASA missions often result in technologies which have applications beyond aerospace. These technologies, while targeted for integration into the mainstream NASA flight programs, can also be commercialized, creating new marketplace products and improving the quality of life for the American public right here on Earth.

For NASA, technology infusion is the process of strategically binding technical needs and potential solutions. These innovative solutions—be they hardware or software, enhancing or enabling, near-term or far-term, low technology readiness level (TRL) or high TRL, NASA



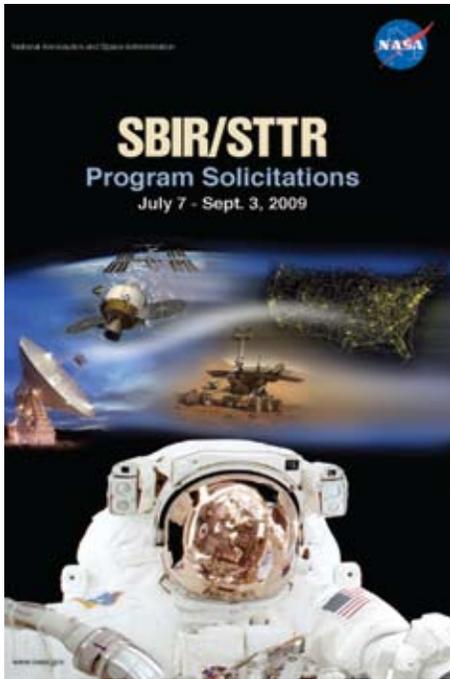
SeaSpace Corporation, of Poway, California, worked with NASA's Jet Propulsion Laboratory under two Small Business Innovation Research (SBIR) contracts to develop satellite ground tracking systems, like the one deployed on this U.S. Coast Guard ship.

internally or externally developed—must all be managed through some aspect of transition from their originating source to the targeted challenges within NASA's programs and projects.

The IPP Technology Infusion element includes the SBIR/STTR programs and the IPP Seed Fund programs. Together, these programs provide pathways from these originating sources to IPP's technology portfolio and provide enabling infrastructures that enhance the infusion of these technologies in NASA missions and programs. These programs allow the Agency to implement successful technology infusion and receive benefits in the following ways:

- Leverage limited program funds for technology development
- Leverage partners' funds/investments to achieve NASA's R&D goals
- Avoid additional program costs by providing a portfolio of technology solutions
- Accelerate technology maturation through concurrent R&D
- Make informed decisions when selecting technologies for programs/projects/missions (i.e., better trade space information)
- Increase the return on its R&D investment with additional marketplace applications of technologies (benefits for both NASA and the public)

NASA issues annual program solicitations that set forth a substantial number of research topics and subtopic areas consistent with stated Agency needs or missions. Both the list of topics and the description of the topics and subtopics are sufficiently comprehensive to provide a wide range of opportunity for small business concerns to participate in NASA research or R&D programs. Topics and subtopics emphasize the need for proposals with advanced concepts to meet specific Agency research needs. The **NASA SBIR program**, <http://www.sbir.nasa.gov>, provides seed money to small U.S. businesses to develop innovative concepts that meet NASA mission requirements. Each year, NASA invites small businesses to offer proposals in response to technical topics listed in the

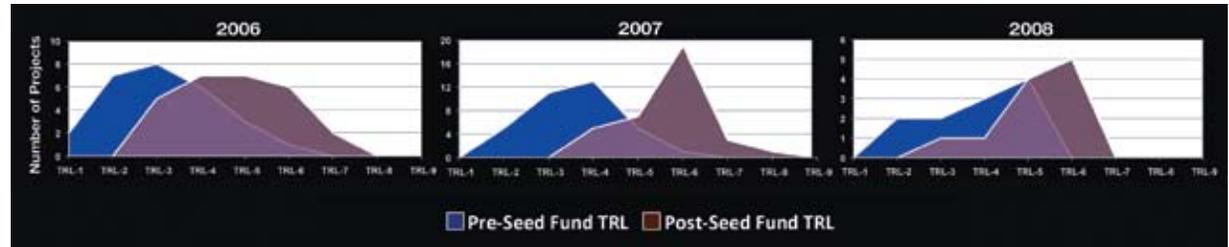


NASA issues an annual program solicitation that sets forth a substantial number of R&D topics and subtopic areas consistent with stated agency needs or missions.

annual SBIR-STTR Program Solicitations. The NASA field centers negotiate and award the contracts, and then monitor the work.

NASA's SBIR program is implemented in three phases:

- **Phase I** is the opportunity to establish the feasibility and technical merit of a proposed innovation. Selected competitively, NASA Phase I contracts last 6 months and must remain under specific monetary limits.
- **Phase II** is the major research and development effort which continues the most promising of the Phase I projects based on scientific and technical merit, results of Phase I, expected value to NASA, company capability, and commercial potential.



IPP's Seed Fund helps technologies reach higher Technology Readiness Levels, the measure NASA uses to assess the maturity of evolving technologies.

Phase II places greater emphasis on the commercial value of the innovation. The contracts are usually in effect for a period of 24 months and again must not exceed specified monetary limits.

- **Phase III** is the process of completing the development of a product to make it commercially available. While the financial resources needed must be obtained from sources other than the funding set aside for the SBIR, NASA may fund Phase III activities for follow-on development or for production of an innovation for its own use.

The **NASA STTR program**, <http://www.sbir.nasa.gov>, differs from the SBIR program in that the funding and technical scope is limited and participants must be teams of small businesses and research institutions that will conduct joint research.

**SBIR/STTR Hallmarks of Success Videos** are short videos about successful companies that have participated in the SBIR and STTR programs. Available online at <http://sbir.nasa.gov/SBIR/successvideo.html>, many of these videos also feature products that have been featured in the pages of *Spinoff*.

As another area of emphasis for technology infusion, the IPP established the **Seed Fund** with the following objectives that:

- Support NASA mission directorate program/project technology needs



Goodyear Tire and Rubber Company is working with Glenn Research Center through a Seed Fund to create non-pneumatic tire technologies for use on the Moon.

- Provide “bridge” funding to centers in support of mission directorate programs
- Promote partnerships and cost sharing with mission directorate programs and industry
- Leverage resources with greater return on investment



The Lunar Lander Challenge, one of the IPP's Centennial Challenges, involves building and flying a rocket-powered vehicle that simulates the flight of a vehicle on the Moon.

## Innovation Incubator

The IPP Innovation Incubator currently includes three distinct elements: Centennial Challenges, the Facilitated Access to the Space Environment for Technology Development and Training (FAST) program, and Innovation Transfusion.

**Centennial Challenges**, <http://centennialchallenges.nasa.gov>, is NASA's program of prize contests to stimulate innovation and competition in solar system exploration and ongoing NASA mission areas. By making awards based on actual achievements, instead of proposals, Centennial Challenges seeks novel solutions to NASA's mission challenges from non-traditional sources of innovation in academia, industry, and the public. Challenges include:

- The **Beam Power Challenge**, which is designed to promote the development of new power distribution technologies. This initiative is managed by The Spaceward Foundation.
- The **Tether Challenge**, also managed by The Spaceward Foundation, whose purpose is to develop very strong tether material for use in various structural applications.
- The **Lunar Lander Challenge**, designed to accelerate technology developments supporting the commercial creation of a vehicle capable of ferrying cargo or humans back and forth between lunar orbit and the lunar surface. This project is run in conjunction with the X Prize Foundation.
- The **Astronaut Glove Challenge**, whose aim is to promote the development of glove joint technology, resulting in a highly dexterous and flexible glove that can be used by astronauts over long periods of time for space or planetary surface excursions. Volanz Aerospace Inc./Spaceflight America manages this program for NASA.



This year, the Regolith Excavation Challenge was held on the campus of the California Polytechnic State University. The competition required teams to build a roving excavator that could autonomously navigate, excavate, and transfer 150 kg of simulated lunar regolith (lunar soil) into a collector bin within 30 minutes.

- The **Regolith Excavation Challenge** promotes the development of new technologies to excavate lunar regolith, which is a necessary first step toward lunar resource utilization. Sponsorship for this challenge is courtesy of the California Space Education and Workforce Institute (CSEWI).
- The **General Aviation Technology Challenge** is intended to bring about the development of



NASA awarded \$97,000 in prizes out of a total available prize purse of \$300,000 at the 2008 General Aviation Technology Challenge.

new aviation technologies, which can improve the community acceptance, efficiency, door-to-door speed, and safety of future air vehicles. For this challenge, NASA has partnered with the Comparative Aircraft Flight Efficiency (CAFE) Foundation.

- The **Moon Regolith Oxygen (MoonROx) Challenge** is designed to promote the development of processes to extract oxygen from lunar regolith on the scale of a pilot plant. Like the Regolith Excavation Challenge, this contest is sponsored by the California Space Education and Workforce Institute (CSEWI).

Another aspect of the Innovation Incubator, the **FAST program**, facilitates access to the space environment

for testing by providing cost-shared access to parabolic flights.

A big challenge to technology infusion is the perceived risk by program and project managers, and they generally desire technologies to be at TRL 6 by their preliminary design review. A key element of achieving TRL 6 is demonstrating a technology in the relevant environment, including the gravity environment—from microgravity to lunar or Martian gravity levels. Toward that end, the FAST program seeks to provide more opportunities for advancing TRLs by providing partnership opportunities to demonstrate technologies in these environments.

Currently, space technology development often stalls at the mid-technology readiness levels due to lack of



The Facilitated Access to the Space Environment for Technology Development and Training program provides opportunities for emerging technologies to be tested in the space environment.

opportunities to test prototypes in relevant environments. In addition, limited testing opportunities often have high associated costs or require lengthy waits. NASA recently selected a commercial service provider for parabolic

***IPP seeks out potential licensees and negotiates license agreements to transfer NASA technology.***

aircraft flight to simulate multiple gravity environments. FAST will purchase services through this new procurement mechanism and provide partnership opportunities aimed at advancing needed space technologies to higher technology readiness levels. The objective is to provide advanced technologies with risk levels that enable more infusion, meeting the priorities of NASA's mission directorates

and their programs and projects. Just as NASA is able to provide support to outside research agencies, there are many creative external organizations implementing innovative processes and methods that could be of benefit to NASA.

**Innovation Transfusion** involves reaching out to some of these organizations on an ad hoc basis. Innovation Transfusion will be a focused activity to more strategically realize the potential from external creativity. Innovation Transfusion will accomplish this goal through the implementation of NASA Innovation Ambassadors, a technical training program that places NASA technical employees at external organizations, and NASA Innovation Scouts, NASA teams participating in focused workshops to exchange information on specific innovations with external organizations. Innovation Transfusion will follow an annual process to select ambassadors and schedule scout workshops with the goal of incorporating innovations into NASA to meet Agency needs.

### **Partnership Development**

The National Aeronautics and Space Act of 1958 and subsequent legislation recognize the transfer of federally owned or originated technology to be a national priority. Accordingly, NASA is obliged to provide for the widest practicable dissemination of information concerning



Image courtesy of Pratt & Whitney

Through a Seed Fund, NASA's Glenn Research Center partnered with Pratt & Whitney and the Air Force Research Laboratory at Wright Patterson Air Force Base to assess alternative fuels for commercial aircraft engines.

results of NASA's activities. The legislation specifically mandates that each Federal agency have a formal technology transfer program, and take an active role in transferring technology to the private sector and state and local governments for the purposes of commercial and other application of the technology for the national benefit. In accordance with NASA's obligations under mandating legislation, IPP, on behalf of NASA, facilitates the transfer of technology to which NASA has title for commercial application and other national benefit.

IPP seeks out potential licensees and negotiates license agreements to transfer NASA technology. IPP typically facilitates over 50 new licenses with the private sector each year.

Over the past 50 years, NASA has performed some amazing feats and made many powerful discoveries. However, aware that it does not have all the answers, NASA continuously looks for partners to help develop new technologies, inform the public about advancements, and to take existing business practices to a new level of effectiveness.



NASA has launched an expanded version of an interactive online program that allows users to discover some of the many NASA spinoff technologies that positively impact everyday life. Visit [www.nasa.gov/city](http://www.nasa.gov/city).

To complement IPP's Partnership Development efforts, the **National Technology Transfer Center (NTTC)**, <http://www.nttc.edu>, links U.S. industry with Federal laboratories and universities that have the technologies, the facilities, and the world-class researchers that industry needs to maximize product development opportunities. The NTTC has worked with NASA since 1989, providing the services and capabilities needed to meet the changing needs of NASA for managing intellectual property and creating technology partnerships.

The **Federal Laboratory Consortium for Technology Transfer (FLC)**, <http://www.federallabs.org>, was organized in 1974 and formally chartered by the Federal Technology Transfer Act of 1986 to promote and strengthen technology transfer nationwide. More than 700 major Federal laboratories and centers, including

NASA, are currently members. The mission of the FLC is twofold: 1) To promote and facilitate the rapid movement of Federal laboratory research results and technologies into the mainstream U.S. economy by fostering partnerships and collaboration with the private sector, academia, economic development organizations, and other entities engaged in technology development; and 2) To use a coordinated program that meets the technology transfer support needs of FLC member laboratories, agencies, and their potential partners in the transfer process.

### Affiliate Organizations

The road to technology commercialization begins with the basic and applied research results from the work of scientists, engineers, and other technical and manage-



Peter Homer, winner of the first Astronaut Glove Challenge, exhibits his designs at the IPP display at the 2008 Smithsonian Folklife Festival.

ment personnel. The **NASA Scientific and Technical Information (STI) program**, <http://www.sti.nasa.gov>, provides wide dissemination of NASA's research results.

The NASA STI program offers users Internet access to its database of over 4 million citations, as well as many in full text; online ordering of documents; and the NASA STI Help Desk ([help@sti.nasa.gov](mailto:help@sti.nasa.gov)) for assistance in accessing STI resources and information. Free registration with the program is available for qualified users through the NASA Center for AeroSpace Information.

The **NASA Technology Portal**, <http://technology.nasa.gov>, provides access to NASA's technology inventory and numerous examples of the successful transfer of NASA-sponsored technology. TechFinder, the main feature of the Internet site, allows users to search tech-

nologies and success stories, as well as submit requests for additional information.

Working closely with NASA's IPP offices and public information offices, the Space Foundation each year recognizes individuals, organizations, and companies that develop innovative products based on space technology. These honorees are enshrined in the **Space Technology Hall of Fame**, <http://www.spacetechnologyhalloffame.org>. The ever-growing list of inductees showcases the significant contributions that space technology has made to improve the quality of life for everyone around the world.

For more than three decades, *NASA Tech Briefs*, <http://www.techbriefs.com>, has reported to industry on

any new, commercially significant technologies developed in the course of NASA R&D efforts. The monthly magazine features innovations from NASA, industry partners, and contractors that can be applied to develop new or improved products and solve engineering or manufacturing problems.

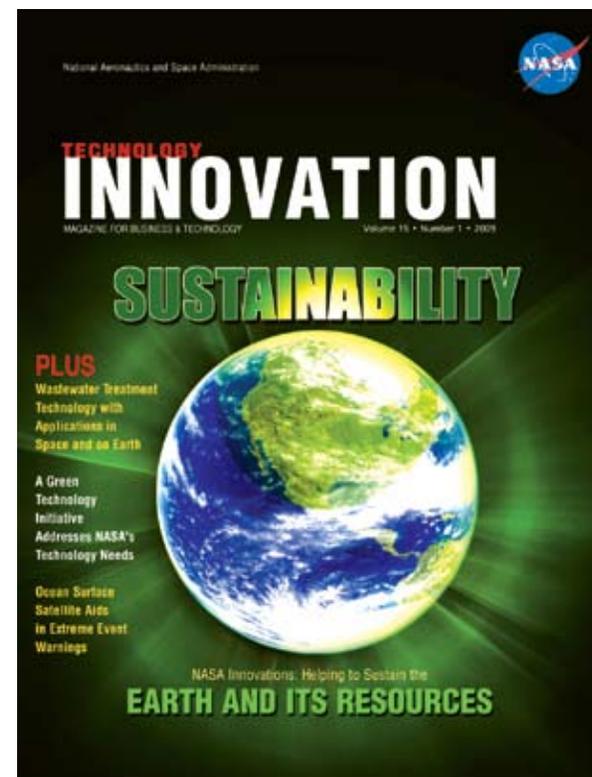
Authored by the engineers or scientists who performed the original work, the briefs cover a variety of disciplines, including computer software, mechanics, and life sciences. Most briefs offer a free supplemental technical support package, which explains the technology in greater detail and provides contact points for questions or licensing discussions.

*Technology Innovation*, <http://www.ipp.nasa.gov/innovation>, is published by the IPP. Regular features include current news and opportunities in technology transfer and commercialization, and innovative research and development.

*NASA Spinoff*, <http://www.sti.nasa.gov/tto>, is an annual print and electronic publication featuring successful commercial and industrial applications of NASA technology, current research and development efforts, and the latest developments from the IPP. ❖

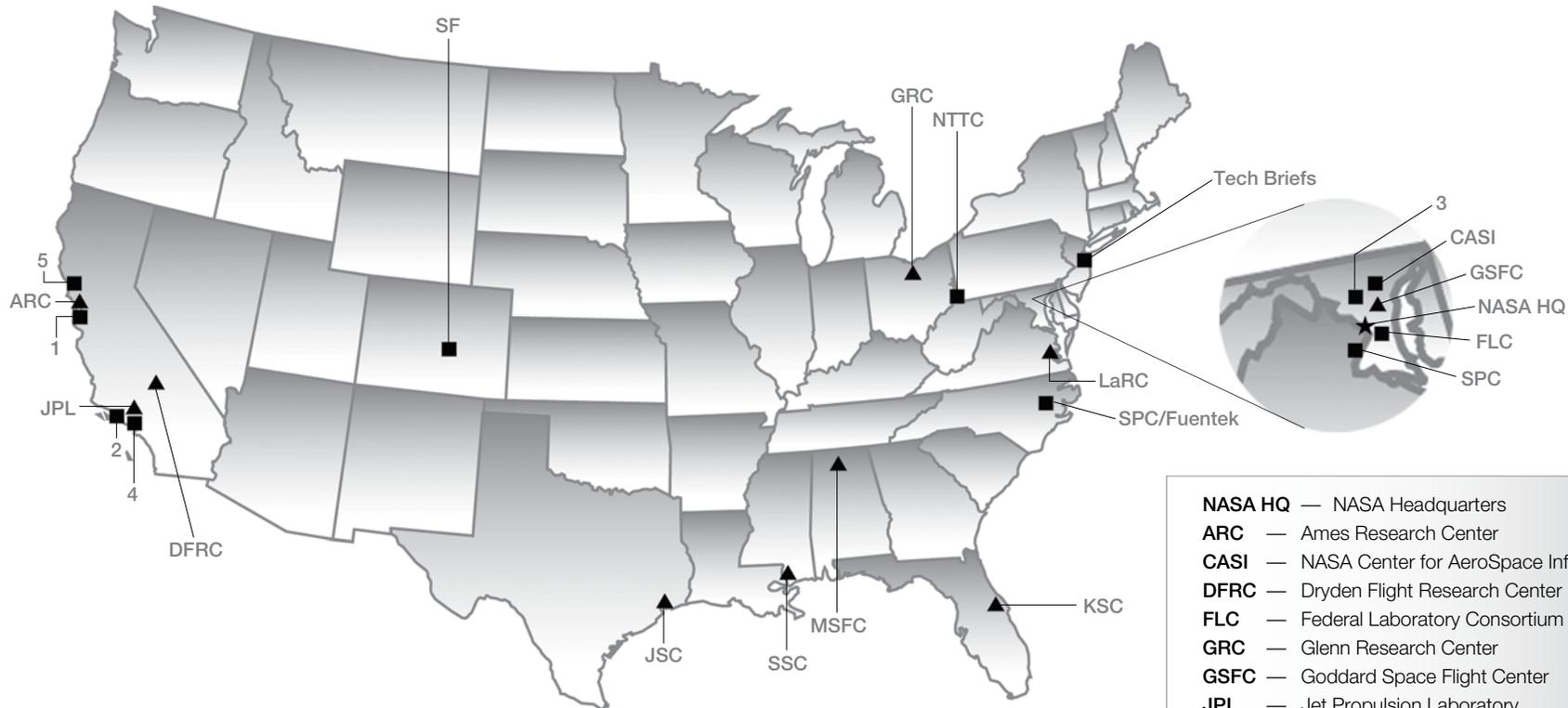


The NASA Research Park at Ames Research Center cultivates diverse partnerships with academia, industry, and nonprofit organizations in support of NASA's missions.



*Technology Innovation* is one of NASA's magazines for business and technology, published by the IPP.

# NASA Innovative Partnerships Program Network Directory



- 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
- NTTC** — National Technology Transfer Center
- SF** — Space Foundation
- SPC/Fuentek** — Systems Planning Corporation/Fuentek
- SSC** — Stennis Space Center
- Tech Briefs** — Tech Briefs Media Group

## Centennial Challenge Allied Organizations

1. Spaceward Foundation
2. X PRIZE Foundation
3. Volanz Aerospace Inc./Spaceflight America
4. California Space Education and Workforce Institute
5. Comparative Aircraft Flight Efficiency Foundation

The 2009 NASA Innovative Partnerships Program (IPP) 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.ipp.nasa.gov>. General inquiries may be forwarded to the Spinoff Program Office at [spinoff@sti.nasa.gov](mailto: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 NASA Center for AeroSpace Information, or visit: <http://www.sti.nasa.gov/tto/contributor.html>.

- ★ **NASA Headquarters** manages the Spinoff Program.
- ▲ **Innovative Partnerships Program Offices** 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 IPP objectives.

## ★ NASA Headquarters

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## ▲ Field Centers

### Ames Research Center

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