National Aeronautics and Space Administration

SPINOFF

2016

Introduction

David Miller

Chief Technologist

National Aeronautics and Space Administration

Hi, I'm David Miller, NASA's chief technologist.

Since 1958, NASA has been developing technology to explore the universe and travel to other worlds. Many of these technologies have also come back down to Earth in the form of commercial products and services that benefit the public, known as spinoffs. Each year, NASA's *Spinoff* publication highlights the best examples of these products and services at work in our economy.

This app presents highlights from the latest issue of *Spinoff*, along with videos and image galleries that let you explore the benefits of NASA technology for our world today. Among my favorites are pressure garments saving the lives of new mothers around the globe, a sophisticated coffeemaker that adapts brews using precise temperature controls, and a web of sensors that allows forecasters to provide advance warning of monsoon flash floods.

If you'd like to learn more about any of the technologies in this app, or if you'd like to request your own free print version of *Spinoff*, please visit us at http://spinoff.nasa.gov. To learn more about NASA's Technology Transfer Program, please visit http://technology.nasa.gov.

Discover NASA technologies for **your** business

Patent Portfolio

Over 1,000 inventions on offer for licensing and partnership opportunities

Software Catalog

An extensive portfolio of software — nearly all free to download

Tech Briefs

Hundreds of new NASA technologies published every year

technology.nasa.gov

TECHNOLOGY TRANSFER PROGRAM

BRINGING NASA TECHNOLOGY DOWN TO EARTH

NASA Technologies Benefiting Society

Health and Medicine

- Rodent Research Contributes to Osteoporosis Treatments
- Pressure Garments Save New Mothers' Lives
- Tool Kit Simplifies Development of High-Affinity Molecules
- Space-Ready Spectrometer Offers Terrestrial Advantages

Transportation

- Unmanned Research Aircraft Test Cutting-Edge Innovations
- Data Visualizer Enhances Modeling for Cars, Consumer Products
- Lightweight, Ultra-Strong Nanotubes to Transform Industry
- Multidisciplinary Software to Help Take Aircraft to the Next Level
- Orbital Trajectory Analyzer Takes Mission Planning to New Heights
- Open Source Aircraft Design Software Helps Industry, Hobbyists

Public Safety

- Rice Crop Models Stabilize Global Markets, Enable Efficient Irrigation
- GPS Sensor Web Helps Forecasters Warn of Monsoon Flash Floods
- Analytic Tool Simplifies Metal Fracture Assessments
- Mars Methane Detector Identifies Harmful Gas Leaks
- Hydrogen Detection Tape Saves Time and Lives
- Single-Photon Lidar Maps Ground Features Quickly, Efficiently
- Temperature Sensors Cement Integrity of Bridges
- Primer Stops Corrosion without Requiring Rust Removal

Consumer Goods

- NODE+ Platform Integrates Sensors with Smartphones
- Precision Coffeemaker Adapts Brews to Beans, Taste
- CO_2 Recovery System Saves Brewers Money, Puts Bubbles into Beer
- Space Blanket-Inspired Cases Protect Expensive Devices
- Antimicrobial Agent Updates Ancient Industry of Prayer Mats
- Heat-Reflecting Material Regulates Body Temperature
- Modified Monitor Provides Glasses-Free 3D for Pilots, Gamers

Energy and Environment

- Flock of Nanosatellites Provides a Daily Picture of Earth
- Multispectral Satellite Imagery Shows Farmers' Fields in New Light
- Software Helps Restore Fire-Ravaged Habitats
- Buildings for Manipulating Magnetism Revolutionize Magnetometers
- Cost-Saving Method Yields Solar Cells for Exploration, Gadgets
- Wide Area Thermal Imaging System Brings the Landscape into Focus
- Photocatalytic Water Splitter Stores Energy as Hydrogen
- Recycling Technology Converts Plastic Waste to Energy
- Tiny Capsules Enable a World of Possibilities

Information Technology

- System-Health Monitor Predicts Failures before They Happen
- Algorithm Predicts and Evaluates Storm Surges
- Mars Rover Work Spawns PDF Collaboration Software
- Open Source Tools Popularize Infrastructure for Cloud Computing
- Software Optimizes Designs from Spaceships to Wind Turbines
- NASA Climate Analytics Support Biological Research
- Artificial Intelligence Targets Advertising by Understanding User
- Modeling Software Helps Rocket Scientists Go with the Flow
- Electro-Optic Ceramic Creates High-Speed Fiber-Optic Networks

Industrial Productivity

- DigitalClone Software Predicts, Extends Machine Life
- Cryocoolers Fuel Exploration in Space and on Earth
- Temperature-Resistant Materials Enable Space-Like Cold on Earth
- Lasers Enable Alternative Power Transmission
- Helium Recapture System Reclaims Hydrogen for Industry Use
- Laser Vision Helps Hubble, Package Shippers See Clearly
- Space-Ready Durometers Measure Hardness on Earth
- High-Temperature Superconductors Deliver Power without Heat
- Electrospray Thrusters Boost Efficiency, Precision

Health and Medicine

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

Rodent Research Contributes to Osteoporosis Treatments

Astronauts know their bodies will be tested during time spent on the International Space Station, from the multiple sunrises and sunsets wreaking havoc on their circadian rhythms to the lack of gravity causing bone-density and muscle loss. NASA is conducting research to counteract these otherworldly challenges to enable long-term human exploration of space—for example, special lighting helps induce sleep, and regular exercise schedules help keep astronauts' bodies healthy—but frustratingly, bone loss continues to occur. With missions to Mars on the horizon, the agency is increasingly interested in potential treatments to help protect astronauts' bodies.

Scientists from Ames Research Center teamed up with BioServe Space Technologies of Boulder, Colorado, and Amgen, a biotechnology company based in Thousand Oaks, California, for a series of three experiments conducted on mice using three different molecules. During space shuttle flights, groups of mice were sent into microgravity for two weeks after receiving one of the molecules, designed to mitigate loss of bone density and muscle strength.

The results were encouraging, with the mice who had received the treatments showing increased bone formation and improved bone structure and bone strength, the same results obtained from mice used in clinical trials conducted by Amgen in more traditional settings. One of the molecules tested by Amgen became the foundation for Prolia, a treatment used to help protect against broken bones in women with osteoporosis. The results also gave NASA another possible tool to consider for longer space exploration trips in the future, to Mars and beyond.

The treatments are classified as biologics because they incorporate recombinant DNA in the composition. That's good news for NASA, as similar treatments will allow astronauts to produce the drugs they need during space exploration far from Earth without having to store large supplies on crew vehicles.

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

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

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

Pressure Garments Save New Mothers' Lives

In the late 1960s, Ames Research Center received an urgent call from Stanford University Hospital. A woman who had given birth continued to bleed excessively despite the use of all standard methods to treat the condition, including multiple surgical procedures. Known as postpartum hemorrhage (PPH), the condition can occur due to a number of different complications during childbirth—and left untreated it can lead to hypovolemic shock, a life-threatening condition.

A trio of researchers from Ames proposed that applying pressure to the woman's lower body might stop the bleeding, and they improvised a garment from a G-suit to accomplish this. NASA has long used G-suits, or inflatable pressure garments that prevent blood from pooling in the legs, to keep its test pilots and astronauts from blacking out during moments of extreme acceleration. In this case, the suit stopped the bleeding, allowing the body's healing process to take over, and the woman made a full recovery.

Throughout the following decades, NASA explored the concept of using a pressure suit to treat a range of conditions associated with internal bleeding, leading to the commercialization of a noninflatable pressure garment. After learning about the suit in 2002, Suellen Miller, medical professor and founder of the Safe Motherhood Program, conducted studies in rural areas around the world to prove its effectiveness in stabilizing women suffering from PPH until they could receive proper medical care.

In 2012 the World Health Organization included the garment in its clinical practice guidelines, and Miller worked with the nonprofit PATH to manufacture the garment more affordably. Now called the LifeWrap, the garment has been purchased in more than 20 countries. "We're taking this suit to the village, we're taking it to the hut," Miller says, "and making a difference for them. Thank you, NASA."

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

Tool Kit Simplifies Development of High-Affinity Molecules

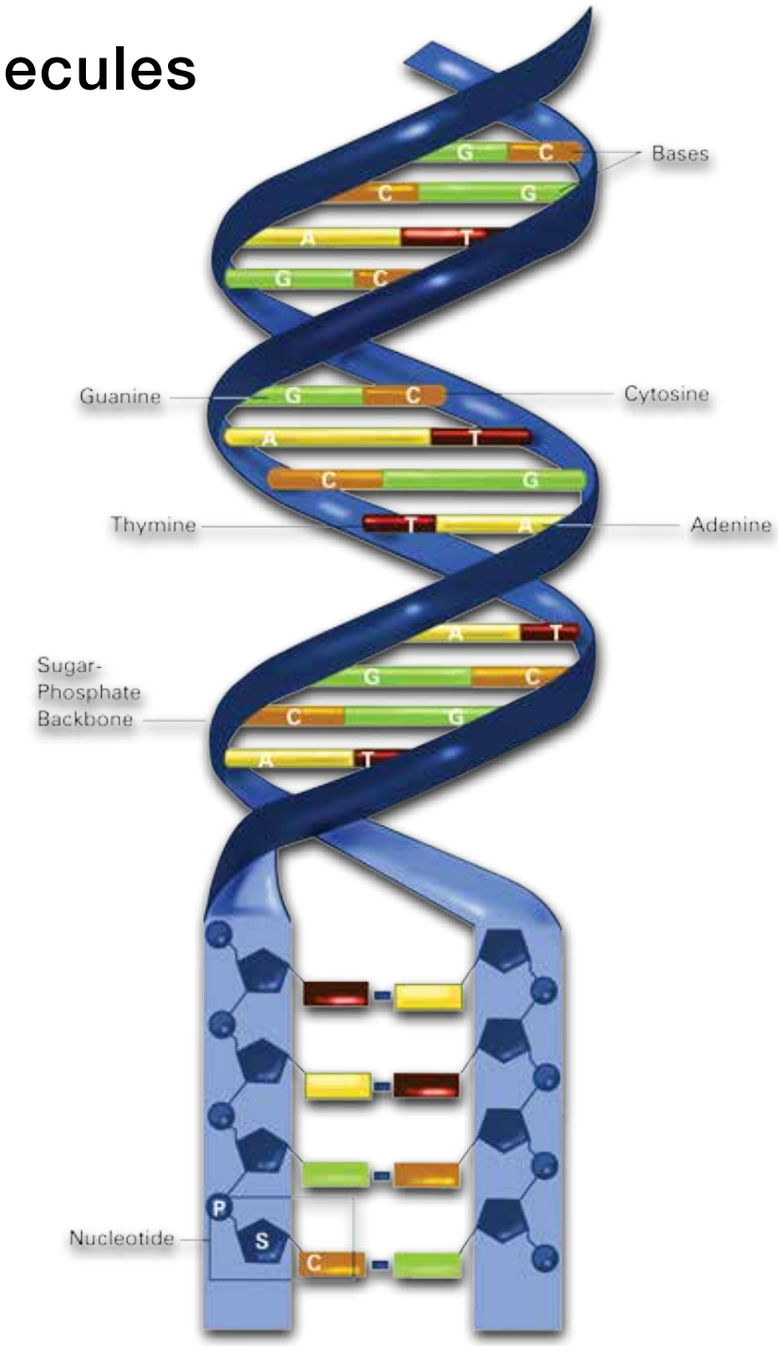
In order to send astronauts on long-duration space missions, NASA will have to develop new diagnostic tools to measure for various biomarkers, anything from white blood cell counts to cholesterol and cortisol levels, to gauge human health. Proteins called antibodies are used to detect biomarkers on Earth, but their three- to six-month shelf life and susceptibility to radiation exposure in space make them poor choices for such missions.

As a workaround, NASA is turning to aptamers: single strands of RNA and DNA that function like antibodies but do not degrade and are impervious to radiation. Yet they too have drawbacks, namely the time-consuming, complicated process required to make them and their sometimes lackluster ability to bind to target molecules. Through NASA Small Business Innovation Research funding from Johnson Space Center, in 2007 Houston-based AM Biotechnologies advanced a faster, simplified method for creating aptamers that bond strongly to their target molecule. The company calls these next-generation aptamers X-Aptamers.

In 2015, AM Biotechnologies made its X-Aptamer Selection Kit available for purchase. Anyone with basic biochemistry lab skills can work with the technology, which, in addition to biomarker detection, can also be used as drugs or as targeting agents for drugs that treat everything from arthritis to cancer.

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

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



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

Space-Ready Spectrometer Offers Terrestrial Advantages

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

Crisp's spectrometer of choice, however, was not onboard.

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

A spectrometer uses light to analyze the chemical composition of a surface or substance by reading the "spectral signature" of the wavelengths the material reflects, absorbs, or emits.

What made Brimrose's device different was the AOTF technology the company had begun developing. An acousto-optic filter is a crystal that responds to different pitches of sound to manipulate the light passing through it, eliminating the need for moving parts. "This was a nifty way of making it rugged," says Crisp.

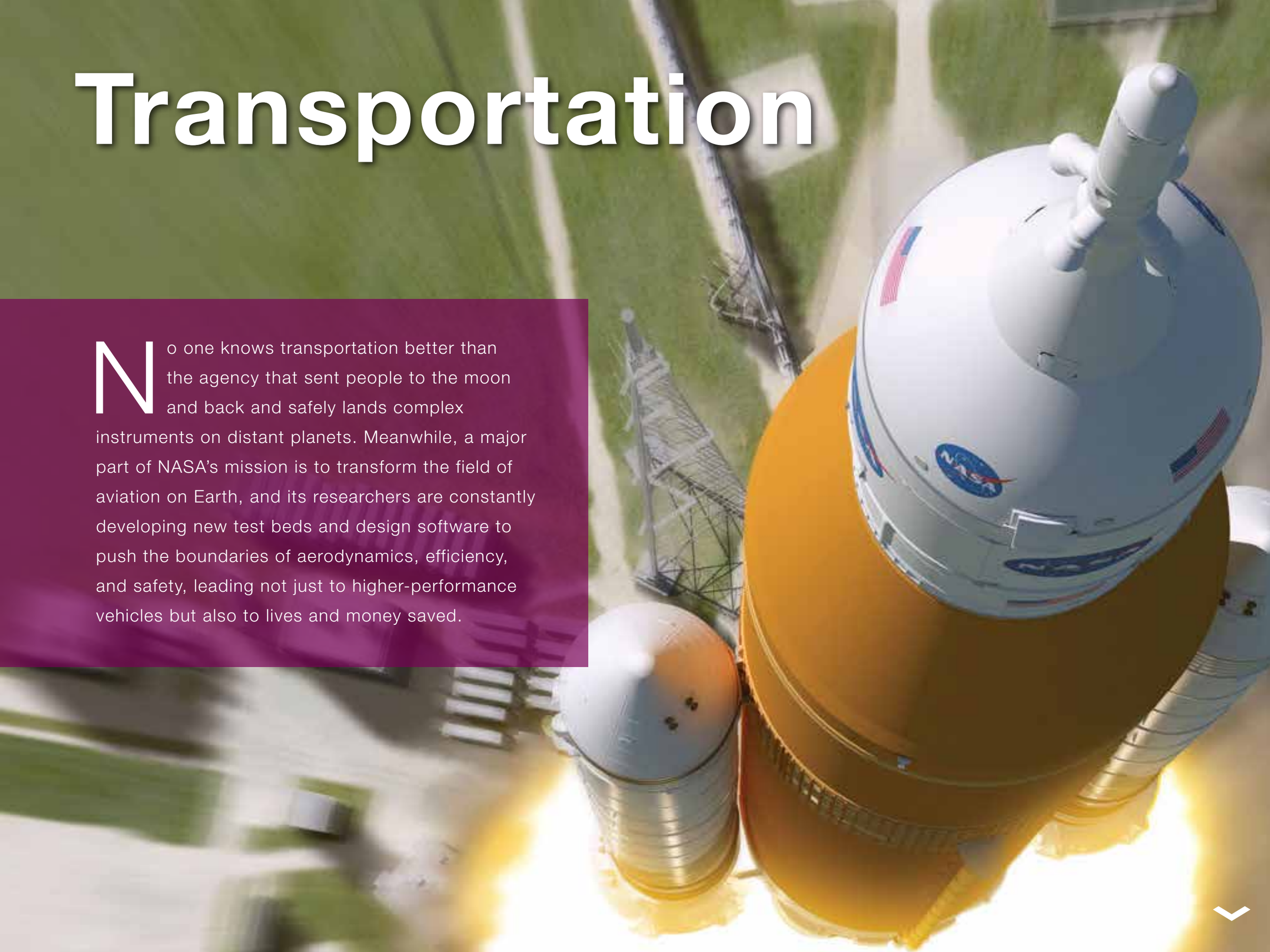
NASA's requirements shaped the device in other ways that would prove useful on Earth. It had to be able to withstand extreme temperatures and radiation exposure in space. It also had to use a minimal amount of power and be as compact and lightweight as possible. These traits led to the success of early commercial models like the Luminar 3050 mini-spectrometer (*Spinoff* 2003).

In the years since, the use of near-infrared spectrometers has exploded across numerous industries, including pharmaceuticals, medical imaging, agriculture, and oil. The company has continued to build on the technology, now offering 14 different AOTF spectrometers, which have been modernized to include touchscreens, longer battery life, the Linux operating system, better manufacturing, and purer materials, in addition to increased efficiency and portability.

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

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

Transportation



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

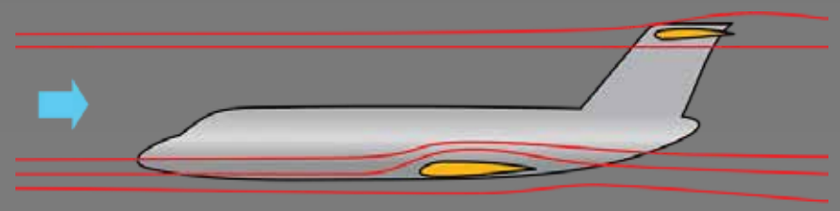
Unmanned Research Aircraft Test Cutting-Edge Innovations

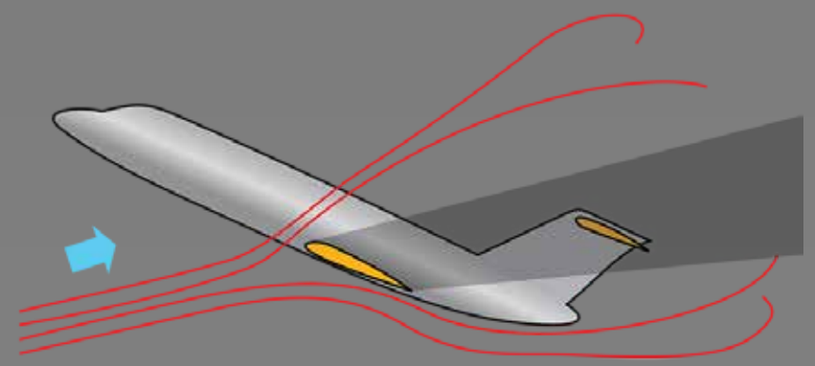
Due to a desire for aircraft to be able to take off and land at airports with shorter runways, in the mid-2000s NASA began experimenting with the circulation control wing concept. The technology would give aircraft greater lift, allowing them to take off and land at a lower speed, thus reducing the length of runway needed. To validate the innovation, Armstrong Flight Research Center put out a call through the Small Business Innovation Research (SBIR) program for an unmanned, sub-scale test aircraft that could be equipped with such wings. Kennesaw, Georgia-based Area-I Inc., which specializes in the development of autonomous aircraft, won the contract and delivered the aircraft to Armstrong in 2011.

Fortuitously, the aircraft that Area-I developed for NASA was highly adaptable. So when Armstrong put out call for another research aircraft, this time a model akin to a medium-range, narrow-body, twinjet airliner, for aerodynamics investigations, and Langley Research Center solicited proposals for a regional-type, sub-scale airplane with a T-tail empennage and a rear engine mount to improve stall recovery, Area-I applied for and received SBIR funding from both centers. By reconfiguring its original NASA-funded, baseline aircraft, which it named the Prototype-Technology Evaluation Research Aircraft, or PTERA, the company successfully built both aircraft, which were delivered to their respective centers in 2014.

Building on its fruitful work with NASA, the company is developing unmanned aerial vehicle airframes for the U.S. Navy and the U.S. Air Force, and is also taking orders for PTERA aircraft from universities and companies. “PTERA is sitting there with an open source flight computer so that you can go in and load up everything you need,” Area-I CEO Nick Alley says. “In a matter of a year you can be up and flying.”

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





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

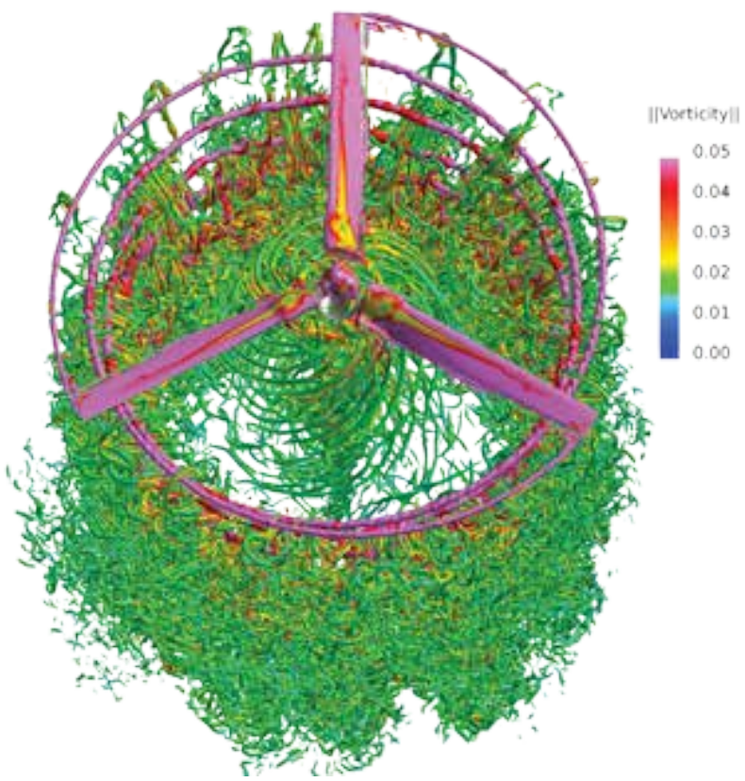
CFD Capabilities Zoom Past Visualization to Assist Cars, Consumers

Nearly 20 years ago, Pieter Buning was in the early stages of his career with NASA, working on an interactive graphics program called Plot3D. The aerospace engineer and research scientist at Langley Research Center didn't have the screens and interactive graphical interfaces available today, which made it difficult to provide visual representations of movement and interactions of substances like air and water with solid surfaces.

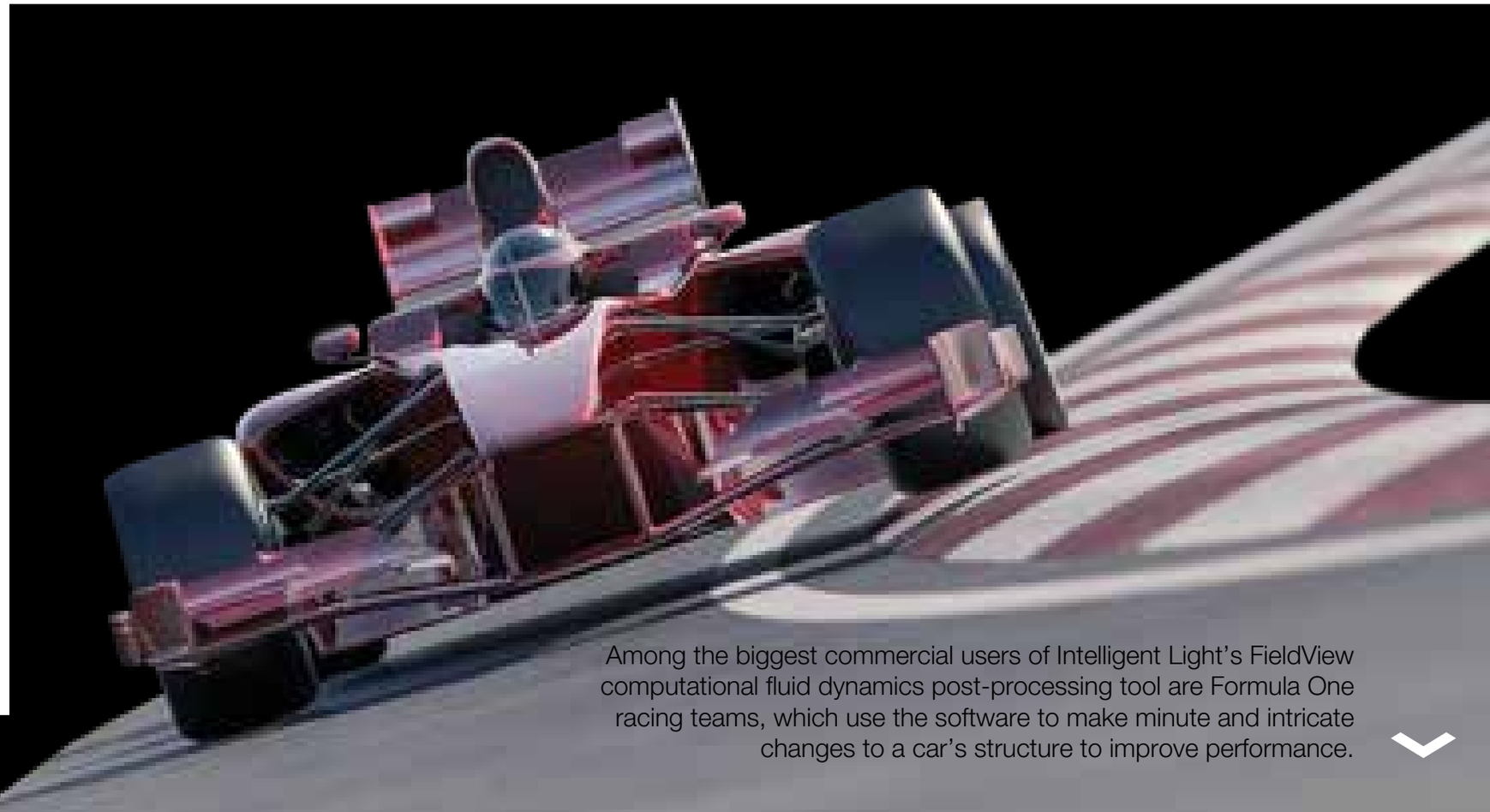
It was the early days of computational fluid dynamics (CFD), and Buning worked with Rutherford, New Jersey-based Intelligent Light, Inc., one of the few companies in the country that had the ability to provide high-resolution, 3D rendering animations at that time. The partnership started with a solver called OVERFLOW, which Buning brought from NASA, and has grown through several Small Business Innovation Research contracts to result in FieldView, Intelligent Light's post-processing visualization tool (*Spinoff* 2003).

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

NASA continues to use FieldView for its visualization needs, but the processor also has become a favorite among the automotive and defense industries. Formula One racing companies are known to use the tool to make quick changes to their cars before competition, and consumer product manufacturers have adopted FieldView to ensure homogeneous mixes for shampoos, among other uses.



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



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

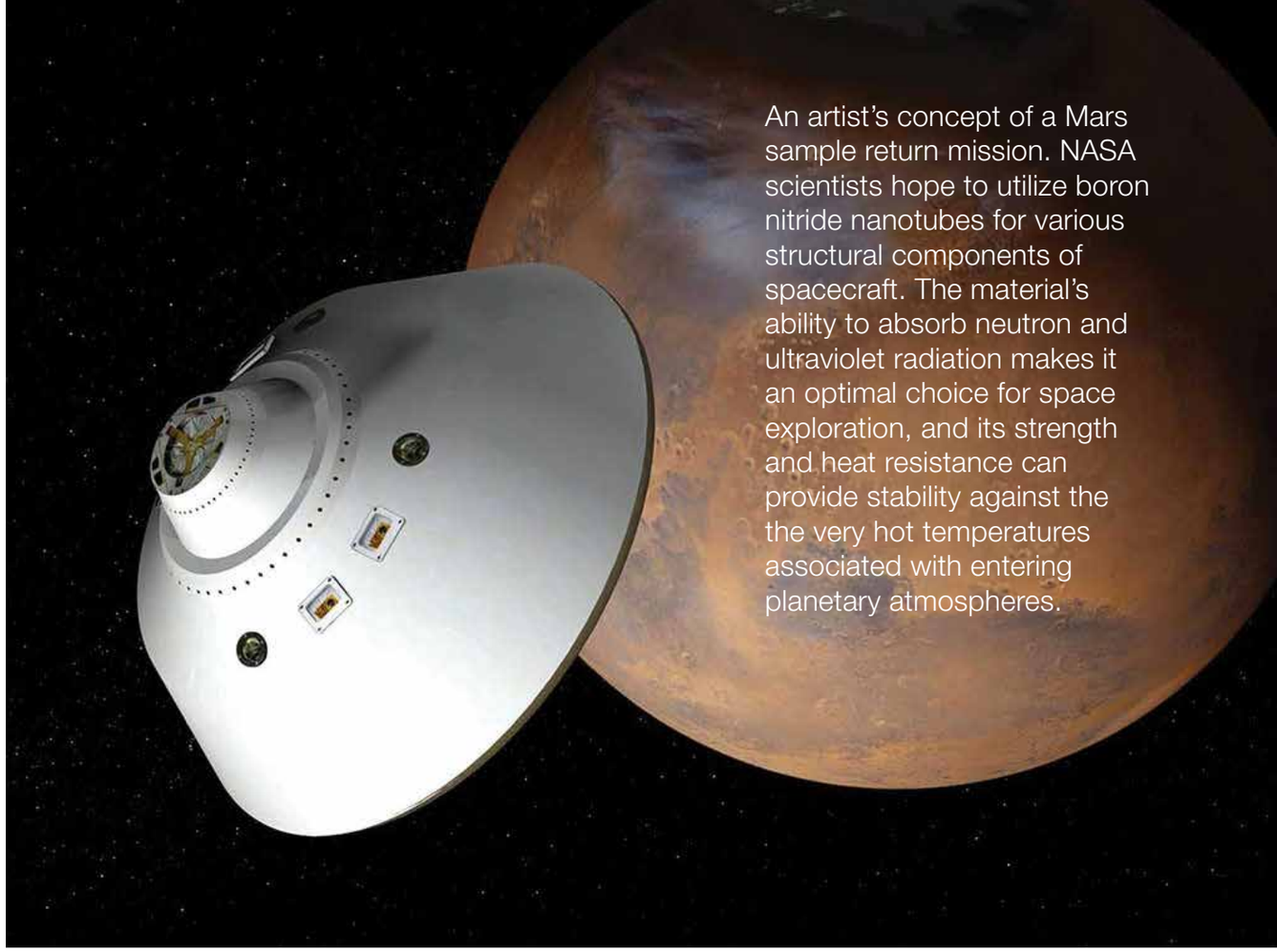
Lightweight, Ultra-Strong Nanotubes to Transform Industry

In 1995, physicist Alex Zettl, a professor at the University of California, Berkeley, was the first to synthesize boron nitride nanotubes, or BNNT. The accomplishment attracted NASA's attention because BNNT is lightweight, strong, temperature-resistant up to 1,650 °F, and absorbs neutron and ultraviolet radiation, which are qualities that make it an ideal composite for the heat shield or entire hull of spacecraft.

There was one major preliminary hurdle: researchers could make no more than a fingertip's worth of the substance at a time. In 2001 Langley Research Center partnered with the National Institute of Aerospace to devise a more efficient method for producing BNNT, and seven years later researchers came up with a winning method whereby a powerful laser is fired into a pressurized chamber containing boron and nitrogen. The two elements heat up and form a vapor cloud that self-assembles into puffy, cotton-ball-like matter. Within the next few years, they were able to fine-tune the process to create 20 milligrams of BNNT per hour using only a standard welding industrial laser.

Recognizing the value of commercially synthesizing such an in-demand, novel molecule, several individuals involved in its development founded BNNT LLC in 2010 and licensed NASA's patents on the technology. Having further improved production to where 200 milligrams can be synthesized per hour, the company now sells BNNT to researchers exploring its uses in anything from electrical insulation to soft-tissue cancer therapy. Through a Space Act Agreement, BNNT LLC also works with NASA to continue optimizing the quality and quantity of the material while reducing production costs, which benefits everyone.

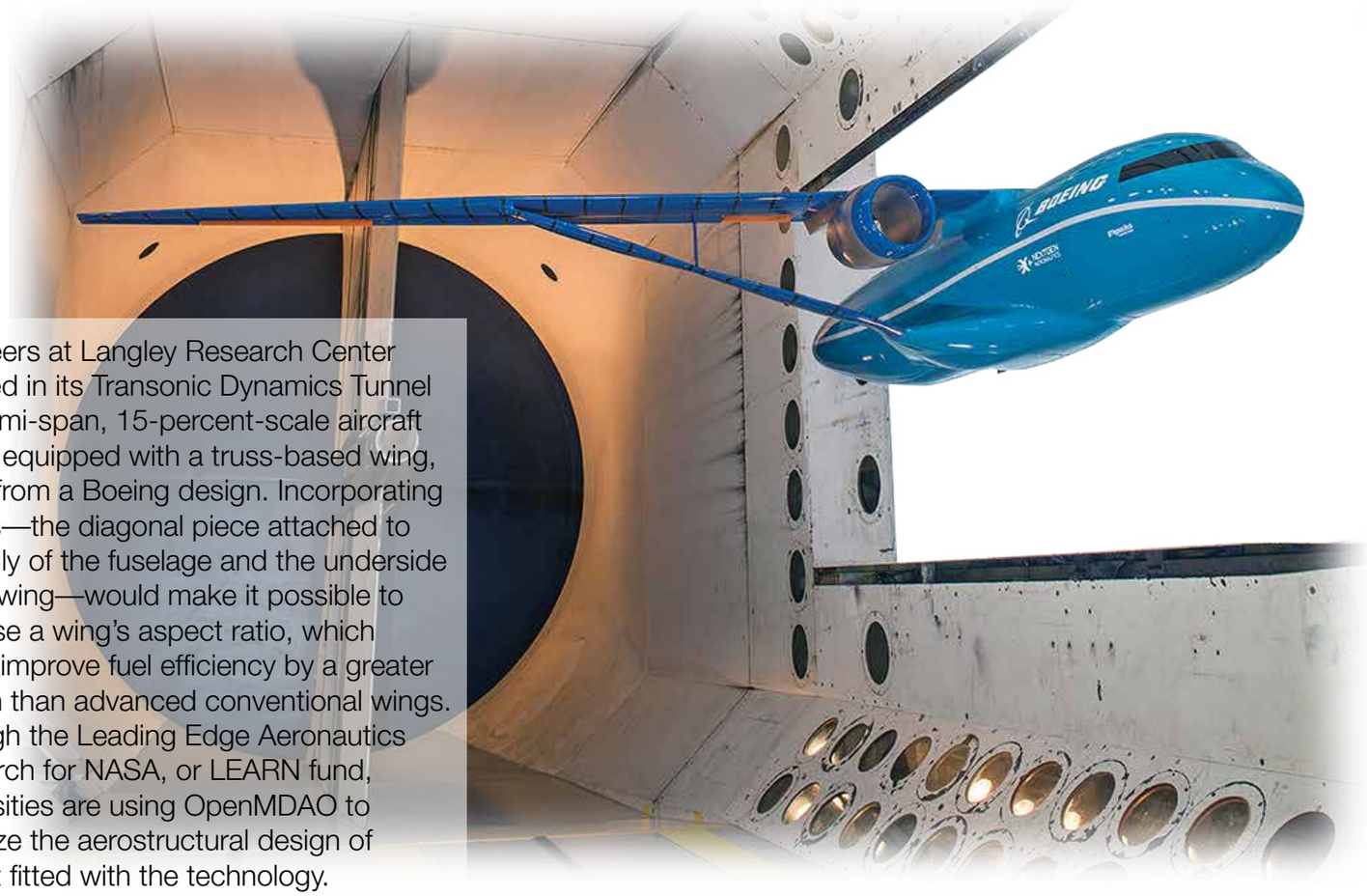
"There's no telling what else BNNT will be used for in the future because it has such unique properties," Mike Smith, the company's chief scientist, says. "Now that we're unlocking more efficient methods for synthesizing them, at least now we'll be able to find out."



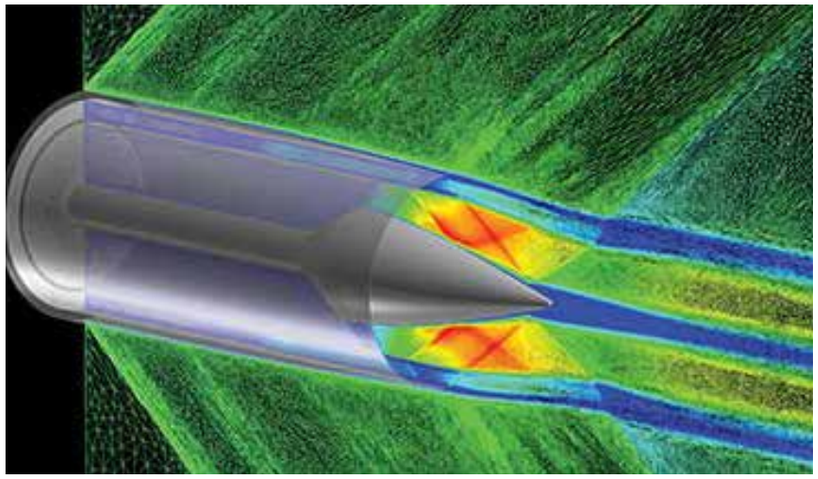
An artist's concept of a Mars sample return mission. NASA scientists hope to utilize boron nitride nanotubes for various structural components of spacecraft. The material's ability to absorb neutron and ultraviolet radiation makes it an optimal choice for space exploration, and its strength and heat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

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

Multidisciplinary Software to Help Take Aircraft to the Next Level



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



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

For decades, engineers and scientists have taken apart and reengineered aircraft components to maximize fuel efficiency, reduce noise, and improve safety. Such advances in aircraft parts have come a long way, but many improvements have come from optimizing a single component in isolation, an approach that's reaching its limits. "Things need to be engineered more holistically, which means that researchers need to consider the system-level effects of their technologies," says Justin Gray, a researcher at Glenn Research Center's Propulsion Systems Analysis Branch.

Making the next generation of aircraft more efficient requires multidisciplinary analysis and optimization (MDAO). In MDAO, researchers from various engineering fields—structures, aerodynamics, propulsion, and materials—work together to figure out how each component can best be coupled with the others to contribute to an overall optimal design. But the computational and mathematical challenges inherent in the process, in addition to the wide-ranging expertise needed, are major barriers. So, in 2010 programmers from Glenn created OpenMDAO, a free and open source software framework that allows researchers to tightly couple their analyses without needing to be experts in MDAO.

NASA is currently providing support for a number of ambitious projects that use OpenMDAO. One is a multi-university effort—supported by the agency's Leading Edge Aeronautics Research for NASA, or LEARN, Fund—to design a next-generation truss-braced-wing aircraft to increase fuel efficiency. Another involves Texas A&M University's work with the agency to reduce the noise created by slats—panels that deploy from the front of an airplane's wings to provide extra lift.

Graduate students at the University of Michigan even used OpenMDAO not only to design a miniaturized satellite but also to control it throughout its orbit. The project used over 25,000 design variables, demonstrating OpenMDAO's ability to analyze and optimize complex systems.

Orbital Trajectory Analyzer Takes Mission Planning to New Heights

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

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

A team of engineers at Goddard Space Flight Center began working on what's become the General Mission Analysis Tool (GMAT), a modeling program that specializes in trajectory optimization, allowing mission-control specialists to plot the best course for their craft. Now a group of 11 engineers, developers, and a tester, the team continues to monitor the program, which contains some 540,000 lines of C++ code, and review it nightly to find and fix any glitches.

The first flight-qualified release came in 2013, the same year NASA launched the Mars Atmosphere and Volatile Evolution mission, whose team used GMAT in preparation for flight. A free, open source software program, GMAT has been embraced by universities, international space exploration partners, and several commercial space companies as a tool for mission planning and trajectory calculations.

Applied Defense Solutions, Columbia, Maryland-based service vendor for companies in the space, national security, and geospatial information systems, used GMAT to support NASA's launch of the Lunar Atmosphere and Dust Environment Explorer. That mission was the first in three decades to fly around the moon's equator and, in planning the mission, the company and NASA wanted to know more about the uncertainties about the gravity model around the moon.

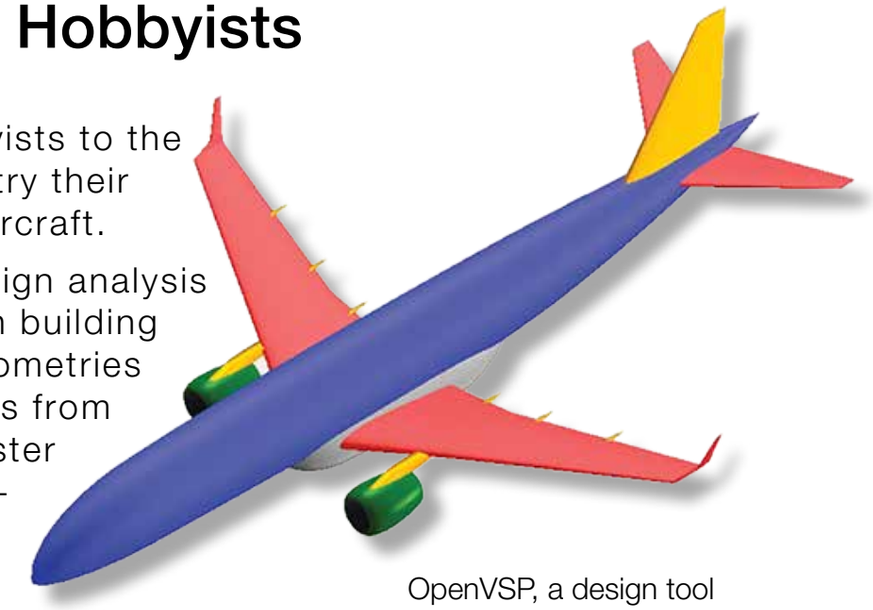
NASA will use GMAT when it launches the James Webb Space Telescope in 2017 to ensure the tool's correct placement into a Lagrangian-point orbit, balancing the gravitational forces of the sun and Earth to maintain a single position relative to both bodies.

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

Open Source Aircraft Design Software Helps Industry, Hobbyists

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

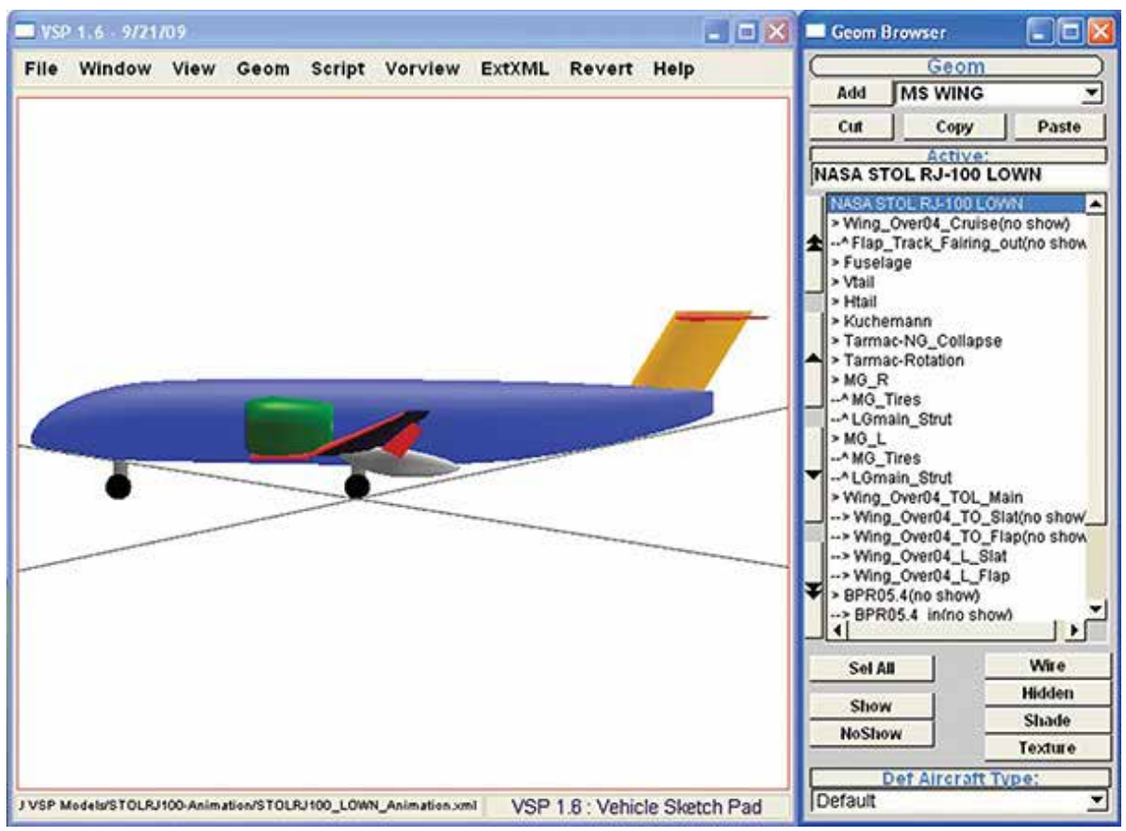
A group of four programmers, designers, and engineers, including Andrew Hahn and Mark Moore from Langley Research Center, developed OpenVSP, or vehicle sketch pad, an open source program that allows anyone with a computer, from NASA to hobbyists to the aircraft industry, to try their hand at designing aircraft.



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

Previously, all design analysis capabilities relied on building analysis-specific geometries that were distillations from the fully defined master that had to be recreated and tweaked if any one input was modified. OpenVSP, by contrast, allows changes to be made throughout an entire design when a single parameter is modified. NASA developed the basic program more than a decade ago, and since it was released as an open source software in January 2012, it has been downloaded more than 50,000 times.

Desktop Aeronautics Inc., an aircraft design software company in Palo Alto, California, uses OpenVSP in concert with its own proprietary tools for aircraft design. The company credits the program as helping to change how the industry designs aircraft, allowing for rapid 3D modeling without having to create a tool from scratch and spend months perfecting it, a process which can take months.



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

Public Safety

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

Rice Crop Models Stabilize Global Markets, Enable Efficient Irrigation

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

Among the world's major dietary staples, rice yields are the most difficult to predict, and that lack of reliable information makes the rice market volatile, putting investors, producers, and consumers at risk. Rice farming, in which fields are often inundated, also requires large quantities of water, which is becoming scarce in some rice-producing areas. And those flooded fields give rise to anaerobic decomposition, which produces methane, the most powerful greenhouse gas.

For all these reasons, Applied Geosolutions, based in New Market, New Hampshire, decided to leverage a decade of research on applications for Earth-imaging satellite data to create a Rice Decision Support System (RDSS) with the help of two Small Business Innovation Research contracts from Stennis Space Center. The company designed a web-based software that uses data from NASA satellites and others, incorporating measures of rice fields, yield modeling, and weather forecasts to generate information in real time about rice coverage, growth stages, deviations from normal, and expected yield around the globe.

Abroad, the system is focused on pilot sites in Java, Indonesia, and Vietnam, where the data gathered is used primarily for supporting food security programs and commodity markets.

In the United States, parts of the country's two biggest rice-producing regions—eastern Arkansas and the Sacremento Valley—are running out of water. There, Applied Geosolutions has paid partnerships with farmers and agencies to help them plan their growing season and manage resources, especially irrigation. The imagery also proves which farms should receive incentives for using alternative irrigation methods, a function the RDSS also performs at a pilot site in Brazil.

And the company is doing work in Vietnam, California, and Arkansas, in part supported by NASA's Land-Cover/Land-Use Change Program, to support alternative rice management strategies and explore the possibility of wealthier countries paying developing countries to use environmentally sound farming practices.

Image courtesy of Feed My Starving Children, CC BY 2.0

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

Image courtesy of Adi Simionov, CC BY-SA 3.0

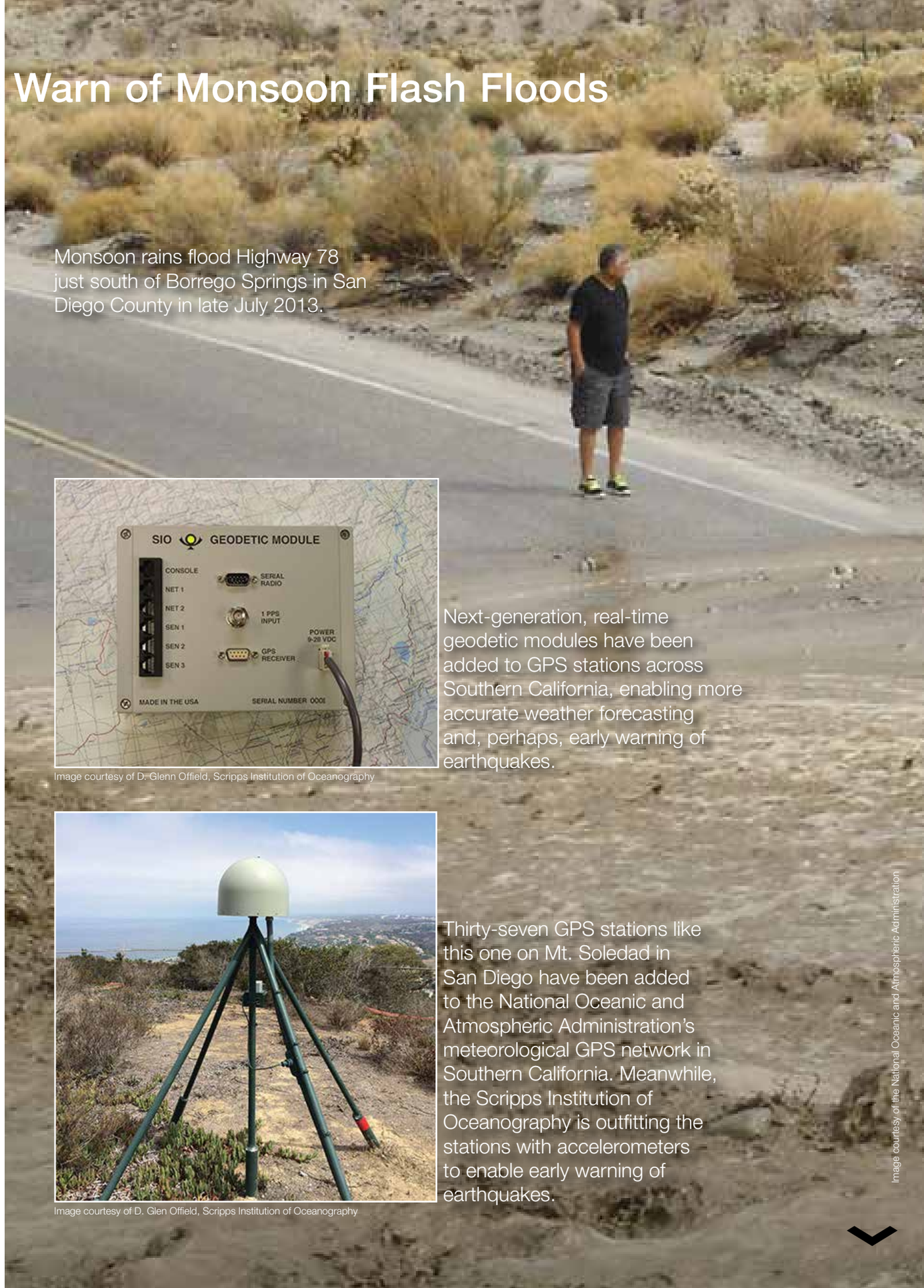
GPS Sensor Web Helps Forecasters Warn of Monsoon Flash Floods

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

The National Oceanic and Atmospheric Administration's (NOAA) local Weather Forecast Offices have a strong interest and difficult challenge in predicting the storms, which can present serious dangers, such as flash-flooding, washed-out roads, driving winds, hail, and barrages of lightning.

The San Diego and Los Angeles/Oxnard offices are now benefiting from the Next-Generation Real-Time Geodetic Station Sensor Web for Natural Hazards Research and Applications project, funded by NASA's Earth Science Technology Office, which kicked off in 2012. Under the project, which is a partnership between NOAA, the Jet Propulsion Laboratory, and the Scripps Institute of Oceanography, 37 GPS stations have been added to NOAA's meteorological GPS network in Southern California, outfitted with meteorological sensors.

The project takes advantage of the fact that scientifically precise GPS calculations have to account for any signal delays caused by humidity, which reveals the amount of moisture in the air. The results, along with temperature and pressure data, are broadcast every half hour and help local Weather Forecast Offices track moisture and decide when to issue a monsoon storm warning, their most important public safety function. The offices' warnings and forecasts go out to all local television and radio stations. Previously, forecasters in the area had relied on data from four weather balloon sites that report twice a day.



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

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

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

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

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

Image courtesy of the National Oceanic and Atmospheric Administration

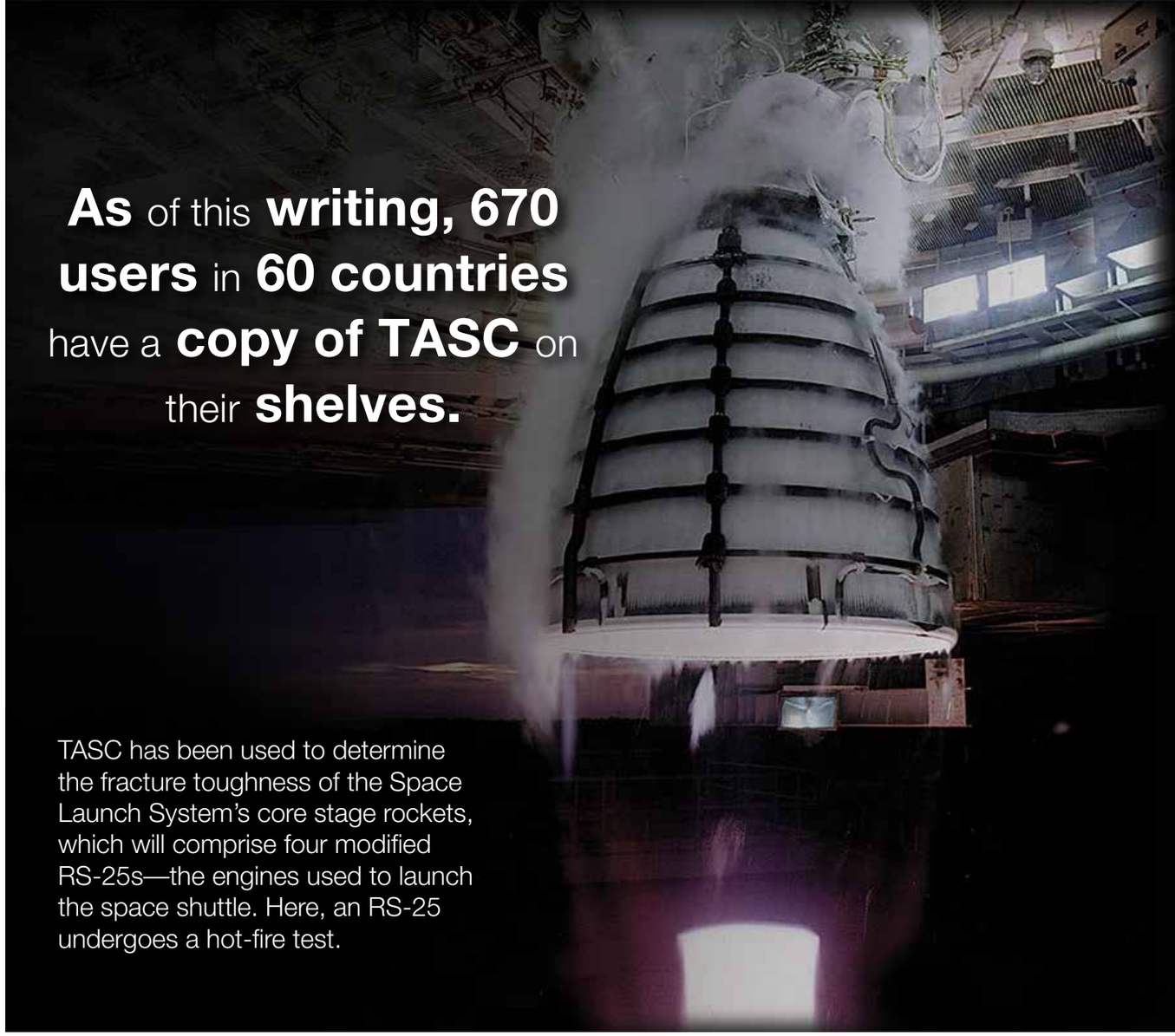
Analytic Tool Simplifies Metal Fracture Assessments

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

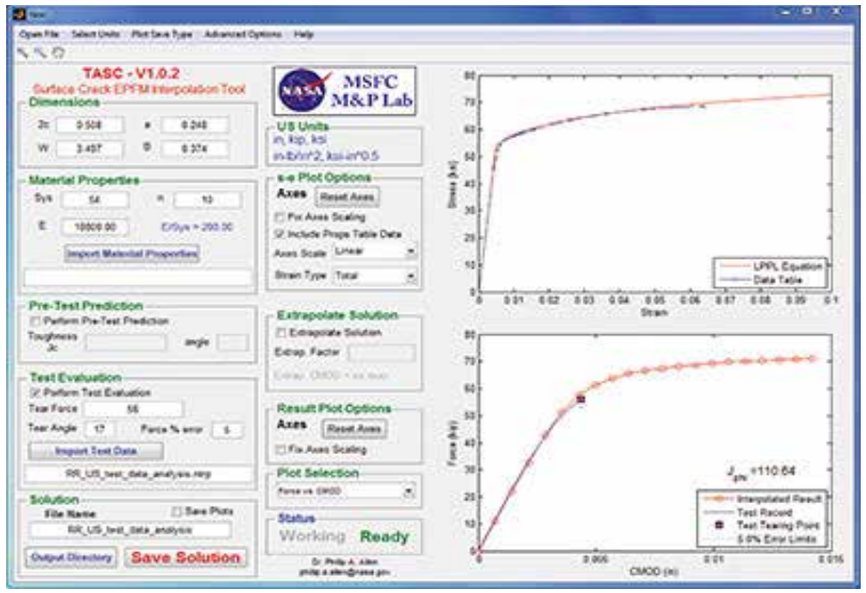
Determining a material's fracture toughness entails running physical tests then performing nonlinear finite element analysis, which requires expertise in several niche fields. "Traditionally, you had to have somebody specifically skilled in nonlinear fracture mechanics and material behavior, and he or she needs to run an analysis of that test, which takes a long time and costs a lot of money," says Phillip Allen, a materials engineer and structural analyst at Marshall Space Flight Center. As a workaround, he developed Tool for Analysis of Surface Cracks, or TASC, which was released in January 2014. The free and open source software is easy enough for a technician to use and cuts the time needed for analysis from hours to minutes.

TASC has applications beyond ensuring a spacecraft's structural integrity. For example, petroleum companies need to monitor their pipelines; the same goes for state and municipal governments and their bridges, overpasses, and other infrastructure. As of this writing, 670 users in 60 countries have a copy of TASC on their shelves.

In recognition of his work, Allen was one of two recipients of NASA's prestigious Software of the Year Award for 2014. Now he's working toward what could be another success story: getting TASC designated as an official standard analysis tool for surface crack testing by the American Society for Testing and Materials.



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



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

Mars Methane Detector Identifies Harmful Gas Leaks

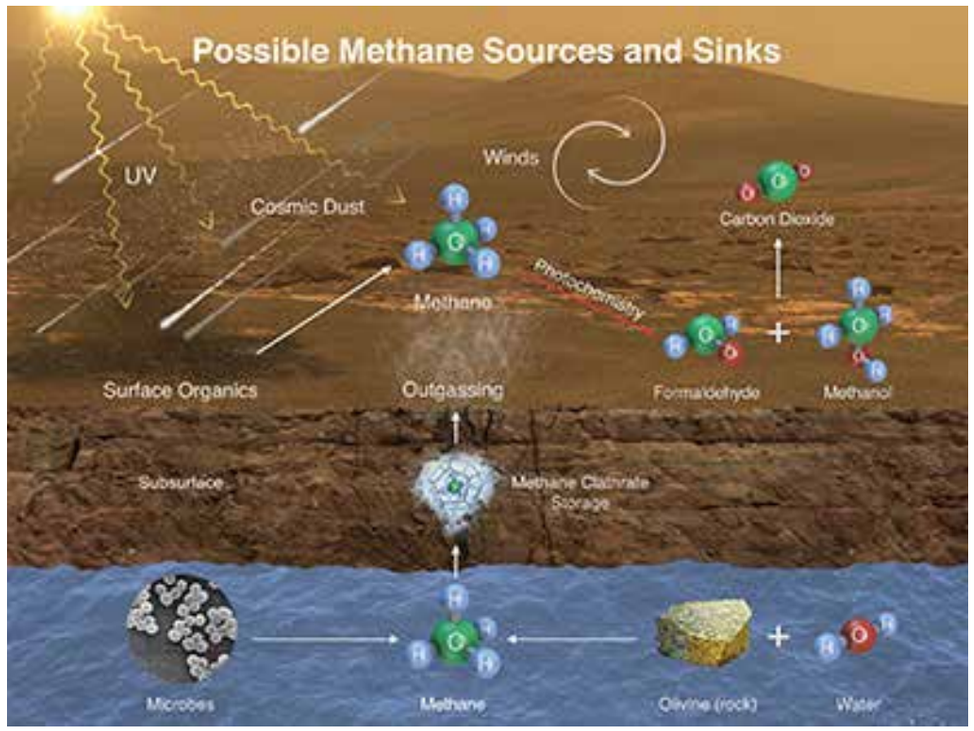
Methanogens are single-celled, primordial organisms that, as their name suggests, produce and release methane as a metabolic byproduct. So when plumes of methane were detected on Mars in 2003, NASA wanted to confirm the gas's existence in the hopes of one day determining if the Red Planet is, or ever was, home to microbial life.

The timing was perfect, as the space agency was in the planning stages of the Mars Science Laboratory, or Curiosity, rover. In the mid-2000s engineers at the Jet Propulsion Laboratory (JPL) developed the Tunable Laser Spectrometer, or TLS, one of three gas-analyzing instruments comprising the Sample Analysis at Mars suite. The TLS uses mid-infrared laser beams to examine gases gathered from the atmosphere. The gas absorbs the light, and a detector gauges the reduction in light to determine the concentration of methane.

While the TLS is at work on Mars, it's also being used on Earth, but rather than detect signs of life it's going to save human ones.

Energy companies are responsible for checking their gas pipes for leaks, lest an explosion occur, but methane detectors have either been too bulky or not sensitive enough. Through a reimbursable Space Act Agreement with Pipeline Research International, JPL built a TLS-based, handheld methane sensor 100 times more sensitive than the prior technology. Industry is hopeful the device will not only prevent accidents but also help to reduce greenhouse gas emissions, as leaks arising from underground pipes supplying energy are a major contributor.

Field workers with Northern California energy provider Pacific Gas & Electric have tested the device and are impressed with its ease of use and its NASA origins. Company spokesperson Hailey Wilson says, "Employees feel really proud that they get to use technology used on Mars to help them do their jobs."



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

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

Hydrogen Detection Tape Saves Time and Lives

From the Apollo missions through the Space Shuttle Program, NASA has relied on liquid hydrogen as a fuel source for the upper stages of its rocket launches. The reason is simple: hydrogen is the most efficient propellant there is. It's also extremely flammable, which is why the space agency took extra care in monitoring its miles of pipeline for leaks. In the Apollo days, inspectors held brooms upside-down and in front of their bodies while they walked the lines; if the head began to burn, there was a leak. During the launches of the 1980s and '90s, ultraviolet sensors detected flames; to find nonburning leaks, electrochemical and combustible gas sensors were used.

But a major problem with either of those instruments is it can only offer up a general area for a leak, which made finding one difficult in areas where many hydrogen transfer lines intersect. As a workaround, in the mid-2000s Kennedy Space Center collaborated with the Florida Solar Energy Center (FSEC) at the University of Central Florida to improve on a Japanese patent for a hydrogen detection tape whereby palladium oxide, when exposed to hydrogen, produces a color-changing chemical reaction. Researchers improved the chemistry of the tape so that the color change is not only more noticeable but occurs quickly.

In addition to using the tape for detecting hydrogen leaks for nearly every shuttle launch, beginning with STS-118, NASA and FSEC entered into a Space Act Agreement and a licensing agreement to sell the tape commercially, resulting in the creation of Rockledge, Florida-based HySense Technology. The 2014 R&D 100 Award-winning technology is now being used across the swath of industry, from chemical plants to gas producers and stainless steel manufacturers.

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

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

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

Single-Photon Lidar Maps Ground Features Quickly, Efficiently

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

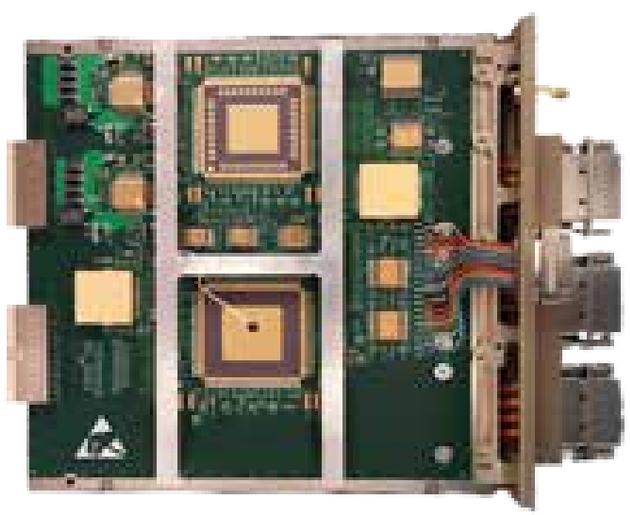
The result is an airborne device that fires 100 simultaneous, low-power laser pulses at the ground at a rate of 32,000 pulses per second and then detects photons reflected back to it, distinguishing them from a storm of sun-generated photons, and determining how long each one's round trip took to an accuracy within twenty-trillionths of a second. In this way, the lidar creates a three-dimensional image with every pulse, which is then integrated into a contiguous, high-resolution image. Furthermore, the lidar uses a fraction of the energy typically required by imaging lidars.

The technology that makes this possible draws from Chief Scientist John Degnan's four decades of NASA laser ranging experience at Goddard Space Flight Center, where he retired in 2003 to join the Lanham, Maryland-based company. Sigma licensed two of his NASA lidar patents and developed several aerial imagers, culminating in the High-Resolution Quantum Lidar System (HRQLS).

By flying at high altitudes, the device can map swaths of up to a few kilometers, making surveys of broad areas faster and more affordable, and it is able to map terrain hidden by forests, measure biomass of tree coverage, and see up to 45 feet beneath the surface of water.

The device has a multitude of applications, from foliage-penetrating military reconnaissance and spotting underwater mines and submarines to rapid, wide-area surveying or seeing whether train tracks are warped or trees are infringing on power lines.

Three-dimensional maps can ensure compliance with arboreal cap-and-trade agreements or be useful to planners who need to know the topography beneath tree canopy to plan pipelines, roads, and other infrastructure.



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

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

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

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

— Anthony Martino, Goddard Space Flight Center

Temperature Sensors Cement Integrity of Bridges

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

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

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

Through the Strong Cities, Strong Communities Initiative, the Obama administration wants to foster partnerships between government agencies and small- to medium-sized manufacturers. Glenn Research Center represented the Cleveland-Youngstown region of Ohio in the initiative, and the center teamed up with the city of Cleveland, Cuyahoga County, and the Manufacturing Advocacy & Growth Network (MAGNET) to brainstorm the best way to select worthy partners. The Adopt a City program was launched, in which eight companies were identified to receive 40 hours each of assistance from experts and specialists from Glenn. The companies also were eligible to receive low-interest loans through the program, now in its third session.

The program paired experts from Glenn with Pile Dynamics Inc. (PDI), a Cleveland-based company that needed assistance making thermal sensors for concrete piles. Concrete warms as it cures, and the company's thermal integrity profilers monitor the temperature within a concrete pile or shaft to identify whether it was poured properly or if any defects have occurred. PDI places its instruments in a rebar cage before it is installed in the shaft and filled with concrete. The temperature is collected for the first day or two after the concrete is poured, which allows the integrity of the pile to be monitored before the end of the 28-day curing process.

Glenn researchers helped validate the strength of the seal made by a special glue selected by PDI to fill the shell of its thermal profiler, in addition to testing the strength of the bond between the shell and the wire used to transmit the temperature readings to an above-ground data collector. The sensors were standardized by the American Society for Testing and Materials in 2014 and have been used in at least 40 projects worldwide, including the new $26 million Innerbelt Bridge on Interstate 90 in Cleveland.

Image courtesy of the Ohio Department of Transportation

Primer Stops Corrosion without Requiring Rust Removal

Image courtesy of the U.S. Navy

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

"The world is made out of bad concrete and rusty steel, and corrosion is the primary cause of deterioration of our infrastructure," says Bob Walde, vice president of technology for Surtreat Holding LLC.

In the mid-1990s the Pittsburgh-based company developed two corrosion inhibitors that worked by chemical means and could migrate from the surface of concrete to the steel rebar inside. Kennedy Space Center, which has serious corrosion issues, entered into a Space Act Agreement with Surtreat to test its products in 1996 (*Spinoff* 1998).

Of the several corrosion inhibitors tested, Surtreat's were top performers and were subsequently used on Kennedy's launch pad and other structures at the center. They went on to be used on balconies, bridges, parking garages, military installations, power plants, and other structures across the country and abroad.

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

Surtreat used a compound similar to the one tested at Kennedy, whose vapor would migrate through the rust to the steel and form a protective film. The Corps of Engineers found it to be effective to the point that it offered 5–10 times the corrosion-inhibiting properties of standard primer.

The product saves costs by extending structures' lifespans and eliminating the cost of rust removal, which can be up to $5 per square foot. The U.S. Department of Transportation has expressed interest in the product, mostly for use on bridges, and the Navy is interested in it for ship maintenance. A number of painting contractors are already using the primer.

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

Consumer Goods

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

NODE+ Platform Integrates Sensors with Smartphones

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

— George Yu, Variable Inc.

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

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

Ames Research Center initially contracted George Yu to create a device that would let a gas and chemical detection system "sniff" the air for samples. What he ended up doing, though, was to develop the interface that allowed a module containing carbon nanotube sensors to draw its power from a smartphone battery and use the phone to digitally process the data it gathered and transmit it to a central location.

While the resulting technology was delivered to the Department of Homeland Security to be used by first-responders for detecting harmful chemicals, Yu used the technology he had developed to let a host of off-the-shelf sensors interface with smart devices. After founding Chattanooga, Tennessee-based Variable Inc., Yu incorporated most of the design for the microprocessor, memory, communication protocol, back-end web structure, data storage, and cloud technology he had developed for NASA into his NODE wireless sensor platform.

Unlike the original sensor, though, NODE operates independently and transmits data to the phone or other device using Bluetooth wireless technology.

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

The product line was released in 2012 and is already in its second generation, NODE+, which is faster, uses less power, is more durable, has more memory, and is compatible with Android devices as well as Apple smart devices.

The invention has garnered multiple technology awards and found markets in supply-chain management, transport, and logistics, among other areas of business. Variable now employs upwards of 25 workers.

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

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

Precision Coffeemaker Adapts Brews to Beans, Taste

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

In 2006, Matt Walliser, now chief engineer at San Francisco-based Blossom Coffee, took on a summer internship at the Carnegie Mellon Innovations Laboratory at NASA Research Park, part of Ames Research Center, where he would also spend the following three summers. There, in the Exploration Aerial Vehicles (EAV) Laboratory, he worked on test platforms for intelligent, autonomous robotic systems, learning about technology that he would later incorporate into the Blossom One Brewer.

His work with proportional-integral-derivative (PID) controllers, which continually monitor and correct the output of a controlled system through error feedback, laid the foundation for the key component in Blossom's coffeemakers. While PID technology was used to keep the EAV Lab's MAX 5 rover moving at a constant speed as it traversed uneven terrain, for example, in the Blossom One, it's used to hold temperatures constant to within one degree in both the water boiler and brew group. This ensures the same beans can produce the same flavors consistently. Meanwhile, the embedded communications technology Walliser was introduced to at Ames lets the Wi-Fi-enabled coffeemakers synchronize brewing processes with recipes stored in the cloud.

Walliser calls the coffeemakers "semiautomatic," noting that they only control certain aspects of brewing, while others are left in the hands of the barista. "It's still a craft product, and you still need training to use it, but it takes over the things that are difficult to control by hand," he says.

CO_2 Recovery System Saves Brewers Money, Puts Bubbles into Beer

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

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

As a NASA contractor and then as founder of Pioneer Aeronautics, Zubrin worked with Johnson's ISRU team to develop technology that could break down elements that are abundant on Mars, such as carbon dioxide (CO_2), and turn them into resources like fuel or oxygen.

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

Major breweries typically have systems that capture the carbon dioxide produced during fermentation for use in carbonation and other functions, but these haven't been available on smaller scales. Instead, microbreweries are left to release the gas from fermentation and buy carbon dioxide from an outside vendor.

Pioneer's CO_2 recovery system produces about five tons of carbon dioxide per month, enough for a brewery that generates up to 60,000 barrels per year, and units can be stacked to increase that capacity.

In addition to saving money for small breweries, the technology allows reuse of a greenhouse gas that would otherwise be released into the atmosphere.

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

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

Space Blanket-Inspired Cases Protect Expensive Devices

Electronic gadgets like smartphones and tablets are sensitive to temperature fluctuations and can be damaged after exposure to extreme hot or cold conditions for long periods of time. To find a way to protect these 21st-century devices, Nick Blanton, founder of Portland, Maine-based Salt Cases Inc., went back to an innovative product from the early days of the space program.

In the 1960s, Marshall Space Flight Center worked to devise a thin, reflective metallic material to protect spacecraft from the dangers of solar radiation. This material, metallized polyethylene terephthalate (MPET), is strong and not only reflects radiation but also serves as powerful insulation to protect electronics from large swings in temperature, and NASA has used it for nearly every mission to and beyond Earth orbit.

The flexible, highly efficient and plastic material had already been back to Earth as a main component of the lightweight "space blankets" used by runners to maintain their body temperature after finishing a race (*Spinoff* 2006). Blanton, who recalled using the blankets during Boy Scout and Eagle Scout camping trips, incorporated the reflective material into cases capable of regulating the temperature of electronic devices. Thanks to a successful Kickstarter campaign, his Salt Cases are now available for iPhones and iPads, with a line of cases for Samsung products in development.

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

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

Antimicrobial Agent Updates Ancient Industry of Prayer Mats

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

Many of these benefits have not been proven, but NASA has demonstrated at least a couple of chitosan's benefits. In 1997 NASA researchers used chitosan to protect adzuki bean plants in space and found the treated plants yielded more biomass and showed greater resistance to pathogens than the control group.

Ten years later, Johnson Space Center undertook an experiment on the International Space Station to determine chitosan's effects on human immunity. The results were unambiguous. Human white blood cells—the warriors of the immune system—injected with both an endotoxin and chitosan-arginine survived the trip and made it back to Earth, while those injected only with the endotoxin were wiped out.

That experiment took place right about the time Nader Sabry and his crew began research that would result in the first significant update to an ancient industry—prayer mats. Sabry, founder and CEO of TIMEZ5 Global Inc., brought on a consultant whose knowledge of NASA's chitosan studies had prompted him to work with the Centers for Disease Control to develop the world's first antimicrobial film.

That film is now applied to a layer of the TIMEZ5 Prayer and Meditation Mat, where it fends off bacteria, fungi, and mold. The company, headquartered in Calgary, Alberta, now employs about 145 people and is selling thousands of mats each month.

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

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

Heat-Reflecting Material Regulates Body Temperature

In the 1990s, NASA was exploring the use of rocket planes to reduce the cost of launching payloads into orbit. Lockheed Martin's X-33 and Orbital Sciences' X-34, both built with NASA funding, were reusable launch vehicles designed for the purpose. In order to protect their hulls from the scorching reentry into Earth's atmosphere, Ames Research Center developed Protective Ceramic Coating Material, or PCCM, which uses high-emissivity, or heat-radiating agents to decrease the amount of heat traveling to the underlying material.

In 1996, Blacksburg, Virginia-based Emisshield licensed the environmentally friendly PCCM technology and incorporated it into a number of products designed to regulate heat distribution, mostly as coating substrates in combustion processes, power generators, furnaces, and commercial ovens. More recently, Mooresville, North Carolina-based Trizar Technology is bringing PCCMs into new markets, namely clothing and furniture.

Brad Poorman, Trizar's CEO, says, "In the summer, you want to reflect the sun away so you stay cooler, and in winter you want to absorb the heat that your body's producing and maintain it so you stay warmer longer." He says PCCMs accomplish just that, with the company making its initial strides in thermal attire. For some cold-weather garments made by Wyoming-based apparel company Cloudveil and the European Penguin brand, for example, the coating is applied to the inside lining, where it deflects outgoing heat, sending it back toward the body.

Trizar is also working on applying the technology to patio furniture to prevent it from overheating in the sun and becoming too hot to sit on. Tests have shown that when a coat of PCCM is applied to an object's surface, it will remain at the ambient temperature, he says. "If it's 90 degrees out, your furniture stays at 90 degrees, versus 140 degrees if you don't have the coating."

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

"Approaching companies with a product **made** and **used** by **NASA gets you** so much **further, faster,** because of the **credibility."**

— Brad Poorman, Trizar Technology

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

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

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

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

Pilots need to translate the two-dimensional information spread across a variety of instruments,panels, and readouts into the three-dimensional sky in which they're flying.

For decades, NASA—most recently Langley Research Center—has worked through Small Business Innovation Research contracts with Dimension Technologies, Inc. of Rochester, New York, to develop, using Small Business Innovation Research contracts, displays that would project 3D images without glasses to help pilots read air, ground, and traffic. Previous iterations were capable of providing vivid imagery (Spinoff 1995, 2002) but required pilots to sit perfectly still in order to see the 3D images.

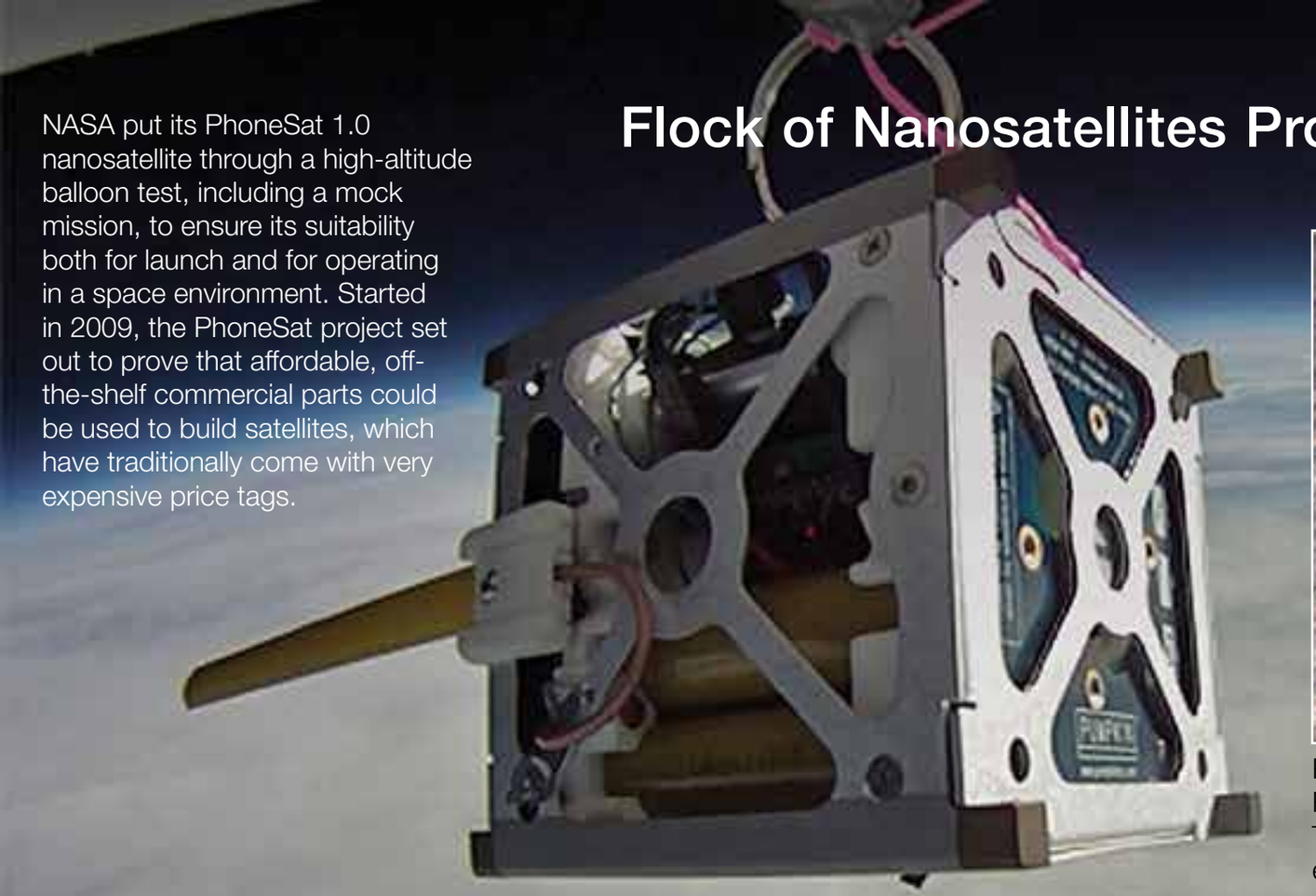
The company has now incorporated eye-tracking technology into its displays, which could be the key to helping pilots, as it allows the 3D images to move with the pilots so there's no loss in clarity.

The monitors are already a hit among gamers, who got a peek at the new technology at a series of video game industry conferences, including Immersed in Toronto, SIGGRAPH in Vancouver, and the NVIDIA GPU Technology Conference and Emerging Companies Summit in Silicon Valley. The company also has been in discussion with car manufacturers about the possibility of incorporating the display into a vehicle's center console, driver instrument cluster, and backseat entertainment packages.

Energy and Environment

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

Flock of Nanosatellites Provides a Daily Picture of Earth



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

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

In the late 2000s, physicist Chris Boshuizen was working at Ames Research Center, helping to transfer NASA technology to the private sector, when engineering director Pete Klupar would come around and tout how a smartphone has more capabilities than many satellites, as it has a bigger computer and better sensors. He'd follow up by asking why satellites are so much more expensive.

Boshuizen took Klupar's words to heart. He and fellow NASA physicist Will Marshall led a team that used smart phone parts to design small satellites, aptly named PhoneSats. In April 2013, NASA launched three PhoneSats into space, where they were able to take photos and send the data back to Earth. On the heels of that success, the agency has continued to improve on their design and functionality through its Small Spacecraft Technology Program.

But even before the launch, Boshuizen, Marshall, and Robbie Schingler, another NASA colleague, had envisioned being able to provide not just a few photos of Earth, but full coverage of the planet every 24 hours. In 2011 the trio launched Planet Labs Inc. and has been launching "flocks" of affordably made nanosatellites—which it calls "Doves"—into space throughout the last few years.

The company has raised more than $160 million in capital and has generated interest from a number of industries. Insurance companies could verify homeowner damage claims by examining before-and-after images of properties, and oil and gas companies could monitor pipelines to ensure integrity and safety. Mobile-phone companies want fresher satellite imagery to improve their map applications.

It would even be possible to stop deforestation, Boshuizen says. "If you're able to plot tree logging in an area where no one is supposed to be logging trees, then you'd be able to do something about it. We have the vision of turning insight into action."

Multispectral Satellite Imagery Shows Farmers' Fields in New Light

Lanny Faleide founded his Agri ImaGIS company, now called Satshot, in 1994 on an idea that may have given offense to the day's tillers of the earth: the idea that farmers didn't really know their fields. Not, at least, in the intimate detail that a multispectral imaging satellite, having passed over their farmland hundreds of times recording images in the visible and infrared spectra over the course of years, knew them.

His first difficulty, however, wasn't winning converts but gathering such imagery in sufficient quantities and, especially, distributing it. The Internet was in its infancy and lacked the capability to transmit or share such huge datasets. Fortunately, a team at the University of Minnesota had run into the same problem when they tried to carry out a project funded by Goddard Space Flight Center.

NASA had given the university a grant to develop ForNet (short for "forest network"), a set of applications that would let the Minnesota Department of Natural Resources use satellite data regarding the state's forests. To enable the work, the group developed MapServer, an open-source development environment still used by thousands of active websites.

Satshot, based in Fargo, North Dakota, still uses the platform to distribute imagery of fields in the United States and Canada in various bandwidths and resolutions from several different Earth-imaging satellites, providing farmers, crop consultants, agricultural dealers, and corporations with invaluable information.

By revealing crop density across a field, the images can help farmers distribute resources like seed, fertilizer, and water more efficiently, saving money and reducing runoff, and can also let them identify problems with their equipment. As more Earth-imaging satellites take to the sky, Satshot expects to be able to provide frequent enough images of fields that farmers will be able to use them to schedule irrigation.

Satshot's various apps offer satellite images of farms in a variety of spectral bands. Often, a quick visual scan can alert a farmer to a problem such as a faulty seeder or irrigation system, but the programs also offer in-depth analyses and allow a tractor to be programmed to deposit seeds and resources according to the fertility of soil in different parts of a given field.

The "biomass maps" Satshot provides allow tractors to deposit more seeds, fertilizers, and pesticide in the most fertile areas of a field while allocating fewer resources to soil that can't support dense vegetation. This targeted approach saves up to 20 percent on resources and also prevents excess fertilizers and chemicals from running off into the watershed.

Software Helps Restore Fire-Ravaged Habitats

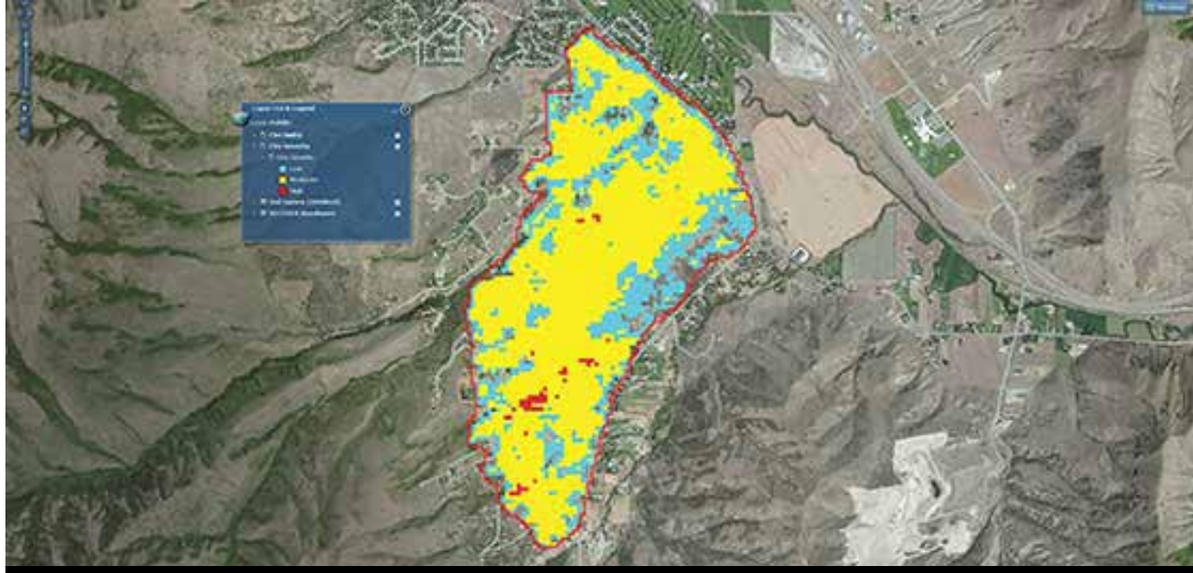
The Department of the Interior's Bureau of Land Management (BLM), in addition to coordinating firefighting efforts on federally held lands, is also responsible for post-fire restoration, which include stabilizing erosive soils to prevent the contamination of nearby streams, replanting native grasses to reestablish the natural ecosystem, and mitigating the damage caused by bulldozers used to suppress the fire.

By law, before the agency can commit to restoration work, it first must submit an Emergency Stabilization and Rehabilitation plan, or ESR, which lays out the proposed course of action based on information gathered on plant species, soil layers, and other data. But producing such a document within the mandated period of 14 days after a fire is extinguished is a tall order, because it's a time-intensive process.

A wildlife biologist and founding director of the Geographic Information Systems Training and Research Center at Idaho State University, Keith Weber teamed up with scientists at Goddard Space Flight Center and, through Research Opportunities in Space and Earth Science grants awarded to them in 2011, developed the Rehabilitation Capability Convergence for Ecosystem Recovery, or RECOVER system. The software utilizes Amazon Web Services' cloud computing technologies to wrangle all the information needed to produce an ESR.

The Idaho BLM used RECOVER for the first time in the 2013 wildfire season, with great results. "We can get all the information in one place in a very short turnaround," says Gregory Mann, a fire ecologist with the agency. In addition, firefighters found the program useful for knowing where an active fire would spread based on identifying adjacent vegetative areas, helping them steer clear of moving flames, and for helping to determine locations that need controlled burns and canopy trimming as preventive measures.

Given RECOVER's early successes in Idaho, the goal is to expand the technology's use to the entire western United States.



By using RECOVER, the Idaho BLM can quickly access upwards of 20 geospatial datasets for a given area, from slopes and elevations to native grasses and endangered wildlife, that assist with active fire containment and post-fire restoration work. Shown is a RECOVER client web map for a wildfire that occurred in Pocatello, southeastern Idaho, in 2012. The colors represent the extent of the fire severity, or loss of organic matter, in different areas.

"It's a good tool for land managers to use to help make the best informed decisions on the ground."

— Gregory Mann, Bureau of Land Management

In the off-season, fire management agencies operate controlled burns and trim understory growth to reduce the potential for fires. Workers are using RECOVER to locate those vulnerable areas and then, after they're done, mark them as completed.

Buildings for Manipulating Magnetism Revolutionize Magnetometers

Two buildings at the edge of Ames Research Center were constructed to calibrate magnetic sensor systems and test space probes that contained highly sensitive magnetic instruments to ensure they'd work properly in space. But by the late 1990s, the buildings were no longer in high demand, and the center considered tearing them down.

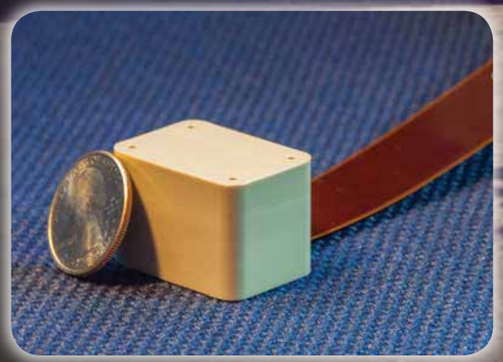
Magnetometers can't be tested in just any facility, as interference from traditional building materials, including rebar and nails, could skew test results or otherwise cause inaccurate readings. The facilities at Ames were built with wood and nonaluminum nails.

A research scientist there begged the agency to reconsider, suggesting NASA might again need the ability to manipulate magnetism to test future equipment, and helped find a company with the same needs to utilize the building. Geometrics Inc., based in nearby San Jose, California, fit the bill: the company makes magnetometers, devices used to measure magnetic fields and detect anomalies. The company signed a Space Act Agreement with Ames to take over the facility, promising to maintain the buildings but also to move aside should NASA need to use them.

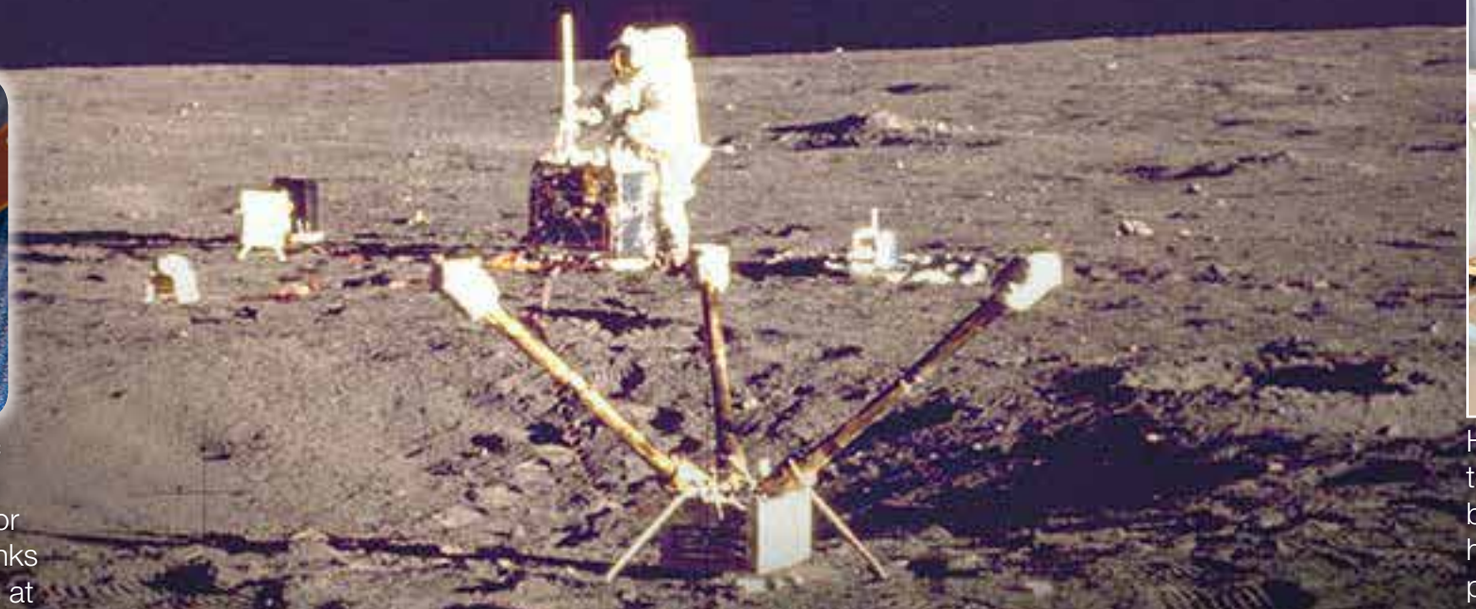
Geometrics has used the buildings to improve their magnetometers, which read magnetic signatures found in soil, water, or other substances. Now smaller and more efficient, the magnetometers are being used by the oil industry to help calibrate underground drill rigs or find buried objects and by energy companies in the North Sea to identify bombs dropped during World War II that might need to be removed before windmills can be installed.

Another use for magnetometers is in the medical field, as they can be used to detect the electrical activity produced by the human brain to determine the long-term effects of a stroke.

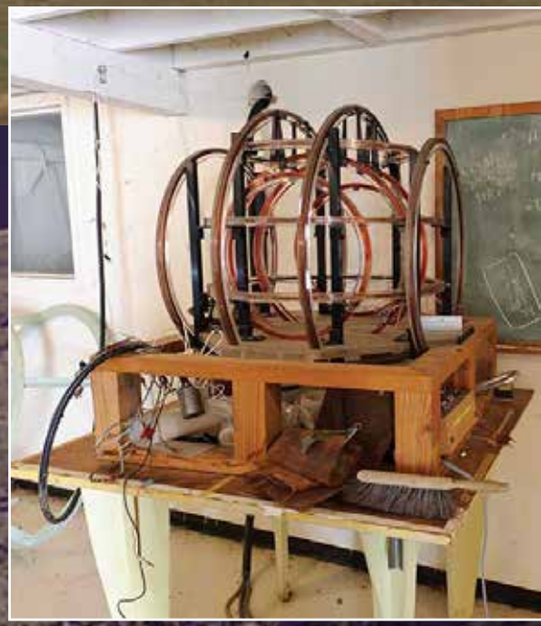
One of two specially designed and equipped facilities at Ames Research Center where magnetic fields can be manipulated. Geometrics used the buildings to help develop their magnetometers, used to detect irregularities in magnetic fields.



Geometrics' micro-fabricated atomic magnetometer, a prototype of which is shown here, has been optimized for miniature deployment platforms, thanks in part to the use of special buildings at NASA's Ames Research Center.



When Apollo 12 landed on the moon, astronauts deployed a special lunar-surface magnetometer, developed at Ames Research Center, to measure magnetic fields there.



Helmholtz coils like this are used to manipulate magnetic fields. Two buildings at Ames Research Center helped test how Earth's magnetic pull would interact with components of early spaceflight vehicles.

Cost-Saving Method Drives New Solar Cells for Exploration, Gadgets

Solar arrays like these, attached to the ISS, will be increasingly important to NASA as the agency works to travel deeper into space.

Troops in desert regions already are using MicroLink Devices' flexible, lightweight solar arrays as a source of portable, renewable energy. The panels attach to a backpack and are capable of charging military batteries, eliminating the need to carry extra ones.

NASA continues to consider new methods of propulsion for explorations deeper into space, with an increasing interest in the capacity of solar-electric propulsion driven by high-power solar arrays. However, large arrays need large quantities of solar cells, and the cost of developing space-qualified cells is hefty.

Currently, there are two companies that supply NASA with most of its solar cells and arrays, but MicroLink Devices, based in Niles, Illinois, is trying to break into the market. Through a series of Small Business Innovation Research contracts with Glenn Research Center, the company has created a new method for growing solar cells, incorporating a reusable gallium arsenide substrate and manufacturing processes that significantly reduce the cost of production. The resulting cells, called inverted metamorphic multi-junction cells, are flexible and lightweight, further reducing the cost of sending them into space for use.

Already MicroLink has sold its solar arrays to the military, which is incorporating the flexible sheets into backpacks as a source of portable energy instead of relying on replacement batteries. The panels were featured in 2014 articles in both *Popular Science and Popular Mechanics,* with the latter lauding the US Naval Research Laboratory's Marine Austere Patrolling System, developed by MicroLink, with its 2014 Breakthrough Award for Innovation.

Thanks to an innovative process that incorporates a reusable substrate, MicroLink Devices has created thin, flexible solar cells and arrays that could be used to help power exploration in space.

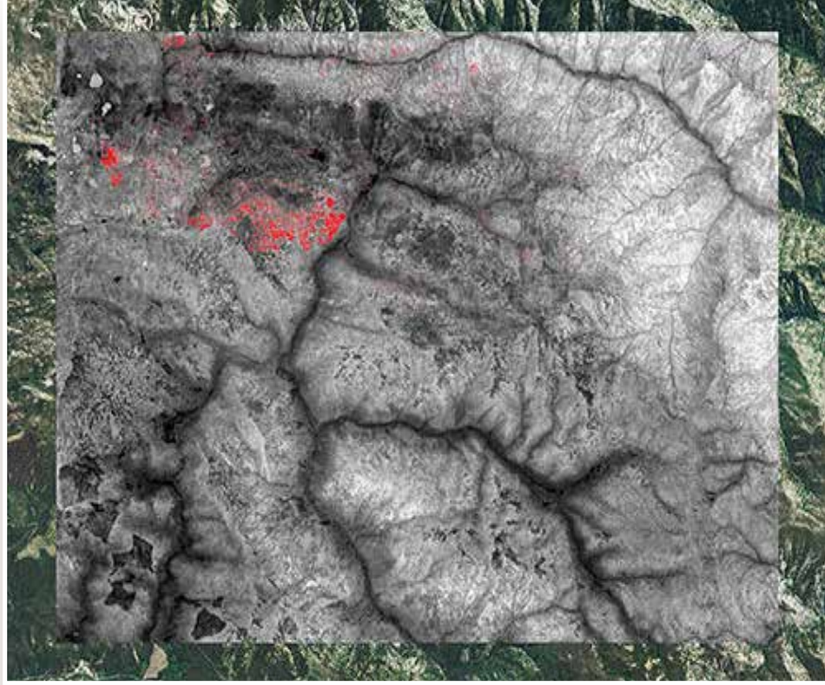
Wide Area Thermal Imaging System Brings the Landscape into Focus

While it's easy to spot a plume of smoke in the distance, it can be difficult to determine the exact location, size, or intensity of a forest fire or where it's spreading. NASA and the U.S. Department of Agriculture's Forest Service have traditionally used sensors and airborne monitoring devices but often found that the fire's signal could overpower sensors, resulting in unusable images.

John Green was an engineer for a sensor manufacturing company when NASA issued a call for a new imaging system, and he immediately set about designing a scanner incorporating attributes of both a whisk broom scanner, which moves back and forth as a satellite orbits Earth and collects information one pixel at a time, and a digital camera, which collects more pixels at once with greater detail.

After starting his own company, Ypsilanti, Michigan-based Xiomas Technologies, Green received several Small Business Innovation Research contracts from Ames Research Center for the development of the Wide Area Imager, an aerial scanner capable of taking several kinds of information and layering that data into a single image. NASA and the Forest Service are now using the scanner to obtain precise information on a fire's location while eliminating false information from nearby large, warm objects or the heat reflected from a road.

Other users, including municipal governments, have worked with Xiomas for aerial imaging work. Jefferson County, Kentucky, awarded Xiomas a contract to map its municipal sewer district, identifying fluids warmer than water flowing into a river from a large industrial building, broken water pipes, and bypassed septic systems.



Combining elements of both a line scanner and a digital camera, Xiomas has developed an aerial scanner that can pinpoint the presence and location of a forest fire from a great distance and indicate its intensity.

Xiomas' Wide Area Imager was developed to help NASA and the U.S. Department of Agriculture's Forest Service detect forest fires more quickly, enabling firefighting resources to be deployed faster and help minimize damage.

Xiomas has combined the resolution of a digital camera with the wide field of view offered by "whisk broom scanners" capable of photographing large geographic areas in shorter periods of time with greater detail than previously available.

Photocatalytic Water Splitter Stores Energy as Hydrogen

At a glance, the surface of Mars appears to offer little in the way of resources to support astronaut crews. Scenes captured by rovers exploring the planet depict a desolate, dusty landscape, strewn with rocks and punctuated by craggy outcrops stretching to meet the rusty sky in all directions.

But NASA's rovers have confirmed the presence of water frozen in Martian soil, a significant find not just because of water's life-giving properties but also because of its constituent parts—oxygen, that other most precious resource, and hydrogen, NASA's rocket fuel of choice.

Before securing two Small Business Innovation Research contracts with Ames Research Center in 2002, scientists at Concord, Massachusetts-based Nanoptek had discovered a way to make titania, a semiconductor that can split water into oxygen and hydrogen, responsive to visible light.

That a semiconductor's properties can be altered by stress was known, but the problem was maintaining high enough stress without the substance bursting. Nanoptek's solution was to grow crystals on a surface nanostructured with tiny peaks. As each layer of the crystalline lattice is added, the strain on its surface increases. Nanoptek is now able to engineer titania with hundreds of thousands of pounds of strain per square inch, making it responsive to 29 percent of sunlight. It took years to get from the company's discovery to a durable, economical solution, but the work began with the NASA contracts.

The company's photocatalytic panels are the first electrolyzers to be able to convert energy to hydrogen, at almost no loss, for use as fuel, and they provide advantages over batteries, such as high performance in hot conditions and zero losses over time.

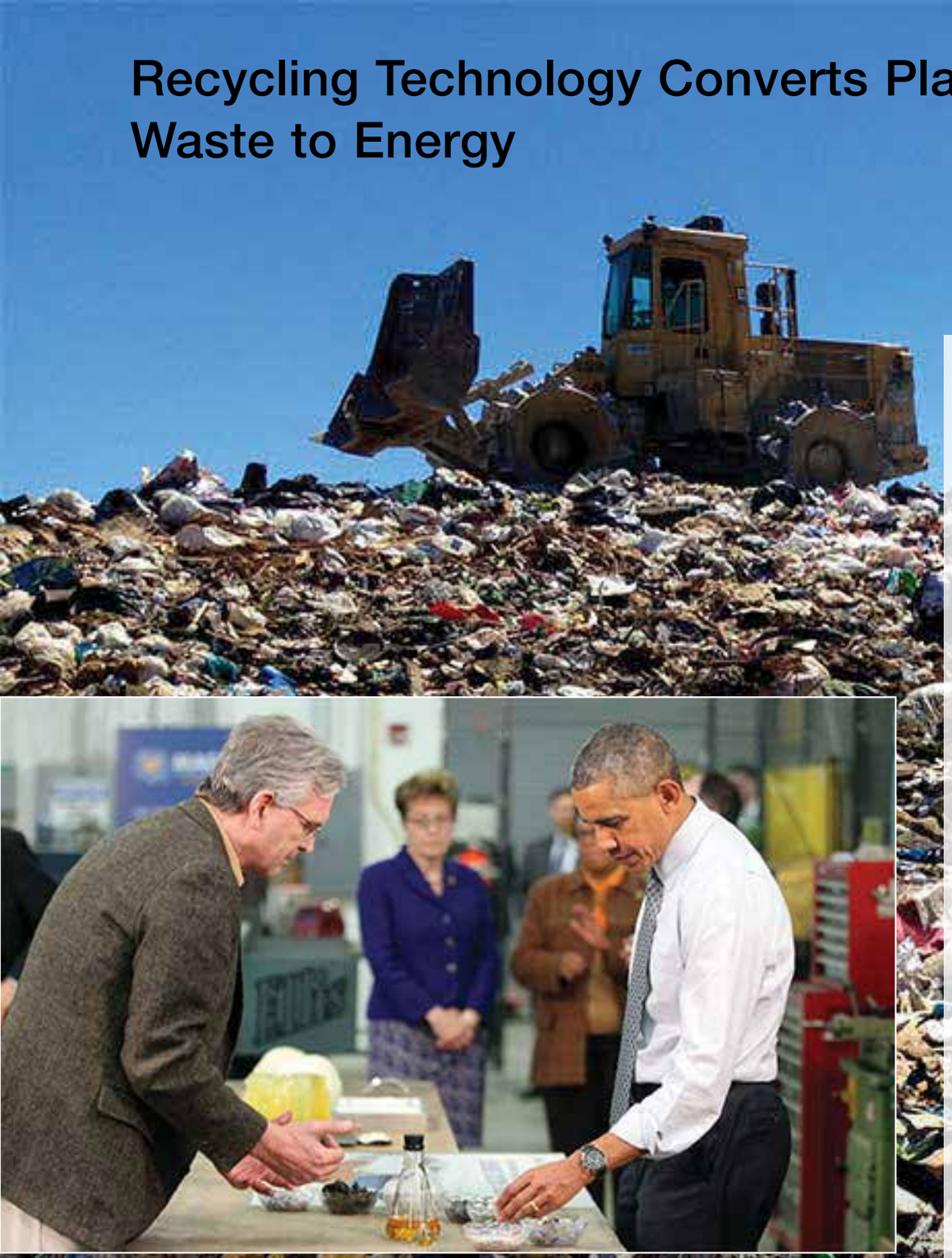
Image courtesy of the U.S. Navy

As automakers and governments begin to turn their attention to hydrogen fuel cell-powered vehicles, Nanoptek hopes its technology will become integral to the new, hydrogen-based transportation infrastructure.

In hotter parts of the world, the batteries used to store energy from solar panels often have heat-related performance issues that a tank of hydrogen stored for energy would not. What's more, Nanoptek's photocatalytic panels become more efficient the hotter they get. The company envisions solar power plants for communication towers in the developing world scaled to also provide reliable power to microgrids for local communities.

Recycling Technology Converts Plastic Waste to Energy

A landfill located in Buckhorn Mesa, Arizona. According to the Environmental Protection Agency, only 9 percent of plastic waste generated in 2012 was recovered for recycling. According to Jim Garrett, president of Vadxx Energy LLC, a major reason for the low number is that many plastics either contain additives and fillers that make them incompatible with current recycling technologies or are contaminated with paper or ink. The company's recycling technology overcomes those limitations as it converts many types of plastic into light crude oil.



Vadxx president Jim Garrett speaks with President Barack Obama about the company's plastics recycling technology at the Manufacturing Advocacy and Growth Network, or MAGNET, Innovation Center in Cleveland. The president visited the town on March 18, 2015, to learn how businesses were benefiting from working with MAGNET, which helped Vadxx connect with NASA Glenn Research Center through the Adopt a City Program, itself a byproduct of the Obama administration's Strong Cities, Strong Communities Initiative.

Image courtesy of Adam Levine, CC BY 2.0

Most of the plastic we throw in recycling bins goes unrecycled, according to Jim Garrett. The reason is many plastics contain additives and fillers or are contaminated with paper or ink, making them incompatible with current recycling technologies. But Garrett's company, Cleveland-based Vadxx Energy LLC, founded in 2009, has advanced an innovative plastics recycling technology that converts plastics of all kinds back to their original form: light crude oil.

The technology works by sending plastic feedstocks through a shredder and then an extruder/kiln combination, where the feedstock is incrementally heated, producing vapor, which is condensed into liquid form and distilled into fuel gas and diesel additive, along with inert char.

The company needed help optimizing the kiln's design, which requires analysis of the kiln's geometry, tilt angle, and rotation speed, along with the polymer's thermodynamic and physical properties. Glenn Research Center's work on rocket propulsion made it a natural choice for a partnership to analyze such a process.

"We have scientists who for decades have been studying the kinematics of oil decomposition for turbine engines and kerosene rocket engines," says Paul Bartolotta, a senior technologist there. Through the Obama administration's Strong Cities, Strong Communities Initiative, in 2012 Glenn provided 40 hours of pro bono consultation to Vadxx, resulting in a model the company successfully used to optimize the output of the oil byproduct.

The company is now building its first commercial kiln in nearby Akron. When fully operational, it will process some 20,000 tons of waste per year to produce 100,000 barrels of petroleum product. While Vadxx will operate that facility, its expansion plans center around licensing the technology. Each unit is projected to make $8 to $12 million per year in revenue for its operator and provide 18 full-time jobs. Waste disposal companies and large manufacturing facilities also stand to gain by paying less to truck material to a Vadxx unit than to the landfill.

Tiny Capsules Enable a World of Possibilities

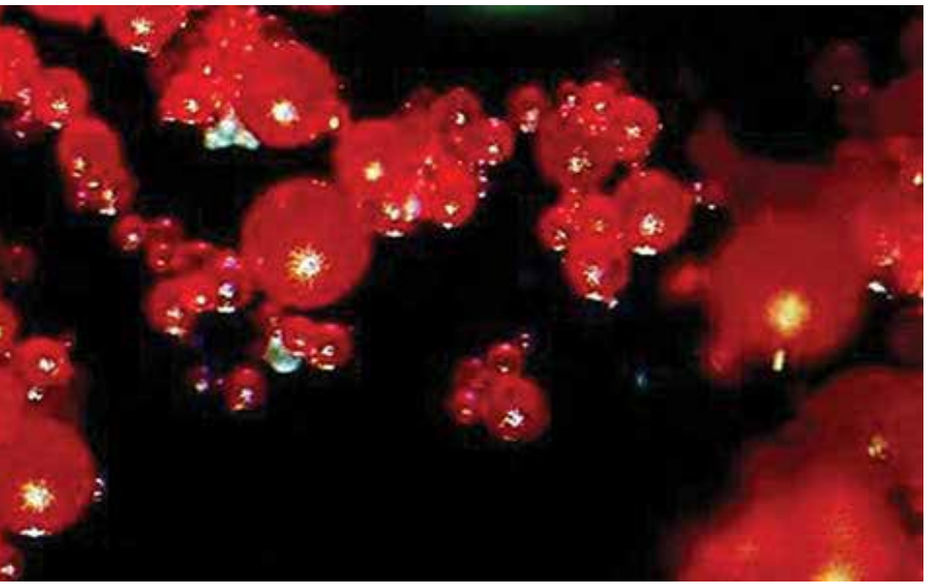
In the 1980s, NASA was working on a method to create hollow, perfectly spherical microcapsules capable of containing live cells for use in time-released antibiotics. After struggling to create uniformly shaped and sized capsules on Earth due to gravitational interference, chemist Dale Kornfield from Marshall Space Flight Center successfully developed a machine that operated in microgravity and produced round capsules, a process he later refined to work on Earth.

At the same time, a graduate student named Joe Resnick received a call inviting him to work on a new external coating for the Stealth Bomber, an assignment that introduced him to Kornfield. Inspired by the capsules made in space, Resnick began fleshing out an idea he'd had for microspheres made from beeswax and obtained a license for Kornfield's device in order to modify and improve it.

The resulting machine produced biodegradable wax capsules measuring 150 microns in size and containing a yeast that could break down oil spilled in water, sold as Petroleum Remediation Product and used in the 1989 cleanup of the Exxon Valdez spill in Alaska (*Spinoff 1994, 2006*).

Through his company, RMANNCO, based in Lenore, North Carolina, Resnick continued to modify the machine, shrinking the capsules to sizes ranging from 1 to 8,000 microns, or from one-fiftieth the diameter of a human hair to the size of an average ladybug. The microcapsules have been used by food manufacturers to enhance the flavor of their products without wasting ingredients, and cosmetic companies to create longer-lasting and self-refreshing lipstick colors.

Currently, Resnick is developing a new supplemental food supply for a variety of stingless honeybee, creating a hybrid pollen from the waxy capsules filled with a synthetic stevia solution that can be a source of food during the winter and monsoon seasons. The honey that results can be packaged and sold as a specialty honey suitable for people with diabetes.



NASA developed a method for making spherical, uniformly shaped microcapsules. Joe Resnick, a scientist and inventor, built on NASA's research and now works with companies to incorporate microcapsules into products ranging from foods and beverages to cosmetics, like these capsules used in lipstick to refresh color after application.

One new use of RMANNCO's microcapsules, made from beeswax, is a hybrid pollen made from wax and extract from the stevia plant. The pollen clings to the bees better than regular pollen, and the honey the bees make can be sold commercially for people who cannot consume regular honey.

Microcapsules made from beeswax are a safe, natural way to enhance the flavor of a product such as grape juice.

Information Technology

Whether monitoring mechanical systems worlds away, analyzing the dynamics of Earth's climate, designing vehicles that push the limits of sturdiness and efficiency, or modeling the behavior of air around vehicles in flight, NASA has a constant need for innovation in software and information systems. The products of these endeavors might find use in anything from optimizing wind turbines and predicting engine failures to cloud computing and targeting online advertising.

System-Health Monitor Predicts Failures before They Happen

A young engineering company is betting that NASA teams at the Mission Control Center, aboard the International Space Station, and in Ground Support at Cape Canaveral—just about all the agency's Hollywood roles—will set a trend that explodes across private-sector industries.

In an era of "smart" devices, what's still absent is any self-awareness in these technologies. CEMSol LLC, based in Phoenix, plans to change that, beginning with its Integrated System Health Management (ISHM) software.

The first version, known as the Inductive Monitoring System (IMS), was developed in 2003 at Ames Research Center. Any system an engineer might want to monitor has sensors measuring temperature, pressure, fuel flow, voltage, and other vital signs. The program collects that data and, by mining an archive of such data samples, determines relationships between these factors and establishes a baseline and parameters for normal system behavior. Deviations from that norm suggest a problem and a possible future failure.

By 2012, IMS had been applied to a dozen programs at NASA Mission Control, and it's now being integrated into launch control systems at Kennedy Space Center and monitoring the carbon analyzer that ensures drinking-water safety on the International Space Station.

CEMSol licensed the program in 2012, along with a software extension and the user interface Ames had created.

That year, CEMSol teamed up with Ames and Lockheed Martin to try ISHM on the Lockheed C-130 Hercules, which had problems during start-up. The program was able to predict a start-up failure three starts before it occurred. Lockheed Martin invested $70,000 in the test and recouped 10 times that amount in reduced maintenance costs and mission delays.

Equating system-health monitoring with the ability to verbalize symptoms to a doctor, the company sees ISHM as just a step toward near-universal self-monitoring in everything from cell phones to medical devices, and from refrigerators to automobiles.

The IMS that CEMSol licensed from Ames Research Center to develop its ISHM software has also been applied to the Black Hawk helicopter engine.

Image courtesy of the U.S. Navy

In 2012, CEMSol teamed up with Lockheed Martin to see if the company's ISHM software could predict failures of the bleed valve that switches air flow between engines on the C-130 Hercules during start-up. Lockheed Martin invested $70,000 in the test and recouped 10 times that amount in reduced maintenance costs and mission delays.

Image courtesy of the U.S. Air Force

During a test launch of the Orion Crew Vehicle in December 2014, the Inductive Monitoring System (IMS) that CEMSol licensed to create its Integrated System Health Management (ISHM) software was used to monitor electrical systems on the space capsule.

Algorithm Predicts and Evaluates Storm Surges

Around the turn of the millennium, NASA embarked on two missions that would have a large impact on Earth science: the Quick Scatterometer, or QuikSCAT satellite, whose data helped scientists compute the speed and direction of winds swirling above the world's oceans more effectively, and the Shuttle Radar Topography Mission (SRTM), which, at the time, resulted in the world's first near-global topographical map of Earth. The improved data brought by these missions compelled NASA's Stennis Space Center, under the Small Business Innovation Research program, to solicit proposals by companies to improve weather forecasting and evaluation tools for disaster management.

The winning proposal belonged to WorldWinds Inc., which is based on the Stennis campus and specializes in radar-based remote sensing products and services. In 2004, the company used the new SRTM and QuikSCAT data to derive a proprietary algorithm that improves the Advanced Circulation and Storm Surge Model, or ADCIRC, which the federal agencies utilize for disaster preparation, to more accurately render storm surge models as well as hindcasts—recreated storm surges and wind profiles of past storms.

In 2007, WorldWinds commercialized StormWinds, which takes advantage of the firm's 852-processor cluster (equivalent to 2,000 desktops strung together) to assist with a number issues. They range from assisting with redrawing storm surge maps for both the Gulf and the East Coast to helping government agencies prepare for hurricanes by running simulations to see which areas are likely to flood, and advising homeowners on how much damage was caused by wind and how much was caused by flooding during a storm so insurance companies are billed equitably.

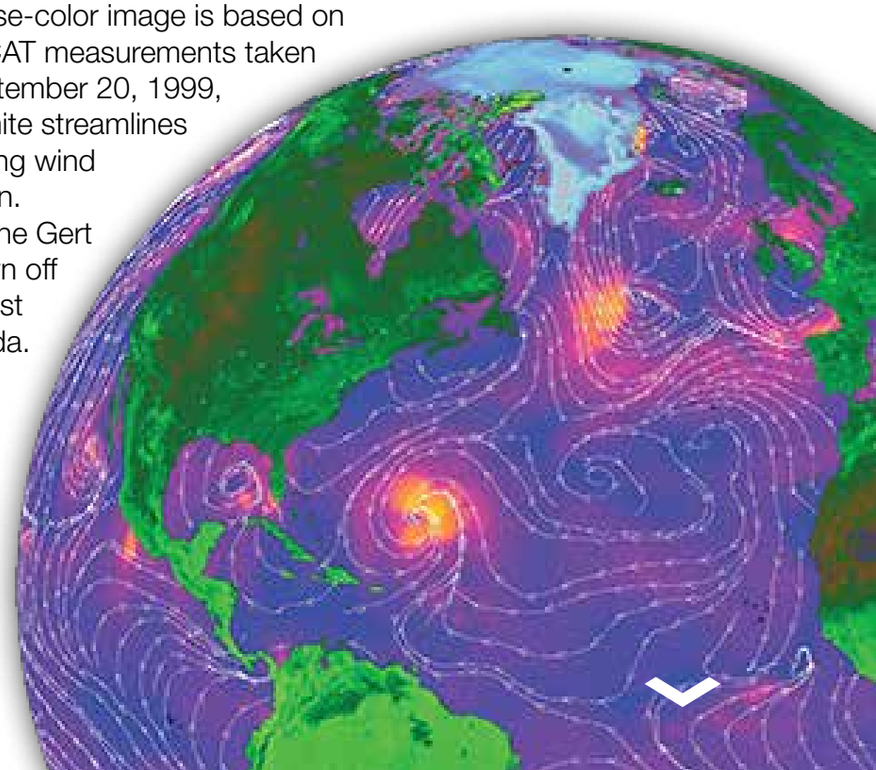
Company president Elizabeth Valenti says, "We're very proud that we're able to tell people what actually happened. We like to say we're in the truth business."

U.S. Navy air crewmen survey the damage inflicted by Hurricane Katrina, the costliest storm in the nation's history, en route to Stennis Space Center. Using its StormWinds application, WorldWinds provided complimentary "Wind vs. Water" profiles for homeowners along the Gulf to help them settle claims for flood and wind damage.

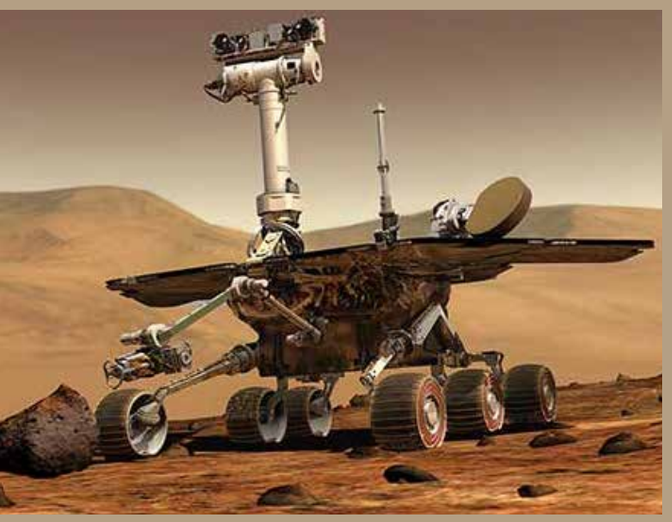
Image courtesy of the U.S. Navy

Using NASA SBIR funding, WorldWinds drew on newly available observational data to develop StormWinds, a program that can provide accurate storm surge simulations as well as hindcasts, which remodel the winds and storm surge in the aftermath of a tempest. StormWinds created this pictograph showing the peak storm surge water levels caused by Hurricane Sandy in areas of New Jersey and New York in late October 2012.

NASA's Quick Scatterometer, or QuikSCAT, was launched in 1999, and for 10 years it recorded ocean wind patterns, helping scientists to improve weather forecasts and glean more data on changes in vegetation and ice extent over land and in the polar regions. This false-color image is based on QuikSCAT measurements taken on September 20, 1999, with white streamlines indicating wind direction. Hurricane Gert is shown off the coast of Florida.



Mars Rover Work Spawns PDF Collaboration Software



Former Jet Propulsion Laboratory Engineers at Alliance Spacesystems created the first Bluebeam software to help them meet tight deadlines for designing the robotic arm for the twin Spirit and Opportunity Mars rovers in the late 1990s. The engineering-geared PDF reader soon spun off into its own company and popular product line.

Although Bluebeam was created to meet the needs of engineers, it has become popular in other industries, especially those that also use computer-aided design, such as architecture. This AutoCAD drawing depicts the Mercury City Tower in Moscow.

Image courtesy of Edvard Wlodyga, CC BY-SA 3.0

Like satellites in orbit, some spinoffs just keep spinning.

One of the first projects undertaken by Alliance Spacesystems, founded by a handful of engineers from NASA's Jet Propulsion Laboratory in 1997, was the robotic arm for NASA's twin Mars rovers, Spirit and Opportunity. To meet tight deadlines on the project, Alliance wanted to become more efficient in tasks like reviewing, marking up, and circulating documents, as well as converting computer-aided design (CAD) drawings into PDF format.

Adobe Reader was already popular in those days, but no one had developed a PDF program to meet engineers' needs. So Alliance engineers developed a plug-in that would convert CAD models into high-resolution, scalable drawings with the click of a button and also facilitated document markup and review.

In 2002, several Alliance engineers founded Pasadena, California-based Bluebeam Software Inc. to market the software as Pushbutton PDF. The program has evolved to add the ability to view, manage, and mark up rotatable, three-dimensional models while including data describing parts and materials, any other relevant properties, and hyperlinks for easy document navigation.

Pushbutton PDF was followed by several other PDF programs that facilitate collaboration and project management and enhance PDF automation and functionality. Bluebeam has found a broad customer base, not just in engineering but also in industries like architecture, construction, and oil and gas. While a majority of the company's clients are in fields where AutoCAD is dominant, its products have also found a place in government and business, where the software reduces paper waste and increases efficiency.

Bluebeam has steadily grown by about 50 percent every year, and in October 2014, the company was purchased for an even $100 million. By then, Bluebeam claimed more than 650,000 users in 96 countries, and it employed about 150 people in four office locations.

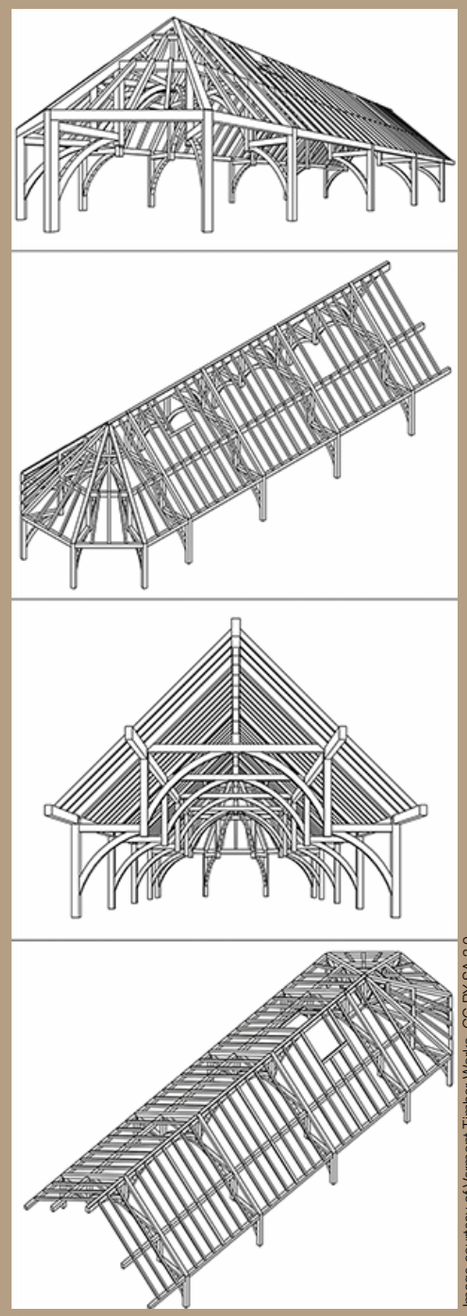


Image courtesy of Vermont Timber Works, CC BY-SA 3.0

One of Bluebeam's earliest and most important features is the capacity to convert three-dimensional computer-aided-design models into high-resolution, scalable PDF drawings.

Open Source Tools Popularize Infrastructure for Cloud Computing

Cloud computing came into its own as a technology starting at about the end of the 2000s. As the metaphor implies, it signifies the centralization of hardware and software resources (in the "cloud") apart from individual devices that utilize them. There they can be more easily secured, efficiently managed, and frequently upgraded.

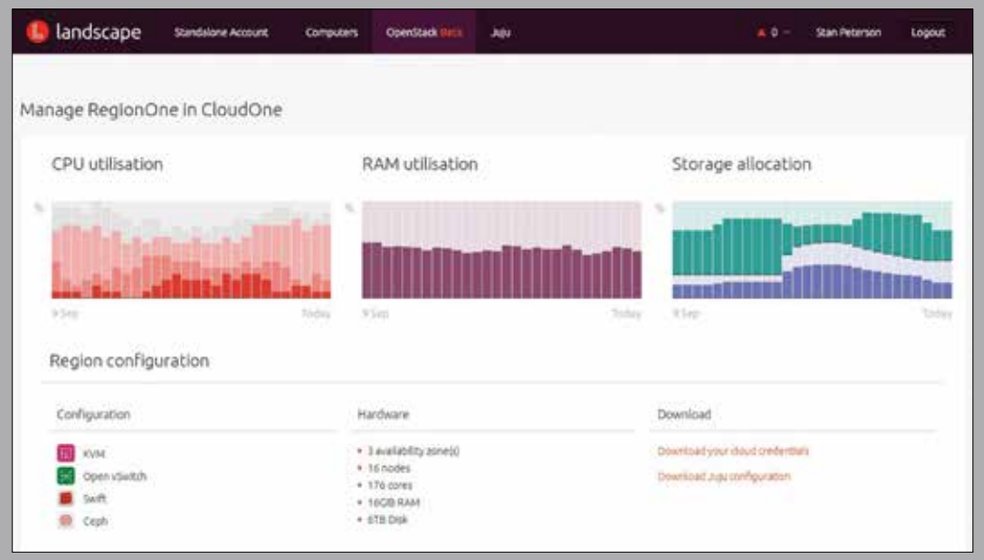
In 2009, when NASA determined it needed a cloud-computing platform for internal web services, the industry landscape was dominated by a few large players, all of whom were offering proprietary solutions. A team of developers at Ames Research Center believed that an open source alternative could meet the needs of many potential users and decided to create it themselves. Partnering with industry, NASA developed OpenStack, now the world's most popular open source cloud-computing platform (*Spinoff* 2012).

OpenStack has been adapted for use by many companies, but Canonical Ltd., an international organization with offices in Boston, decided that it would incorporate it into its own Linux-based operating system called Ubuntu.

In the Canonical Distribution, which is Canonical's version of OpenStack, the company offers a tightly integrated suite of software products that enhance the technology and make it more accessible to companies that don't have the resources to maintain full-time cloud-computing engineering teams. Canonical also offers a range of hardware- and service-based products that let companies have a private cloud without having to manage it themselves at all.

Now a billion-dollar technology in its own right, OpenStack continues to evolve and develop at a furious pace. "It's fair to say that OpenStack is just getting going," says Mark Baker of Canonical. "There are a lot of places it can go, and a lot of us in this space are aiming to make it more broadly accessible to organizations over the next few years."

The Canonical Distribution manages and even automates many tasks that until now have required engineers to visit data centers.



Early adopters of OpenStack were typically big companies that could devote entire engineering teams to making it work smoothly. Canonical's free and open source distribution of OpenStack combines the platform's power with ease of use. Users can progress from downloading the files to a completed installation within a few mouse clicks, and Canonical provides intuitive, graphical interfaces to control every aspect of its cloud resources.

Software Optimizes Designs from Spaceships to Wind Turbines

Sharing computer code with industry has become a major component of NASA's Technology Transfer Program, but when Craig Collier developed the ST-SIZE program for Langley Research Center in the late 1980s and early '90s, the agency had never before issued a software license.

Collier created the program to assist with the design of the National Aerospace Plane, known as X-30, planned to fly 20 to 25 times the speed of sound. ST-SIZE would help determine the best materials and configurations to keep the spaceplane as light as possible.

After X-30 was cancelled, Collier founded Newport News, Virginia-based Collier Research Corporation, which, in 1996, obtained a license for ST-SIZE, becoming the first company to license NASA software.

Retooled as HyperSizer (*Spinoff* 1997, 2003, 2009), the program was marketed as a design optimizer, one that could calculate the weights of different vehicle configurations based on their materials and suggest design changes. Beginning in 2005, Small Business Innovation Research contracts with Glenn Research Center and Langley funded improvements to the software, making it better suited to designing alternate versions of the Orion Crew Module and its heat shield carrier, which NASA hired the company to work on.

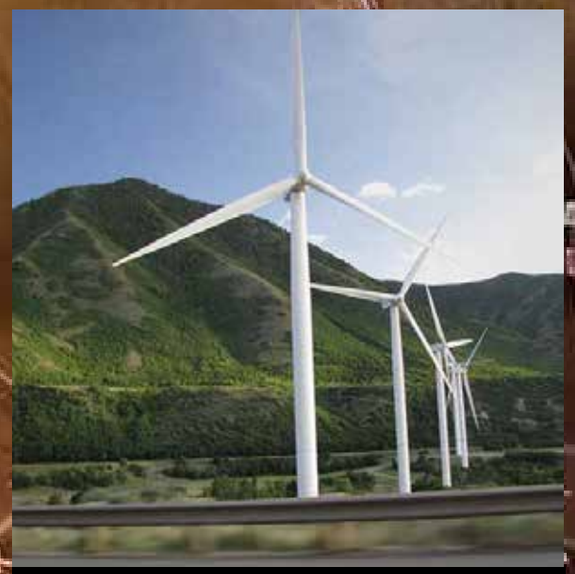
HyperSizer can now tell the user how laminates should be stacked and other structural details. It can also alter designs for manufacturing ease, minimizing the number of cuts, ply drops, and layers of laminate and the number of movements the factory's tape head has to make.

Almost every American company designing space vehicles uses HyperSizer, as do many aircraft companies, saving untold time and money. Recently, the software found a terrestrial application when Collier signed a contract with the country's largest wind turbine manufacturer.

NASA's first licensed software now earns around $4 million per year and is used in 20 countries around the world.

Bombardier's Learjet is one of several commercial planes designed with the help of Collier Research Corporation's HyperSizer software.

Image courtesy of JetRequest.com, CC BY-SA 3.0



HyperSizer recently found its first terrestrial application in helping to design blades for wind turbines. In 2014, Collier Research Corporation signed a contract with the country's largest wind turbine manufacturer.

Image courtesy of Scott Tere12sl, CC BY-SA 2.0

Beginning in 2007, NASA engineers used HyperSizer to design the Orion Composite Crew Module, a carbon-graphite alternative to the original aluminum-lithium capsule. In 2012, HyperSizer was again employed to design a lighter heat shield carrier for Orion. Both projects resulted in significant improvements to the software.

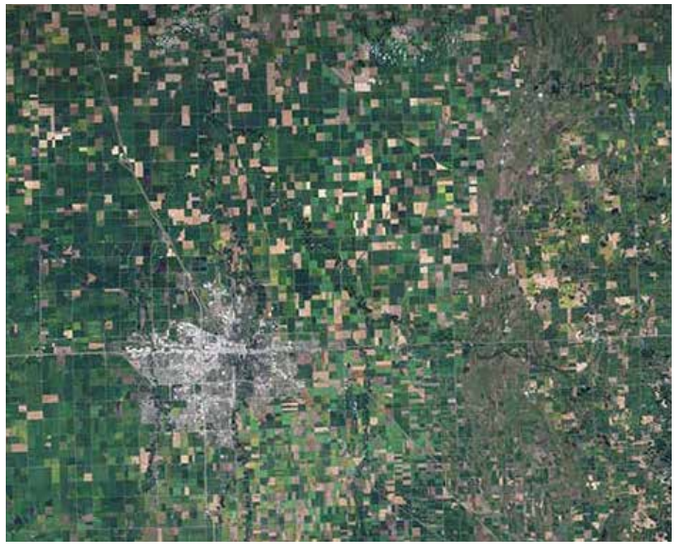
NASA Climate Analytics Support Biological Research

Every few seconds, NASA satellites transmit more than a gigabyte of data back to Earth. As the agency continues to accrue more data, so do various programs that utilize them. Take MERRA, shorthand for Modern-Era Retrospective Analysis for Research and Applications. Run out of Goddard Space Flight Center's Global Modeling and Assimilation Office since 2008, MERRA integrates data from a variety of satellite systems into numerical models to recreate a synthetic data record of the weather at any point in time from 1979 to the present.

MERRA is used by outside researchers for investigating past weather conditions and for computing climate projections and how they impact habitats and food systems, for instance, but it's becoming more challenging to download and work with MERRA files as they become larger. "You'll find that people using these big datasets are spending days, if not weeks, moving data over to their workstations," says Goddard senior computer scientist John Schnase. "That's not including the time it takes them to manipulate the data and run their experiments once they have it."

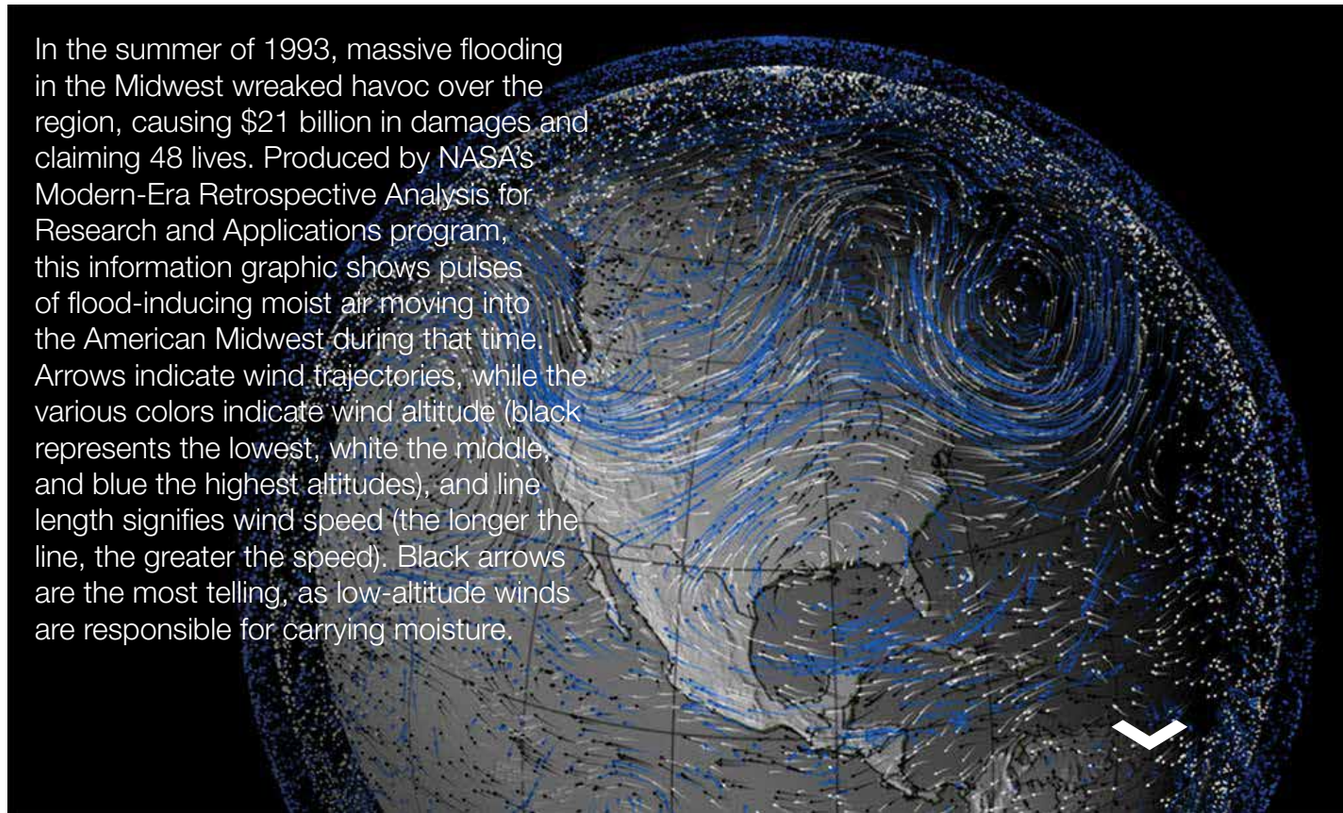
In 2012 Schnase and fellow Goddard computer scientist Dan Duffy received funding under the agency's Research Opportunities in Space and Earth Science program to develop a software-as-a-service model for tapping into MERRA, the idea being that MERRA performs the necessary computing work and delivers only the results, a much smaller dataset, to users for further analysis. Two years later, Climate Analytics-as-a-Service, or CAaaS, was born.

One of the first organizations utilizing the new technology is the iPlant Collaborative, which supports life sciences research. iPlant has developed a graphical interface for CAaaS that's available to member scientists to, as examples, perform crop simulation models to project where plants will grow best, given different weather conditions, or see how projected climate changes would impact the health of livestock.



In this image shared by NASA's Earth Observatory, Minnesota's farmlands look like a patchwork quilt. By utilizing CAaaS, researchers can run climate projections to investigate where crops would grow best, given different scenarios.

NASA's Moderate Resolution Imaging Spectroradiometer captured an image of an uncommonly early blizzard that blanketed northeastern Wyoming and western South Dakota from October 3-5, 2013. The cattle hadn't yet grown their thick winter coats that allow them to survive winters, resulting in the deaths of about 15 to 20 percent of South Dakota's herds. By using the agency's Climate Analytics-as-a-Service, or CAaaS, researchers could run projections to determine what regions may no longer be suitable for raising cattle in the future due to climate change.



In the summer of 1993, massive flooding in the Midwest wreaked havoc over the region, causing $21 billion in damages and claiming 48 lives. Produced by NASA's Modern-Era Retrospective Analysis for Research and Applications program, this information graphic shows pulses of flood-inducing moist air moving into the American Midwest during that time. Arrows indicate wind trajectories, while the various colors indicate wind altitude (black represents the lowest, white the middle, and blue the highest altitudes), and line length signifies wind speed (the longer the line, the greater the speed). Black arrows are the most telling, as low-altitude winds are responsible for carrying moisture.

The Jet Propulsion Laboratory's Spacecraft Health Inference Engine (SHINE) first proved itself when it discovered an anomaly in the Voyager spacecraft's telemetry system just before the craft's encounter with Neptune in 1989. Since then, the software has been used to monitor the health of a host of NASA systems.

Artificial Intelligence Targets Advertising by Understanding User

A couple of years ago, AJ Abdallat went online and bought a bracelet as a gift for his wife. He wasn't happy with the product, he says, but to this day, he continues to receive online advertising based on that one negative experience.

This is the kind of ham-handed online advertising that Abdallat, CEO of the startup Beyond Limits Corporation, based in Thousand Oaks, California, says will soon become a thing of the past. The company has licensed two artificial intelligence programs from NASA's Jet Propulsion Laboratory (JPL) that will enable Beyond Limits to more precisely target digital marketing.

Traditional expert-system software, which simulates the knowledge and judgment of a human expert in a given field, uses a vast knowledge base and relies on a large mainframe computer or server. By contrast, JPL's Spacecraft Health Inference Engine (SHINE) compiles the same knowledge base into a compact representation, which can be executed on the user's computer much faster, and which it uses to synthesize a lean, custom solution for each problem.

The other program Beyond Limits licensed is Hunter, a natural language-understanding system developed at JPL, able to extract specified content from even poorly structured text.

Beyond Limits made improvements to the software and figured out how to use it to target online advertising to individual users. Rather than push content based on a user's previous purchase or search terms, the software seeks to understand a person's intent and sentiment at a given time and push relevant content.

"This is a market where artificial intelligence capability is taking a major role," Abdallat says of the online advertising business, noting that it's the only advertising sector that's growing. "It's an area looking for a solution because the industry is changing. We think the NASA technology can make a significant difference here."

SHINE, an artificial intelligence program NASA designed to monitor the health of space systems, is now being used to determine the intent and sentiment of Internet users to better target advertising.

NASA ushered in an era of simpler, more efficient turbopumps with the invention of Fastrac in the 1990s. To minimize costly test stand launches, the agency created the Generalized Fluid System Simulation Program, or GFSSP, to analyze computational fluid dynamics. SpaceX used Fastrac as a blueprint for developing its Merlin family of rocket engines for the Falcon 9 launch vehicle, which is responsible for delivering payloads to the ISS.

Modeling Software Helps Rocket Scientists Go with the Flow

Rocket science and simplicity normally don't go hand in hand, but that's what NASA had in mind when it developed the Fastrac turbopump in the mid-1990s. Designed for smaller, less expensive spacecraft, Fastrac was made to run more efficiently and with simpler plumbing and fewer parts. But getting there still required rocket science knowhow, namely computational fluid dynamics (CFD), which involves three disciplines: thermodynamics, fluid mechanics, and heat transfer.

NASA was at a disadvantage because the agency did not have access to a general-purpose code for performing such analyses, which is the preferred method for ironing out most of the kinks, as opposed to firing up imprecisely designed turbopumps on the test stand. "A single test of the space shuttle main engine cost a million dollars, just for a couple minutes of firing," says Alok Majumdar, an aerospace technologist at Marshall Space Flight Center.

To meet that need, in 1994, just as Fastrac was getting underway, Majumdar began developing the Generalized Fluid System Simulation Program, or GFSSP, which was first used by the agency's analysts in October 1996. While the code is free for government employees and contractors, turbomachinery design company Concepts NREC, based in White River Junction, Vermont, and engineering consulting firm Mode Technology Group in Denver have licensed the technology and sell the software to the public.

NASA's Software of the Year award winner in 2001, GFSSP is now being used in the design of NASA's Space Launch System, which is slated for crewed missions deep into the Solar System, and also Virgin Galactic's LauncherOne spacecraft, aimed at the small satellite launch market.

Majumdar and his team show no signs of letting up. In addition to improving pre- and post-processor speeds, the program's next iteration, version 7.0, will include a separated phase model, which looks at mixtures of gas-liquids that move at different speeds.

An artist's concept showing Virgin Galactic's LauncherOne spacecraft just after stage separation. Engineers are designing LauncherOne to be able to launch small satellites in space and are using GFSSP for tank-sizing and pressurization analysis.

Electro-Optic Ceramic Creates High-Speed Fiber-Optic Networks

By 2002, Corning Applied Technologies had developed a new electro-optic ceramic, one that promised efficient, rugged, low-cost optical components for a variety of uses. That year, however, the subsidiary was shut down before its new OptoCeramic could be proven. The managers and engineers formed their own company, Boston Applied Technologies Inc. (BATi), and the same year a contract with Langley Research Center allowed the new business to demonstrate the technology that would become the basis for future product lines.

The Small Business Innovation Research contract with BATi, based in Woburn, Massachusetts, was for an electro-optic Q switch for a lidar system. A material is electro-optical when its refractive index can be changed with an applied electric field, meaning it can alter the color, polarization, and intensity of light. The electro-optic materials traditionally favored by industry have been single crystals such as lithium niobate.

BATi, however, had refined a ceramic with a high response speed and an electro-optic effect nearly 100 times higher than that of lithium niobate.

"The NASA project . . . financially got us off the ground and verified the concept that got our electro-optic switch business growing," says BATi cofounder Kevin Zou. Based on the experience, the company used the ceramic to expand its product line into the high-speed optical switch business. "Most of our commercial products are based on this OptoCeramic technology," Zou says.

In photonic systems, he says, speed is critical. "If you compare them to similar products, nobody's switches are as fast as ours."

As an added advantage, being polycrystalline ceramics, the materials can be made by hot-pressing, a process much cheaper and easier than growing crystals.

Devices made with these materials have been proven reliable and rugged, and because the ceramic requires only a small electric field to change its optical properties, the devices are compact and easily controlled.

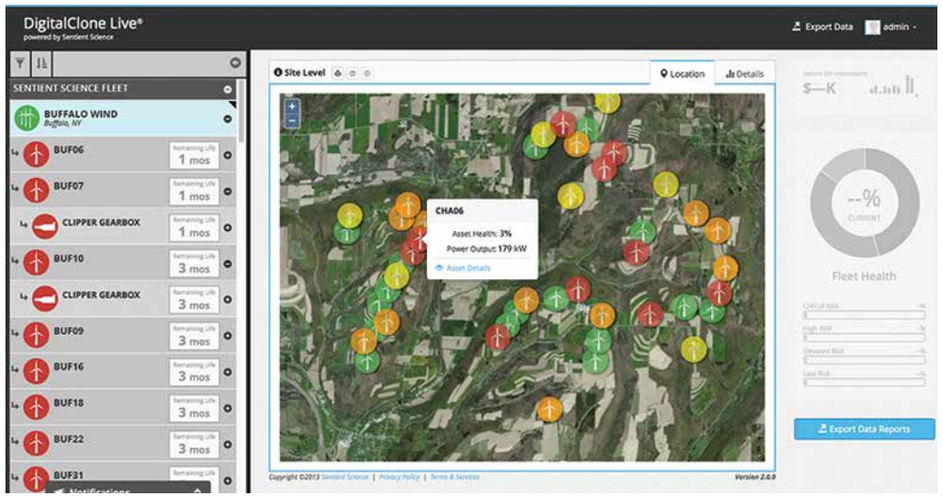
Boston Applied Technologies manufactures a variety of products, such as the high-speed, fiber-optic switches and free-space, mid-infrared Q switch cores seen here, using the electro-optic ceramic it first verified under an SBIR contract with Goddard Space Flight Center. Electronic control circuits like the one on the right drive the optical switches.

NASA uses lidar to monitor various conditions of the atmosphere, such as moisture, pollution, and temperature. In February 2014, Goddard Space Flight Center released a report on the amount of Saharan dust that crosses the Atlantic and nourishes the Amazon rainforest, based on images such as this, from the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation orbiter. Boston Applied Technologies first verified its trademark electro-optic ceramic technology with a Q-switch it developed for NASA's lidar atmosphere imaging work.

Industrial Productivity

NASA's various missions have spawned groundbreaking advances in industrial applications as varied as predicting machine lifespans, transmitting power in new ways, and producing both extreme temperatures and materials capable of surviving them. These and countless other innovations have steadily found their way from space applications into terrestrial industry, helping to keep American businesses at the forefront of efficiency and productivity.

DigitalClone Software Predicts, Extends Machine Life



Sentient Science's DigitalClone Live product builds sensors into wind turbine gearboxes and uses live data to update performance and failure predictions in real time. DigitalClone Live had its first sale in mid-2013, and by late 2014 it was in use on more than 5,000 wind turbines from eight operators in North America.

Medical scientists have made progress in recent years toward understanding how genetics play a role in susceptibility or resistance to various diseases. Meanwhile, the engineers at Sentient Science have been figuring out how to do similar prognostics for machine systems and components.

"What we set out to do was really hard," says Ward Thomas, president and CEO of the Buffalo, New York-based company. "We set out to decode the material genome."

Following almost a decade of work and a string of Small Business Innovation Research (SBIR) contracts, it was a validation test at Glenn Research Center, carried out under another NASA SBIR contract, that proved Sentient had cracked the code.

The company had combined mountains of material-performance data with models of the physics of surface fatigue and built on existing analytical and computer models to process the information. To test the product, named DigitalClone, it needed a component with a well-documented history.

Glenn maintains a gear-performance database, and a helicopter gear with 25 years' worth of data was chosen as the test subject. The company used the software to create a digital model of the gear and then input various materials, surfaces, and working conditions, comparing the resulting predictions with the historical data on the gear. When the comparison turned up a match, the company went commercial.

"Instead of running physical tests for a year and getting three test points, we can give you thousands of test points in days," Thomas says.

By late 2014, the technology was in use on the Hubble Space Telescope, several military helicopters, one medical company's hip implants, and the wind turbines of eight operators, including giants like NextEra Energy and Clipper Windpower.

Since DigitalClone's validation with NASA data, Sentient's staff grew from 10 to 26 by 2014, and annual revenues rose from $1 million in 2010 to $3.5 million in 2013.

DigitalClone was first validated on a helicopter spur gear at Glenn Research Center and, in the following years, came to be used on several military aircraft, including the Super Stallion, pictured here.

Cryocoolers Fuel Exploration in Space and on Earth

Astronaut Tracy Caldwell Dyson, an engineer with Expedition 24 on the ISS, uses the General Laboratory Cryogenic ISS Experiment Refrigerator (GLACIER), which uses a Sunpower cryocooler.

When preparing to launch a solar spectroscopic imager, NASA needed a cryocooler capable of powering the detectors aboard the imager at a steady temperature of -324 °F for its entire lifespan while withstanding the extreme conditions of space, all without needing repairs.

Sunpower, a company based in Athens, Ohio, sold a line of cryocoolers that fit the bill perfectly. The coolers utilize the Stirling cycle, a thermodynamic process that uses shifting pressures created by heating and cooling an enclosed gas to move pistons back and forth, ultimately transferring heat away from the cooler and radiating it out into space. Unlike other cryocoolers, Sunpower's machines require no liquid lubrication—which would freeze in space and become useless—instead relying on gas bearings to keep the pistons centered in their cylinder bores, like air jets on an air hockey table.

NASA first purchased a cryocooler from Sunpower for the 2002 launch of the Reuven Ramaty High Energy Solar Spectroscopic Imager—a device still in operation as of mid-2015—and has since purchased another dozen for use aboard the International Space Station.

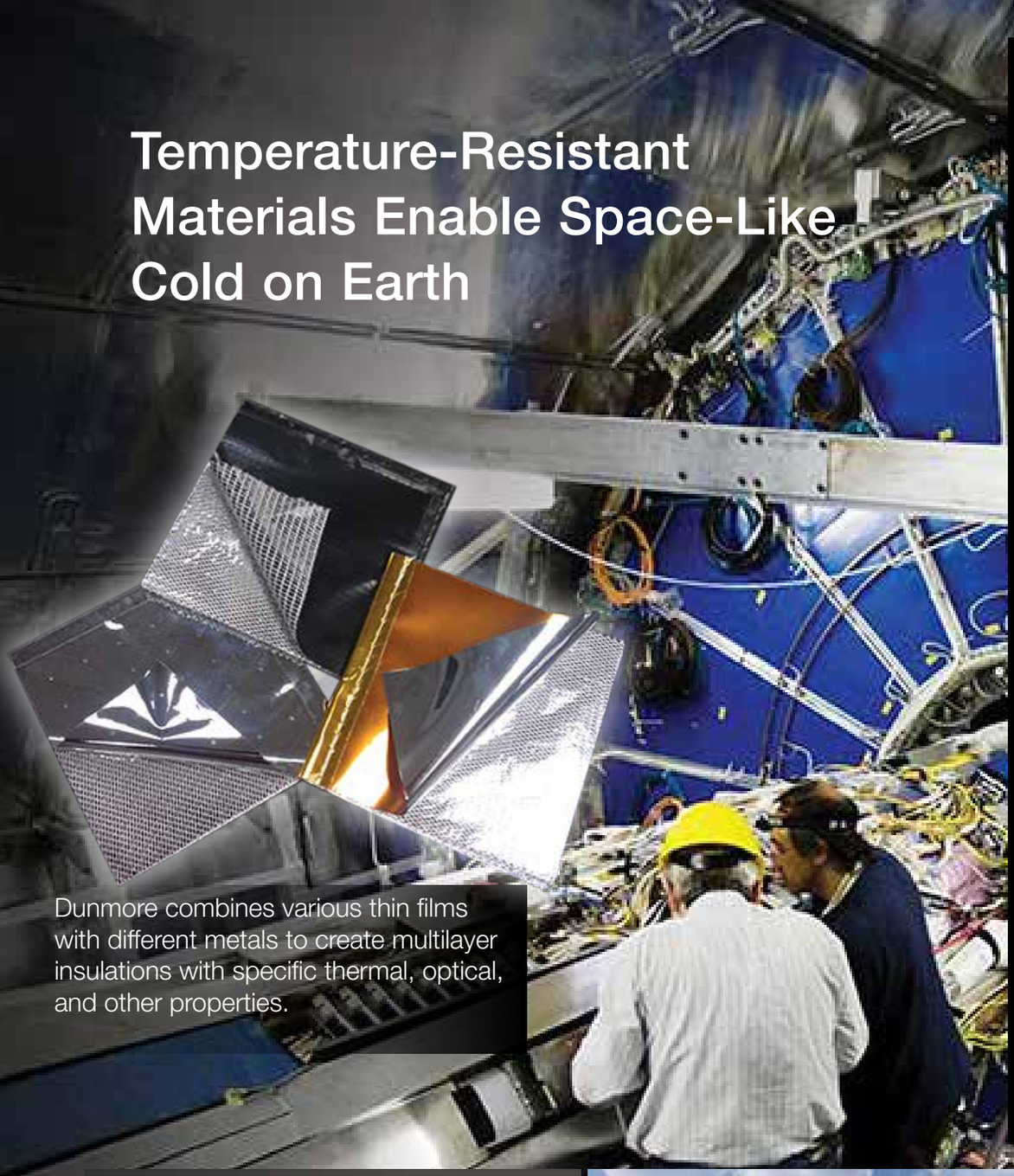
Furthermore, Sunpower has received 18 Small Business Innovation Research contracts from both Goddard Space Flight Center and Glenn Research Center for its continued development of high-performance cryocoolers, and the company has utilized those contracts to improve efficiency of its Stirling engines and incorporate thermoacoustics, or the use of sound waves to transfer heat, to further reduce moving parts.

The company's coolers, improved over the years through its work with NASA, are today used in high-temperature superconductivity applications, nuclear-magnetic resonance instruments for cold science research applications, and for powering detectors for military, scientific, and commercial purposes.

Sunpower's CryoTel cube is a ready-to-use cryogenic cooling solution used on the ISS but also on Earth for astronomical telescopes, nuclear magnetic radiation, infrared detection, gas chromatography, and medical uses.

Sunpower's CryoTel CT-F cryocooler has made more than 30 launches into space and is capable of reaching and maintaining temperatures ranging from 39 °F to -301 °F.

Temperature-Resistant Materials Enable Space-Like Cold on Earth



Dunmore combines various thin films with different metals to create multilayer insulations with specific thermal, optical, and other properties.

During the mid-1990s, engineers at the Jet Propulsion Laboratory (JPL) were tailoring an outfit for the Cassini probe that would shield it from the extreme temperature fluctuations and other harsh conditions of space. They needed a tape to reinforce the edges of the insulating blankets to allow them to be attached with laces, but there was none available with the necessary optical properties.

The team turned to Bristol, Pennsylvania-based Dunmore Corporation, a major supplier of specialized films for space applications since the 1980s. Based on NASA's needs, the company came up with a line of specialized tapes, including the one used on Cassini. This was just one example of an instance when Dunmore's work to meet NASA specifications ended up expanding its product catalog.

While early NASA missions used reflective foils for insulation, Dunmore helped to pioneer the process of vacuum-metalizing polyimide films for space insulation, combining thin films of substances like Mylar and Kapton with metals from aluminum to germanium, giving them specific thermal, optical, and other properties.

"It involved a great deal of trial and error and ultimately produced a highly efficient family of products," says Neil Gillespie, vice president of new business ventures for Dunmore.

These multilayered insulations are now sold for use in buildings, cryogenic transport and storage tanks, MRI machines, and particle accelerators. Dunmore has made other advances due to its work with NASA that have now found commercial applications, such as labels for circuit boards that can withstand the heat of soldering and lightly metalized films to dissipate static electrical charges.

And that family of tapes? Their heat tolerance has made them suitable for consumer electronics, and they're also used as wire and cable insulation aboard aircraft due to their strength and effectiveness.

Dunmore has a long line of temperature-resistant tapes, including varieties for wire and cable wrap, for sealing the edges of the company's multilayer insulation, and for creating nonstick surfaces. Several of these were originally created for NASA applications.

Dunmore's multilayer insulations, made with thin, metalized films, have found uses not just in protection against the temperature extremes of space but also for insulating liquefied gas tanks and superconductive elements of magnetic resonance imaging machines, among other Earth applications.

The same multilayer insulations that Dunmore pioneered for space applications are used in particle accelerators, such as the Large Hadron Collider at the European Organization for Nuclear Research, or CERN, pictured here. The insulators keep conductive metals cooled below a certain threshold, at which they become superconductive.

Image courtesy of Antonio Saba, CC BY-SA 3.0

Lasers Enable Alternative Power Transmission

The space elevator concept is simple yet provocative: its design calls for a cable to rise 24,000 miles from Earth's equator to a satellite in geosynchronous orbit. Spacecraft and payloads would climb up the cable and launch into space, upending the costly, resource-intensive rocket launch method currently used.

Enter NASA's Space Technology Mission Directorate Centennial Challenges Program, which offers cash prizes for inventors to come up with innovative solutions to technical problems. The program's Space Elevator Power Beaming Challenge had participants attempt to perfect the only currently feasible way for powering the elevator—by beaming light onto photovoltaic arrays installed on robot "climbers," which would convert incoming photons into electricity.

The Power Beaming Challenge was held for four years—2005, 2006, 2007, and 2009. The only team that took home prize money was Seattle-based LaserMotive, led by scientists Tom Nugent and Jordin Kare, in 2009. While most of competitors were using spotlights to direct light onto their climbers, LaserMotive used diode lasers to provide greater light intensity, and they also optimized their climber's photovoltaic arrays so that they maintained efficiency even when the beam was not uniform or not properly centered. Theirs was the only team whose climber ascended the cable the required full kilometer and at speeds above the minimum two meters per second, netting the crew a $900,000 prize purse.

Using the expertise and money gained from the competition, in 2012 LaserMotive commercialized its Power over Fiber technology, which provides electricity to devices by using lasers that make contact with the photovoltaic panels via fiber optic cables. The innovation benefits laboratories running experiments that require either electrical isolation (to prevent equipment damage) or radio signal isolation (to prevent data interference).

Development is also underway on a ground-based laser that recharges unmanned aerial vehicles in mid-air, saving customers the time and money associated with having to land them and replace their batteries.

LaserMotive's success in the Power Beaming Challenge allowed the company to commercialize its Power over Fiber (PoF) technology, which provides electricity to devices through fiber optic cables. PoF is most commonly used to provide electricity to devices that require electrical or radio frequency isolation.

Spaceward Foundation volunteer Michael Keating served as the "tetherman" for the 2009 competition, responsible for making sure the cable did not snag and that each robotic climber was brought back to Earth gently. Here, Keating prepares to catch LaserMotive's climber after an attempt.

Helium Recapture System Reclaims Hydrogen for Industry Use

Rising helium prices might not put much of a dent in the average party balloon budget, but they add up quickly for NASA, which uses up to 100 million cubic feet of helium each year.

NASA uses helium to purge hydrogen lines around launch pads and rocket test stands. The hydrogen is piped to test stands in liquid form, and any that's left in the lines turns to gas, which, being flammable, has to be blown out before the lines are disconnected. Helium is used because it's the only element that liquefies at a lower temperature than hydrogen.

With helium prices set to rise, Stennis Space Center, NASA's largest rocket test facility, put out a call for a technology that would buffer it from price changes. Among those who responded was Sustainable Innovations LLC, based in East Hartford, Connecticut. The company had been developing a reverse form of fuel cell technology that would separate and purify hydrogen.

In 2009 and '10, the company entered into two Small Business Technology Transfer contracts with Stennis and developed its H2RENEW system, which separates and recombines hydrogen protons and electrons, leaving any other element behind. In the case of NASA's hydrogen lines, the only other element present is helium, which is then stored for reuse.

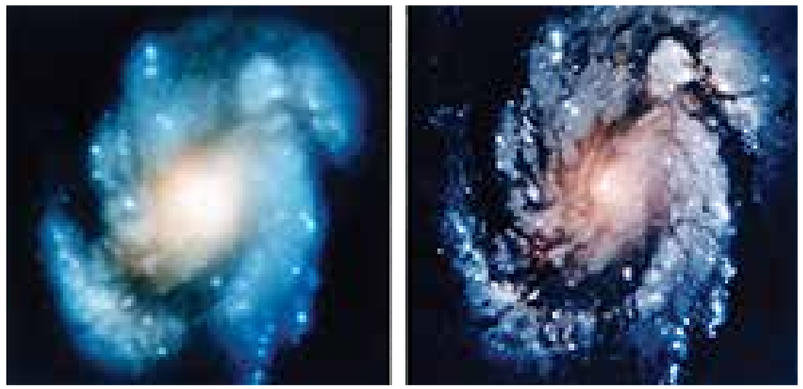
Hydrogen is used in several industrial processes, especially for the removal of oxides from steel, glass, and semiconductors such as silicon wafers. A major advantage of the H2RENEW is that it not only separates and cleans hydrogen for reuse but also simultaneously pressurizes it for storage, normally the job of a separate system.

Further contracts with various NASA field centers have continued to advance the technology, and the company, which now has about 16 employees, also has two more products in the pipeline, based on the same electrochemical platform.

Stennis Space Center is in the business of testing rocket engines, which requires cryogenic liquid hydrogen and oxygen to be piped to rocket test stands. Helium, being the only element with a lower freezing point than hydrogen, is then used to blow any residual hydrogen out of the lines. Sustainable Innovations' hydrogen capture technology will allow that helium, which is set to increase in price as the Federal Government gets out of the helium business, to be isolated, stored, and reused, saving the center hundredsof thousands of dollars a year.

Sustainable Innovations took a technology it created to allow Stennis Space Center to reuse helium and applied it to the recapture, cleaning, and pressurizing of hydrogen used in industrial processes, saving companies money. In addition to H2RENEW, the company is planning two more devices based on the same electrochemical platform, a sort of reverse hydrogen fuel cell technology.

Laser Vision Helps Hubble, Package Shippers See Clearly



A misshapen mirror aboard the Hubble Space Telescope caused the first images beamed back to Earth to be fuzzy and out of focus. After the installation of new optics, tested by an abberated beam analyzer invented by AOA Xinetics to ensure the new lenses would work perfectly, Hubble began sending back crystal-clear, vivid images from across the observable universe.

The images beamed back to Earth by the Hubble Space Telescope were a bit of a letdown, initially, as a primary mirror had been ground to the wrong shape and was too flat by 2.2 micrometers, or one-fiftieth the thickness of a human hair, resulting in fuzzy pictures. NASA embarked on a two-step approach to correct the problem, replacing Hubble's Wide Field Planetary Camera with an improved version featuring advanced detectors and more accurate contamination control, and replacing one of Hubble's original components with the Corrective Optics Space Telescope Axial Replacement, which was designed to work like a pair of eyeglasses to better focus the telescope's view of the universe.

In order to ensure the repairs would fix the problems, Goddard Space Flight Center issued a call to optics companies to verify the shape of a mirror and detect any defects. AOA Xinetics, a subsidiary of Northrup Grumman based in Cambridge, Massachusetts, invented an abberated beam analyzer (ABA) and, after successfully proving it was capable of determining the shape of the mirror to within three-thousandths of a wavelength of light, was selected to help NASA on the Hubble project. The ABA was used to verify the shape of mirrors on both the new camera and the optics system, and Hubble has been providing breathtaking images ever since.

AOA has since used the ABA in work with FedEx to design a system for quickly and accurately creating three-dimensional images of packages that might require additional charges due to size or weight, instead of having to individually measure and weigh boxes. Furthermore, the company has worked with Kroger grocery stores to create the Scan Tunnel, which allows customers with large orders to use self-checkouts. The tunnels use 14 scanning cameras and and two types of dimensioners while also cross-referencing packaging information to ring up products.

Utilizing the improved optics capabilities it developed for NASA, AOA Xinetics has worked with Kroger grocery stores on a scanning system that better and more rapidly identifies products, allowing customers with large orders to take advantage of self-checkout aisles.

A view of the Space Shuttle Endeavour as the STS-118 crew puts the spacecraft though a rendezvous pitch maneuver, allowing the crewmembers on the nearby ISS to document the vehicle's thermal protection system condition.

Space-Ready Durometers Measure Hardness on Earth

There are no mechanic shops in space, but following the Space Shuttle Columbia accident in early 2003, NASA implemented additional safety inspections to look for and repair any tiles on the underbelly of shuttles that might have fallen off or been damaged after launch. On approach to the space station, shuttles would flip nose-over-engine so crewmembers on the station could snap photos to send to Mission Control for analysis.

If the examination uncovered missing or damaged tiles, astronauts had a specially formulated "goo" capable of filling cracks or replacing tiles in full, but they needed a way to be sure the tiles were fully hardened before reentry.

Johnson Space Center contacted Grove, Illinois-based Rex Gauge, one of three U.S. manufacturers of durometers—or instruments that determine the hardness of materials—and asked if the company could make some modifications to its standard gauge for use in space. The company ruggedized the instrument and also made it easier to grip for astronauts wearing gloves. The dial was made larger and given a red and green background to allow for a quick reading of whether the "goo" was sufficiently cured to handle the heat of reentry.

An astronaut in training holds the modified durometer, made by Rex Gauge, that was used to ensure any repaired or replaced tiles on the underside of a space Shuttle were hard enough to withstand the heat of reentry from orbit.

Back on Earth, Rex incorporated these features into its new line of digital durometers, changes that the company says helped increase sales by 35 percent. The company also created a special website featuring the SG-5000 durometer made for NASA, earning a certification from the Space Foundation in recognition of its work.

High-Temperature Superconductors Deliver Power without Heat

It came to be known as the "Woodstock of Physics." Thousands of scientists squeezed into a ballroom of the New York Hilton, overflowing into the halls, as the American Physical Society's March 1987 meeting began. The presentations would last until after three o'clock in the morning, with hundreds of attendees lingering later, buzzing with excitement at the revolutionary technological breakthroughs on the horizon.

Newspapers that year foretold electric cars, magnetically levitating trains, nuclear fusion plants, and extraordinary savings in energy. The miracle behind the excitement? High-temperature superconductive (HTS) ceramics.

Superconductive materials at very low temperatures allow electricity to pass with no resistance, zero losses, and maximum efficiency. The ceramics discovered in 1986 and '87 become superconductive at temperatures as high as 92 K (-294 °F), warm enough to be maintained by liquid nitrogen, which can be cheaper than bottled water.

But the ceramics posed a host of challenges, being chemically complex and brittle and needing their grains to be perfectly aligned.

In 2008, as work began on Japan's ASTRO-H orbiting observatory, researchers at Goddard Space Flight Center needed HTS leads to carry a current from a room-temperature source to a cooling system operating near absolute zero. NASA is contributing an X-ray spectrometer, whose detectors are made ultrasensitive by such low temperatures.

Tai-Yang, now called Energy to Power Solutions (E2P), based in Knoxville, Tennessee, had developed a means for slitting superconducting tapes that were more robust than the rods used on previous ASTRO-H missions.

For the project, the company developed compact leads that deliver power but virtually no heat, which can prove useful in Earth applications like MRI machines. By developing such niche applications of these ceramics, people in the industry bring down the technology's cost and eventually enable the kinds of advances envisioned decades ago, says E2P President Chris Rey.

NASA contributed the soft X-ray spectrometer for Japan's ASTRO-H X-ray astronomy satellite. To carry electricity, but not heat, from a room-temperature power source to a cryogenic superconducting electromagnet aboard the satellite, Energy to Power Solutions developed a set of hybrid, superconductive leads. The electromagnet is used to cool the instrument's detectors to near absolute zero, making them ultrasensitive.

One clear Earth application for the sort of ultra-low-heat superconductive leads that Energy to Power Solutions developed for the ASTRO-H satellite is in magnetic resonance imaging machines, which are also powered with cryogenic superconductors.

Electrospray Thrusters Boost Efficiency, Precision

When NASA thrusters are mentioned, most people imagine something like the breathtaking launch of the Saturn V rocket that sent astronauts to the moon and shook tiles off the ceiling of the observation room three miles away. But the agency is now demonstrating the most delicate thrusters ever flown, so gentle they max out at a thrust equal to the weight of a grain of sand.

The Jet Propulsion Laboratory is contributing the disturbance reduction system (DRS) for the European Space Agency's LISA Pathfinder craft, which will demonstrate technology planned to detect gravitational waves. These are so slight that the DRS must counteract influences as negligible as photons striking the craft.

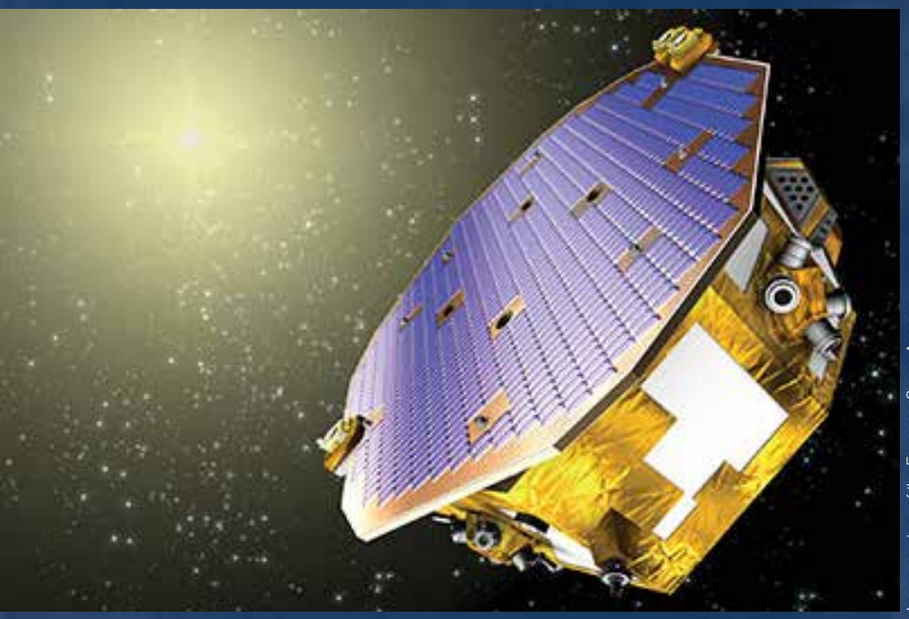


Image courtesy of the European Space Agency

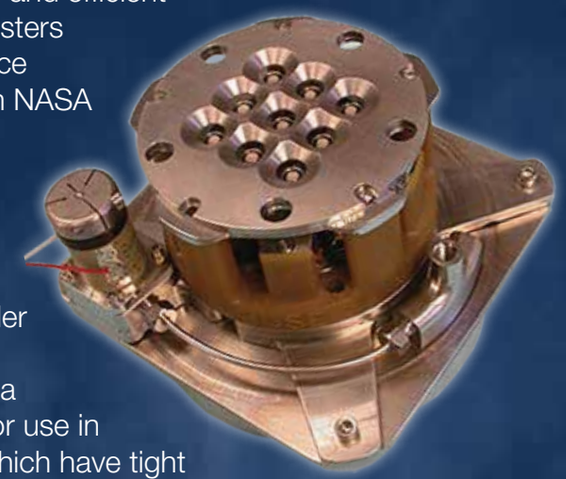
As part of NASA's Space Technology 7 project, Busek developed electrospray thrusters that max out at the weight of a fine grain of sand for the disturbance reduction system on the European Space Agency's LISA Pathfinder spacecraft. The craft is trying out technology that could be used in the future to detect gravity waves, which are predicted by the theory of relativity but have never been directly observed.

As work began, Busek, based in Natick, Massachusetts, was developing electrospray thrusters for nanosatellites. Electrospray applies an electrostatic field to an ionized, conductive liquid. The charge distorts the surface into what's called a Taylor cone. At a certain threshold, surface tension is overcome, and a fine spray is ejected from the cone's tip. Busek refined its control of the thrusters by developing a piezoelectric valve that can control force down to the number of atoms accelerated.

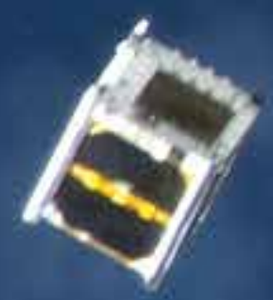
The company was selected to supply thrusters for the DRS, which it delivered in 2008.

These were capable of forces up to 30 micronewtons. Busek has since scaled up the technology and returned to its original intent—propulsion for nanosatellites. There are virtually no thrusters that meet the space constraints of these tiny spacecraft, leaving them unable to change orbit or control how quickly their orbits decay.

Busek has produced 100-micronewton and 1-millinewton electrospray thrusters for nanosatllites, as it works its way up to a 20-millinewton booster that could alter a small satellite's orbit. They operate at about 70 percent efficiency, compared to the 50 to 60 percent efficiency of traditional ion thrusters.



Following its development of extremely precise, delicate, and efficient electrospray thrusters for the disturbance reduction system NASA provided for the European Space Agency's Laser Interferometer Space Antenna, or LISA, Pathfinder spacecraft, Busek designed a similar thruster for use in nanosatellites, which have tight space constraints.



NASA Technology Transfer Program Network Directory

NASA HQ — NASA Headquarters
ARC — Ames Research Center
AFRC — Armstrong Flight Research Center
FLC — Federal Laboratory Consortium
GRC — Glenn Research Center
GSFC — Goddard Space Flight Center
JPL — Jet Propulsion Laboratory
JSC — Johnson Space Center
KSC — Kennedy Space Center
LaRC — Langley Research Center
MSFC — Marshall Space Flight Center
SF — Space Foundation
SSC — Stennis Space Center
Tech Briefs — Tech Briefs Media Group

Bringing NASA Technology Down to Earth

NASA's Technology Transfer Program pursues the widest possible applications of agency technology to benefit U.S. citizens. Through partnerships and licensing agreements with industry, the program ensures that NASA's investments in pioneering research find secondary uses that strengthen the economy, create jobs, and improve quality of life.

Learn more about licensing NASA technology, http://technology.nasa.gov. General inquiries may be directed to the Spinoff Program Office at spinoff@sti.nasa.gov. To suggest a story about a commercial product or service developed with NASA technology, assistance, or know-how, contact *Spinoff* at the email address above, or visit http://spinoff.nasa.gov.

- **NASA Headquarters** provides leadership, policy, strategy, resource allocation, and media relations for technology transfer activities agency-wide.
- **Technology Transfer 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 Technology Transfer Program objectives.

NASA Headquarters

National Aeronautics and Space Administration
Technology Transfer Program Executive:
Daniel Lockney
Phone: (202) 358-2037
E-mail: daniel.p.lockney@nasa.gov
300 E Street, SW
Washington, DC 20546

Field Centers

Ames Research Center
Technology Transfer Office Chief:
Carolina Blake
Phone: (650) 604-0893
E-mail: carolina.blake@nasa.gov
Moffett Field, California 94035

Armstrong Flight Research Center
Technology Transfer Office Chief:
Laura Fobel
Phone: (661) 276-3967
E-mail: laura.j.fobel@nasa.gov 4800 Lilly Drive, Building 4839
Edwards, California 93523-0273

Glenn Research Center
Technology Transfer Office Chief:
Kim Dalgleish-Miller
Phone: (216) 433-8047
E-mail: kimberly.a.dalgleish@nasa.gov
21000 Brookpark Road
Cleveland, Ohio 44135

Goddard Space Flight Center
Technology Transfer Office Chief:
Nona Cheeks
Phone: (301) 286-5810
E-mail: nona.k.cheeks@nasa.gov
Greenbelt, Maryland 20771

Jet Propulsion Laboratory
Technology Transfer Office Chief:
Daniel Broderick
Phone: (818) 354-1314
E-mail: daniel.f.broderick@jpl.nasa.gov
4800 Oak Grove Drive
Pasadena, California 91109

Johnson Space Center
Technology Transfer Office Chief:
Charlene Gilbert
Phone: (281) 483-0474
E-mail: charlene.e.gilbert@nasa.gov
Houston, Texas 77058

Kennedy Space Center
Technology Transfer Office Chief:
Dave Makufka
Phone: (321) 867-6227
E-mail: david.r.makufka@nasa.gov
Kennedy Space Center, Florida 32899

Langley Research Center
Technology Transfer Office Chief:
Kathy Dezern
Phone: (757) 864-5704
E-mail: kathy.a.dezern@nasa.gov
Hampton, Virginia 23681-2199

Marshall Space Flight Center
Technology Transfer Office Chief:
Terry Taylor
Phone: (256) 544-5916
E-mail: terry.taylor@nasa.gov
Marshall Space Flight Center,
Alabama 35812

Stennis Space Center
Technology Transfer Office Chief:
Duane Armstrong
Phone: (228) 688-2180
E-mail: curtis.d.armstrong@nasa.gov
Stennis Space Center, Mississippi 39529

Allied Organizations

Space Foundation
Kevin Cook, Vice President,
Marketing and Communications
Phone: (719) 576-8000
E-mail: kcook@spacefoundation.org
310 S. 14th Street
Colorado Springs, Colorado 80904

Federal Laboratory Consortium
Diana Hoyt, Collaboration Program Manager
Phone: (202) 358-1893
E-mail: diana.hoyt@nasa.gov
300 E Street, SW
Washington, DC 20546

Tech Briefs Media Group
Joseph T. Pramberger, Publisher
Phone: (212) 490-3999
www.techbriefs.com
1466 Broadway, Suite 910
New York, NY 10036

Spinoff Program Office
E-mail: spinoff@nasa.gov

Daniel Coleman, Editor-in-chief
Phone: (301) 286-4058
E-mail: daniel.p.coleman@nasa.gov

Mike DiCicco, Senior Science Writer
Amber M. Healy, Science Writer
John Jones, Senior Graphics Designer

Goddard Space Flight Center, Building 26
Greenbelt, Maryland 20771

There's more space
in your life
than you think.
Since 1976, Spinoff
has documented nearly
2,000 NASA technologies
improving life on Earth.
http://spinoff.nasa.gov/

TECHNOLOGY TRANSFER PROGRAM

BRINGING NASA TECHNOLOGY DOWN TO EARTH

National Aeronautics and Space Administration

Office of the Chief Technologist
NASA Headquarters
Washington, DC 20546

www.nasa.gov

NP-2015-10-2096-HQ