National Aeronautics and Space Administration

SPINOFF

2018

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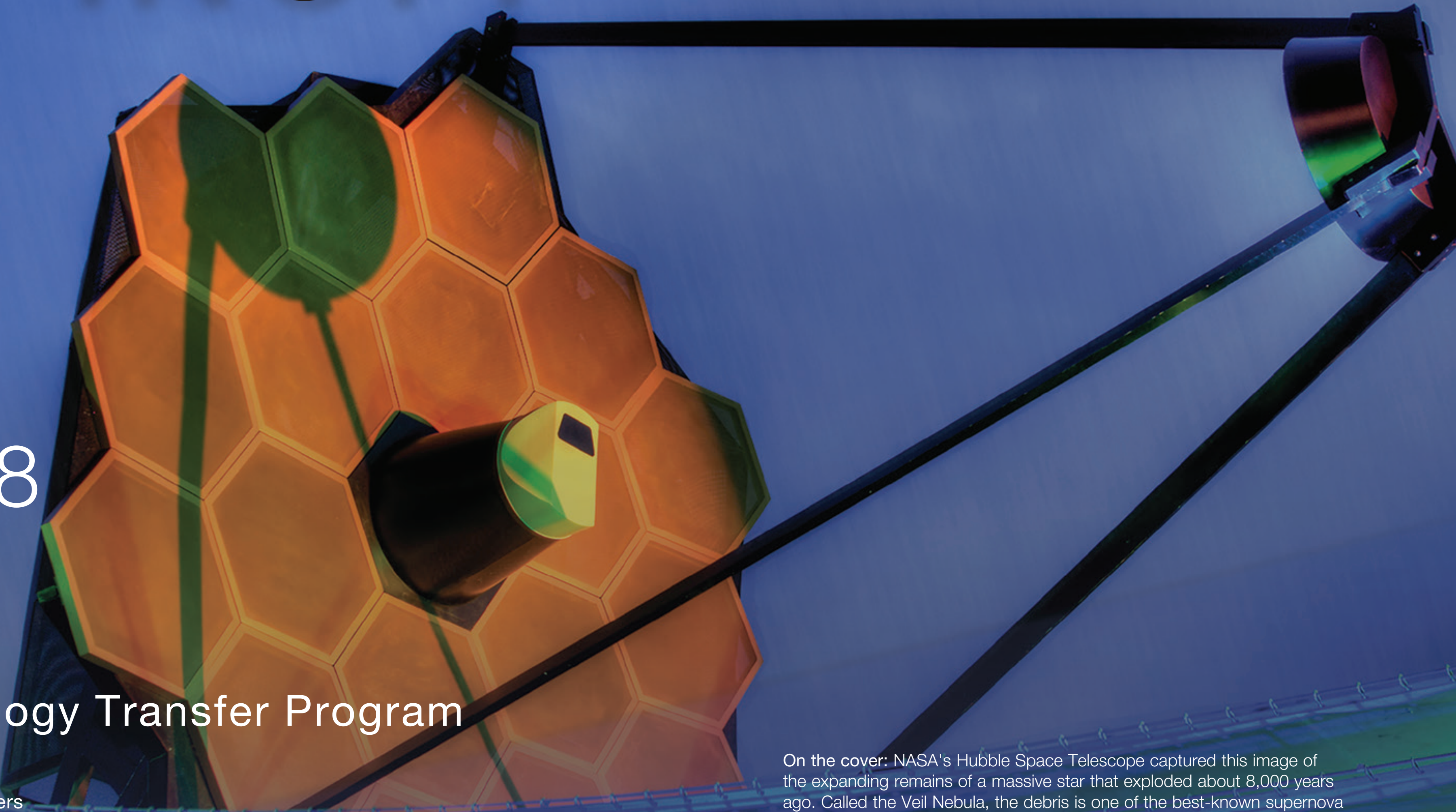

Technology Transfer Program

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On the cover: NASA's Hubble Space Telescope captured this image of the expanding remains of a massive star that exploded about 8,000 years ago. Called the Veil Nebula, the debris is one of the best-known supernova remnants, deriving its name from its delicate, draped filamentary structures. Although this image shows an area roughly 2 light years across, the entire nebula is 110 light years across.

On this page: Pictured above is the James Webb Space Telescope, a large, space-based observatory scheduled to launch in 2019 and serve as successor to the Hubble Space Telescope. Webb will cover longer wavelengths of light than Hubble and will have greatly improved sensitivity. The longer wavelengths enable Webb to look further back in time to see the first galaxies that formed in the early universe and to peer inside dust clouds where stars and planetary systems are forming today. Webb may also study exoplanets, including the composition of exoplanet atmospheres, which may give us clues to the presence of life on other worlds.

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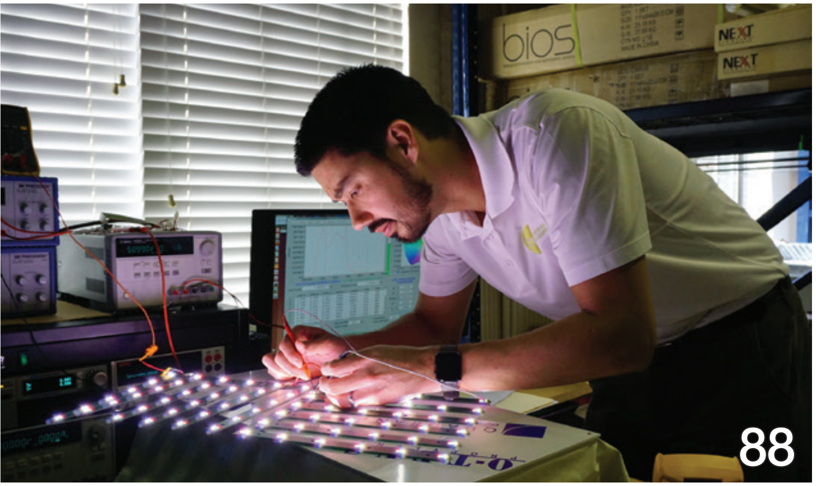

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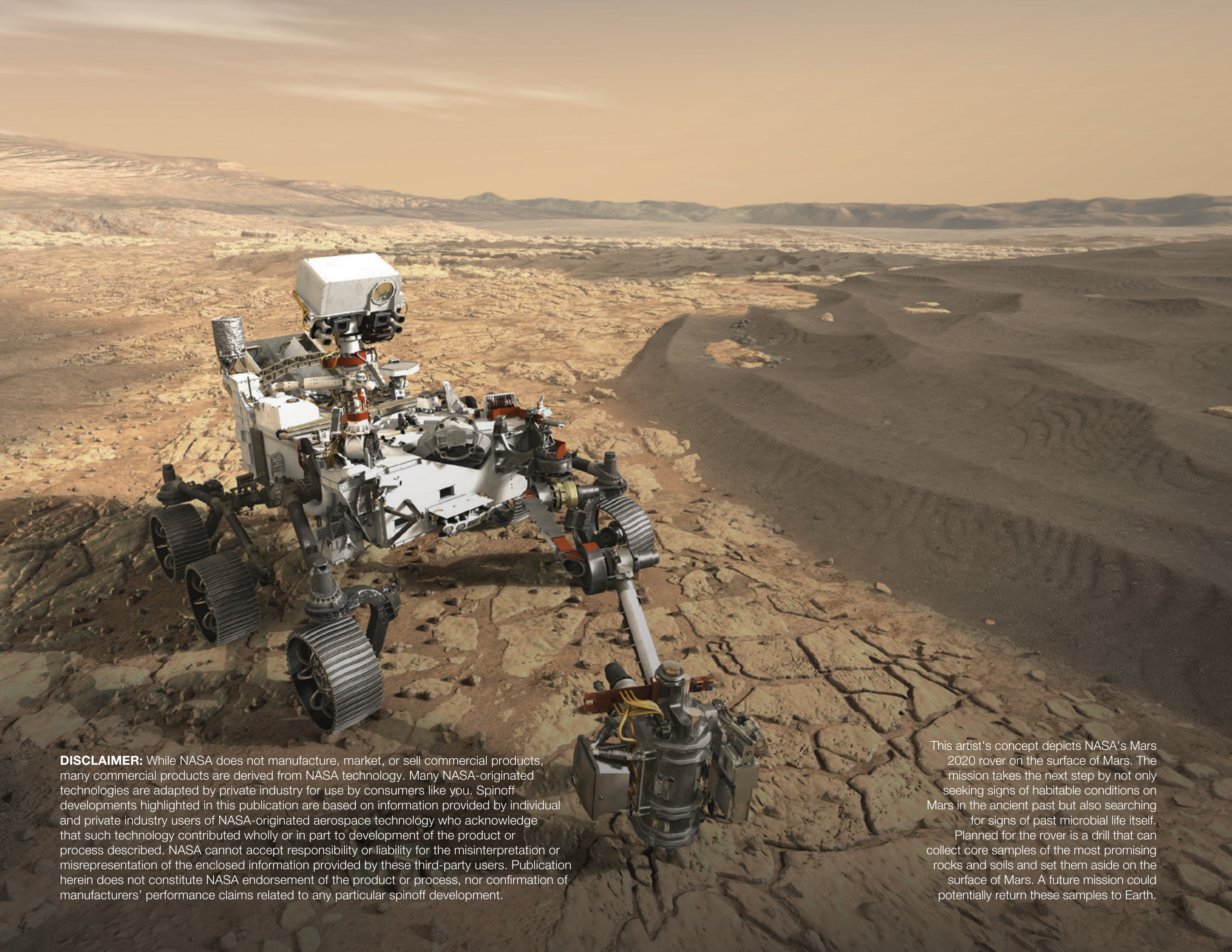


This artist's concept depicts NASA's Mars 2020 rover on the surface of Mars. The mission takes the next step by not only seeking signs of habitable conditions on Mars in the ancient past but also searching for signs of past microbial life itself. Planned for the rover is a drill that can collect core samples of the most promising rocks and soils and set them aside on the surface of Mars. A future mission could potentially return these samples to Earth.

DISCLAIMER: While NASA does not manufacture, market, or sell commercial products, many commercial products are derived from NASA technology. Many NASA-originated technologies are adapted by private industry for use by consumers like you. Spinoff developments highlighted in this publication are based on information provided by individual and private industry users of NASA-originated aerospace technology who acknowledge that such technology contributed wholly or in part to development of the product or process described. NASA cannot accept responsibility or liability for the misinterpretation or misrepresentation of the enclosed information provided by these third-party users. Publication herein does not constitute NASA endorsement of the product or process, nor confirmation of manufacturers' performance claims related to any particular spinoff development.

Foreword

When most people consider NASA's achievements, they think of destinations like the Moon, Mars, or the most distant galaxies in the universe. But you don't have to look that far to appreciate the benefits of space exploration: commercialized NASA technology—known as NASA spinoffs—can be found in your phone, furniture, and car. They have improved nearly every semi-trailer truck on the road, airplane in the sky, and tractor working the fields.

Indeed, the spinoff benefits from NASA research in space and aeronautics are everywhere and continually accruing. Thanks to technology developed one or two decades ago, you use NASA innovations when you snap pictures or record video, feed formula to an infant, ride an elevator or escalator, or receive directions from GPS navigation. Meanwhile, the Space Agency continues to pursue a slate of ambitious missions that, in addition to their exciting scientific value, promise even more public-benefiting spinoffs now and in the future.

The James Webb Space Telescope, for example, launches next year to serve as the successor to the Hubble Space Telescope. Among other feats, Webb will peer further back in time than any instrument before it, showing the universe's earliest structures in unprecedented detail. It may also assist in the search for potentially habitable exoplanets. During its years of development and preparation for space, the telescope has already generated several commercialized spinoff technologies—with more on the way, thanks to NASA's efforts to transfer technology.

Perhaps the most fruitful areas of technology development and commercial spinoffs, though, are NASA's efforts in human exploration. The Apollo, Shuttle, and International Space Station programs have given us many of the most ubiquitous commercialized NASA technologies, and I am looking forward to seeing how future missions beyond our planet will benefit society. As President Trump has said, "American footprints on distant worlds are not too big a dream." NASA is working step by step to make this dream a reality, creating new technologies today that could take future astronauts back to the Moon, to Mars, and beyond. From rockets to lift crew and cargo to next-generation robotics, nanotechnology, and life support systems, tomorrow's exploration systems are being developed here at the Space Agency.

NASA is making sure as many of these innovations as possible go beyond their original use to benefit the public. In the following pages, you can read about nearly 50 NASA spinoffs—some from missions taking place as recently as this year, such as our project to grow vegetables on the space station. Taken together, they provide a vivid picture of how the Nation's investment in space and aeronautics exploration continues to make a positive impact on society.

I hope you enjoy reading *Spinoff* 2018 and share what you learn with your family, friends, and colleagues. As we like to say at NASA, there's more space in your life than you think.

Robert M. Lightfoot Jr.
Acting Administrator

National Aeronautics and
Space Administration

NASA's Parker Solar Probe, which launches in 2018, will be the world's first mission to a star. Following a series of Venus flybys intended to slow the spacecraft down so its orbit moves closer to the sun, it will swoop to within 4 million miles of the sun's surface. There, solar intensity is approximately 520 times that of Earth's orbit, and the spacecraft will face an unprecedented environment of heat and radiation. The primary science goals of the mission are to trace the sun's flow of energy, investigate the heating of the solar corona, and study what accelerates solar wind.

Spinoff (spin´ôf) -noun.

1. A commercialized product incorporating NASA technology or expertise that benefits the public. These include products or processes that:
    - were designed for NASA use, to NASA specifications, and then commercialized;
    - are developed as a result of a NASA-funded agreement or know-how gained during collaboration with NASA;
    - are developed through Small Business Innovation Research or Small Business Technology Transfer contracts with NASA;
    - incorporate NASA technology in their manufacturing process;
    - receive significant contributions in design or testing from NASA laboratory personnel or facilities;
    - are successful entrepreneurial endeavors by ex-NASA employees whose technical expertise was developed while employed by the Agency;
    - are commercialized as a result of a NASA patent license or waiver;
    - are developed using data or software made available by NASA.
2. NASA's premier annual publication, featuring successfully commercialized NASA technologies.

Introduction

NASA expands the boundaries of human knowledge and exploration through its space and aeronautics missions, and this cannot be done without continually pushing the limits of what we are capable of achieving. Every day, NASA researchers and engineers must constantly advance the Agency's technological capabilities. The Technology Transfer Program then takes on another critical part of the Space Agency's mission—to ensure that the entire country benefits from those advances.

As NASA works to develop and mature technical solutions for the Agency's broad array of future missions, these inevitably can also be applied to challenges facing U.S. businesses, institutions, and citizens. We often forge industry partnerships to overcome technical challenges and to ensure that the resulting solutions are also applied here on Earth. But that's just one of many ways NASA technology finds its way into the hands of the public. In 2016, for example, the Agency issued close to 100 patent licenses and more than 2,600 software usage agreements, setting two new records.

Since 1976, NASA's *Spinoff* publication has documented the stories of more than 2,000 spinoff technologies, from their origins in NASA missions to their successful commercialization and positive impact on society. In the following pages, you can read about 49 more. Some of my favorites are:

- A device that locates survivors trapped under rubble. At the request of other Federal agencies, engineers at the Jet Propulsion Laboratory built a tool that detects slight physical movements, basing it on NASA's technology that allows analysis of weak data signals amid huge amounts of noise. In space, this technology has helped us identify minor alterations in a satellite's path that indicate fluctuations in the gravity field of the planet it orbits. On Earth, the device has already saved four people buried in debris after an earthquake in Nepal by identifying their breathing and heartbeats through rubble. (Page 56)
- A fogger that sterilizes ambulances. The company knew what it wanted to make but couldn't arrive at a product until a NASA expert was assigned to the case through a local partnership program. The NASA researcher knew about the corrosive power of atomic oxygen in Earth's upper atmosphere and helped design a device that decontaminates surfaces by oxidizing organic compounds. It's now preventing the spread of disease and infection in ambulances across the country, as well as in a school and in police cars and jail cells. (Page 24)
- Sophisticated software used to design aircraft. Computational fluid dynamics software (CFD) has been helping air- and spacecraft engineers test their designs since the 1990s. Pegasus 5 software, designed through NASA partnerships and now hosted at Ames Research Center, greatly simplifies the use of CFD, eliminates large amounts of tedious work, saves time and money, and improves designs. For its pervasive impact on commercial and government air and space travel Pegasus 5 was recognized with NASA's 2016 Software of the Year Award. (Page 43)

In addition to these success stories, this issue of *Spinoff* also features 20 NASA technologies that the Technology Transfer Program identifies as promising future spinoffs, as well as information on how to license them or partner with us to further develop them for commercialization. (Page 152)

Transfering technology into the private sector, as well as across other Federal agencies, has been a part of NASA's congressional mandate since its founding, and *Spinoff* 2018 demonstrates the continued success of that mission. Over the decades, NASA spinoffs have saved thousands of lives while generating tens of thousands of jobs, billions of dollars in revenue, and billions more in dollars saved. I hope you enjoy this look at the wide variety of benefits America's investment in aeronautics and space brings to the public.

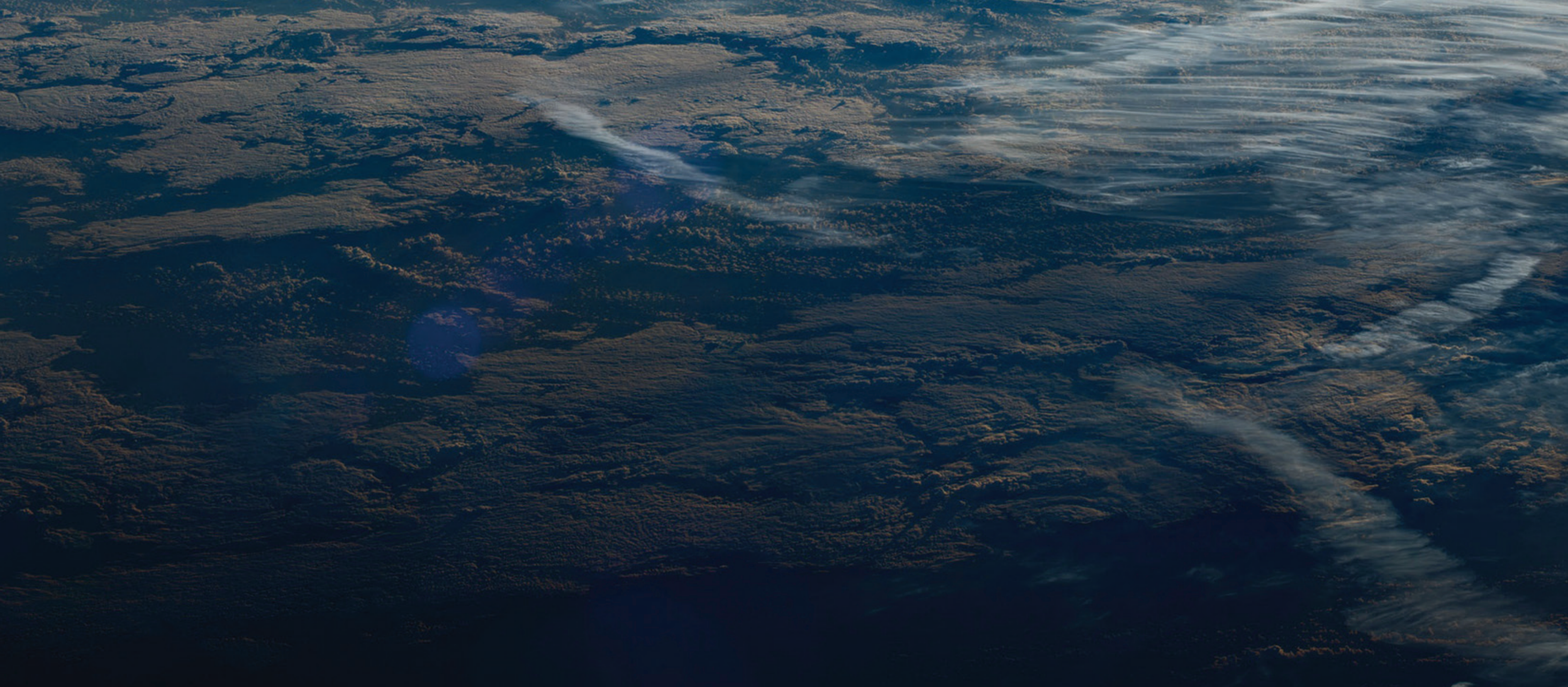
Stephen Jurczyk

Associate Administrator

Space Technology
Mission Directorate

Executive Summary

Each year, *Spinoff* features dozens of commercial products derived from NASA technology that improve everything from medical care and software to agricultural production and vehicle efficiency. The companies featured in this year's publication span a broad range of industries and geographic locations, showing the diverse benefits our Nation enjoys from its investment in aeronautics and space missions.



Executive Summary

Health and Medicine

(24) Sterilizing Fogger Cleans Ambulances with a Breeze

When paramedics come racing, the last thing anybody worries about is where the ambulance was earlier that morning. But traces of those earlier calls could be lingering—and they could be spreading disease. With help from the Regional Economic Development Program at Glenn Research Center, Kent, Ohio-based Emergency Products + Research designed a device that sterilizes the rig and gear to make it safer for the patients and the paramedics. It's already being adopted across the country.

(28) Biometric Sensors Optimize Workouts

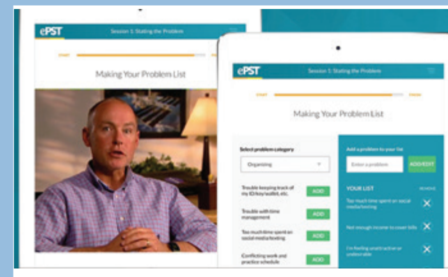
Biometric sensors could give warnings when astronauts near a blackout while pulling heavy G-forces. LifeBEAM founder Omri Yoffe and his team made a prototype of such a sensor when they won the opportunity to work with NASA personnel as part of a program run by Singularity University, which has a Space Act Agreement with Ames Research Center. Afterwards, New York City-based LifeBEAM used that experience to build a commercial exercise tracker that monitors biometric indicators to help wearers optimize their workout.

(30) Optimized Imager Tracks Cancer, Stem Cells in Medical Research

Under the Adopt a City Program, Cleveland-based BioInVision was selected for 40 hours of free technical expertise from Glenn Research Center, aimed at developing a smaller version of its CryoViz imaging system. The device maps the location of fluorescent-tagged cancer or stem cells in a specimen, usually a mouse, for medical research. The desktop version is still in the works, but advice on a cheaper, more efficient, more sensitive optical system was immediately incorporated into the original imager.

(32) Weightless "Weight"-Lifting Builds Muscle on Earth

Loss of bone density and muscle during long stays in zero gravity posed a dilemma without a clear solution: weights are useless in a weightless environment. Paul Francis was working on exercise equipment based on resistance rather than weight, called SpiraFlex, and answered NASA's call for ideas. Francis worked with Johnson Space Center to build SpiraFlex FlexPacks into a system with up to 300 pounds of resistance. He's now founded Kansas City, Missouri-based OYO Fitness to market the SpiraFlex-based DoubleFlex portable gym.



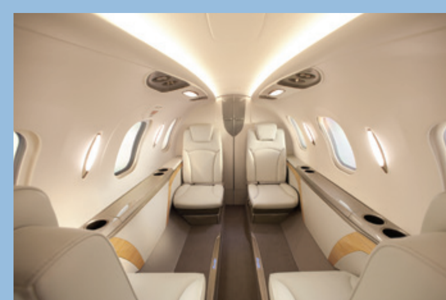
(34) Virtual Therapist Offers Out-of-This-World Depression Treatment

Mental health problems could be a real challenge for NASA crewmembers on long-duration missions—and it's not like they can pop out to the therapist. With grants from the Johnson Space Center-funded National Space Biomedical Research Institute, James Cartreine built a computer-based system called Virtual Space Station that would help diagnose and treat a range of mental health issues. In 2012, Cartreine and Claudia Zayfert founded Norwich, Vermont-based everMind to adapt and sell the virtual treatment modules on Earth.

(36) Compact Spectrometers Unveil Clues to Diagnose Cancer

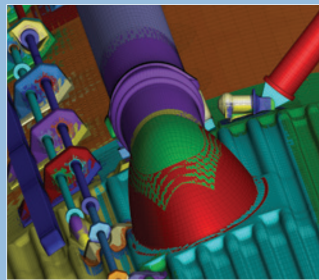
Hindsight Imaging Inc. founder Arsen Hajian began working to build a better spectrometer to look for distant planets and stars in the 1990s at the Naval Observatory, where much of his funding came from NASA. Now the Boston-based company's small but mighty devices—Hajian says they pack the resolution of machines nearly 30 times larger and 10 times more expensive—are helping uncover hidden details on this planet, and could be incorporated into future instruments at Goddard Space Flight Center.

Transportation



(40) Innovative Design Propels Small Jet Faster, Farther with Less Fuel

Honda is best known for budget-friendly, fuel-efficient family cars—not high-powered jets. But that's just what Honda Aircraft, a division of Honda based in Greensboro, North Carolina, sells. The HondaJet's innovative design was validated at Langley Research Center's National Transonic Facility, one of only two wind tunnels like it in the world. NASA facilities and expertise gave Honda confidence to move into production. Since late 2015, the company has delivered more than 100 of its affordable and speedy private jets around the world.



(43) Design Software Transforms How Commercial Jetliners Are Built

Computational fluid dynamics (CFD) software that simulates aerodynamics has been a major boon to aircraft designers. NASA funded the creation of Pegasus 5, a preprocessor that greatly decreases the work necessary to prepare a design for CFD analysis. Ames Research Center took over the program and refined it with Seattle-based Boeing Commercial Airplanes, which has used it to design a number of its airliners. Pegasus 5 opens up CFD preprocessing to less experienced users, speeds it up, and drastically reduces user error.

(46) Original Cryogenic Engine Still Powers Exploration, Defense, Industry

The first cryogenic rocket engine, the RL10, remains the most-used upper-stage rocket engine in the country more than 50 years after its creation. The engine, powered by liquid hydrogen and oxygen, was matured under a contract between what are now known as Glenn Research Center and Aerojet Rocketdyne. Built in West Palm Beach, Florida, the RL10 helped launch most commercial satellites for three decades and remains the upper-stage engine of choice for NASA and the military.

(50) Time-Triggered Ethernet Slims Down Critical Data Systems

Ethernet traditionally could not be used for critical systems because it couldn't guarantee when or whether signals would reach their destinations. TTTech, whose U.S. headquarters is in Andover, Massachusetts, developed a more reliable system, called Time-Triggered Ethernet, which it honed under a Johnson Space Center subcontract to build avionics for the Orion capsule. The technology, which allows for far simpler data handling on fewer computers, is now applied to launch vehicles, planes, wind turbines, and driver assistance and self-driving cars.

(52) Simplified Aircraft Modeling Packs Weeks of Analysis into Minutes

Using software to model how an airplane flies in real-world conditions requires major computing power. Langley Research Center engineer Walter Silva designed software that makes at least one aspect of this modeling much faster, by creating a simplified version of the structure using a mathematical tool called system identification. The software, called Reduced Order Model, is now available for license, and Huntsville, Alabama-based CFD Research Corporation is using it for current and planned future contracts.

Public Safety

(56) Radar Device Detects Heartbeats Trapped under Wreckage

NASA often analyzes weak signals hidden in noise, like alterations in a satellite's path that indicate gravity fluctuations in a planet. With funding from other Government agencies, the Jet Propulsion Laboratory adapted the technology to create FINDER, which uses radar to detect the breathing and heartbeats of victims trapped under rubble. Edgewood, Maryland-based R4 Inc. licensed the technology and continues to develop it. The device has already seen its first sales and saved its first earthquake victims.

(60) Surveillance System Captures, Maps Lightning Strikes

Lightning strikes cause critical damage that can delay a launch, so NASA wanted a better system to detect and monitor them near its launch pads. Carlos Mata, then of Kennedy Space Center, built a highly accurate system using sensors and high-speed cameras, and then founded Titusville, Florida-based Scientific Lightning Solutions to sell it commercially. The Optical Jupiter precision lightning surveillance system could help keep wind farms functioning and help insurance companies investigate claims.

(64) Virtual Reality Platform Helps Pilots Land in the Sky

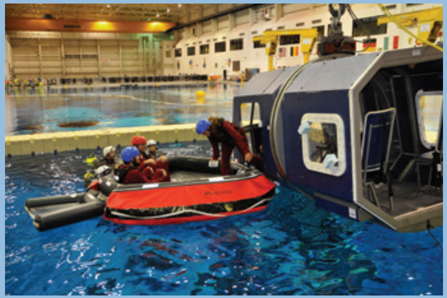
A pilot can practice landing on a virtual runway in the air, thanks to a Fused Reality platform built by Hawthorne, California-based Systems Technology Inc. SBIR contracts from Armstrong Flight Research Center helped the company turn a ground-based system first developed by the Air Force into an in-flight simulator. By superimposing virtual elements over a view of the real world, it allows for safer, more accurate, and cheaper training. The technology will also help plane manufacturers evaluate and design aircraft.

(66) Autonomous Robots Take On Dangerous Warehouse Jobs

Engineers at Johnson Space Center worked with programmers at Carnegie Mellon University to create a prototype robot team capable of working autonomously to build a solar array on the Moon. The project never flew, but one of the graduate students who worked on it is now a senior research scientist at Cambridge, Massachusetts-based Vecna Technologies, where he used the experience to design software that turns any collection of standard warehouse vehicles into an autonomous team.

(68) Drone Traffic Forecasts Show Commercial Skies of the Future

As Ames Research Center worked with the Federal Aviation Administration to craft regulations for future drone traffic, the team ran into a problem: it needed data on drone flights that wouldn't exist until regulations were already in place. Under Ames SBIR contracts, Rockville, Maryland-based Intelligent Automation Inc. created a drone traffic forecast by contacting scores of companies and agencies which, they were surprised to learn, already had drone operations planned. The enormous dataset is now commercially available to anyone planning drone operations.



(70) Offshore Oil Workers Learn Survival Skills in Astronaut Training Pool

At Johnson Space Center's Neutral Buoyancy Lab, astronauts practice spacewalks underwater to simulate weightlessness. To offset the cost of maintaining the enormous and well-equipped pool, the center charges outside groups to use the facility under a Space Act Agreement. The biggest customer is Houston-based Bastion Technologies, which provides offshore survival and fire training to oil and gas workers. The facility provides the company with a proven safety system, comfort, heavy equipment, and an ample staging area.

Consumer Goods

(74) Apollo 11 History Archive Helps Virtual Reality Program Come to Life

So much NASA data is available online that Waterford, Ireland-based Immersive VR Education was able to recreate the first Moon landing as a highly realistic and rich virtual reality experience. NASA Headquarters maintains a vast trove of images, design plans, data, and more, with the Lunar Surface Journal among its most popular records. The company's Apollo 11 VR, an app which lets users experience Apollo 11 from takeoff to the lunar surface and back to Earth reentry, has sold more than 40,000 copies.

(77) Light-Induced Oxidation Cleans Air, Surfaces, Clothes

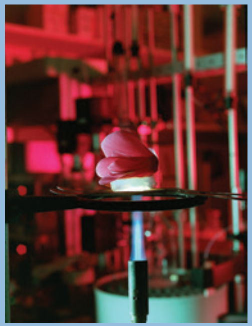
Under a Marshall Space Flight Center research partnership in the 1990s, scientists at the Wisconsin Center for Space Automation and Robotics discovered photocatalytic oxidation, a process that creates charged hydroxyl radicals that oxidize airborne organic contaminants, turning them into carbon dioxide and water. Dallas-based Aerus Holdings acquired and improved an active form of the technology that emits hydroxyls to purify air and surfaces and has incorporated it into several product lines, even including detergent-free clothes washing.

(80) Ferrofluid Technology Becomes a Magnet for Pioneering Artists

Magnetized ferrofluid was developed in the 1960s at what is now Glenn Research Center and has since found a number of industrial uses. More recently, artists have begun experimenting with it. When Nikola Ilic developed a liquid in which ferrofluid could be suspended without staining its container, he founded Hamburg, New Jersey-based Concept Zero, which sells a line of glass displays that let the user manipulate the ferrofluid inside. The company also supplies and collaborates with other artists working with ferrofluid.

(82) The Martian Garden Recreates Red Planet's Surface

In 2006, the Jet Propulsion Laboratory tested dust and rocks from a basalt quarry in the Mojave Desert and found it mineralogically and chemically similar to the surface of Mars. The center now uses the resulting Mars Mojave Simulant (MMS) to test rovers bound for the Red Planet. The Martian Garden, based in Austin, sells kits that use MMS to simulate the challenge of gardening on Mars and is also now the only remaining supplier of Mars surface simulant.

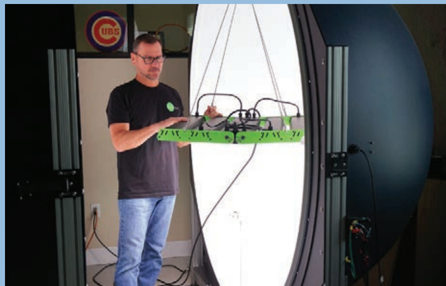


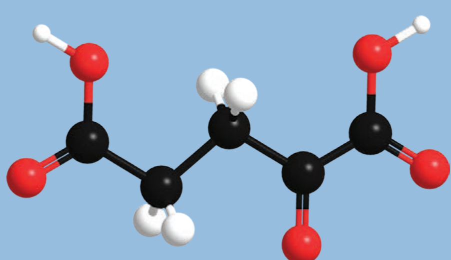
(84) Aerogel Insulation Makes Thinner, Warmer Outerwear

After a bundled-up trip up a Swiss mountain, Oros cofounder Michael Markesbery wanted to make thinner, more lightweight outerwear. He came across aerogel insulation—first made practical when Aspen Technologies, under SBIR contracts from Kennedy Space Center, infused the brittle material into flexible, durable composite blankets—when he won a scholarship from the Astronaut Scholarship Foundation. Markesbery took the $10,000 award and additional seed money and started making jackets with Aspen Aerogel insulation. The Cincinnati-based company continues to improve aerogel technology in its ever-expanding product line.

(86) Space-Grade Insulation Keeps Beer Colder on Earth

NASA didn't invent reflective insulation, but the Space Agency mastered it in the form of layered metalized polyester thin films first made for Marshall Space Flight Center in the mid-1960s. Known as radiant barrier technology, this durable, lightweight "superinsulation" is used in all spacecraft and spacesuits and a host of applications on Earth. JUNTO LLC, based in Philadelphia, now uses the technology to make KegSheets, which, coupled with ice, can a keep beer keg cold all through a hot day.





(88) High-Efficiency LEDs Grow Crops, Stimulate Alertness

Two former Kennedy Space Center contractors are using expertise gained from NASA work in LED lighting to benefit agriculture and human health. The two engineers are now vice presidents at BIOS Lighting, based in Melbourne, Florida. The company produces agricultural LED lighting that maximizes efficiency by emitting light only in the wavelengths that drive photosynthesis, as well as human lighting with peak output in wavelengths in the blue-green region, which suppresses melatonin production, inducing wakefulness.

(92) Paired Sleep Tracker, Light Therapy Tools Retrain Circadian Rhythms

Since around 2000, the Johnson Space Center-funded National Space Biomedical Research Institute (NSBRI) has supported research on the use of blue light wavelengths to regulate circadian rhythms. Based on this research, London- and San Francisco-based Circadia developed a light therapy system to train the user's sleep cycle. A cell phone app based on software partially funded by the NSBRI uses data from a sleep tracker to program each day's light therapy, via a portable lighting device, inducing daytime wakefulness to facilitate nighttime sleepiness.

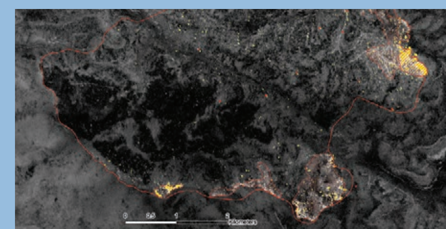
Energy and Environment

(96) Organic Compound Turns Toxic Waste into Harmless Byproducts

A team of university researchers discovered that a particular metabolite neutralizes hydrazine, a hazardous chemical often used as rocket propellant. Extensive NASA testing, mostly by Kennedy Space Center, proved the safety of using alpha-ketoglutaric acid to neutralize hydrazine, and after Kennedy developed procedures for doing so, the university licensed the resulting product to let Marietta, Georgia-based Hydrazine Neutralizing Solutions Inc. market it as ZeenKleen. Customers for the product line include nuclear power plants and, potentially, the plastic and pharmaceutical industries.

(99) LED Lighting Improves Efficiency, Imaging, Cuts Maintenance

In an effort to improve energy efficiency, Stennis Space Center issued two STTR contracts in 2009 to Solon, Ohio-based Energy Focus to develop LED-based replacements for lighting in two rocket engine test stands. While crafting floodlights and general area lights, all for use in hazardous areas, the company developed heat-management and beam-focusing techniques that have improved efficiency and lifespan in its other LED lighting, and the work also led to commercial lighting for hazardous areas.



(102) Plant Food for Space Grows Crops on Earth

Florikan's controlled-release fertilizers had already benefited from a partnership with Kennedy Space Center that generated a more robust polymer coating when Kennedy again approached the Sarasota, Florida-based company looking for a fertilizer to grow tomatoes in space. Flowering plants required a different ratio of nutrients than Florikan's existing products, so the company developed and packaged a new formula in its signature coating. Here on Earth, it's the first controlled-release fertilizer to work in vertical hydroponic farming, replacing liquid feed and the need for multiple fertilizer applications.

(104) Remote Sensing Technology Fights Forest Fires Smarter

A long-standing partnership between NASA and the Washington, DC-based U.S. Forest Service aims to help firefighting agencies make good use of advanced technology to better fight forest fires. One recent collaboration with researchers at Ames Research Center led to installing a digital downlink connection on the Forest Service's instrumented aircraft, to make it easier to send the latest fire updates to people on the ground.

(106) Earth Images Enable Near-Perfect Crop Predictions

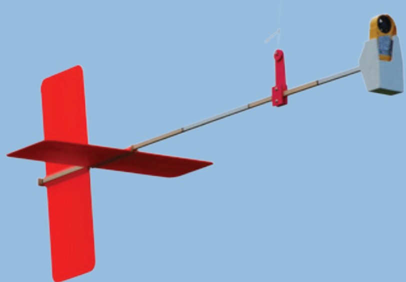
NASA has been enabling and producing constant imaging of Earth's surface since the 1970s. One of TellusLabs' cofounders has worked extensively—and often with NASA's involvement or funding—with this image archive as a Boston University scientist. The Boston-based startup developed a crop prediction model that combines Earth-imaging data with historical data, weather models, and other information. Its first product, Kernel, predicted 2016 U.S. soy crop yields with 99 percent accuracy. After a year, Telluslabs has more than 600 subscribers.

(108) Micronutrient Formula Strengthens Plants, Increasing Yields

Keeping astronauts healthy on long-duration space missions will require packing maximum nutrition into small packages. Boca Raton, Florida-based Zero Gravity Solutions Inc. developed one solution under multiple Space Act agreements, including one with Ames Research Center, infusing extra micronutrients into plants as they grow. Multiple studies have shown that the formula adds nutritional value and helps increase yield—both of which could be powerful tools on Earth, especially in developing countries. The company now sells it as BAM-FX around the world.

(110) Chemical Simulation Software Predicts Climate Change, Air Quality

Climate scientists use physical measurements coupled with computer models to observe what is happening across the entire planet over time. This requires supercomputers and can be very slow, especially for modeling chemical reactions. Baltimore-based ParaTools Inc., with SBIR funding through Ames Research Center, built faster and easier-to-use software for advanced computer processors to analyze chemical kinetics. Now it is being used around the world, including by the air quality research division of Environment and Climate Change Canada.



(112) NASA Kite Invention Spurs Ever-Growing Educational Program

When leaders at Wayne Regional Educational Service Agency (RESA) of Wayne County, Michigan, contacted NASA about aerial monitoring of ponds and streams, they learned of AeroPods, invented at Goddard Space Flight Center's Wallops Flight Facility. The devices stabilize imagers suspended from kite string. With funding through a NASA Cooperative Agreement Notice award, Wayne RESA and Wallops personnel created the Investigating Climate Change and Remote Sensing Project around the AeroPod, including 60 lesson plans now used at numerous middle and high schools.

Information Technology

(116) Planet-Navigating AI "Brain" Helps Drones and Cars Avoid Collisions

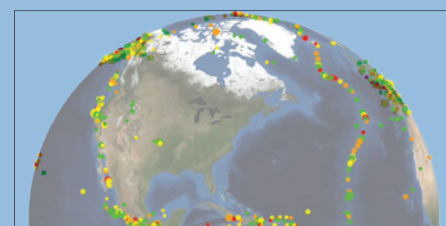
When a Langley Research Center engineer read of Neurala's efforts to develop computers based on neural systems, he called the Boston-based company. Neurala carried out development under three NASA STTR contracts, working to house both processing and memory capabilities in one "brain" rather than relying on cloud computing. This uses less energy, speeds reaction time, and would be essential for a self-learning Mars rover. Neurala's software development kit lets developers incorporate its Neurala Brain into computing platforms for drones, self-driving cars, robots, and more.

(118) Early NASA "Dream Computer Program" Still Optimizes Designs

Half a century after it was created at Goddard Space Flight Center, NASTRAN remains at the cutting edge of computer-aided engineering as perhaps NASA's most successful software spinoff. It has helped design everything from cars and turbines to buildings and roller coasters. Its code is also incorporated into many commercial programs, including Newport Beach, California-based MSC Software's Apex platform, which makes modeling and simulation up to 10 times faster and allows computer-aided engineering to be introduced earlier in the design process.

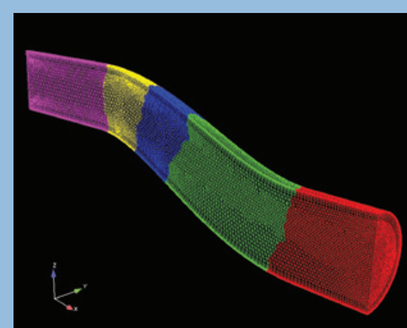
(122) 2D Analysis Software Clarifies Medical, Weather, Intelligence Images

In the 1990s, a Goddard Space Flight Center oceanographer developed a mathematical formula to analyze ocean and atmospheric data, now called the Hilbert-Huang Transform (HHT), but it only worked on a one-dimensional signal. Another Goddard scientist later created software that could apply the transform across two dimensions. Arlington, Virginia-based Syneren Technologies Corporation licensed the HHT2 software and developed its own program, which can tease information out of images for medical, defense, and meteorological applications, among countless others.



(126) Quake Hunter Maps a Century of Quakes Worldwide

Government agencies, companies, and individuals use the NASA-created World Wind software development kit, based on a virtual model of Earth developed at Ames Research Center, for many different purposes. In 2016, interns at Ames used it to create Quake Hunter, which charts every earthquake of the last century, offering an unprecedented visualization of seismological data. The team also used World Wind to build SpaceBirds, which tracks about 15,000 satellites in Earth's orbit, and WorldWeather, which maps weather for the entire globe.



(128) Free Aerodynamic Simulation Code Supports Industry, Education

In the 1990s, what is now Glenn Research Center, the Air Force, and McDonnell Douglas cooperated to produce the versatile, publicly available Wind-US program for computational fluid dynamics, which predicts how aircraft surfaces will interact with air. Alan Cain, who worked on a precursor software at McDonnell Douglas, founded Chesterfield, Missouri-based Innovative Technology Applications Company (ITAC) based largely on his knowledge of the program and the problems it can solve. ITAC and others use Wind-US for free through software usage agreements.

(130) Software Models Atmosphere for Spacecraft

When the Curiosity rover made its spectacular landing on Mars, most of the attention was focused on the revolutionary "sky-crane maneuver" that helped slow the spacecraft down. But behind the scenes, atmospheric modeling software developed at Marshall Space Flight Center helped with another make-or-break factor: choosing the landing site. Boeing, whose aerospace business is based in Berkeley, Missouri, is now one of many companies that license this software to ensure spacecraft can fly—and land—safely.

(131) Software Takes Cost Estimating to the Stars

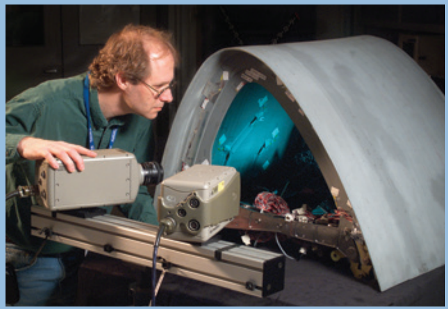
When imagining what it takes to design a spacecraft, few people think about the engineering that goes into getting an accurate cost estimate before the building begins. And yet software designed at Marshall Space Flight Center to do just that, called Project Cost-Estimating Code, has become one of the center's most-downloaded codes. Bethesda, Maryland-based Lockheed Martin is one of dozens of companies, universities, Government agencies, and international organizations that use the software.

(132) Communication Devices Ease Contact with Commercial Spacecraft

As part of an overhaul of the ISS communications system, Johnson Space Center contracted Colorado Springs-based AMERGINT Technologies to build a new data processor for Mission Control to receive data from the space station. The company was developing its reconfigurable SOFTLINK architecture of software devices, each of which carries out a specific function. Now AMERGINT's commercial offering benefits from rigorous testing, security requirements, and the many new software devices it had to create to carry out the work.

(134) Mission Control Software Manages Commercial Satellite Fleets

Saber Astronautics—based in Sydney, Australia, with offices in Denver—used data from Goddard Space Flight Center's Advanced Composition Explorer to validate data-mining software that models and predicts the behavior of spacecraft components. Upon validation, the company started building its Predictive Interactive Groundstation Interface (PIGI) mission control software. The company uses PIGI, which can predict and track component performance for dozens of satellites simultaneously, in its mission control service, and it will soon enable a commercial software package.



(138) High-Speed Cameras Test Material Performances on Impact

After Space Shuttle Columbia suffered a catastrophic failure, NASA spent months investigating what went wrong and how to prevent it ever happening again. One of the tools it needed, a high-speed stereo photogrammetry system, didn't exist, so Glenn Research Center worked closely with Philadelphia-based Trilion Quality Systems to take existing ARAMIS software and adapt it to work with high-speed cameras. The resulting product, now commercialized, helps make cars and airplanes safer, and much more.

(141) External Platform Enables Space Research

Many ISS investigations test how materials perform outside our atmosphere or use the vantage point for Earth, sun, and star observations. Houston-based Airbus DS Space Systems has built external platforms for NASA, working with Johnson Space Center, to enable that kind of research, and most recently used that expertise to build a commercial platform, which will allow private companies to test materials and mount sensors in space.

(142) All-in-One Lab Device Gets New Instruments via Software Update

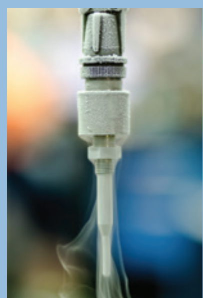
Researchers at Australian National University who worked on the Jet Propulsion Laboratory's (JPL) Gravity Recovery and Climate Experiment under an agreement with the Australian government, some of whom had also worked on the Laser Interferometer Space Antenna for JPL, used their expertise in signal processing and chip programming to build a device that can reconfigure itself into eight common electronics test and measurement instruments. Configurations for new instruments are available via download to the Moku:Lab as Canberra, Australia-based Liquid Instruments develops them.

(144) Gold Coating Keeps Oscars Bright

The Academy Awards is not a place most people look for NASA technology, but it's there: the coveted Oscar trophy is coated in the same gold that helps telescopes glimpse distant galaxies. In the 1990s, Brooklyn-based Epner Technologies, a longtime NASA partner, improved its process to make the gold more durable while retaining its high shine for a Mars Orbiter instrument. Now that process is used for art, medical instruments, the James Webb Space Telescope constructed at Goddard Space Flight Center—and the Oscars.

(146) 3D Printer Aims to Accelerate Materials Development

PrintSpace 3D founder Mark Jaster built the expertise he needed to design the Altair 3D printer in part during his years at Glenn Research Center, where he learned about cutting-edge materials, thermal management, and more. His printers now sell to universities, businesses, and research labs across the United States and overseas, and his Rexburg, Idaho-based PrintSpace 3D is working on adding metals and advanced materials to the more than 25 materials its printers can already use.



(148) Silicon Diode Sensor Tracks Extreme Temperatures

It's important to keep close track of rocket fuel temperatures, which must remain hundreds of degrees below zero. NASA uses special sensors to get the extremely accurate reads it needs at those low temperatures, and West Palm Beach, Florida-based Scientific Instruments Inc. has been supplying them to Kennedy Space Center since the Apollo Program. A more recent version, first used and improved for the Space Shuttle Program, is now sold to private space companies and the medical industry.

(150) Tunable Filter Grabs Particles and Cells Using Only Light

Filtering different wavelengths of light can help reveal important information, such as clues to how well a plant is growing. Frederick, Colorado-based Meadowlark Optics, with help from an SBIR contract from the Jet Propulsion Laboratory, developed a light filter that could be tuned to different wavelengths with a flip of a switch, hoping it could be useful for NASA's many Earth-observing missions, but the result turned out to have wide-ranging applications far beyond plant stress, from nuclear fusion to brain research.

Seven companies in this book developed their commercial products with SBIR/STTR funding

Learn how the SBIR and STTR programs can work for you: sbir.nasa.gov

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America's Seed Fund

NASA Spinoff Technology across the Nation

Health and Medicine

1. Sterilizing Fogger Cleans Ambulances with a Breeze (OH)
2. Biometric Sensors Optimize Workouts (NY)
3. Optimized Imager Tracks Cancer, Stem Cells in Medical Research (OH)
4. Weightless "Weight"-Lifting Builds Muscle on Earth (MO)
5. Virtual Therapist Offers Out-of-This-World Depression Treatment (VT)
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24. High-Efficiency LEDs Grow Crops, Stimulate Alertness (FL)
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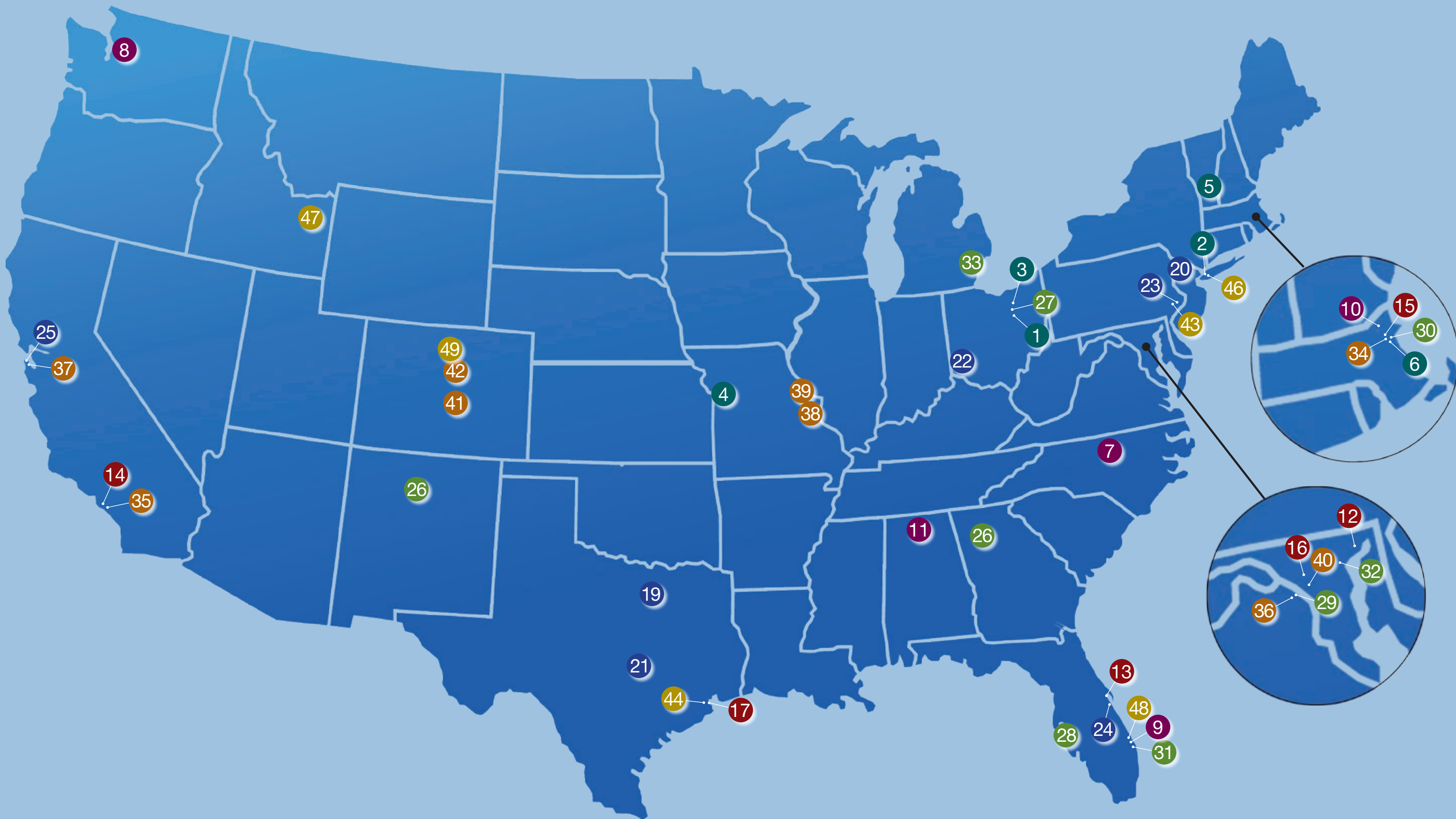


This map details the geographic locations of the companies that appear in *Spinoff* 2018.

NASA Technologies Benefiting Society

NASA continuously launches new or improved technologies into space, and these innovations often prove just as useful here on Earth, where software for spacecraft design might also make better cars, or advances that keep astronauts healthy can also improve healthcare for the rest of us. Spinoffs create jobs, generate revenue, and save costs. They even save lives. Through agricultural products, innovative consumer goods, manufacturing advances, and more, NASA technology works for the benefit of the country and the world.

Health and Medicine

Sometimes it's an innovation to meet the unique health challenges of the space environment. Other times it's a technology for analyzing distant objects or protecting components from the harsh conditions of space that happens to find a medical application on Earth. This section highlights exercise equipment, sterilizers to prevent the spread of infection and disease, and a device to improve cancer and stem cell research, all built on innovations to support space exploration or the deep expertise NASA's missions require.

Sterilizing Fogger Cleans Ambulances with a Breeze

The oxygen we breathe consists of stable, paired oxygen atoms. But high up in the atmosphere, single oxygen atoms, or atomic oxygen, seen here as green, are more prevalent and can become a destructive problem for spacecraft.

NASA Technology

When paramedics come racing into a home, the last thing anybody is worrying about is where the ambulance was earlier that morning. But traces of those earlier calls could be lingering on the equipment, bags, or even the uniforms the EMTs are wearing—and they could be spreading disease. An innovative new product, designed with NASA's help, aims to sterilize the rig and gear to make it safer for the patients and the paramedics.

The product uses atomic oxygen and oxidation, two things NASA is familiar with, explains Sharon Miller. "I work in space environment testing here at Glenn Research Center, and primarily what I do is look at how materials on spacecraft react when they're in the environment of upper atmospheres of planetary bodies and in space."

In stable form, oxygen, which is in the air that we breathe, is made up of two oxygen atoms bonded together as a pair. In contrast, atomic oxygen is a single O atom, which means "it is not stable and wants to react with anything that it comes in contact with to make a stable chemical compound. Carbon on a surface, for example, is easily oxidizable," Miller says. The atom is essentially looking for something to pair with, and it will react with anything it can to get there.

At altitudes above Earth's breathable atmosphere, atomic oxygen is far more prevalent than here on the ground and can become a destructive problem. For example, Miller recalls, the original design of the solar array blanket to power the International Space Station called for it to be constructed of a lightweight polymer material that broke down when exposed to atomic oxygen to make carbon dioxide and carbon monoxide gas.

"We were able to show that the solar array blankets weren't going to last for longer than half a year on orbit," she says. "We were able to come up with a coating that would protect them from the attack by atomic oxygen. And they've been up there more than 15 years now."

The coating protected the polymer because it was made out of silicon dioxide, basically vapor-deposited glass, Miller explains. In silicon dioxide, oxygen atoms are all already bonded to other atoms, which means the atomic oxygen had nothing to react with: "it provides a barrier."

Here on Earth, however, the destructive properties of atomic oxygen can be harnessed for a very positive outcome: sterilization. "Atomic oxygen removes any hydrocarbon from a surface," Miller explains; typically, the infectious material left on surfaces consists of things like cells and cell wall material that are full of carbon. "Even dead cells react with atomic oxygen," she says.

That makes atomic oxygen an extremely effective sterilizing agent, which is just how it is used to disinfect ambulances.

Technology Transfer

Jason Thompson started working as a paramedic more than 20 years ago, but he didn't start thinking about disinfecting ambulances until 2014. Like every emergency

Emergency Products + Research consulted with NASA to determine the best way to deliver atomic oxygen in a device to sterilize ambulance interiors. This small, inexpensive device creates a mist that can kill close to 99 percent of microorganisms in less than an hour.

medical responder, he knew and followed "universal precautions," Thompson says, but that only included "using good hand hygiene: wash your hands, always make sure you wear your gloves."

Unfortunately, there was no accompanying protocol for cleaning the ambulance or medical equipment after a call. "We weren't looking at our gear or ourselves as being vehicles or hosts for disease," Thompson explains. "Even in training, we didn't talk about decontamination and disinfection, because it's not something a paramedic can treat."

But in 2014, the Ebola epidemic was at its height, and medical personnel, including first responders, were among the most vulnerable to infection, bringing the question of infectious disease exposure to the forefront.

Thompson, who by then was working for a Kent, Ohio-based company called Emergency Products + Research (EP+R), said he and his colleagues quickly realized that Ebola was only the tip of the iceberg, and they came to the conclusion that there needed to be a fast and inexpensive way to sterilize an ambulance and everything in it.

Systems already existed to sterilize hospital operating rooms, but they cost upwards of $50,000. Plus, running those systems took hours from start to finish. Emergency medical services (EMS) departments didn't have that kind of money or time.

EP+R wanted something that was inexpensive and fast and left no residue—since wiping takes extra time and, if an unsterile cloth is used, could risk recontaminating the entire surface.

By 2015, EP+R had decided on a machine that sprayed out the sterilizing chemical in a mist or fog, but the team had many questions—what was the best chemical agent to use? would the fog interfere with the electronics on the ambulance?—and didn't know where to find the answers.

Enter NASA. Through the Regional Economic Development Program, field centers offer a limited amount of consulting with a NASA subject matter expert for just this purpose. "If we can help a company make a better product or create new jobs, improve on a process they need help with, those are all part of the goal," explains Laurel Stauber, senior program specialist at Glenn's office of Technology Incubation and Innovation.

Stauber paired EP+R with Miller, and Thompson says the advice made all the difference. "It was a key turning point. We were ready to walk away—really frustrated."

Miller says the team wasn't as far from a solution as they thought. "They had a pretty good idea of what they wanted to do, but technically they couldn't figure out how to get from where they were to the end product," she recalls.

She helped them set up a testing protocol to see what impact, if any, the sterilizing process had on the sensitive electrical equipment on the ambulance and helped them find scientific literature that would answer their questions.

"The testing was pretty much similar to what we do in simulations, only it's a ground application," so it was a natural fit for her to guide them, she says.

"I'm really **hopeful. Talk** about making a **difference** around **the world."**

— Jason Thompson, Emergency Products + Research

Paramedics wear gloves to ensure their hands don't spread germs, but the rest of the equipment, from oxygen tubes to gurneys to the medic's uniform, could all carry traces of previous calls. EP+R's device sterilizes everything, making it safer for both patient and medics. An international aid group has already expressed interest.

Among other things, Miller helped EP+R realize that the electrostatic fogger they were considering was potentially a risk for the electronics on the ambulance. She provided advice that helped them to move in another direction.

Just a few months following the NASA consultation, Thompson says, EP+R was delivering its first units.

Benefits

The product is called AMBUstat. It uses a small fogger to create a mist with a solution that consists of water, peracetic acid, and hydrogen peroxide. Peracetic acid and hydrogen peroxide are both excellent disinfectants, and mixed together in a solution tend to be more stable and work at lower concentrations.

Both work against organic contaminants because they are strong oxidizers—which means they easily break down into their component elements and give off an "oxygen radical" or single oxygen atom that looks to react with other atoms to form a more stable oxide. "Microbes are made up of carbon, so their chemical structure is attacked by the oxygen atoms and their cells are converted with time to harmless vapor byproducts," like carbon dioxide and water vapor, explains Miller.

The chemical reactions take just minutes, Thompson says. To get a full clean, however, there are a few more steps: "we recommend EMTs open the drawers, the doors, their oxygen bags, and their supply bags and hang them from the horizontal rail." That means the fog will be able to hit everything. And if the engine and air conditioning are running, it will also clean the vents and ducts.

"All you need to do is a five-minute cleanup—strip linen, throw away any visible trash, spot clean any visible matter—and run the fogger for 22 minutes. Let it sit for 15 minutes with the doors shut, and let it air out another 10 minutes," he says: under an hour from start to finish to destroy "pretty close to 99 percent of the organisms in that space."

The units are small—everything fits into a single backpack—and cost just $2,195 for a starter set, which includes a first case of the disinfectant fluid. Refills cost around $250 per case and provide enough for 24 to 30 treatments, depending on the size of the ambulance.

The same oxidation process that kills microbes also causes metal to rust. One of the challenges the NASA consulting helped EP+R overcome was to ensure the sterilizing mist wouldn't rust or otherwise harm the ambulance engine or any of the delicate electronics on board.

The first order came from a county in southern Texas after officials read an article in *EMS World*. "They sent in a blank purchase order—they didn't know how much it would cost, but they wanted in," says Thompson. Since then, EP+R has fulfilled orders with EMS groups in Ohio, Florida, Georgia, New York, and Canada.

To his surprise, the units are also being used beyond ambulances: in a school in Ohio, as well as in police cars and jail cells. And the interest continues to grow.

"Now we're getting courted by an international aid group for Liberia and Sierra Leone," two of the countries hardest hit by the 2014 Ebola epidemic, Thompson says. "I'm really hopeful. Talk about making a difference around the world." ❖

Biometric Sensors Optimize Workouts

Pulling heavy G-forces can cause a pilot or astronaut to black out. A biometric sensor could monitor heart rate and other indicators to give a warning when he or she hits a danger zone.

NASA Technology

What if, as a pilot was pulling heavy G-forces and headed toward a blackout, a voice in his or her ear said, "Pull out of the turn"? What if ground control had a screen with an astronaut's biometric indicators, and it set off a warning when he or she was hitting a danger zone?

It could be helpful, says astronaut Yvonne Cagle, not least because astronauts and fighter pilots tend not to say anything when they're feeling funny: "We're very driven to complete the mission, and we may not be as aware of physiologic urgencies until it actually interferes with our performance."

But if they wait, say, until their vision is graying out and they're about to lose consciousness, it may be too late. "Much of what we do is so intense, fast, and dynamic that, by the time you have symptoms, it's very difficult to intervene," Cagle says.

That was the motivation behind a research project Cagle mentored with Omri Yoffe, an Israeli entrepreneur whose team won the opportunity to work with Cagle and other NASA personnel in 2011 as part of a program run by Singularity University. The organization, which has a Space Act Agreement with NASA, aims to be "a global community using exponential technologies to tackle the world's biggest challenges," from water scarcity to universal education to space exploration and more.

For their project, Yoffe and his team aimed to improve biometric monitoring for pilots and astronauts, and Cagle says she helped give "some of the relevant clinical and operational situation awareness, to make it relevant to different scenarios that might come up and also streamline it for air or space operations."

Technology Transfer

Yoffe and his team came up with a prototype during the three-month Singularity program, and he says the experience was immensely beneficial when they decided to create a new, commercial biometric sensor.

"It really set the bar, to be able to measure biometrics in a very noisy, very dynamic aerospace environment," Yoffe says. That experience "trained the team and trained our know-how to be able to approach the consumer market in an easy way."

For the consumer version, the new company, New York City-based LifeBEAM, had to go back to the drawing board, because, as Yoffe explains, "the expectations of the consumer user are not at the level of the astronaut, so you can make some compromises at the R&D level" to achieve a lower cost.

But that wasn't difficult, he says, because the team had already worked on the harder task of meeting NASA-level specs. "We started at the highest bar, so then it was easier work to do it for the consumer level."

Benefits

LifeBEAM is now offering a product named Vi: "the first voice-activated, fully immersive, and real-time AI [artificially intelligent] personal trainer." Like the biometric sensor the team worked on at Singularity University, Vi tracks heart rate, but since it is designed for exercise rather than

> “It really set the bar, to be able to measure biometrics in a very noisy, very dynamic aerospace environment.”
>
> — Omri Yoffe, LifeBEAM

aerospace, it also tracks steps, mileage, weather, elevation, and more.

And unlike other wearable exercise trackers, this one is built into voice-activated earphones, so it can communicate with the user, responding to voice commands to read out heart rate, for example, and analyzing data to make suggestions on how to maximize fat burning or work toward any other set goal.

“We’ve created the first true AI fitness companion,” Yoffe says, noting that Vi can help with any fitness plan, whether it’s running a first 5K, eating healthier, or sleeping better. “We’ve leveraged our core bio-sensing tech into a more self-learning and interactive system.”

Vi seems to have hit a nerve: an initial funding round through Kickstarter raised nearly $1.7 million and sold more than 8,000 units.

Cagle says she’s pleased to see the work Yoffe and his team did for aerospace find a purpose here on Earth. “It’s exciting to show how innovations like LifeBEAM can be applied in a lot of different operational environments, and reinforce that there are benefits that come back from space that have universal applications.” ❖

Based in part on expertise gained through a NASA-linked program, LifeBEAM built an artificially intelligent “personal trainer” that aims to use a biometric sensor to maximize the impact of exercise.

Optimized Imager Tracks Cancer, Stem Cells in Medical Research

NASA Technology

After earning his doctorate, Debashish Roy set about creating a business from the biological imaging device he'd helped invent as a graduate student. The system held promise for cancer and stem cell research, among other possible applications. But he soon realized he could use some help.

"In the first-generation system, we weren't sure if it was the best possible configuration or how to verify the components and get the best performance," he recalls. The task of selecting and configuring optical and robotic parts required a high level of expertise. "We didn't have a lab to try out all the possible scenarios. We didn't even have the equipment we needed."

NASA's Glenn Research Center, located just on the other side of Cleveland from Roy's fledgling business, however, had that lab, equipment, and expertise.

Electro-optical engineer Michael Lewis had recently taken charge of the optics lab for Glenn's Research and Engineering Directorate when he first met Roy in 2012.

"We've mainly been dealing with diagnostic imaging systems for combustion and fluid physics that are usually flown on the space station," Lewis says, adding that optical communications, custom sensors, and light-based metabolic analysis have also been high on the lab's priorities for supporting NASA missions. The facility is full of optical tables, cameras and other imaging systems, laser illumination systems, spectrometers, and loads of electronics equipment.

"I'm in love with his lab—he's got the coolest toys," Roy says.

The system Roy had developed was what he called an imaging cryomicrotome, a device that could take a frozen block containing a biological sample—typically a mouse—and repeatedly slice off extremely thin sections while taking multiple high-resolution images of the block face to capture any cells tagged with a fluorescent marker, ultimately reconstructing a digital three-dimensional version of the specimen with locations and counts of all the fluorescent cells within the specimen.

The goal is to track the movement of particular cells, especially cancer and stem cells, through a lab mouse's body. "If I want stem cells to do cardiac repair, are my stem cells going to the heart?" Roy asks. "Are micrometastases going to other parts of the body and starting new tumors?"

Help from an electro-optical engineer at Glenn Research Center let the BioInVision company make its CryoViz imaging device more sensitive, more efficient, and cheaper to manufacture. The optimized optics design will also figure into a smaller desktop version the company is working on.

To answer these questions, researchers tag cells grown in petri dishes with fluorescent labels and inject them into a mouse. At some point, the mouse is frozen to preserve cellular structure, and Roy's device turns it into thin-sliced cold cuts while taking thousands of images at cellular resolution.

The machine can be programmed to do all this with no assistance from the user.

By 2012, Roy's startup, BioInVision, had made its CryoViz device commercially available but hadn't yet made any sales. In addition to optimizing his existing system, Roy wanted to develop a smaller, cheaper version, and it was with this desktop version in mind that he applied to participate in Glenn's first round of the Adopt a City Program.

Technology Transfer

Adopt a City, one of the programs under NASA's Regional Economic Development initiative, grew out of the White House's Strong Cities, Strong Communities initiative, announced in 2011, which sought to partner Federal agencies with local businesses and governments. Under Adopt a City, Glenn joined forces with Cleveland, Cuyahoga County, and the Manufacturing Advocacy and Growth Network and selected small and mid-sized manufacturers to receive 40 free hours of technical expertise from its specialists to resolve specific technical challenges that, if solved quickly, could result in a significant payoff for the company. In the case of BioInVision, that specialist was Lewis.

"I was unfamiliar with the microtome initially," says Lewis, but once he knew what the device was and what Roy was trying to achieve with it, it wasn't difficult to come up with some ideas. "In its basic form, a microtome is high-resolution imaging, and we certainly have the cameras and the optics in the lab to do that," he says.

Since the idea was to create a smaller, cheaper version that wouldn't require quite the performance level of the original, Lewis says, "I took the approach of trying to utilize existing commercial components put together in a way that would optimize the system."

For example, the imager has to pick up on dim signals without being overwhelmed by bright ones, Roy says, so choosing the right sensors, lenses, and other optical components is crucial, especially to achieve a size reduction.

Lewis ultimately gave Roy a spreadsheet detailing four or five different combinations of parts.

"He looked at that as a really nice way to keep the cost of the system down but still give him a higher level of performance than he was expecting," Lewis recalls.

While Roy and his team are still working through mechanical issues with the desktop version, they started applying Lewis' optimized optics designs to their original product almost immediately.

Benefits

The updated CryoViz is more sensitive, more efficient, and cheaper to make than the original design, Roy says. "[Lewis] knew his stuff."

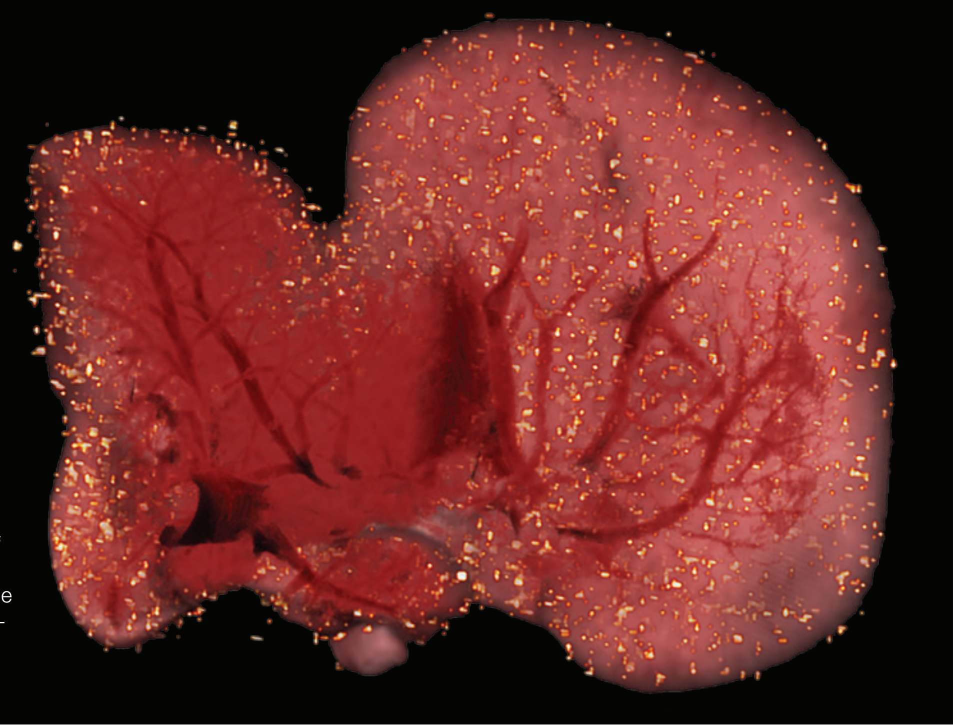
Using Lewis' designs, BioInVision was also able to eliminate a component, which reduced manufacturing time and cut out a possible point of failure, as well as a vendor.

Anne Richie, the company's vice president of administration and finance, says the assist from Glenn saved BioInVision development money up front, as well as the potential costs of any design errors and the cost of moving forward with a more expensive product. "As a start-up, you can make a lot of mistakes and lose a lot of money. For a smaller company, it can really hinder your process," she says.

Instead, the money saved was invested in speeding up development.

"It was the right expertise, and it was available locally, and that really accelerated the process," she adds, noting that this helped the company stay at the forefront of its field. "In a tech company, time is never your friend."

Now with eight employees, BioInVision has clients across the United States and in Canada, Europe, and Asia. The company offers both a product and a service: a larger, busier lab might purchase a CryoViz device, while a smaller one might send in specimens for the company to analyze on its behalf.



A CryoViz image shows stem cells tagged with fluorescent markers in a mouse liver. After a specimen, usually a mouse, is frozen in a block, the device shaves thin slices off the block, taking multiple high-resolution images of the block face to create a three-dimensional image showing the location of every tagged cell within the body.

"It was the right expertise, and it was available locally, and that really accelerated the process. In a tech company, time is never your friend."

— Anne Richie, BioInVision

"Our service side is pretty strong in the United States," Roy says.

He notes that Case Center for Imaging Research of Cleveland in University Hospitals has purchased a device, opening up research possibilities in area institutes like the Cleveland Clinic and Case Western Reserve University.

The company was also chosen as a partner in the European Union's MERLIN Project, which aims to develop stem cell-based therapies for liver disease.

Roy says BioInVision has found the most traction in stem cell research. Stem cells can morph into different cell types, giving them the potential to treat or prevent a variety of conditions. But scientists still have a limited understanding of how and why a stem cell becomes a nerve cell or a muscle cell, for example, or how it travels through the body. While the academic community might use the CryoViz system for basic research to advance this understanding, drug companies are using it in attempt to create new therapeutic products. Cancer researchers, meanwhile, use it to track the behavior of cancer cells.

Other medical imaging techniques, such as MRI or CT scans, don't offer the kind of resolution that can track individual cells through the body.

Roy says he aims to make the smaller, more affordable version of the CryoViz available in the near future, increasing smaller labs' access to the technology. In the longer term, he hopes the research it enables will lead to new stem cell therapies and breakthroughs in the search for a cure for cancer. With further development and regulatory approvals, it could also be used in hospitals for clinical procedures like biopsies, he says.

"Any of these would be of immediate importance in solving problems with human health," Roy says. ❖

Weightless "Weight"-Lifting Builds Muscle on Earth

NASA Technology

NASA astronaut Shannon Lucid spent hundreds of hours exercising during her 188-day stay on the Russian space station Mir in 1996. Although it was her least favorite part of living on Mir ("It was just downright hard," she wrote later), toward the end of her mission she felt she needed even more than the daily Russian protocols she was following. She started running extra kilometers, attached to one of the station's two treadmills with bungee cords.

At the time, it was normal for astronauts to be carried off spacecraft after lengthy stays in microgravity, due to loss of muscle and bone density. Lucid's goal was to walk off the Space Shuttle on her own two feet when she touched back down to Earth after the longest stay in space for any woman or American at the time.

When she emerged from the Atlantis Space Shuttle on September 27, 1996, largely unaided, it was a testament to her strict compliance with prescribed exercise routines and her self-diagnosed need for even more. Still, Lucid had lost muscle mass and bone density in space and was a little wobbly. NASA medical officers knew they had to find a better way for astronauts to keep fit on longer missions.

"There wasn't a good solution at the time," recalls Roger Billica, who was chief of the Medical Operations Branch at Johnson Space Center from 1991 to 2001.

"We were actively preparing for the International Space Station (ISS), and the NASA-Mir Program was a stepping stone for that partnership," he says. "It made us aware that muscle loss and bone loss due to prolonged weightlessness was a major problem."

Mir had a bicycle and two treadmills that required users to wear harnesses that could attach to the exercise devices with elastic cords. But these exercises alone weren't maintaining the muscles people use to simply stand around on Earth, where we're constantly working against gravity.

"It was clear that we needed resistive exercise," Billica says, "something to mimic weightlifting against gravity."

In zero gravity, the human body quickly loses significant muscle and bone mass, making a rigorous workout schedule crucial to long-term health. OYO Fitness founder Paul Francis worked with NASA to develop a resistive exercise device suitable for use on the space station, pictured here in use by NASA astronaut Garrett Reisman. The innovation led to several lines of Earth-bound exercise devices, most recently OYO Fitness' DoubleFlex Silver portable gym.

Weights themselves obviously wouldn't work in space, where they'd just float away. Billica and his team decided to put out a call for countermeasures to address the problem.

Technology Transfer

That was the call that caught Paul Francis' attention. The architect-turned-inventor remembers sitting in a Kansas City coffee shop reading a newspaper about Lucid's return to Earth, the loss of muscle mass and bone density, and Billica's search for solutions.

Francis had been developing a new type of home gym equipment, initially using steel power springs for resistance. He found the metal springs would start breaking at about 10,000 cycles, so he began designing parts with a mostly rubber elastomer that he developed into a spiral torsional spring he named SpiraFlex (*Spinoff*, 2001).

Francis reached out to Billica and eventually won the competition, after demonstrating SpiraFlex to a roomful of NASA medical officers, researchers, and astronauts. There was no time for delays, as Billica and his team realized if they didn't decide on a technology quickly, the first crew to live on the ISS wouldn't have access to the right kind of exercise.

"With NASA funding, we started into a fast-paced development process to take this technology and design a resistive exercise device that would fit NASA's requirements and be able to be used on the space station," Francis says.

Francis' company worked through contracts with Lockheed Martin and Wyle Labs to develop the new NASA device, which became known as the Interim Resistive Exercise Device (IRED). The SpiraFlex core units, or FlexPacks, were stacked inside dual IRED canisters, each with a spiral pulley system that provided linear resistance through the range of cable extension, enabling up to 300 pounds of resistance.

NASA physiologist Michael Rapley worked with Francis on various iterations of IRED at Johnson. "This was the first resistive exercise hardware that anyone had ever built for spaceflight," he notes. "We learned a tremendous amount—not just about building exercise hardware but also about what type of capability we needed for maintaining muscle and bone in space. We wouldn't have learned that if it wasn't for this technology at the time."

A version of the IRED device was completed in time for Expedition 1, when a three-person crew stayed on the space station from November 2000 to March 2001, the first long-duration stay on the ISS. IRED wasn't replaced until 2009, when the Advanced Resistive Exercise Device (ARED) was sent up, and the two devices overlapped for about a year. Rapley says that while the current device, ARED, uses different technology, its development owes much to the knowledge gained from working with SpiraFlex.

Benefits

After working with NASA to build the initial device, Francis was issued additional patents on the technology and licensed it to Nautilus Inc., a fitness device company that incorporated SpiraFlex into its Bowflex Revolution line of home exercise equipment.

NASA continued to improve IRED while it was on the space station. "We spent a number of years adding things to it and tweaking the design," Rapley says. The NASA team worked with Francis and engineers at Schwinn Fitness—another brand bought by Nautilus—to develop a more reliable and maintainable version of the technology that also greatly improved the number of cycles they could get out of each FlexPack.

Nautilus' Bowflex Revolution line, meanwhile, has gone on to achieve more than $200 million in sales, according to Francis, who used royalties from that license to develop his own line of SpiraFlex-based fitness equipment, which he sells through his new venture, OYO Fitness.

OYO Fitness' first product, the DoubleFlex Silver portable gym, which retails for $119, launched in January 2016. The company crowdfunded the production of an upgraded version, the DoubleFlex Black, on Kickstarter, raising over $659,000 from more than 4,200 backers. The DoubleFlex Black, which retails for $165, has more resistance and cable extension, and for $65 more, the Pro version adds integrated sensors and Bluetooth connection to the OYO Coaching app. The company is also working on group exercise and corporate wellness programs.

For the DoubleFlex line, Francis miniaturized SpiraFlex technology again to create a device that weighs only two pounds but produces up to 25 pounds of linear resistance and folds up to fit in a small backpack. Users add 5 or 10 pounds of resistance by snapping on FlexPacks, which, in the case of the DoubleFlex, are wheel-like cartridges that resemble tiny barbell weight plates but contain the torsional SpiraFlex spring instead of weight.

Francis describes the DoubleFlex as the world's only exercise device that applies resistance to both sides of muscle groups in one motion, enabling balanced bodybuilding in half the time. "Combining strength with movement, without weight or momentum, our portable gym is the new way to get fit anywhere, anytime," he says.

NASA's Rapley notes that the technology is the result of a collaborative back-and-forth relationship between the Space Agency and the private sector. "What is great about this story is how both sides continued to benefit from a single idea," he says. Francis' idea helped NASA solve one of the initial challenges at the start of the ISS, and collaboration with NASA improved the design for a more reliable technology that he was able to license to Nautilus.

Engineers at Schwinn and Nautilus went on to improve the system further. "Years later, NASA again benefited from this collaboration by working with industry to incorporate those FlexPack design changes back into our IRED design," Rapley says. "Those changes ultimately reduced the sustainability costs of IRED by improving its reliability and making it more maintainable in space." ❖

The DoubleFlex uniquely applies resistance to both sides of a muscle group through one motion, which Francis claims greatly improves the efficiency of workouts. It boasts an extremely portable form factor, and, while the device itself weights just 2 pounds, it provides up to 25 pounds of resistance.

Virtual Therapist Offers Out-of-This-World Depression Treatment

NASA Technology

Imagine being stuck in a small space with just a few coworkers for months at a time. Each person's work is crucial to the success—even the survival—of all. Now imagine one person, or more, starts to feel the stress of confinement. Maybe he or she starts to feel a little depressed. Maybe a couple of people start getting on each other's nerves.

NASA has done more than imagine it, because during long-duration stays at the International Space Station, as well as future trips to Mars and beyond, these could be very real problems. But here on Earth, there are also many who struggle with mental health problems who may not have ready access to treatment, whether because of the cost or where they live.

The latter was the inspiration for an idea to offer video-based therapy via computer software, explains researcher and licensed clinical psychologist James Cartreine. "I could see there was no way to meet the demand for mental health treatment out there in rural settings," he says, because not enough clinicians live in the areas that need serving.

There had been earlier attempts to create computer programs to provide mental health treatment, but these were mainly text-based and not very effective. Among other problems, "certain mental health disorders, like depression, can sap your concentration and make it difficult to read," Cartreine notes.

Also, live therapists are engaged and compassionate listeners, something that was lacking in the text-based programs. Cartreine, who has a background in video production, felt he could offer a much more effective and engaging experience by using video, especially now that technology had advanced so much since the earlier attempts.

In April 2017, astronaut Peggy Whitson broke a record, becoming the American who has spent the most cumulative days in space. "Working aboard the space station for long duration is definitely a challenge," she wrote in a Tumblr post a few weeks later, adding that "psychological and emotional support is extremely important in space."

Although he initially expected to find funding from the National Institutes of Health or other medical research organizations, he soon discovered another source of funding that surprised him: the National Space Biomedical Research Institute (NSBRI), a Johnson Space Center-funded nonprofit focused on health risks associated with long-duration spaceflight.

At the time, the NSBRI was putting out a call for research focused on giving astronauts increased autonomy in dealing with medical conditions, including mental health issues like depression and interpersonal conflict. Although he hadn't originally imagined his program for space, he realized, "this is exactly what I've been trying to do, create an autonomous mental health treatment for various disorders."

Applying for funding from the NSBRI, Cartreine envisioned a therapy program called Virtual Space Station, which would provide a system to run modular programs depending on the astronauts' needs. A first round of funding allowed him to create the architecture and interface, and—following a tour of Johnson to present his work in progress and invite feedback from flight surgeons—Cartreine used a second round of funding to begin creating content.

The first treatment module Cartreine developed was designed for depression, based on an intervention called problem-solving treatment (PST). It was a good starting point, he recalls, because the treatment is brief, often just six sessions; has been shown in trials to be very effective for most people; and—especially helpful for a software-based system—is extremely structured.

Technology Transfer

"I wanted to provide the same experience you would get if you were receiving treatment from a master clinician and make this treatment available to all astronauts," says Cartreine. In total, he spent 13 years developing the Virtual Space Station for NASA with grants from the NSBRI.

However, he's quick to add, "my interest all along has truly been in public mental health": even while working with NASA, it was "with the idea that everything I'm building is very easy to convert into something that can benefit thousands and millions of people."

So as the second grant was ending, around 2009, he negotiated to transfer the intellectual property to a private company he started. Around that time, he also founded a separate company with fellow psychologist and researcher Claudia Zayfert, focused on using technology to treat post-traumatic stress disorder (PTSD).

A couple of years later, Zayfert explains, she and Cartreine decided to "merge the work we were doing on PTSD with the work he had already done with NASA" into a new company, which they called everMind.

Benefits

In 2015, the Norwich, Vermont-based company released its first product, a direct translation of the Virtual Space Station module for depression. ePST, for electronic problem-solving treatment, "was the first software cleared by the FDA for depression treatment," Cartreine notes, and "really provides a third alternative to live therapy or medication."

While the Virtual Space Station was filmed on sets that make it look like the real space station, ePST was restaged to look like a standard therapist's office, featuring an expert clinician who talks directly to the camera.

"All the clips are very short, typically a minute or less," explains Cartreine. "The goal is to have a conversation of sorts, to emulate a therapeutic conversation."

The treatment starts by asking patients to type in their problems—not the internal struggles, but the tangible life problems caused by, or that they feel unable to fix because of, depression— like a messy house, a broken-down car, or problems getting dressed and out the door every day.

"PST is really appealing to people who want a here-and-now focus and who want to get results and get them quickly," says Zayfert.

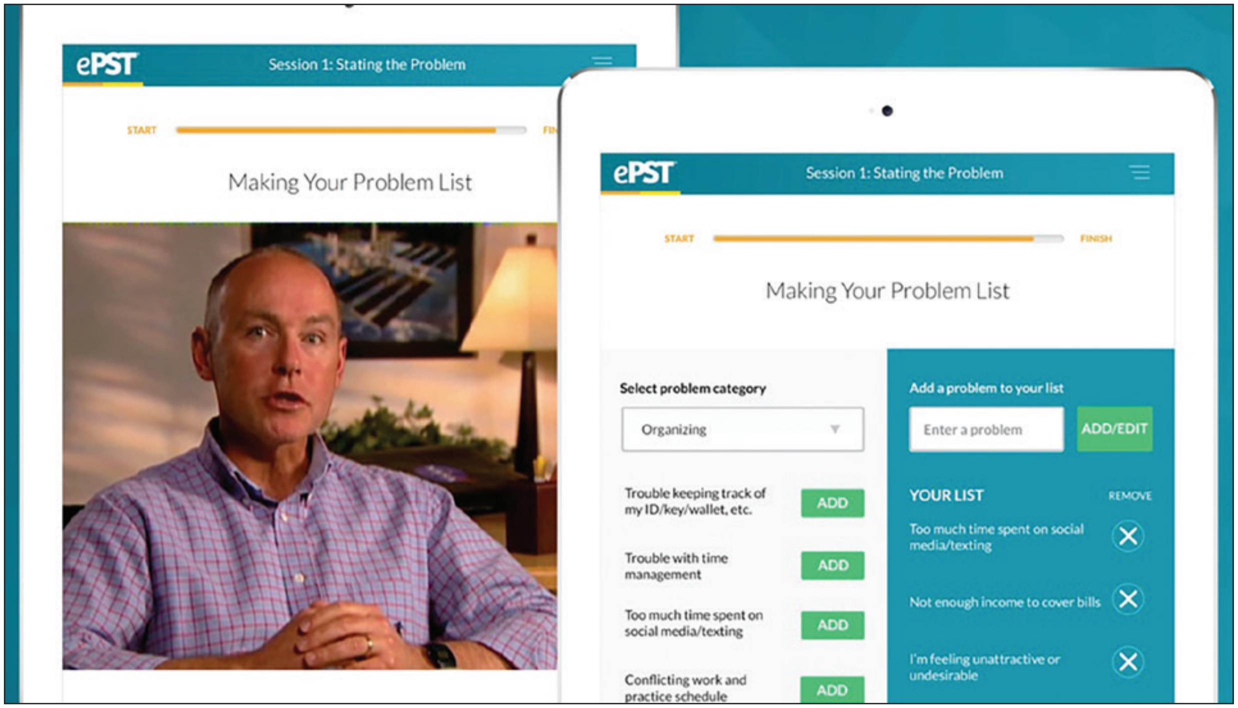
Subsequent sessions ask the patient to pick a small problem and brainstorm steps to improve it, then to evaluate how well the plan worked. Unlike a real therapist, the computer program "doesn't understand natural language: it's just reflecting back what you're typing in," Cartreine explains. "But it guides you through the process of completing a plan to address a manageable life problem."

The main advantage over live clinicians is accessibility: cost; logistical barriers, like lack of transportation or childcare; reluctance to seek treatment because of stigma; and the severe shortage of mental health clinicians are major obstacles in the United States, and even more in other countries, Zayfert notes. There have been five clinical research studies so far, showing patient improvement with ePST at a level comparable to therapy from a live clinician, and significantly better than no treatment, Zayfert says.

A desktop version of ePST has been available at Michigan State University health center, and the company is in talks to expand access at other universities and medical systems.

everMind also plans to upgrade in 2018 to a web-based version of ePST that patients can use right on their own devices—but they intend to continue to make it available through clinical settings to ensure oversight from medical health professionals. "There is a lot of potential benefit very broadly, but we also want to do it in a systematic way so we can evaluate the safety as we go," Zayfert says.

She notes that there has been some reluctance from medical providers to adopt this new avenue of treatment—but the NASA connection helps. "We find that it lends quite a bit of credibility," she says. "You see people's ears perk up when you talk about NASA." ❖



With the psychological challenges of long-duration space missions in mind, the Johnson Space Center-funded National Space Biomedical Research Institute supported an initiative to develop video-based software to help diagnose and treat mental health and interpersonal issues. everMind has adapted the depression module for the ground, aiming to greatly expand access to evidence-based treatment.

Compact Spectrometers Unveil Clues to Diagnose Cancer

Early on, NASA searched for alien worlds using spectrometers, which detect a star's "wobble" to infer the presence of a planet tugging on it. Future efforts may use spectrometers in conjunction with a technique that detects a planet's transits between its sun and the observer, which could help gather clues about the exoplanet's atmosphere.

NASA Technology

It may seem hard to remember now, with thousands of planets of various types and sizes discovered throughout the galaxy, but back in the 1990s, the field of detecting exoplanets was still in its infancy, and the tools used to look for them were too. Now, an instrument first imagined to look for distant worlds is helping uncover hidden details on this one—and it owes much of its development to NASA funding.

Arsen Hajian builds small but mighty spectrometers—he likes to say his company's hyperspectral imagers pack the high resolution of machines nearly 30 times larger and as much as 10 times more expensive. He founded his latest company in 2015 but has been working on spectrometers for more than 20 years.

"Back when Arsen was first working on some of this stuff, exoplanets were really something of a new field," recalls Goddard Space Flight Center astrophysicist Stephen Rinehart. "People were looking for them using radial spectroscopy"—a technique using measurements of a star's wobble to infer the presence of a planet tugging back at its sun. Although spectroscopy had been around since the 1800s, the existing tools weren't precise enough to get the results astronomers wanted. Hajian was one of the engineers working to make better ones.

Rinehart, who has been unofficially collaborating with Hajian off and on since the two went to graduate school together, works on instrumentation for NASA's Observational Cosmology Lab. "I focus on what kind of mission or instrument we need for the next bit of science: how to design it, what does it need to do, and then work on building it," he says.

That expertise has offered him the opportunity to work on a range of missions from the Hubble Space Telescope to, most recently, the Transiting Exoplanet Survey Satellite (TESS), and has brought him back to Hajian's spectrometers as he considers the next big space telescope.

In recent years, astronomers have moved away from radial spectroscopy, instead favoring a technique using photometric transits—catching the faint dimming of a star that comes when a planet passes between it and the observer. But Rinehart thinks the next-generation telescopes may combine the two techniques into transit spectroscopy, which could help "astronomers get some clues to what the atmosphere of the exoplanet is like."

If NASA decides to go that route, he says, "we will want to build the biggest telescope we can, using the smallest spectrometer we can, which is where Arsen's tool comes in."

Technology Transfer

Although Hajian's company, Hindsight Imaging Inc., is young, the technology is based on a discovery the physicist made decades earlier at the U.S. Naval Observatory—with funding from NASA.

Many scientists get Government grants through the National Science Foundation, Hajian says, but as a Government employee, he was discouraged from applying for those. Instead, he turned to funding mechanisms available from NASA, including both the Advanced Technology Initiative (ATI) and ROSES, or Research Opportunities in Space and Earth Sciences.

"Basically, all of my funding during my 13 years at the Naval Observatory came either from the Navy, NASA, or corporations," Hajian recalls. The grants funded his efforts to build better spectrometers for star cataloging and exoplanet detection, of interest to both the Navy and NASA.

But his big breakthrough came in large part because his training was in another field altogether, he says: "I'm a radio astronomer by training; nobody taught me optics."

Most spectrometers are either small and low-resolution or very large but high-powered, following what Hajian calls "one of the basic rules of optics: a telephoto lens (typically long and bulky) magnifies the image, while a fisheye lens (typically much smaller) demagnifies."

But since radio astronomy doesn't require that tradeoff, Hajian was open to looking for a different approach. He found one, essentially adding two extra reflecting surfaces to the standard optical design to change the shape of the light as it enters from a round point to a long and skinny ellipse, without changing the focal ratio.

The result? "We got around that law. It allowed us to build spectrometers that are a bit more than three times

Hindsight Imaging Inc.'s spectrometers are nearly 30 times smaller than conventional instruments with similarly high resolution.

smaller in all three directions than conventional instruments. It saves on volume by a factor of about 30."

The breakthrough, which Hajian has patented, didn't happen all at once, but the NASA-funded work he did at the Naval Observatory gave him an important foundation for the work that came later. "The whole point was learning how to build spectrometers and understanding the problems that needed to be solved," Hajian says.

"A lot of times it felt like beating your head against the wall: what makes a spectrometer good or bad, and how is it connected to all of the other things that matter? That took me a long time to figure out. Then figuring out how to build it took me less time."

Benefits

For now, Boston-based Hindsight mainly sells spectrometers as components to be integrated into larger instruments, and the company has quickly amassed "a wide variety of customers in multiple spectrometry markets," Hajian says.

In the small but growing precision agriculture market, spectroscopy can be used to look for invasive species or for signs of plant disease, Hajian says, or to help farmers see precisely where they fertilized yesterday and where they didn't.

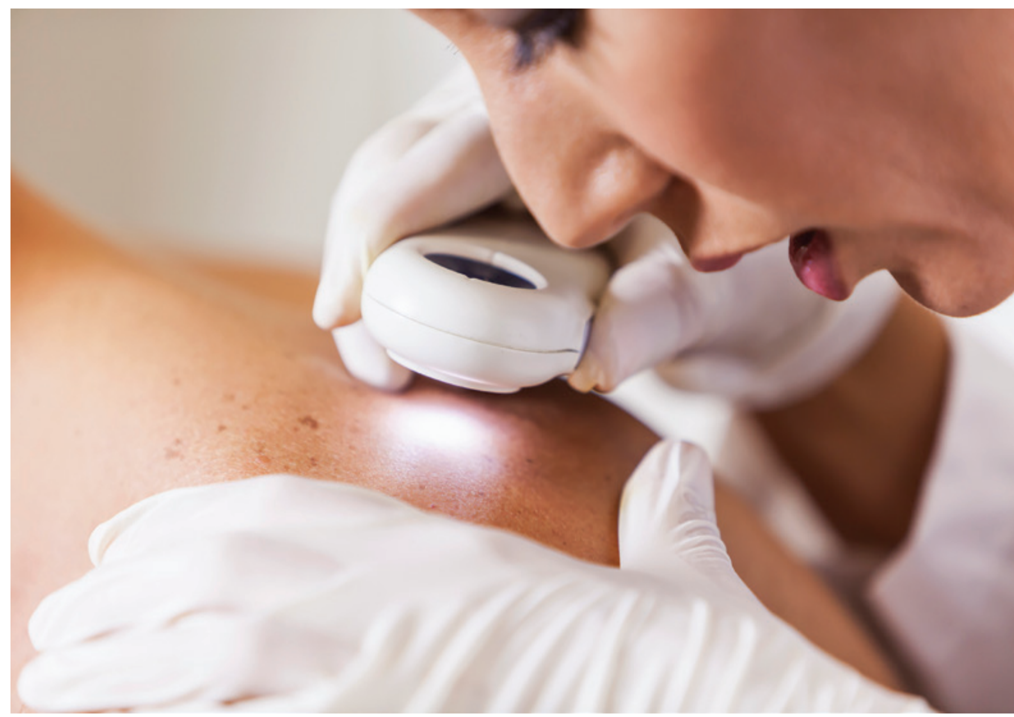
Hindsight spectrometers are also integrated into devices that look for chemical explosives and monitor the content of medications. Both applications measure the spectrum of light absorbed, reflected, and emitted by a sample and compare it to the spectra of known substances, but they are packaged differently and use different software.

In mid-2017, the company also released its first two complete spectroscopy systems, one for detecting drugs and explosives at a short distance and another for detecting skin cancer. "The reason we have these two specific devices is because there is a lot of customer interest," Hajian says. Hindsight already had orders for both, he added.

Down the road, he envisions game-changing medical advances from optical spectroscopy, including using spectrometers like his melanoma-detecting device to diagnose tumors underneath the skin, eliminating or reducing the need for biopsies.

He's also working on devices that could replace traditional laboratory blood tests: "What we're trying to do is deploy products where you look at a drop of blood or look at it through the skin, and right there you find out what is in your blood," he explains.

The sky's the limit, he says, for his devices. "In moderate volumes, our prices come down to affordable price points that are not possible with conventional technology. That opens up lots of opportunities, because if you can make it cheap and light and easy to use, it can fly off the shelves."



Hindsight recently released one of its first complete spectroscopy systems, designed to detect melanoma in the skin without a biopsy.

And indeed, notes Rinehart, the sky's no limit for applications at NASA. Beyond using the spectrometers on future space telescopes, another idea he is exploring is taking a small spectrometer, like what Hindsight is making, and putting it on a high-altitude balloon, to look for exoplanets and their atmospheric composition from near space.

That would put the instruments above 99 percent of the atmosphere, Rinehart says, which isn't as good as 100 percent but would be a far less expensive way to "pick off the low-hanging fruit."

And it wouldn't be possible without a high-powered, very compact spectrometer. "This has always been the direction Hajian's been going. He's been working with the basic concepts for over 20 years now, coming up with better ways of doing things." ❖

Transportation

Technology is never finished confronting the challenges of air and space travel, and we all benefit from these steady improvements to flight technology, from software to ease aircraft design to advanced avionics capabilities that apply to planes, wind turbines, and self-driving cars. Also in this section is the high-performance rocket engine that's put countless commercial and defense satellites in space and the specially outfitted NASA facility that tested the fastest business jet in its class.

Innovative Design Propels Small Jet Faster, Farther with Less Fuel

NASA Technology

These days computers handle a lot of the work for designing an airplane, but when it comes to seeing how well the new design will really handle in the air, there's nothing like a real-life test in a wind tunnel. NASA's National Transonic Facility is one of the best—and when the Agency's engineers aren't using it to test their own aeronautic innovations, private companies are sometimes able to use the available space by reimbursing NASA for time not already scheduled.

That's just what Honda did when it was designing a new business jet. The plane body and its over-the-wing engine mount were designed after conducting "extensive research, using computational fluid dynamics, or CFD," explains Honda Aircraft Company CEO and President Michimasa Fujino. "We found that if we put the engine at the optimum location relative to the wing, we find a sweet spot to reduce wave draft."

NASA is using the National Transonic Facility (NTF) to test the Hybrid Wing Body airlifter, which could be more fuel-efficient and aerodynamic than the traditional airplane shape. The NTF is pressurized and can pump in pure nitrogen gas, which makes it better able to mimic real conditions in the air than other wind tunnels.

But before Honda was ready to invest in a new company offshoot and product line, it needed to test design variables in real-world conditions. "In order to experimentally validate our concept, we were searching for a wind tunnel all over the world," Fujino recalls. The National Transonic Facility, or NTF, at Langley Research Center, was the clear choice.

The NTF "was the first of its kind in the world, and there are only two like it in the world now," explains Richard Wahls, senior technical advisor to the director of NASA's Advanced Air Vehicles Program, where the facility is housed. Opened in 1983, the NTF aimed to help design the bigger airplanes that were being developed.

"In the 1960s and '70s, there were always surprises during initial flight tests. For example, the aerodynamic loading might be different than expected if the shockwave over the wing was in a different location than expected," Wahls says.

"But by that stage of the development process, you couldn't start from scratch, so you had to figure out how to make a fix." Those kinds of fixes tended to add weight to the plane or were in other ways non-optimal.

It wasn't that nobody had wind tunnels. They did, including NASA. But none of them corrected for an important problem: the models of aircraft used for testing were much smaller than the real thing, often as much as 50 times smaller, while the molecules in the surrounding air were the same size.

"There's a certain kind of spacing, which you can't see with your eye, characteristic to air," Wahls says. That air moves across the curves of an aircraft in specific ways. "But the air will act differently over that small-scale model, because the molecules are spaced the same way, but now they're flowing over a smaller geometry."

The mathematical term that expresses that relationship is called the Reynolds number. To partially correct for these Reynolds-number disparities, the NTF, like several other wind tunnels, is pressurized, so the air can be compressed proportionally to the scale of the aircraft. However, to simulate large aircraft, this pressurization is not enough to match flight conditions. To finish the job the NTF can also pump in pure nitrogen gas at temperatures as low as -250 °F, which further increases air density to simulate the real conditions airplanes experience at altitude.

NASA has used the NTF for many projects, including foundational research on how air flows over simple shapes at different Reynolds numbers, which can improve computational models. The Agency has also tested innovations in aircraft design there—some of which, like the winglet, have become standard in modern jets.

Today NASA uses the NTF to test advanced aircraft concepts like the blended wing body, a flattened, triangular design that could one day replace the more familiar airplane shape of a tube fuselage with wings sticking out.

Technology Transfer

When the Agency doesn't need the NTF, private companies can step in to take advantage. These contracts can be cooperative, where NASA and the company share the costs and the resulting data, or fully reimbursable, where the company pays for the wind tunnel time in full and retains full rights to its data.

Honda Aircraft negotiated the second type of contract, Wahls says. Fujino and his team had already mostly designed their aircraft but needed to do final testing.

"In order to have both high Reynolds and high Mach number conditions simultaneously, NASA is the best facility to give that condition," Fujino remembers. "And also NASA's wind tunnel gave us very high accuracy of test results because its instruments are capable of very sophisticated tabulation and data collection."

The team worked with NASA wind tunnel experts in advance to ensure their model, 10 percent the size of

“Only very few people have that **expertise in the world,** so **[NASA’s] experience** was very **valuable** for me to **assess** the **experimental accuracy.”**

— Michimasa Fujino, Honda Aircraft Company

HondaJet was tested at the NTF to see whether the computer models of its innovative over-the-wing engine mount were accurate in real flying conditions. The successful test results gave the company more confidence to move to the commercial phase.

a full-scale jet, was properly designed to withstand the highspeed testing and could interface with all the instruments. Then they underwent a week of testing, from which they gathered "several tons of data from the very efficient NASA experiment process," he says.

Fujino says the test allowed him to choose the best among several options for the fairing of the over-the-wing engine mount configuration, but mainly it proved the existing design worked as expected.

"Because I could confirm my concept from test results, I had more confidence to go into the commercial phase," Fujino says. "The experiment was proven: not only theoretically proven but experimentally proven."

Benefits

Following the wind tunnel testing in 2005, Honda launched its general aviation subsidiary Honda Aircraft in Greensboro, North Carolina, where 1,700 workers are employed to manufacture the planes.

The key innovation of the new jet is the over-the-wing engine mount, a major departure from previous light jets, which generally mount the engine on the fuselage, the main body of the aircraft. Mounting the engine over the wing can interfere with air flow, but Honda's design, born out in the NTF testing, found a "sweet spot" that actually reduced the shockwave, thereby decreasing drag.

As a result, the HondaJet has the fastest maximum cruising speed in its class, 422 knots (nearly 500 mph), and can fly at a maximum altitude of 43,000 feet, also highest in its class. The light jet recently set two speed records, flying from Teterboro, New Jersey, to Fort Lauderdale, Florida, in just two hours and 51 minutes, and from Boston, Massachusetts, to Palm Beach, Florida, in two hours and 58 minutes.

The lower drag also increases the jet's fuel efficiency, which makes the airplane less expensive to operate than other light jets. Honda Aircraft estimates its engine configuration uses up to 17 percent less fuel over a given distance than typical configurations, assuming similar flight conditions and operator.

Mounting the engine over the wings also increases passenger comfort, Fujino says: there is more room in the cabin, because the engine isn't taking up any space, and vibrations don't transfer, reducing noise.

The company markets to owner pilots and to small business owners who need to travel frequently. It began delivering jets in late 2015 and has already sold more than 100, with prices starting around $5 million, in North and South America and Europe. The company has recently expanded sales to Central America and is looking to the Middle East as well.

And back at Langley, the NTF continues to test the cutting edge in aeronautics.

"You can think about it as risk reduction," Wahls explains. "Someone has an idea and it's on paper, but you need to make it real. Part of making it real you can do with CFD, and that's come a long way, but you still want to see some experimental data." And that's something that can be done at the NASA facility better than almost anywhere else in the world. ❖

The over-the-wing engine mount design allows the plane to fly faster using less fuel, but it also increases space and comfort in the cabin, since the engine is no longer attached to the plane body.

Design Software Transforms How Commercial Jetliners Are Built

Boeing has used the Pegasus 5 software widely, including on its 777X, which is slated to fly in 2020.

NASA Technology

In the late 1990s, as computers were becoming vastly more powerful, Stuart Rogers began working on Pegasus 5—software that made use of this increasing processing power to dramatically transform how airplanes and spacecraft are designed and built.

The code enables designers to do the bulk of their work on the computer, reducing the number of expensive and time-consuming wind tunnel models and tests required for a new aircraft or upgrade.

"It can be applied to many, many different types of problems, from airplanes to spacecraft to rockets to internal flows," says Rogers, who has worked at NASA's Ames Research Center since arriving in 1984 as a student. "If you've already studied your whole design space in the computer, then you only need to build a wind tunnel model to verify that performance."

The software itself is a preprocessor for overset-grid computational fluid dynamics (CFD) simulations. This CFD approach divides large domains into smaller, more workable segments. Pegasus 5 reassembles the pieces, stitching together the various parts of this complex geometry for what's called a flow solver. The flow solver then computes the aerodynamics or fluid dynamics for the problem at hand. Before Pegasus 5, piecing these segments together was a painstaking process consuming much more time and user input, creating opportunities for errors.

"We set about trying to improve the capabilities that we had and really sped up the process dramatically," says Rogers, who took over the project from Norman Suhs and William Dietz, both of whom were working for Micro Craft in Tullahoma, Tennessee, at the time. Suhs and Dietz had developed earlier versions of the software, which began as a NASA-Air Force partnership. The two then completed the initial Pegasus 5 implementation before handing it back to the Space Agency's in-house team, where Rogers continued to update and maintain it. Suhs and Dietz kept in regular touch with Rogers after that.

When Pegasus 5 won the NASA Software of the Year Award in 2016, all three developers were recognized.

"Pegasus 5's primary goal was to come up with new algorithms to really automate the process of gluing together all these geometrical parts without so much user input, so you didn't need a super-experienced user to do it," Rogers says, crediting Suhs as the primary developer of the new algorithms, a number of which were published in 2002 for public-domain use by any developer.

Technology Transfer

Rogers' work on Pegasus 5 began in 1998 at NASA's Advanced Subsonic Technology (AST) Program, a joint research effort with Boeing. The multiyear program supported the development of Pegasus 5 for two years, a process that involved Boeing from the beginning, as the company helped define the technical requirements of the final product.

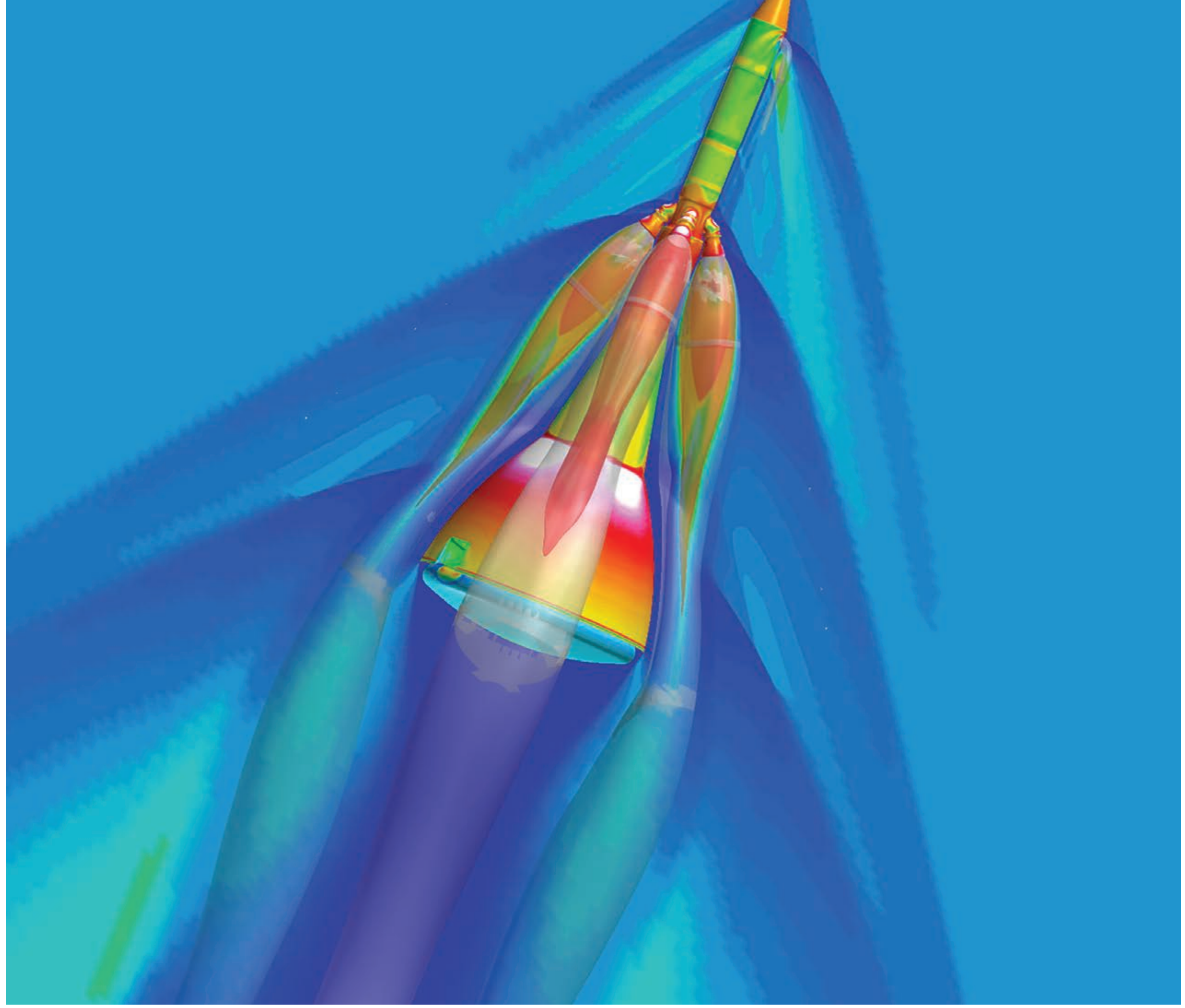
Boeing was one of the first companies to apply Pegasus 5 "to very complex and realistic aircraft configurations," according to Robb Gregg, chief aerodynamicist for the company's Commercial Airplanes Division, located in Seattle, Washington. The company lobbied "for a greatly streamlined and automated alternative to PEG4," Gregg says, referring to Pegasus 4, the upgrade's predecessor, which Boeing also used. "The AST Program recognized the need to improve the overset grid connectivity process and funded the code development," he says.

The aircraft manufacturer also used NASA's flow solver, OVERFLOW CFD, for aerodynamic and fluid dynamic problems. As soon as it was established that PEG5, as Gregg calls the upgrade, could preprocess grid data for OVERFLOW, "PEG5 rapidly became the primary overset connectivity tool within Boeing," he says.

After the AST Program wound down in the early 2000s, Rogers went on to use Pegasus 5 on numerous large projects at NASA, including the Space Shuttle Program, where he helped investigate the 2003 accident of the Space Shuttle Columbia and helped the program return to flight.

As he used Pegasus 5 over the years on increasingly powerful computers, Rogers saw how to make it better. "We made incremental improvements to the software, none of which were actually funded directly by any program," Rogers says. "The more you use it, the more you find, 'Hey, it'd be great to do this or add a couple features to that.' That's how it's been developed since then. When I have spare time I try to put in new features and improve the code a little bit."

Every once in a while, Rogers releases a new version and sends it to NASA users, Boeing, and other companies. The code has been distributed to more than 470 organizations in industry, academia, and the U.S. Department of Defense. The latest version of Pegasus 5 is available in NASA's online software catalog, which automates the process of obtaining software by generating the required nondisclosure agreements. Unlike the early days, Rogers is no longer in personal contact with everyone using his software.



Flow around the Orion Launch Abort System, computed with Pegasus 5. The surface is colored by pressure coefficient, and Mach contours illustrate the flow around the vehicle. The transparent surfaces illustrate the plumes from the abort motor nozzles.

Benefits

Pegasus 5 has been used to develop or upgrade essentially every major NASA spacecraft in the last 15 years. In addition to his Space Shuttle work, Rogers has used Pegasus 5 to run simulations for NASA's next crewed spacecraft, Orion, as well as the Space Launch System, which is being built by Boeing and will transport astronauts aboard Orion into orbit and beyond.

Boeing meanwhile has been using the software widely to develop and support its commercial airplanes, military aircraft, and spacecraft. The company used Pegasus 5 in the development of its wide-bodied 747-8—the longest passenger aircraft in the world—and the latest versions of the 787 Dreamliner. Pegasus 5 simulations also played a

> “Sometimes I’m still amazed at what we’re able to do now compared to what we could do 20 years ago.”
>
> — Stuart Rogers, Ames Research Center

role in developing the 737 MAX, which first flew in early 2016, and the 777X, which is slated to fly in 2020.

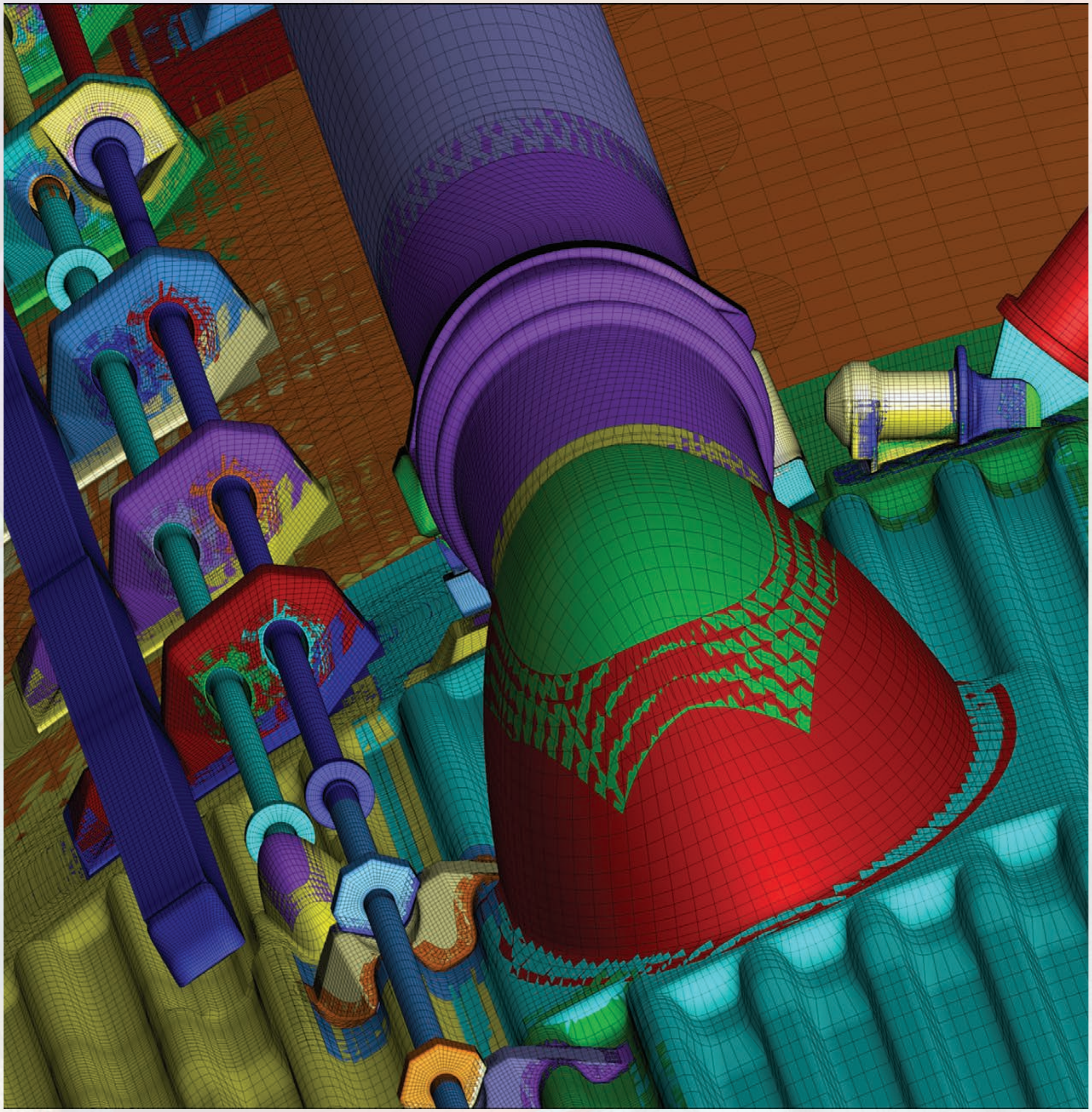
The company has also used Pegasus 5 for smaller tweaks to jetliners currently in use, such as when, at the request of airlines, Boeing added new antennas to improve Internet service on passenger flights.

“Once you decide that there’s a business case for an upgrade or just a new airplane of a slightly different size, you want to get it to market as soon as possible and don’t want to spend billions of dollars designing it,” Rogers says. “The more you can do ahead of time in the computer and the faster you can turn it around, the better your product’s going to be—and the better you are at getting a good product to market and beating the competition.”

Boeing’s Gregg notes that while Pegasus 5 helps the company save time, an even more important benefit is the reduction in potential user errors. “Previously we had to either simplify geometry or strictly limit the use of overset-grid CFD to the verification of the design, which was typically developed using other in-house capabilities,” Gregg says. “Today, much of the uncertainty of analysis and design has been eliminated,” and much of that is thanks to Pegasus 5.

In May 2016, when Gregg wrote a letter on behalf of Boeing encouraging NASA to consider Pegasus 5 for the Agency’s Software of the Year Award, he wrote that “without PEG5, we would not be able to efficiently design and analyze the wide array of aerospace products that we build at the Boeing Company.”

“While we always knew this whole approach was pretty powerful,” Rogers says, “sometimes I’m still amazed at what we’re able to do now compared to what we could do 20 years ago.” ❖



This rendering of the surface of the Space Shuttle’s external tank illustrates the complex geometry capabilities of the Pegasus 5 software.

Original Cryogenic Engine Still Powers Exploration, Defense, Industry

NASA Technology

At a time when cell phones and automobile features are outdated after a few short years, it may seem impossible that any technology would remain virtually unchanged over decades. But the world's first cryogenic fuel-powered rocket engine, a NASA spinoff, remains the most-used upper-stage rocket engine in the United States more than 50 years after its creation.

The RL10 rocket engine, first successfully flown in 1963, has been crucial to NASA's space exploration and has also put hundreds of commercial and military payloads into orbit, enabling satellite communications and satellite-based defense operations. What's more, after more than half a century, only a handful of countries have the technology, pioneered under the program, to power rockects with liquid hydrogen and oxygen.

The RL10 was matured under a contract between NASA's Lewis Research Center, now Glenn Research Center, and a division of Pratt & Whitney Aircraft, now part of Aerojet Rocketdyne. Both entities had previously worked on the technology independently.

In the 1940s, Lewis, then part of NASA's predecessor, the National Advisory Committee for Aeronautics (NACA), had carried out extensive testing on high-energy liquid rocket propellants, including liquid hydrogen. Cutting-edge propulsion and cryogenic-handling technology remain two of the center's specialties today.

Pratt & Whitney's work with liquid hydrogen began in the 1950s, when Lockheed Corporation subcontracted with the company to create a liquid hydrogen-powered airplane engine, part of a top-secret project for the Department of Defense. To have space for noisy engine testing, Pratt & Whitney opened a facility on a large tract of land near West Palm Beach, Florida, where Aerojet Rocketdyne still builds RL10s.

Known as the SUNTAN project, the work was eventually abandoned as the team determined liquid hydrogen was too unwieldy for use in an airplane engine, at least with existing technology for handling cryogenics. However, a modestly funded liquid hydrogen engine test program within SUNTAN, known as Project Bee, was established at Lewis. Project Bee was a success and solidified the center's reputation as an expert institution in handling liquid hydrogen for propulsion.

The project to build the first rocket powered by cryogenic engines, the Centaur upper stage, began in 1958, the year NASA was created. It started as a Department of Defense project, with the aim of putting heavy payloads into orbit, but the Space Agency took over the work a year later, moving it to Marshall Space Flight Center, with Pratt & Whitney designing and building the RL10 engines that would launch it.

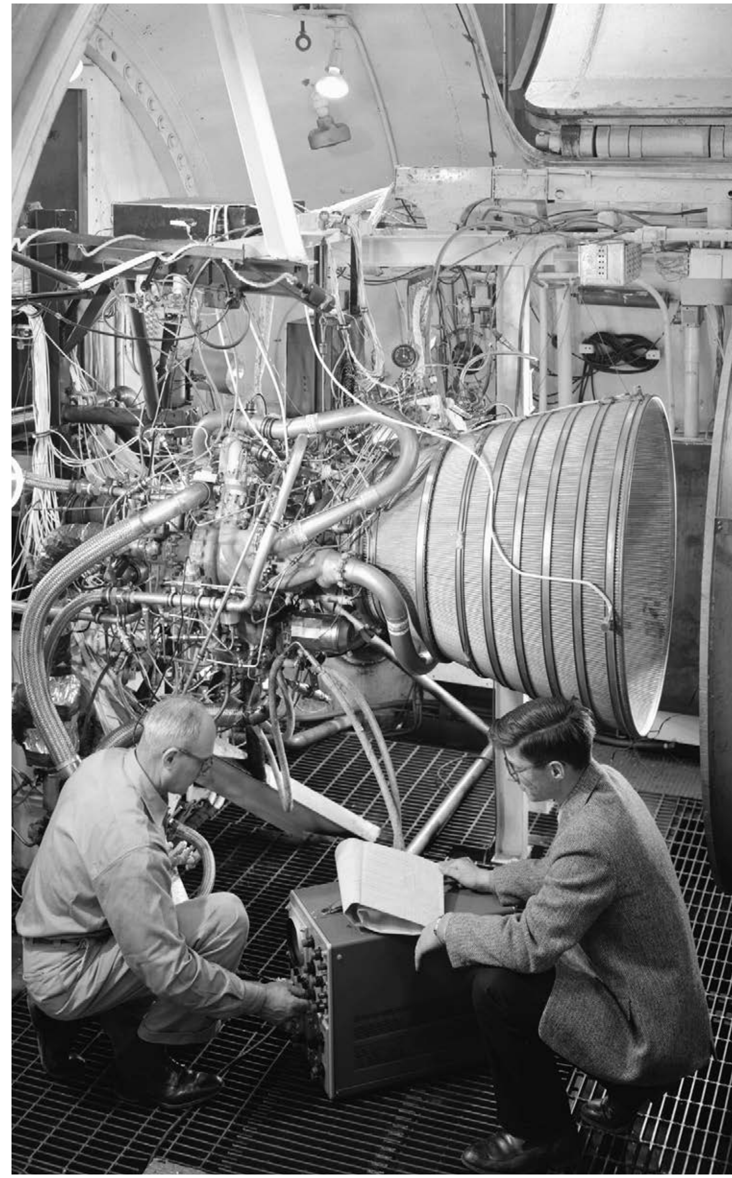
After the Centaur exploded during its first test launch in 1962, Marshall officials were prepared to kill the program, but Abe Silverstein, center director at Lewis, convinced NASA Headquarters to move it to Lewis, whose test data and designs from years before in Project Bee had heavily influenced the Centaur and SUNTAN teams.

One of the engineers who carried out some of Lewis' early cryogenic work was Bill Goette, who worked on injectors for different propellant combinations at Lewis under NACA and later would spend a decade heading the RL10 program.

Among other takeaways from the early Lewis research, Pratt & Whitney ended up adapting a concentric tube injector design created at the center.

"It was all on a research basis—there was never a specific end use in mind," Goette says of the early work under NACA. "That was NACA's role, working on basic research, taking risk out, and giving companies a heads-up on how to do things."

Even after the Centaur program moved to Lewis, the engine work initially stayed at Marshall, because the RL10 was also planned to be used on the upper stage for the Saturn 1 launch vehicle, predecessor to the Saturn V that was to launch the Apollo missions. But Goette and others



NASA engineers examine an early RL10 rocket engine in the Propulsion Systems Laboratory at Lewis Research Center (now Glenn Research Center).

at Lewis, as well as contractor General Dynamics, worked to ensure the engine would also meet Centaur's needs.

In 1963, the work paid off. Centaur launched on top of an Atlas booster rocket, marking the first successful flight of a cryogenic rocket engine. A few years later, NASA decided to shift direction for Apollo's upper-stage rocket, but Centaur and the RL10 project lived on at Lewis, with Goette in charge of the engine program.

"Before it came to Lewis, they had built a number of the engines and tested them," he says. "A lot of the bugs had been fixed."

He says the engine was and remains remarkable for its efficiency. The high-performance combination of liquid hydrogen fuel and a liquid oxygen oxidizer generates more thrust per unit of fuel burned than any other propellant combination. That means a rocket can carry less fuel, which keeps the weight down, allowing more payload to be carried to orbit.

But the RL10's expander cycle goes one step further in fuel efficiency and simplicity by eliminating the need to burn fuel to turn turbines that drive the fuel pumps. Instead, the cryogenic liquid hydrogen is used to cool the combustion chamber and nozzle, where it picks up heat and turns into hydrogen gas. This expansion of the hydrogen gas drives the turbine, which powers the pump.

"That's essentially free energy," Goette says, comparing the engine's expander cycle to using the heat generated by a car engine to warm the interior. "I don't think anyone else has built an engine with that kind of cycle."

Following Centaur's success, the liquid hydrogen propulsion technology developed under the RL10 program was also used to create the J-2 upper-stage engines for Saturn V that enabled the United States to put astronauts on the Moon. Critical technologies and knowledge such as injector design, mitigating combustion instability, inhibiting propellant slosh, and hydrogen gas venting were essential for the success of the Saturn V. Eventually, liquid hydrogen and oxygen became the Nation's go-to fuel for boosters and upper stages alike, including the Space Shuttle main engines and the Air Force's most powerful launch vehicle, Titan IV. Liquid hydrogen is slated to be the fuel for both the core and upper stages of NASA's planned Space Launch System. Centaur continues to fly today as the upper stage for Atlas V, and the RL10 also flies on Delta IV.

One challenge that remained when the program came to Lewis was that the engines needed to be capable of multiple starts in space to meet mission needs. But without gravity in orbit, the remaining fuel tended to float aimlessly in the tank. The Centaur already used small hydrogen peroxide thrusters to control its orientation, and Goette says a few more thrusters at the rear of the tank fixed the problem by creating enough forward momentum to keep the liquid propellants settled at the bottom of the tanks where the engine inlets were located.

Other changes included extending the engine's nozzle and narrowing the thrust chamber throat to increase power and efficiency. Over the nearly 30 years that Lewis oversaw the Centaur program, both the rocket design and the RL10 engine continued to change and evolve.

The Centaur upper-stage rocket, always powered by one or two RL10 engines, remains the country's most-used upper stage more than half a century after its first flight.

Technology Transfer

Pratt & Whitney eventually took over management of the engine, but by then the engine that had arrived at Lewis with problems restarting was fully developed in several versions.

"The early 1960s version of the RL10 that was developed and matured under Lewis' stewardship was a revolutionary prototype. But a lot of additional effort went into maturing that early model into the RL10A-3-3 that became a reliable workhorse engine during the 1970s," says Jeff Breen, head of RL10 evolution at Aerojet Rocketdyne and formerly at Pratt & Whitney. "We have since evolved the RL10A-3-3 model six more times to achieve better performance and durability. However, I'd suggest that the current model, the RL10C-1, retains a large percentage of the heritage that can be attributed to the Lewis and Pratt & Whitney development partnership."

Both the Centaur and the RL10 proved immensely popular from the late 1960s to the early '90s, when the United States dominated commercial space launches. Breen

Four RL10 engines are planned to power the Exploration Upper Stage that will be the first to carry astronauts in NASA's Orion capsule. In its storied history, the RL10 has not yet been used in human spaceflight.

estimates RL10 engines helped put into space about 90 percent of the large commercial satellites launched during that period. Today, it remains the upper-stage engine of choice to launch payloads for the U.S. military and other performance-demanding civilian missions. Many of the GPS satellites, an Air Force program that has come to play huge roles in industry and daily life, were inserted into orbit by RL10 engines.

NASA has used the Centaur to launch countless lunar and interplanetary exploration missions, from Surveyor 1, the first successful Moon lander, to the Viking landers that were the first to explore the surface of Mars, to the twin Voyager spacecraft that explored Jupiter, Saturn, Uranus, and Neptune and now are the first probes to enter interstellar space. Current RL10-launched missions include the Juno probe at Jupiter, the Curiosity rover on Mars, Cassini in orbit at Saturn, and the New Horizons spacecraft that flew to Pluto and is now on its way to the Kuiper Belt.

Benefits

A major reason for the RL10's popularity has been its exceptional performance capability, which has only increased over time. Measured as "specific impulse"— the ratio of thrust per unit of propellant mass flow rate—the engine's original thrust of 424 seconds has increased to about 465 seconds today. While the first model could produce 15,000 pounds of thrust, present models produce up to 25,000 pounds.

Its unique pumping method and other design elements also bestow reliability. "It has proven itself to be the most reliable engine ever built," Breen says. "There's been only one failure attributed to the engine in all its flights."

Goette says this is because, in an era before computer design tools, Pratt & Whitney's approach was to come up with a conservative design "and then test, test, test, and when it breaks, fix it." During testing, for example, the engine had to run 10 times as long as it would need to run in space, and the valves were cycled many times more than they would in flight. "It was designed with beaucoup margin, and they tested the hell out of it and got rid of any failure points," Goette says.

Given the cost and importance of most rocket payloads, whether they're satellites or astronauts, reliability is the biggest consideration, Breen says. "There's a lot riding on each launch. That's why customers come to you—they know the engine can both deliver the performance and reliably place the payload into the correct orbit. The RL10 engine provides customers with confidence in mission success."

The ability to make multiple restarts in space, which increases the performance capability and allows longer launch windows, is also a major benefit that was not easily achieved. If it's difficult to start a car on an Alaskan winter night, it's harder to restart an engine in the frozen void of space, Breen says. While there are other rockets with that capability, the RL10 is the only one that has restarted up to seven times during a single mission.

All this has made the engine and the RL10-powered Centaur the premier upper-stage engine and the most-used upper stage, respectively, in U.S. rocketry. The year 2009 marked the 400th flight powered by RL10 engines.

The ability to harness liquid hydrogen gave the U.S. civilian Space Program, the commercial aerospace industry, and the military a distinct edge over other nations. Recent military uses include launches of the Navy's Mobile User Objective System satellite constellation and the Air Force's X-37 space planes.

Commercially, throughout the early decades of the space age, virtually all U.S. satellite television, radio, and phone applications, as well as some weather, Earth-observation, and navigational satellites, got an assist from the RL10 engine.

The engine, however, has never been used in human spaceflight, despite its distinguished track record. That's about to change. Boeing's CST-100 Starliner and Sierra Nevada's Dreamchaser both plan to use dual-engine Centaur upper stages to carry astronauts into space, and NASA's Space Launch System will carry out crewed missions with the help of four RL10 engines on its Exploration Upper Stage.

"We're eager to finally fly astronauts," says Breen. "Adding the human spaceflight milestone will complete the RL10's legacy."

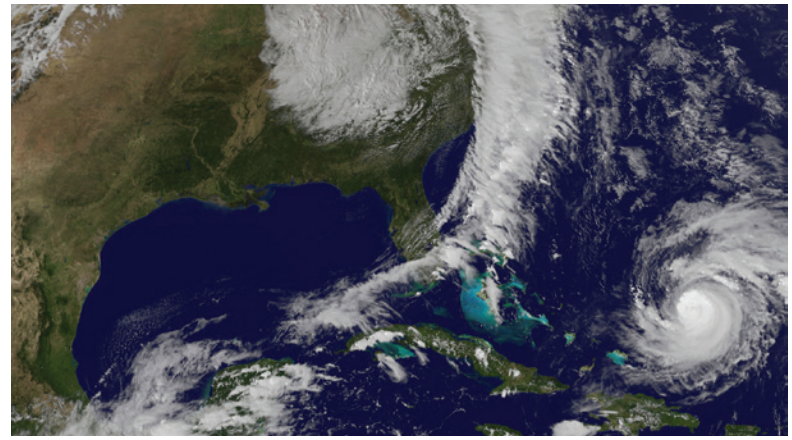
While it's still based on the same design that was matured at Lewis in the 1960s, the engine has been updated for the 21st century. The RL10 A and B series are being phased out and replaced with the RL10C-1, which was completed in 2014 and incorporates the best aspects of the older lines, says Breen.

And in spring of 2016, Aerojet Rocketdyne successfully test-fired an RL10 engine with a 3D-printed core main injector, which reduced the part's cost and production time by about half. By 2019, Breen expects about 95 percent of the engine's complex geometrical parts to be 3D printed. Helping with that effort are the Air Force and, once again, Glenn.

"3D printing is a new manufacturing approach, but the upgrade will maintain the soul of the RL10 engine—its expander cycle—intact. So we keep the performance and simplicity that has made the engine so reliable, but now it's significantly more affordable to manufacture," Breen says.

Such updates ensure that the world's first cryogenic engine isn't going away anytime soon.

"It's just hard to improve on it," says Goette. ❖



From the 1960s to the 1990s, most GPS, weather, and communications satellites were put into orbit with the help of RL10 engine-powered upper-stage rockets.

Time-Triggered Ethernet Slims Down Critical Data Systems

NASA Technology

Ethernet computer networks date back to the 1970s and are now used virtually everywhere, including in space. Inexpensive, ubiquitous, and easy to use, Ethernet has often connected astronauts' computers, cameras, and other noncritical devices on the Space Shuttle and International Space Station (ISS).

Until recently, though, Ethernet could never be used for critical systems like the spacecraft avionics responsible for navigation, communication, and other essential functions, because it's imprecise. There's no guarantee how long it will take to transmit a message or even whether it will arrive at its intended destination. Messages can interrupt each other or be lost or damaged.

But a sophisticated deterministic Ethernet system developed for NASA's new Orion space capsule allows all the spacecraft's systems to communicate on a single Ethernet network—and the technology is also being applied to integrate systems for self-driving cars, industrial applications, defense programs, commercial spacecraft, and more.

Traditionally, critical spacecraft subsystems have been housed on separate computers connected with point-to-point links or dedicated buses, says Andrew Loveless, command and data handling domain lead for NASA's Advanced Exploration Systems Avionics and Software project and an engineer at Johnson Space Center. For example, he says, the ISS has a highly tiered network, with subsystems communicating indirectly by sending messages up the network "tree" and back down.

"That's generally not ideal, because you have more complexity, and you have all the size, weight, and power concerns," Loveless says, noting that the arrangement requires each function to be housed on a separate computer, each with its own power supply.

As they were planning Orion, NASA engineers wanted to take a new approach, replacing this federated architecture with a more integrated network, but the technology to do so didn't exist in a mature form.

Technology Transfer

TTTech Computertechnik AG, based in Vienna, Austria, with its U.S. headquarters in Andover, Massachusetts, was already working on technology to build a more reliable Ethernet network. The company had been partnering with Honeywell for aerospace applications since 2000, contributing, among other things, early versions of the company's Time-Triggered Protocol chips. Cooperation between the two companies started with a five-year NASA project that enabled the application of Time-Triggered Ethernet to several of Honeywell's engine programs, as well as the Airbus A380, the Boeing 787, Bombardier's C Series of airliners, and Embraer's Legacy 450 and 500 business jets.

"What Time-Triggered Ethernet does is create three traffic classes for messages of different criticality," Loveless explains. Only the most critical data is time-triggered, meaning it's scheduled into time slots that don't interfere with each other and is guaranteed to be transmitted and received at specific times. "You're essentially reserving that bandwidth ahead of time," Loveless says. Less-critical but high-priority data is rate-constrained, meaning it is transmitted reliably within strict timing constraints. The rest of the bandwidth is available for noncritical messages.

"No matter what you do with noncritical data, you're not going to interrupt any of those time-triggered messages," he says. This is why all the systems can run on the same network. "It's a pretty big departure from the way past space avionics have been developed."

TTTech products like this 24-port AFDX Switch A600 Pro, which meets civil aerospace standards for bandwidth-regulated traffic filtering and policing, are built on Time-Triggered Ethernet technology the company refined and expanded under a NASA subcontract to develop avionics for the Orion space capsule.

Honeywell early on became part of the team developing the avionics for Orion, so by the time Johnson Space Center and TTTech signed a Space Act Agreement in 2009, the company's technology was already being incorporated into Orion's electronics.

Rather than passing messages up and down tiers, anything on Orion's network can potentially communicate directly with anything else on the network. The arrangement allows engineers to maximize computing power and reduce the number of computers, because one computer can carry out more than one function. Loveless says this has dramatically lowered the avionics' size, weight, power consumption, and complexity.

Another major benefit of scheduling high-priority messages is that it allows networks to be built with a modular approach, with individual functions able to be added or removed without interfering with each other or affecting the rest of the network, says Mirko Jakovljevic, engineer and marketing manager at TTTech. "I don't need to retest everything together when I change a function."

Loveless says the setup, known as integrated, modular avionics, provides additional flexibility by allowing functions to be moved from one computer to another. "A computer that's processing sensor data doesn't have to be collocated with that sensor," he says. "You're decoupling functions from the platforms they're running on."

Although the ability to move functions around isn't all that pertinent to Orion's network, he says, "that's the direction our avionics are going."

To help other industries also go in that direction, NASA's 2009 Space Act Agreement with TTTech set about developing an official standard for Time-Triggered Ethernet through the engineering association SAE International. Loveless says NASA engineers are now helping the Consultative Committee for Space Data Systems create additional international standards enabling the use of Time-Triggered Ethernet for spacecraft.

Benefits

"NASA helped give us major credibility and launched standards others could follow," says Perry Rucker, director of sales and operations for the Americas at TTTech. "They helped to open up markets by sharing with the press and the markets what they were doing with the onboard data network."

The application of the technology to the Orion avionics and the feedback and lessons learned from that work ensured Time-Triggered Ethernet products that are more refined and robust and now marketable across several industries, says Jakovljevic.

In particular, NASA's help in developing a standard for the technology supported market development and led to adoption by key players, he says.

Airbus Safran Launchers has now contracted TTTech to supply the avionics backbone of the European Space Agency's coming Ariane 6 launch vehicle.

TTTech also provides Time-Triggered Ethernet control systems for Vestas wind turbines, a contract it won around the time of the technology's standardization. Rucker and Jakovljevic note that the modular systems can be reconfigured for different turbines and increase reliability for machines that are often in harsh environments and difficult to reach to make repairs or adjustments.

The company's largest market, however, is the automotive industry, where Time-Triggered Ethernet integrates advanced driver assistance systems and is expected to enable autonomous systems. TTTech is developing an embedded platform to host all the applications that will support driver assistance and, eventually, self-driving cars for automaker Audi, a part-owner of the company. As in space travel, an autonomous vehicle requires timely, reliable delivery of critical information from radars, lidars, cameras, and other subsystems, Jakovljevic says.

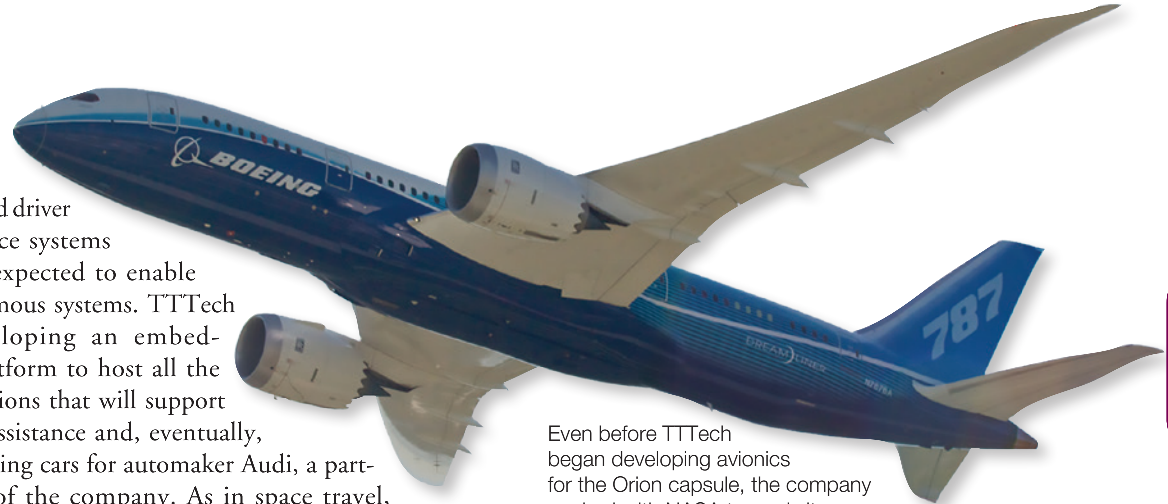
The company also works with semiconductor manufacturers to integrate time-triggering technology into new devices. For example, Rucker says, NXP Semiconductor uses TTTech's technology to build components geared toward driver assistance and self-driving cars. "With time-triggering, you can build complex systems with standard components."

Rucker estimates that by 2025, about three-quarters of cars on the market will have the ability to drive themselves, thanks in part to Time-Triggered Ethernet.

He says the company also plans to break into industrial applications, where it could optimize manufacturing operations, as well as the railroad industry.

"In all the transportation industries, it's about adding functionality while reducing the number of computers and network devices, increasing robustness, and improving the capability to move easily from one generation to the next," Rucker says. "This all leads to reductions in cost."

TTTech now has more than 550 employees worldwide, three or four times the company's size when the Orion work began, Rucker says. He credits much of that growth to the springboard NASA provided by standardizing, publicizing, and proving Time-Triggered Ethernet in a highly demanding application. "This was really great support from NASA." ❖



Even before TTTech began developing avionics for the Orion capsule, the company worked with NASA to apply its Time-Triggered Ethernet to a number of commercial airliners, including the Boeing 787 Dreamliner.

Around the time NASA helped to create an official standard for Time-Triggered Ethernet, TTTech, which pioneered the technology, won a contract to provide control systems for Vestas wind turbines.

Image courtesy of Dirk Ingo Franke, CC BY-SA 2.0

Simplified Aircraft Modeling Packs Weeks of Analysis into Minutes

NASA Technology

It wasn't Walt Silva's job to invent a technique to dramatically speed up computational modeling of aircraft. But the NASA researcher did it anyway.

Over the last couple of decades, computational fluid dynamics (CFD)—computer software that models how an aircraft will perform while it's flying, a sort of virtual wind tunnel—has become increasingly important in how engineers design and test new aircraft. But even supercomputers sometimes need weeks to solve these incredibly demanding and complex scenarios.

"You need a very big grid to capture everything happening on the wing, as well as around the wing, let's say a million grid points through the field. That's many millions of equations you're solving," Silva explains.

And that's not even getting into the complexities of aeroelasticity, which is the field Silva specializes in at Langley Research Center. Aeroelasticity is the interaction between aerodynamics, or how the air moves, and the structure, because although most aerodynamics calculations assume a rigid vehicle, as he puts it, "everything bends."

Silva and his team model and calculate how the aerodynamics will affect the structure—how much the air movement will cause the structure to vibrate or bend—and how the flexing of the structure will impact the aerodynamics. The two factors can create a feedback loop, which generally fades out safely. But under certain conditions, that feedback loop grows, and "if you get uncontrolled growth, you get flutter, and that leads to destruction of the structure," he says.

Discovering flutter means engineers must either go back to the drawing board or specify the conditions under which it is safe to fly the vehicle.

A full analysis of aeroelasticity requires running the equations again and again under different flight conditions. "Let's say we're flying at 100-feet-per-second velocity. We do this analysis, which could take a week, and find out at a velocity of 100 the vehicle is stable." Then the engineers rerun the simulation, this time with a velocity of 200 feet per second. "That takes another week. Then we find out at 200, the oscillations are growing."

In this scenario, "we just spent two weeks trying to find out at what velocity we get this flutter instability. And even then, you're not getting a full picture, just stable or unstable," Silva says.

He figured there had to be a way to speed things up. He was right—and the key insight turned out to come from his experience that had nothing to do with computational fluid dynamics. "If I had been working in CFD from day one, I don't know that I would have thought of this."

Technology Transfer

Silva first had the idea for how to simplify flutter modeling some 20 years ago. But between one thing and another—and his actual day job—he didn't make much progress for a few years. He also had to push back against those who said his solution would never work. "That's the nature of the beast with innovation—until you have all the details sorted, and then you just show that it works," he says.

It finally started coming together in the early 2000s, culminating in a patent Silva applied for in 2008—"when it became clear I had something drastically new," he says—and

Aeroelasticity engineer Walt Silva examines an aircraft model undergoing testing in the Transonic Dynamics Tunnel at Langley Research Center. Silva created innovative software that speeds up computational modeling of aircraft to reduce the need for costly wind tunnel tests.

was granted in 2011. Three years later, Silva's work was awarded an honorable mention for NASA's Invention of the Year, and Silva himself was honored with a Space Act Award from NASA.

The Space Agency has made good use of Silva's innovative technique, including previous aeroelastic analyses of the since-cancelled Ares Crew Launch Vehicles and, more recently, of a supersonic low-boom configuration, "as a rapid way to assess the structural safety of the vehicle."

And now, two decades after its inception, the product is starting to spread beyond NASA into the commercial sector, provided to big companies like Boeing and smaller ones like Huntsville, Alabama-based CFD Research Corporation (CFDRC).

That's just how the process of invention goes, Silva says. "You have to work it and work it and work it, and when you're tired, frustrated, angry, and upset, go back and work it some more."

Benefits

So how does it work? The software creates a simplified version of the structure using a mathematical tool called system identification, which is typically used for things like structural or flight dynamics.

"When I apply system identification, I get a specific type of info that allows me to create a simplified model of the aerodynamics," Silva explains. Instead of a million grid points, it's on the order of 100 or fewer. That process could take hours, but it makes the rest of the work go much more quickly.

"Now I put that on my laptop—I don't need a supercomputer—and change the velocity to 100, it runs in seconds," he says. "Then 200, and I see flutter. What was taking me two weeks is now taking a day or two."

He calls it a Reduced Order Model (ROM). It doesn't give you 100 percent of the information you'd get from running the full CFD models, he says, but "it allows you to capture 90 percent of the essence of the behavior," and to pinpoint the specific areas that need further investigation.

"If I've got to do 20 solutions, maybe 15 are trivial. Then I can focus my resources on the ones that are most challenging," Silva says.

CFDRC first began using the Reduced Order Modeling software package on a project it was doing with NASA's Armstrong Flight Research Center on the X-56A MUTT, which stands for multi-use technology test bed.

"For fuel efficiency, we want to develop vehicles with a very large wing span," explains Yi Wang, director of advanced technologies at CFDRC. These long wings are built out of lightweight composite materials and are very flexible, which means flutter is a big issue.

"The ROM software was a huge help," Wang says. "It can take days and weeks for analyses, but with the tool Silva provided, once the ROM is generated, we can predict the flutter within minutes."

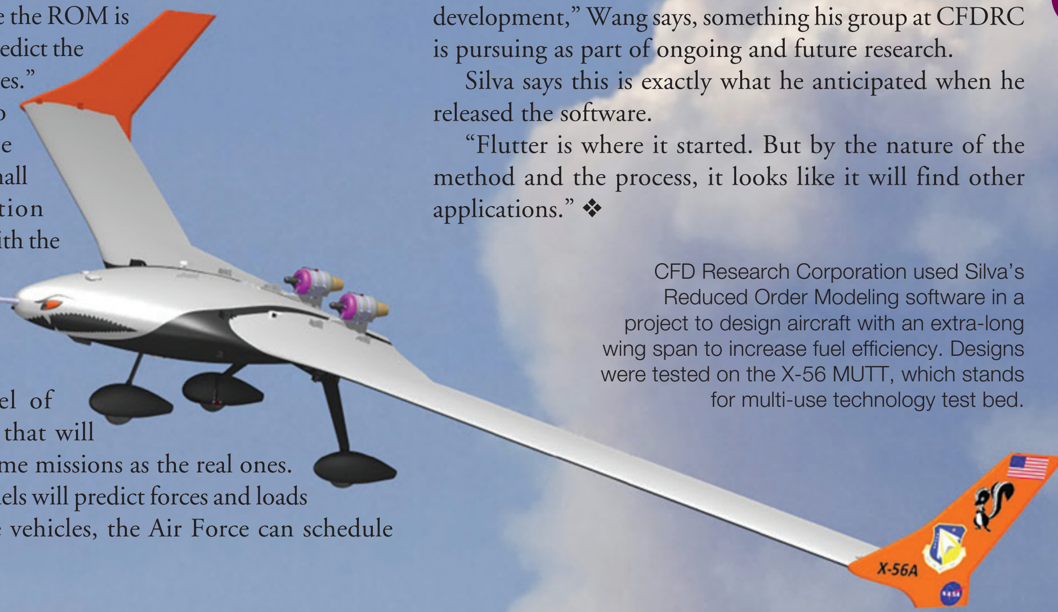
CFDRC is also using the software for work under a Small Business Innovation Research contract with the U.S. Air Force as part of the Digital Twin program, which aims to create a computer model of aerospace vehicles that will virtually run the same missions as the real ones.

Because the models will predict forces and loads experienced by the vehicles, the Air Force can schedule maintenance based on the actual wear and tear of the specific maneuvers and flights the aircraft has undergone, instead of doing preventive maintenance on a fixed schedule. That could reduce maintenance costs across the fleet and increase safety by pinpointing which vehicles need repairs.

But the company has bigger plans for the ROM software: Wang says it is working on taking the same technique and expanding it beyond analyses of just one given speed and altitude to include the many conditions experienced during an entire flight regime. "When Walt came up with this software, he built a strong foundation for further development," Wang says, something his group at CFDRC is pursuing as part of ongoing and future research.

Silva says this is exactly what he anticipated when he released the software.

"Flutter is where it started. But by the nature of the method and the process, it looks like it will find other applications." ❖



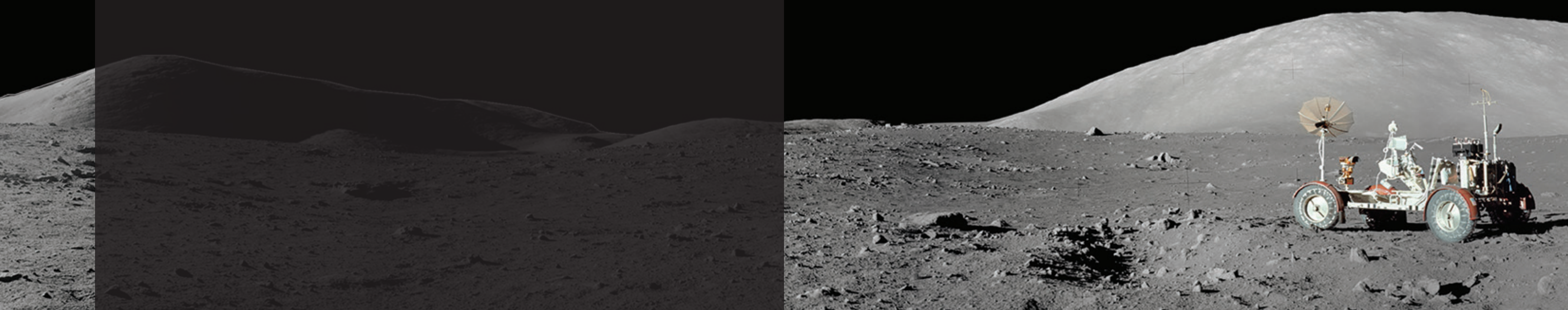
CFD Research Corporation used Silva's Reduced Order Modeling software in a project to design aircraft with an extra-long wing span to increase fuel efficiency. Designs were tested on the X-56 MUTT, which stands for multi-use technology test bed.

"You have to work it and work it and work it, and **when you're tired,** frustrated, **angry, and upset,** go back **and work** it **some more."**

— Walter Silva, Langley Research Center

Public Safety

The Space Agency is renowned for its culture of safety and ability to protect astronauts in the harshest environments—but even seemingly unrelated scientific missions can end up keeping us safer here on Earth. Technology used to map gravity is repurposed to find survivors trapped under rubble. Software to direct a robot construction team improves warehouse safety. These and more are featured in the following pages.



Radar Device Detects Heartbeats Trapped under Wreckage

NASA Technology

Late on a sweltering morning in July 2016, David Lewis Jr. crawls into a concrete tube in a heap of rubble amid what used to be a Northern Virginia prison complex.

Only the toe of Lewis' shoe is visible. As bystanders look on, R4 Inc.'s new FINDER device—that's Finding Individuals for Disaster and Emergency Response—is trained on the scene and begins quietly clicking away, calibrating its radar to the objects and environment, before entering detection mode.

Within about three minutes of the radar's initiation, it reports the results of its search on a handheld graphical user interface: "FINDER detected one victim," the screen reads, above a high-definition photo of the concrete jumble where it spotted Lewis. It has also taken an infrared image to capture any possible body heat signature, and Lewis' breathing and heart rates are reported.

Shawn Crockett, vice president of business development at R4, where Lewis is a project manager, notes that his colleague's heart rate was higher than in another trial moments before.

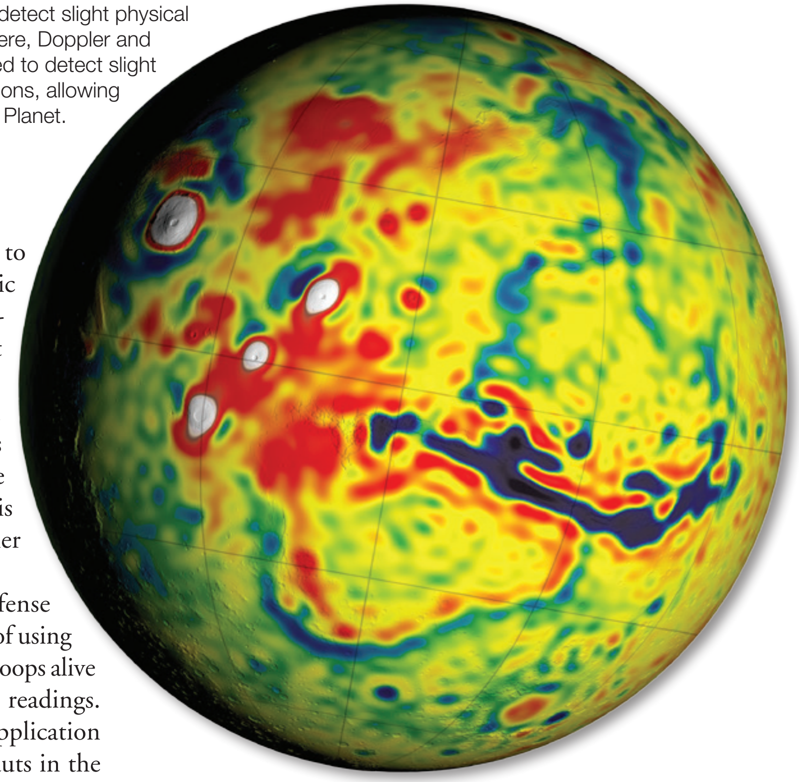
"It was a little hot in there—there's no breeze," Lewis explains.

Using FINDER is still not an exact science: during the first test, the device mistook Lewis for two people. But even as it continues to improve, its lifesaving potential is already clear and has even been proven in the field, where it has been used to find earthquake victims trapped under rubble.

In the case of the double hit on Lewis, Crockett says, "For us it doesn't matter. If we think there's a life in there, we're going in."

The Edgewood, Maryland-based company is developing a line of such remote sensing devices to aid search and rescue teams, based on advanced radar technologies developed by NASA and refined for this purpose at the Agency's Jet Propulsion Laboratory (JPL).

NASA has long experience analyzing weak signals to detect slight physical movements, cancelling out huge amounts of noise. Here, Doppler and range tracking data from three Mars orbiters were used to detect slight movements in their paths that indicate gravity fluctuations, allowing scientists to construct a gravity map of the entire Red Planet.



NASA has long analyzed weak radio signals to identify slight physical movements, such as seismic activity seen from low-Earth orbit or minor alterations in a satellite's path around another planet that might indicate gravity fluctuations, explains Jim Lux, JPL's task manager for the FINDER project. However, to pick out such faint patterns in the data, these devices must cancel out huge amounts of noise. "The core technology here is measuring a small signal in the context of another larger signal that's confusing you," Lux says.

In the early 2000s, the Department of Defense approached JPL wondering about the possibility of using remote sensing to determine whether there were troops alive on a battlefield and to take remote biomedical readings. Some work was done, and Lux says the latter application could still be of interest for monitoring astronauts in the International Space Station, for example. But funding dried up.

The work, however, was not forgotten, and years later, members of the Department of Homeland Security (DHS) Science and Technology Directorate approached JPL, recalling that engineers there had worked on remotely detecting a heartbeat. The Federal Emergency Management Agency (FEMA), which falls under DHS, wanted such a device for locating trapped survivors. With DHS funding, Lux's team set about developing the FINDER prototype.

Being NASA engineers, they were well-versed in the art of designing and packaging small, low-energy, rugged hardware, which the units required. Identifying working hearts and lungs by reflected microwave radar was trickier, but they had picked out slight movements from overwhelming data streams before. "This is a combination of a bunch of things NASA has been doing," Lux says. "A lot of the pieces of this existed in some form or another."

Once the engineers were able to identify a heartbeat, they had to further refine signal-processing algorithms to distinguish a human heartbeat. For example, even a large dog has a faster heart rate and, especially, a faster breathing rate than a human, Lux explains. And to pick out multiple victims, the device had to be able to recognize the rhythms of distinct pairs of heart and breathing rates. This is possible because the heart speeds and slows with each breath, says Lux.

FINDER can detect up to five separate victims in a given area.

"The core technology here is **measuring** a **small signal** in the **context** of another **larger signal** that's **confusing you."**

— Jim Lux, Jet Propulsion Laboratory

Image courtesy of Voice of America

Earthquakes are the deadliest of natural disasters, crushing tens or even hundreds of thousands of people under fallen buildings. Inevitably, many survivors are trapped alive but are difficult to find under the rubble. Engineers at NASA's Jet Propulsion Laboratory (JPL) used their experience with analyzing weak signals to develop a technology that uses radar to identify unseen people by detecting their breathing and heartbeat. A company called R4 Inc. licensed and developed the technology and is now making sales to government entities in the United States and abroad.

Technology Transfer

R4's founders, two U.S. Army veterans, came across an online article about FINDER several years ago, after JPL had developed a prototype and DHS had tested it. The California Institute of Technology (Caltech), which manages JPL, was looking for a company to commercialize the technology.

R4 reached out, and before long, Caltech had awarded licenses for FINDER to R4, as well as the company SpecOps Group Inc., which is working to commercialize its own version of the technology.

Over the next couple of years, R4 developed lighter-weight housings for the technology, made it more rugged, and improved the graphical user interface. "We improved all those things so it's something a first responder could use in a real-world situation," says Lewis.

A big test and major success came when a 7.8-magnitude earthquake rocked Nepal just northwest of its capital of Kathmandu in late April 2015, killing more than 8,500 people. Lewis' father, one of R4's founders, arrived four days after the quake with two FINDER prototypes and joined search and rescue crews. Using the devices, rescue workers in the hard-hit village of Chautara located two men trapped beneath the remains of a textile factory and two more pinned under the debris of another building.

Upon their discovery, all four men, who had been buried in rubble as deep as 10 feet, were rescued. They all survived.

Despite this triumph, the experience also exposed weaknesses the company would go on to address. The JPL version of the device had sensors facing in four directions, making it difficult to estimate a victim's location, so current models look in just one direction at a time. The company also decided that a five-minute lag time for calibration and detection was too long and managed to cut that time in half.

And rescuers in Nepal found that some devastated areas were too difficult to navigate for the device to be put to use. R4 has since begun mounting units on drones and land vehicles.

Benefits

FINDER has proven capable of detecting humans through 30 feet of dense rubble and up to 100 feet away in the open with 80 percent accuracy. That's up from the JPL prototype's 65 percent accuracy.

In its current iteration, it is most useful in confirming suspicions that a live victim may be trapped in a given area, whether the hunch comes from human witnesses or search dogs, says Crockett. But he says the company is working on what he calls "persistent detection"—continuous scanning and detection while the FINDER is in motion, searching for survivors as it passes one heap of rubble after another.

In October 2015, FEMA officially announced it would provide funding to U.S. municipalities that apply to purchase R4's FINDER units, which are now on the agency's Authorized Equipment List under the category of "seismic, acoustic, and radar devices and accessories for locating trapped and entombed victims not detectable by other means."

R4 had to do quite a bit of its own development to make FINDER functional, although JPL engineers have continued to partner with them. Though the units are now available for sale, the team continues to improve the technology.

R4 is developing a model that can continually scan for trapped victims while passing over mounds of debris on an octocopter drone. Other models are meant to fit on a truck or a motorcycle.

"This allows first responders to have some type of funding to get these new technologies," says Lewis, noting that emergency response teams in Los Angeles, San Diego, and San Francisco, as well as Virginia Task Force 1 and several nonprofit organizations, have expressed interest.

Meanwhile, FINDER's first official customers are the Army's Intelligence and Information Warfare Directorate and the Quito Fire Department in Ecuador. As the company demonstrates the technology around the country and the world, it has also drawn interest from Taiwan, Japan, South Korea, the United Arab Emirates (UAE), Guatemala, Columbia, and Argentina, Crockett says.

While most of these are in quake-prone regions, R4 is working on a security pilot program in the UAE's capital of Abu Dhabi. Due to the heat, drivers there are allowed dark tint on all windows, so border police are experimenting with using FINDER to determine whether the number of passengers in a vehicle matches the number of passports presented. By charting heart and breathing rates, the devices may also be useful in spotting telltale panic.

"People are coming up with all kinds of ideas for ways we could use it," Crockett says.

The company has also designed prototype versions that would mount on a remote-controlled octocopter, a pickup truck, and a motorcycle, all to search hard-to-reach areas. Efforts are underway to combine GPS and lidar for accurate, continuous navigation aboard the drone, as well as to combine readings from a hovering drone unit with those from another FINDER on the ground to more precisely triangulate a victim's position.

Even in its current state, though, FINDER presents a capability never seen before, and one that rescue crews welcome gladly wherever the company brings it, Crockett says. "It's a one-of-a-kind technology that really does save lives."

With all the enhancements R4 is making to render FINDER more and more effective across a variety of situations, Crocket says, "The secret sauce is in the algorithms and the specialized sensors that we use."

That's the hardware and software rooted at JPL, which continues to act as a strategic partner, for example working with R4 to try to enable distance readings and helping the company get FINDER into testing events and demonstrations, Crockett says.

"They're still supporting the product, so that's been a great help to us," says Lewis. ❖

“It’s a **one-of-a-kind technology** that really **does save lives.”**

— Shawn Crockett, R4

After a magnitude 7.8 earthquake hit Ecuador in April of 2016, R4 President David Lewis Sr. brought the company’s FINDER system to look for victims trapped under rubble. Here, Lewis, right, shows local firefighters how to operate the system.

Surveillance System Captures, Maps Lightning Strikes

In 2011, Space Shuttle Atlantis launched for the final voyage of the Shuttle program—but the launch was almost delayed because of a lightning storm the day before. An advanced lightning detection system, then still under development, helped show that the bolts had not been close enough to damage the spacecraft.

NASA Technology

On July 7, 2011, as Space Shuttle Atlantis sat on the launch pad just one day before it was due to make the final voyage of NASA's 30-year Shuttle program, lightning struck. Twice.

The crucial questions for engineers and officials hoping to keep the launch on schedule were: where exactly did those strikes hit, and were they close enough to do any damage to the Shuttle's electrical systems?

There were two systems monitoring lightning activity around Kennedy Space Center in 2011: the local Cloud-to-Ground Lightning Surveillance System (CGLSS) operated by the Air Force, which has a base nearby, and the National Lightning Detection Network (NLDN), a nationwide detection system owned and operated by a private company.

According to CGLSS, both lightning events struck pad A at Launch Complex 39, where Atlantis was waiting for launch. Neither system had a great track record at Kennedy—NASA investigations had determined they reported only 70 to 80 percent of lightning strikes and were prone to reporting strikes in locations where they did not actually occur.

Nevertheless, a launch, especially one with crew on board, cannot go forward when there is any question the spacecraft may have been damaged. "Problems on the ground are fixable, but if you launch something that has been compromised, you can get into a lot of trouble," emphasizes Carlos Mata, who was the lightning subject matter expert at Kennedy for more than a decade before moving into the private sector.

In previous cases, a storm like this, with strikes so close, would have certainly demanded a delay while engineers retested potentially affected systems.

"And the retest could take a long time depending on which systems are involved. Several days to a week," explains Kevin Decker, an engineer at Kennedy.

That is exactly why NASA had already begun working on a new lightning monitoring system focused directly on the launch pads, Mata says, "to make sure that if lightning struck within a certain radius, we will detect it. Period.

"We also wanted to be able to accurately locate it, but that was a secondary requirement."

The new system incorporated a suite of high-speed cameras designed to capture visual evidence of any lightning striking the pad directly or nearby. The cameras are mounted on three lightning protection towers, as well as on the vehicle assembly building seven miles away, explains Decker, who serves as NASA's lead design engineer on the system. The cameras' overlapping fields of view ensure that, wherever there is a strike, images will be recorded by multiple cameras.

The towers also serve to support a lightning protection system for the launch vehicle. Wires are strung between the towers and down to the ground, providing a preferential place for lightning to strike and a path for the current to travel away from the vehicle on the pad.

Around a wider perimeter, there are electromagnetic field sensors installed at ground level, Decker adds. The electromagnetic sensors record the electric and magnetic fields generated by the lightning to measure both the intensity and strike location. “If you had a strike near the road leading up to the pad, for example, each of the electric field sensors would experience the field at slightly different times. And because we know how fast electric fields travel, we can actually triangulate within several meters of where that strike hit.”

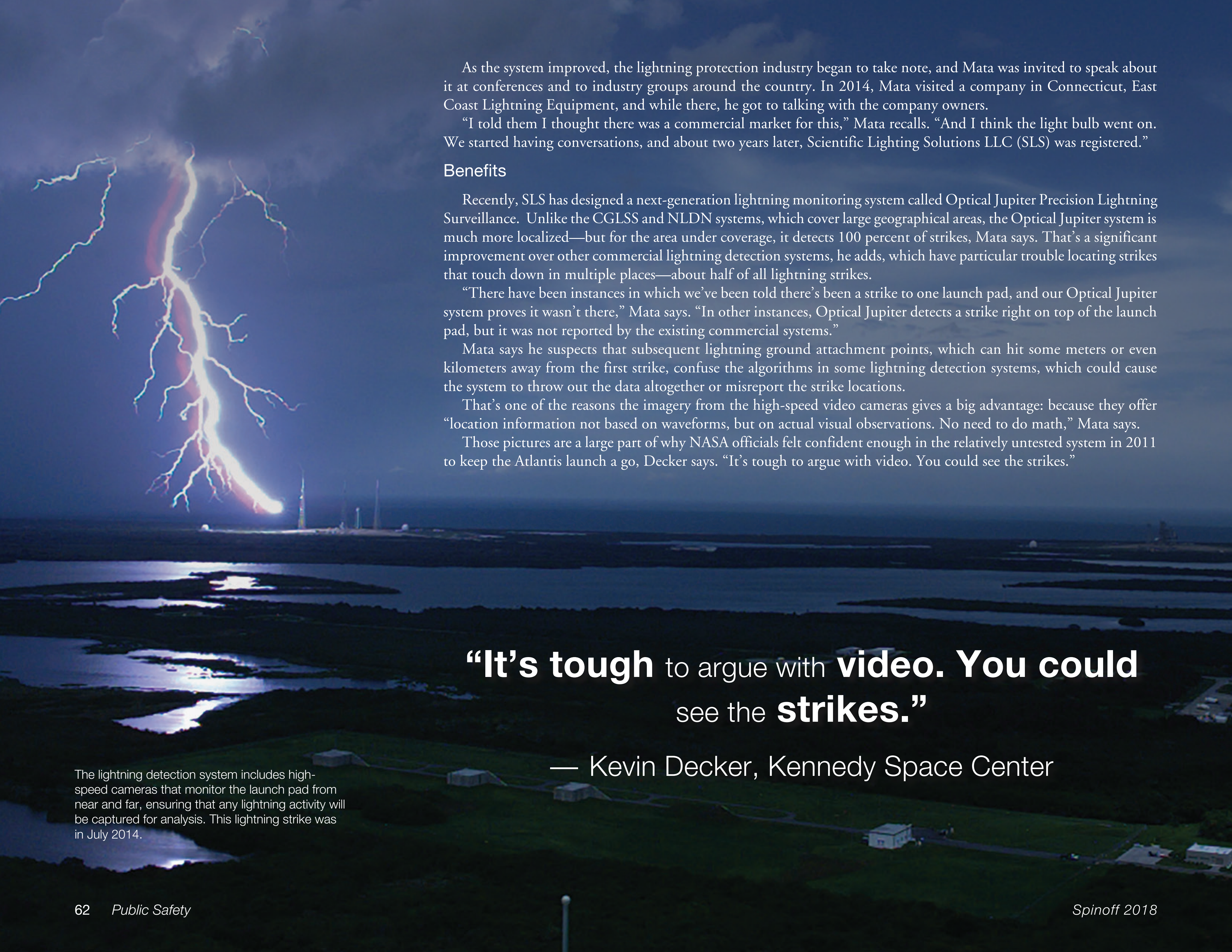
In 2011, this system was not yet fully installed, but the cameras on the lightning protection towers were already operational and mounted at pad B, less than two miles from pad A, where Atlantis sat ready for launch. So when the storm hit, “the electromagnetics folks came to me and said, ‘Carlos, did you see anything?’” Mata recalls.

Indeed, the cameras had captured both strikes. Still pictures and video were able to show the bolts hitting nearby but not directly on the pad. As a result, STS-135 was not scrubbed that afternoon and took off the next day.

Technology Transfer

Mata spent several years fine-tuning the system at Kennedy. At NASA’s request, he built it almost entirely from off-the-shelf commercial components, but many needed to be modified and improved to meet his needs. For instance, he says, they modified the timing of the data acquisition system that records the outputs from the various sensors to better map lightning strikes that hit the ground in multiple places.

After debuting his lightning detection system at NASA, Carlos Mata left and founded Scientific Lightning Solutions to develop a commercial model, which includes high-speed video cameras powered by solar panels (inset). The company also still maintains the system at Cape Canaveral, and in December 2016, it helped ensure the Cyclone Global Navigation Satellite System launch could proceed on schedule despite a fierce lightning storm days earlier.



As the system improved, the lightning protection industry began to take note, and Mata was invited to speak about it at conferences and to industry groups around the country. In 2014, Mata visited a company in Connecticut, East Coast Lightning Equipment, and while there, he got to talking with the company owners.

"I told them I thought there was a commercial market for this," Mata recalls. "And I think the light bulb went on. We started having conversations, and about two years later, Scientific Lighting Solutions LLC (SLS) was registered."

Benefits

Recently, SLS has designed a next-generation lightning monitoring system called Optical Jupiter Precision Lightning Surveillance. Unlike the CGLSS and NLDN systems, which cover large geographical areas, the Optical Jupiter system is much more localized—but for the area under coverage, it detects 100 percent of strikes, Mata says. That's a significant improvement over other commercial lightning detection systems, he adds, which have particular trouble locating strikes that touch down in multiple places—about half of all lightning strikes.

"There have been instances in which we've been told there's been a strike to one launch pad, and our Optical Jupiter system proves it wasn't there," Mata says. "In other instances, Optical Jupiter detects a strike right on top of the launch pad, but it was not reported by the existing commercial systems."

Mata says he suspects that subsequent lightning ground attachment points, which can hit some meters or even kilometers away from the first strike, confuse the algorithms in some lightning detection systems, which could cause the system to throw out the data altogether or misreport the strike locations.

That's one of the reasons the imagery from the high-speed video cameras gives a big advantage: because they offer "location information not based on waveforms, but on actual visual observations. No need to do math," Mata says.

Those pictures are a large part of why NASA officials felt confident enough in the relatively untested system in 2011 to keep the Atlantis launch a go, Decker says. "It's tough to argue with video. You could see the strikes."

"It's tough to argue with video. You could see the strikes."

— Kevin Decker, Kennedy Space Center

The lightning detection system includes high-speed cameras that monitor the launch pad from near and far, ensuring that any lightning activity will be captured for analysis. This lightning strike was in July 2014.

One application for the Optical Jupiter lightning detection system is on wind farms. Amid acres of turbines, it can be hard to pinpoint where damage occurred, but if you are able to identify which one was struck, you can shut it down before it catastrophically fails.

But the instruments also provide other important data, including intensity measurements, which can help gauge potential damage. A stronger strike will be more damaging at its epicenter and could also be damaging over a wider area.

Kennedy continues to use its version of the system, and now the launch pad contractor has a subcontract with SLS, based in nearby Titusville, Florida, to continue maintaining and monitoring it on NASA's behalf.

The technology is also useful outside of the aerospace industry. For example, lightning is a problem on wind farms, where the tall turbines are prone to damage from strikes. Amid acres of turbines, it can be hard to pinpoint which one was hit, Mata says, especially if it continues operating.

"The turbine blade could start falling apart, and once you lose one of the three, you lose the balance and then the whole tower collapses," Mata says. However, if you are able to tell a particular wind turbine has been struck, "you can shut it down before it catastrophically fails. You'll have time to fix it and bring it back to operational mode before you lose a wind turbine."

Insurance companies can also use the Optical Jupiter system to reduce their need for in-person claims investigations, Mata says. Rather than sending a person each time a client reports a lightning strike, the company can use data from Optical Jupiter to verify whether and where a strike occurred.

Each standalone system works on solar power, communicates through telephone lines, and can cover an area around three kilometers in diameter, though Mata says the best coverage is within about a kilometer or so.

SLS can also build custom lightning detection and monitoring systems that include both high-speed cameras and electromagnetic field sensors. Its current customers include lightning protection businesses looking to provide lightning location services across wider areas, such as airports, military installations, and cities.

The designs of the Optical Jupiter and other SLS lightning detection and monitoring systems were strongly influenced by the work Mata and his team did at Kennedy.

"The learning that we went through at Kennedy helped tremendously in the development of SLS's more advanced, next-generation products," Mata emphasizes. ❖

Virtual Reality Platform Helps Pilots Land in the Sky

NASA Technology

When a plane overshoots the final approach for a landing, often the pilot's natural—and dangerous—instinct is to pitch up the aircraft to slow down and land.

It's one of the leading causes of accidents, especially with small airplanes. Increasing the plane's angle at a slow, approaching-landing speed can easily throw it into a stall and result in the plane crashing.

But what if that same mistake happened at 5,000 feet instead?

A new head-mounted virtual reality tool, branded Fused Reality and developed in cooperation with NASA's Armstrong Flight Research Center, can help military, commercial, or even hobbyist pilots train for such potentially dangerous scenarios in real life, in the air, but with far less danger.

Pilots have long been using virtual reality on the ground for training purposes, but fixed-place ground simulators have limitations. For one thing, "there's not a lot of fear factor, because you're not really doing it. You screw up, you hit the reset button, you try again," says Bruce Cogan, an aeronautical engineer at Armstrong.

Also, he says, the simulator is only ever as good as its programming. "It's challenging to replicate how the aircraft feels. You may be training a pilot to land, but if the dynamics of the simulation aren't very good, it's not going to be very useful and could even be harmful."

The new simulator hooks into any airplane and layers a virtual reality scene over the real world outside the cockpit. "You actually get the dynamics of the exact airplane you're flying," Cogan says. That means external factors like cross winds, as well as intrinsic ones like how the plane handles, are all real.

With a virtual runway created by the software, "you can train for this landing task at 5,000 feet, so if you mess up, you won't hurt the airplane. You can go try again."

Using virtual reality software designed and tested in part with NASA funding, pilots can practice difficult maneuvers much more safely. The pilot here just landed the plane—on a virtual runway some 5,000 feet in the air.

"You can actually demonstrate that you will stall and roll over and it will look like you're crashing into the runway," adds David Landon, CEO of Systems Technology Inc. (STI), which built Fused Reality. "What you teach them is, you don't want to do this. You just roll your wings level and increase your airspeed and go around" to try the approach again.

Technology Transfer

NASA's initial interest in the Fused Reality platform wasn't for training, Cogan explains, but for evaluating how well an aircraft flies.

"As part of flight controls and new aircraft designs, we have pilots evaluate aircraft handling qualities: When he puts in a control input, does the airplane do what he wants? Is it too slow? Too fast?"

Testing those maneuvers requires actually flying them, and that can be an expensive proposition. For example, aerial refueling not only requires a second airplane—an added cost—but also carries the risk of a collision, even with an experienced pilot.

With a virtual reality platform, however, the second plane can be simulated.

Hawthorne, California-based STI started working on Fused Reality under Small Business Innovation Research (SBIR) contracts with the Air Force and Navy, but in the early phases, it was designed to be used in a static vehicle on the ground.

"They wanted the crewman to wear a device that would let him see the interior of the cabin of the aircraft as it was—so he'd see his hands and the gun he was firing—but when he looked out the door of the helicopter, he would see a virtual world," Landon explains.

Cogan's team at Armstrong wanted to take the simulator up into the air. So in 2008, STI was awarded additional Phase I and Phase II SBIR contracts from NASA to develop the platform as a potential in-flight simulator.

The biggest challenge, explains Landon, was figuring out how to cue the technology on what should be visible as normal and what should be overlaid with the virtual scene. On the ground, they used color, much like a green screen for a television weather map. But NASA wanted the pilot to be able to see the real view outside the windscreen, so they had to develop a new system that cued off of brightness and infrared light.

Three years later, Armstrong and STI worked together again, through center innovation funds, on additional development and test flights. Among other improvements, STI worked on making the system compatible with any type of aircraft, even one that doesn't have a fully automated onboard computer to feed flight data into the virtual reality simulator.

STI adapted their system to work with an inexpensive, off-the-shelf, instrumented measurement unit, "basically a black box, about $5,000, that you put on the seat next to you. It takes external GPS signals and internal accelerometer data and feeds it into your laptop," which tells the Fused Reality system what the aircraft is doing, where it's positioned, its speed, and its roll and pitch.

Benefits

The beauty of the Fused Reality platform, says Landon, is that "going forward, every aircraft can become its own simulator." Pilots and airplane developers can test and practice maneuvers in real conditions with just one system that can be moved from one plane to another and even to a helicopter.

The system can be used to train pilots on difficult, potentially dangerous maneuvers and to test pilots and aircraft in extreme conditions that are typically too risky to try, he notes.

"Say I want to practice doing a cross-wind landing in winds that are very close to the limits of how you could actually do a landing," Landon says. "If I did it using that virtual runway, I can make an approach down to a virtual touchdown," and since the plane is still very high from the ground, the potential danger is far lower.

Fused Reality also reduces the need for additional equipment and personnel during training, whether it's the tanker plane in aerial fueling or a person in the water in a helicopter rescue.

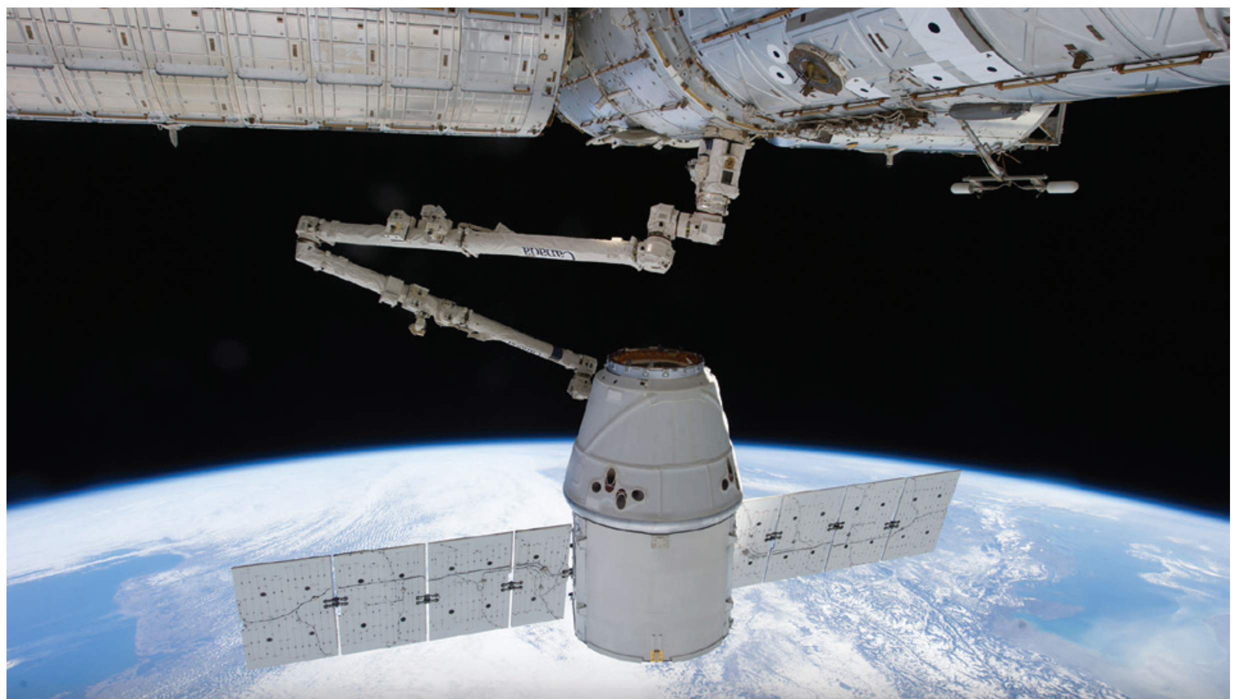
To keep costs down further, STI has designed its system to work almost entirely with interchangeable off-the-shelf components, from the virtual reality headset to a standard laptop. "Our secret sauce is in the software, the algorithms we developed. It's not hardware-specific."

With head-mounted displays coming down in price, the system is poised to become more affordable than ever, he adds.

The system is commercially available, and STI has been in talks with airplane manufacturers interested in using Fused Reality both to evaluate their planes and market them—as well as to help in designing features like the head-up display, so tweaks can be tested without the cost of rebuilding the display every time.

Training academies are also interested, and the company has a new contract with Johnson Space Center to investigate use of the system on the International Space Station, where astronauts could use it to practice complicated maneuvers with the station's robotic arm, among others.

Looking forward, Cogan says, NASA sees applications for longer-duration voyages, like to Mars, where the Fused Reality simulator could be adapted to, for example, provide diagrams that overlay broken hardware to help repair it, or even provide visual aids for surgery or other medical procedures. ❖



There are many possible applications for Systems Technology Inc.'s Fused Reality system, including in space. A new contract with Johnson Space Center investigates use of the system on the space station, to practice complicated maneuvers of the robotic arm.

Autonomous Robots Take On Dangerous Warehouse Jobs

NASA Technology

"Where does a 600-pound spider go? Anywhere she wants to."

The spider in question, dubbed "Spidernaut," was part of a prototype robot team built in 2005 to assemble a solar array on the Moon. The goal was not only to have robots do the manual labor but for them to work cooperatively without human direction.

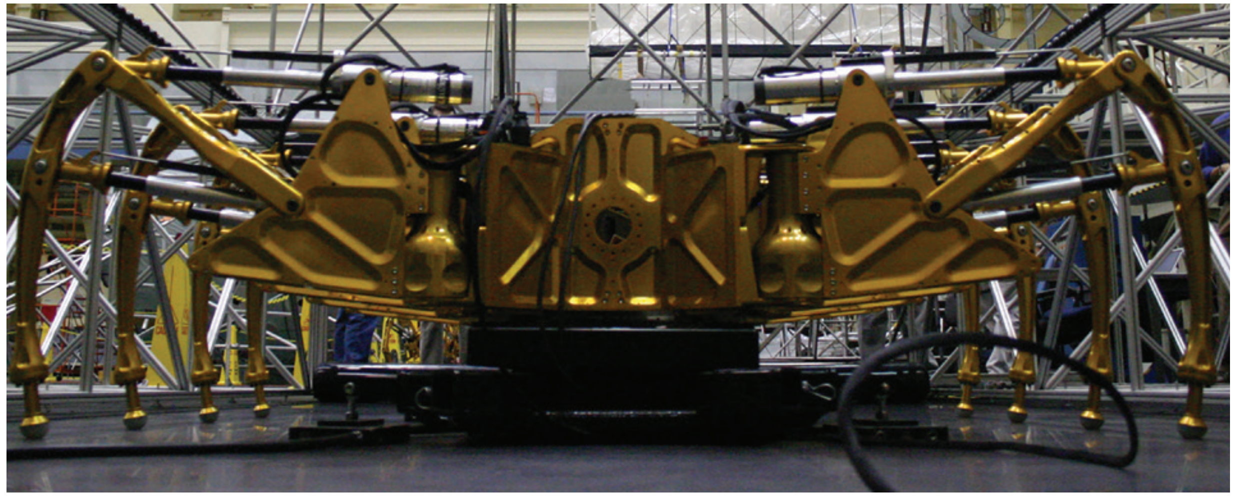
To achieve that, engineers needed robots optimized for various tasks as well as software capable of directing the entire operation from start to finish. That work continues to this day, and some of the team involved in programming Spidernaut and her sisters have taken that experience into the commercial sector, where their software is poised to automate difficult and dangerous drudge work in warehouses and beyond.

The slightly menacing-looking Spidernaut was designed to climb up the truss that supported a solar array, carrying flat panels to where they needed to be installed. "For a given mass, we wanted to get the most acreage possible, which means a very lightweight truss," explains Rob Ambrose, principal technologist of the Software, Robotics, and Simulation Division of Johnson Space Center's Game Changing Development Program.

"And what's the best kind of machine that can climb on a web-like truss? A spider, of course." The team also designed a six-limbed robot that could fasten joints with torque tools, and a third robot with a camera mounted on a thin tendril-like limb.

Designing the software to drive three very different robots through such a complex task was a big job. The NASA team, led by Ambrose at Johnson with contributions from the Jet Propulsion Laboratory and Langley Research Center, turned to computer programmers at Carnegie Mellon University.

Among other challenges, recalls Fred Heger, who was a graduate student when he worked on the project at Carnegie Mellon, was ensuring the robots completed each task in the right order, "so you don't have a robot on the inside of a half-finished building with no way out."



"Spidernaut" is part of a team of robots designed at Johnson Space Center to autonomously assemble a solar array on the Moon. Vecna Technologies senior research scientist Fred Heger honed his programming skills on the project, developing a system to ensure the robots completed the tasks in the optimal order.

Technology Transfer

Within just nine months in 2005, the NASA and Carnegie Mellon team had working prototypes of all three robots and the software to drive them, Ambrose says.

Although that program was ultimately cancelled amid shifting Agency priorities, Ambrose says, "a number of key component technologies led to major innovations in later robots that NASA built."

The work also paid dividends for Heger, now a senior research scientist at Cambridge, Massachusetts-based Vecna Technologies. The company recently released a suite of robots designed to move items through warehouses, which is built in part on the work Heger did for NASA.

"The physical shape is standard, commercially available equipment that people use today in warehouses. Except today, people are riding them and controlling them. Our computers, sensors, and robot software based on artificial intelligence enhance traditionally manual equipment to automate that," explains Vecna cofounder and chief innovation officer Daniel Theobald.

With this system, "we've got a bunch of basic robotic drivers and then a robot supervisor that's telling them where to go," he says.

The software, which Heger was integral in developing, traces directly back to the software he worked on for NASA. "The math and the models are the same, but new lines of code have been written to implement it in more modern frameworks," Theobald explains.

Benefits

Vecna's autonomy kit is designed to work in places like shipping warehouses, where one truck brings packages that must be distributed to different delivery trucks.

It's already a highly automated system, explains Heger, with conveyor belts and scanning machines, but "with the rise of e-commerce and people wanting more strangely shaped things more and more quickly, shipping companies

> We designed a robotic system that could work on any vehicle—pallet jacks, forklifts, golf carts, larger, smaller—anything that moves can be automated.”
>
> — Fred Heger, Vecna Technologies

end up having to transport material that they can’t put on a conveyor belt.”

For example, a rolled-up carpet or a bicycle would instead require a person to unload it from the truck and onto a cart, which would then be driven by a person to the outgoing truck, where another person would have to manually load it up again.

Vecna’s smart robots can drive the cart and other equipment themselves, leaving people to only do the loading and unloading. And because the software links a fleet of robots, it can direct them to deliver the packages in the most efficient way across the entire warehouse, making the whole process faster.

“The software knows where all the trucks are and knows where packages are piling up. It can figure out, based on known demand and predicted or learned demand patterns, where it should send these robots,” Heger explains, noting that this is a type of problem-solving humans aren’t particularly good at.

The robots also make people more efficient, he adds, because the software is able to, for example, “always make sure they have empty carts they can load onto, so they’re not waiting for a robot to come by.”

Beyond speeding up the process, the robots also significantly reduce accidents, which cause thousands of injuries each year. “We designed a safety-certified system to have a check, a double check, a triple check that if the robot is potentially going to hit something, it will automatically shut down before that happens.”

That means, Heger says, “even if the robotics system only worked as efficiently as a human for the cost for the delivery from point A to point B, you’d still come out way ahead in terms of the reduction in accidents.”

Currently, Vecna has a contract with a major U.S. shipping company, and they see big potential for the market even beyond the warehouse. “One of the neat things is that our system doesn’t require a brand-new piece of equipment. You can add our sensors and software to existing equipment, and that becomes a robot,” Theobald explains.

The company envisions a day when “anything you see in your office will be delivered by a robot in its journey from wherever it’s manufactured to your door,” Heger says.

“That was part of the strategy: we designed a robotic system that could work on any vehicle—pallet jacks, forklifts, golf carts, larger, smaller—anything that moves can be automated.”

That kind of system, Ambrose says, is something he sees as also being crucial for NASA’s plans. “The challenges we’re looking at for sending people into deep space are best met by having robots predeployed to set things up. It’s not cost-effective to have people go there for the very first effort,” he says. The robots could also maintain equipment during long absences between human visits and help support astronauts on the ground.

“So Fred’s experience orchestrating very different robots as a team is the kind of thing we’re going to have to focus on.” ❖

Using expertise built on NASA projects, Vecna Technologies has built an “autonomy kit” for commercial warehouse equipment to automate, for example, package handling. Software coordinates the robot’s tasks to ensure packages are moved through the warehouse in the most efficient possible manner.

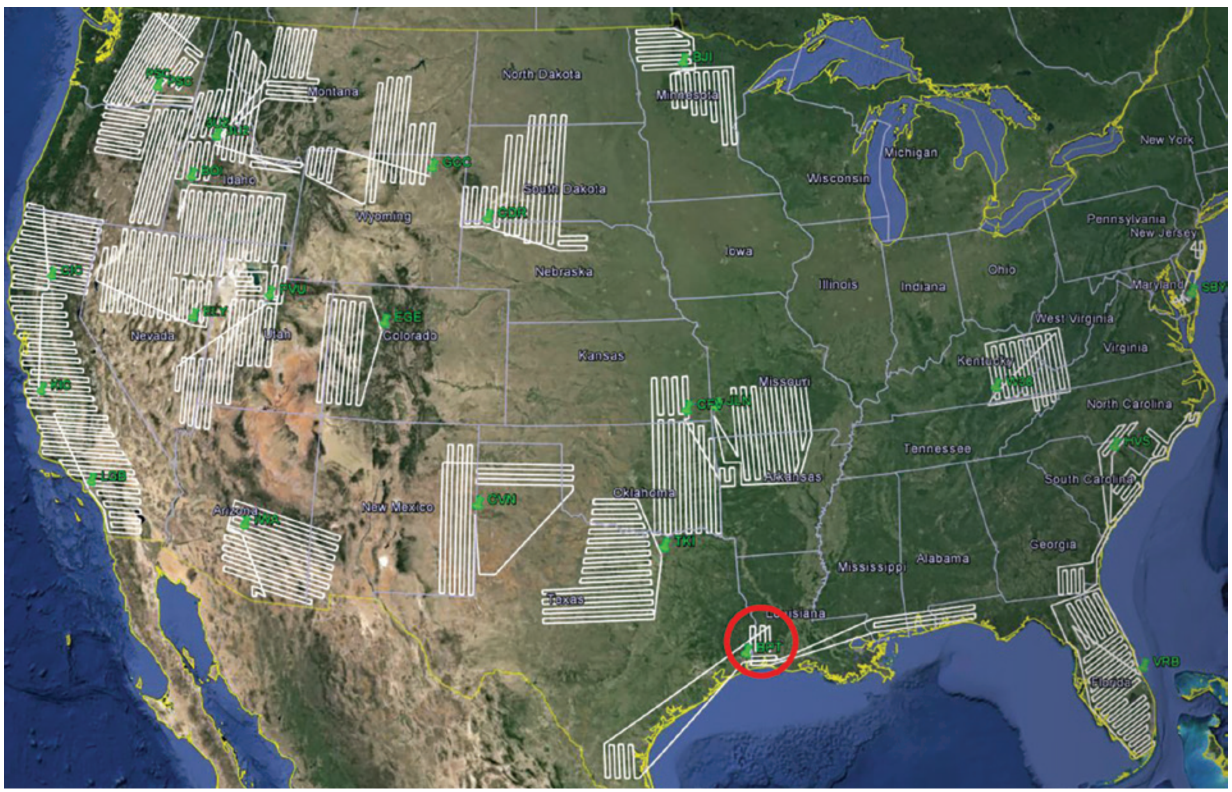
Drone Traffic Forecasts Show Commercial Skies of the Future

NASA Technology

It's a safe bet that the skies of the future will be hosting a lot more drones than they do today. If you can see beyond the low-flying pizza and package delivery drones, higher-flying autonomous aircraft will be performing friendly tasks like monitoring air quality, mapping floods, gathering news, and maybe even carrying passengers on quick jaunts as air taxis.

Some of these activities have already begun, but they currently require special permission from regulators who haven't yet determined all the technical and policy details of how to let everyone fly at once while maintaining safe airspace. The idea is to have large drones operate like other civilian aircraft according to existing rules in the air transportation system, but this will require additional technical specifications regarding what kinds of sensors and communications the drones should have.

"We expect a highly trained pilot to operate in a certain way because they understand the conventions of the air traffic system," says Eric Mueller, who led a team at NASA's Ames Research Center that worked with the Federal Aviation Administration (FAA) and others to reduce technical barriers to introducing drones into the national airspace. "We had to quantify that expected behavior and then turn it into requirements on the electronics."



Shown here are flight plans for routes drones might fly to provide early detection of nascent wildfires. Intelligent Automation Inc. (IAI) used burn probability data to determine what types of flights would be useful and then mapped possible routes.

The team was specifically focused on how drones might detect and avoid objects in the airspace—called a see-and-avoid capability when referring to aircraft with onboard pilots who are watching the sky immediately in front of them. "We couldn't simply build a system and fly it around and see if we ran into anybody and then say, 'I guess the system isn't good enough,'" Mueller says.

The team opted to understand the airspace through simulations. "We simulated tens of thousands of aircraft interactions," Mueller says, "and we simulated the performance of the proposed detect-and-avoid system to see whether it met the safety requirements the FAA or community had established."

The researchers had plenty of information about actual air traffic to feed into their simulations, but they also needed realistic information about drone trajectories and flight plans to set against the current air traffic data. It became something of a chicken-and-egg problem: to help the FAA write good drone regulations, NASA needed data on drone flights, but until the regulations were in place, that real-world data wouldn't exist.

Technology Transfer

That's how Mueller found himself working with Fred Wieland, director of research and development for air traffic management at Intelligent Automation Inc. (IAI), a technology development company in Rockville, Maryland.

In 2012, NASA funded future drone traffic research conducted by IAI, with help from Virginia Polytechnic Institute and State University, through an Ames-awarded Small Business Innovation Research (SBIR) contract. Mueller was NASA's technical representative.

The difficulty was coming up with a credible forecast—something skeptics wouldn't call a crystal ball. "When we began, we were perplexed," Wieland admits. "Where would we get this data, and why would anyone possibly believe us?"

The IAI team started by looking at previously identified likely drone missions and then began contacting scores of subject matter experts—people in positions to know about the likely autonomous flights in their organizations or fields.

Wieland says his team expected civilian agencies and other organizations would simply shrug and say they didn't know what they might do with drones. "Our first surprise was that was not the reaction we got," he says.

In fact, every agency the company contacted already had people working out the logistics of future drone flights. In many cases, entire offices had already been set up to oversee drone operations. "They knew where they would be flying, when they would be flying, altitudes, flight paths," Wieland says. "Our work, surprisingly, turned out to be fairly straightforward."

Once the company demonstrated that credible forecasts were possible, it received SBIR Phase II money to continue building its database of likely flights, and then, eventually, more money specifically to commercialize the final product.

Wieland and his colleagues additionally looked at scholarly literature and socioeconomic data to determine 19 broad mission types, such as mapping and border patrol. They also included missions that don't currently exist, like on-demand self-flying air taxi services. But they omitted likely delivery drones and amateur quadcopters that fly below 2,000 feet, because those aircraft are unlikely to encounter commercial aircraft outside the immediate airport vicinity.

The company identified 26,312 likely daily drone flights that would join the 27,000–28,000 commercial flights that currently fly each day—a striking addition to the airspace. Then IAI set about gathering as much information as possible on these drone flights—what airports would they use? What altitudes, trajectories, and flight paths would the unmanned aircraft systems (UAS) take?

"There already were projections of UAS activity out there," Wieland says, "but they tend to be broad projections about manufacturing capability or the types of UAS aircraft that will be used in the future. To my knowledge there are no other projections that go flight-by-flight, as we did. No one else has this type of projection."

Benefits

Back at NASA, Mueller and his team were able to plug the IAI data into their simulations.

"We didn't say that any particular mixture of those flights was going to be the future scenario," Mueller says. "What we did instead was look at a variety of possible scenarios with different combinations of missions. That way we could see where the safety metrics were sensitive to different selections of mission types."

Mueller's team went on to write detailed technical drone requirements in a several-hundred-page document it handed over to the FAA. "It's basically an instruction manual for how the drone systems should be built by manufacturers," Mueller says.

It was clear to both NASA and IAI that this enormous set of data on drone flight projections would have additional commercial applications—that's why they chose the SBIR Program as the funding vehicle. IAI built an interface that allows users to easily filter the drone categories, altitude, duration, or virtually any aspect of the data, and the company currently sells the dataset on its website as a product called UAS-Max.

Instead of setting a date for the traffic projections, IAI says the dataset includes likely drone flights several years after regulations are finalized, so the project is ongoing in a sense. The company has already made some updates to the original set of flights.

IAI doesn't discuss its customers or sales, but Wieland said broadly that drone researchers, regulators in charge of airspace safety, and military organizations are interested in datasets like UAS-Max. NASA remains the largest government consumer of the product, he says.

The project could have other benefits, as well, if the collection of tens of thousands of friendly missions can help counter drones' image problem. "Most of the time when you hear about drones, it's related to military operations overseas or invasions of privacy domestically," says Mueller, who now works in a different NASA division on a project to enable a future urban air taxi transportation system. "This data could be useful to show the public potential benefits of unmanned aircraft operations." ❖

Image courtesy of Wikipedia user Don McCullough, CC BY 2.0

The skies of the future will likely host many drones doing tasks ranging from package and food delivery to monitoring air quality, gathering news, and perhaps carrying passengers. Software developed by IAI has helped regulators predict future drone traffic and develop the regulations that will allow them to function safely and smoothly.

Offshore Oil Workers Learn Survival Skills in Astronaut Training Pool

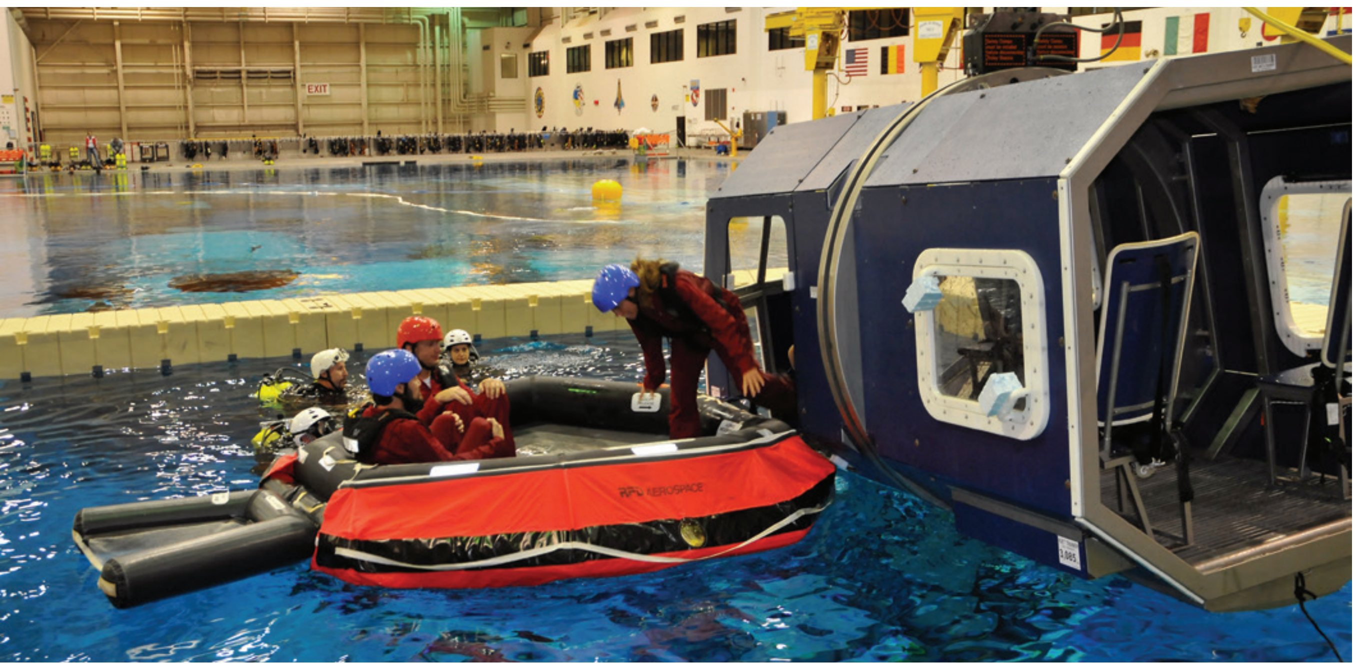
NASA Technology

To simulate weightlessness while rehearsing for NASA's 1966 Gemini 12 mission, astronauts Buzz Aldrin and Gene Cernan practiced spacewalks underwater, floating fully suited around a mockup of the space capsule in the swimming pool of a Maryland prep school.

After that mission both demonstrated the effectiveness of such training and proved astronauts could easily work outside a space vehicle, the Space Agency began investing heavily in underwater spacewalk simulation, which would become a staple of astronaut training. As a result, offshore oil workers and others who need controlled aquatic training environments have better options than renting a school's swimming pool.

NASA has constructed a handful of underwater training facilities over the years, but the one where astronauts currently train is the largest and most sophisticated yet. Built in the mid-1990s to accommodate mockups of the enormous International Space Station (ISS), the Neutral Buoyancy Lab (NBL) at Johnson Space Center's Sonny Carter Training Facility is 202 feet long, 102 feet wide, and 40 feet deep and holds 6.2 million gallons of water.

The facility is outfitted with more than just space vehicle mockups: overhead cranes, audio and video communication systems, skybox-style control rooms, an uninterruptible power supply, nearby staging areas, light manufacturing capabilities, a hyperbaric chamber to treat decompression sickness, and an onsite medical team all support complex operations there.



In the Neutral Buoyancy Lab at Johnson Space Center, participants in Bastion's Helicopter Underwater Escape Training evacuate a helicopter mock-up and board a life raft.

In the years after the NBL was built, while NASA was flying frequent Space Shuttle missions to build the ISS, the Agency used the facility almost constantly, with two crews often practicing spacewalks simultaneously, five days a week. With the U.S. portion of the space station largely completed in 2011, training tapered off, with one astronaut crew at a time currently training there three to four days a week, says Angela Prince, the NBL's external customer business development manager.

As a result, she says, the Agency decided to offset the cost of maintaining the lab and its full-time staff by allowing outside entities to utilize the facility for a fee. "This is really about cost savings and making sure we can maintain the unique aspects of this facility for future NASA needs, while making it available to industry and other government agencies," Prince says.

Technology Transfer

Under a Space Act Agreement, Johnson allowed Raytheon, which has been the prime contractor managing the facility since 2003, to partner with industry to offer training and testing services to external customers. Offshore survival and fire training classes began in 2011.

In 2015, Bastion Technologies, a subcontractor to Raytheon providing NBL divers and engineering services, expanded its product line and became the provider of offshore survival and fire training at the NBL. A small business that started out in the aerospace industry in 1998, Bastion had also branched out into the defense and petroleum markets.

"This is a great fit," says Jorge Hernandez, president of Bastion, which is headquartered in Houston. "It makes sense for us, because we're already doing a lot of work for Exxon, BP, Transocean, and others who are customers on the engineering side."

Offshore oil and gas workers going into the Gulf of Mexico and European waters are required to have certain levels of survival training, standards that are set by the Offshore Petroleum Industry Training Organization

(OPITO). "OPITO is an international organization that sets the highest safety standards for its training. As such, OPITO is thrilled that we offer our training from such a world-class facility," Hernandez says.

Originally, only three basic OPITO-certified courses were offered at the NBL: Basic Offshore Safety Induction, Further Offshore Emergency Training, and Helicopter Underwater Escape Training. Bastion has since earned certification for seven more courses, including Minimum Industry Safety Training for Experienced Workers, Escape Chute Training, and alternate versions of the basic courses, geared toward tropical environments. Bastion is the only company in the Western Hemisphere certified to offer the Hydrogen Sulfide Safety course and one of two that offer the Compressed Air Emergency Breathing System course.

"We've done quite a lot to expand the curriculum," says Mike Reece, Bastion's manager for offshore survival and fire training. "We've set an industry record for the most successful certification audits in one year."

The company also has a contract with the University of Houston to provide students from the university's Cullen College of Engineering and College of Sciences with offshore survival training.

The NBL is the only place Bastion offers this training, and the company is by far the facility's largest non-NASA user.

Benefits

As for the advantages of offering the training at the NBL, Hernandez says, "By far, the most important factor for us is safety. The safety culture of NASA and our training team at the NBL is second to none."

"We have a medical team in the facility to support NASA operations, so if anything happens, they're the first responders," Prince says. Another safety precaution comes in the form of color-coded helmets. Personnel survey new trainees to learn who doesn't know how to swim or is afraid of water, and those students are assigned red helmets, Prince says. "They self-identify, and then the instructors can see who's nervous and might panic."

Reece notes that creating a safety system usually involves trial and error. "Here, NASA safety standards were already established, and the safety record is impeccable."

In what Hernandez estimates has been about 200,000 hours of diving time, the NBL team has never lost work time due to a safety incident, he says.

The facility is also spacious and keeps air and water controlled for temperature, Reece says. "That creature comfort is a big thing we provide. That's an all-new concept in the oil and gas industry."

> "[The Offshore Petroleum Industry Training Organization] is thrilled that we offer our training from such a world-class facility."
>
> — Jorge Hernandez, Bastion Technologies

He adds that having equipment like overhead cranes comes in handy, as does the ample staging area. There, the company has set up its smoke maze, where trainees learn how to navigate in low visibility, and the "fire ground," where they learn to use fire blankets, extinguishers, and other equipment.

Other Federal entities are also making use of the facility, including the Coast Guard, Army Corp of Engineers, and Air Force, as well as Navy divers supporting Orion landing and recovery efforts, Prince says. Among the other private companies working there, Oceaneering International provides remotely operated underwater vehicles for oil and gas testing. Petroleum companies have used the pool to conduct research and development, for example trying out various inspection methods on full-size pipes and other equipment.

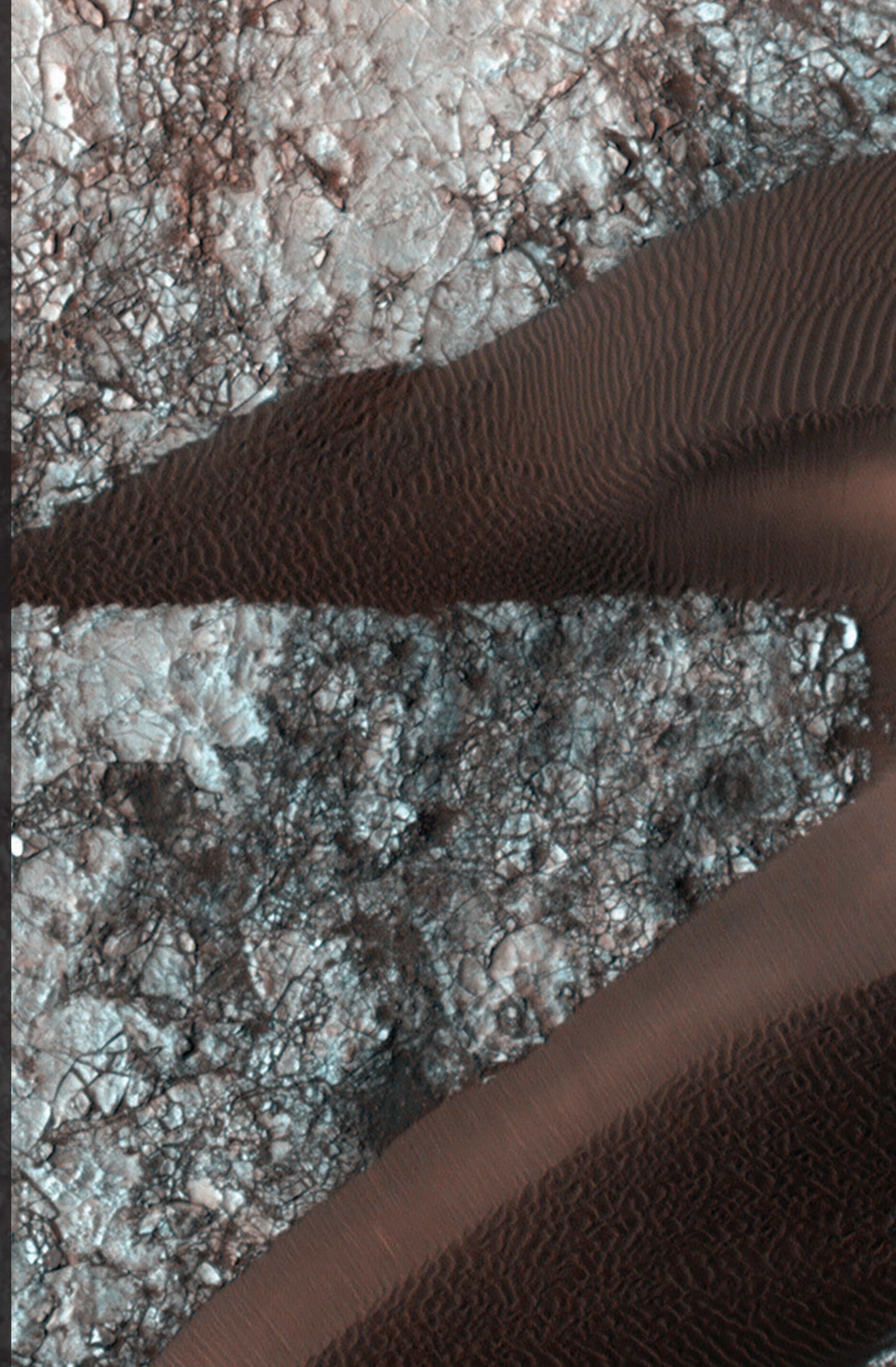
Even assuming NASA ramps up its activities at the NBL in preparation for the first crewed Orion missions, scheduled for the early 2020s, Prince says there will still be time and space available for outside groups. "We always expect to be able to do external customer operations," she says, noting that the facility still isn't operating at 24-hour-a-day capacity.

For Bastion's part, the company also plans to continue the partnership well into the future. "We're very proud and lucky to be able to work with NASA, growing both the NASA and oil-and-gas sides of the business," Hernandez says. "This really benefits both sides of our company." ❖

Workers who will deploy to offshore oil and gas rigs are often required to have certain levels of fire and survival training, a need that Bastion Technologies is able to meet through the use of NASA's Neutral Buoyancy Lab.

Consumer Goods

Many of NASA's most memorable spinoffs have been consumer goods, such as memory foam and the Dustbuster. This year's issue of *Spinoff* adds to that list advanced LED lighting for greenhouses, art made with magnetic fluid, a system for retraining sleep cycles, a long line of air purifiers, and more.



Apollo 11 History Archive Helps Virtual Reality Program Come to Life

NASA Technology

Imagine yourself in the cramped cockpit of the Apollo spacecraft heading to the Moon. Look around to see Earth out one window and stars lighting up black space from another. Reach out to the control panel.

This is Apollo 11 VR, a virtual reality experience that enables users to relive the Apollo 11 mission and take some of the first steps on the Moon—not the very first, because Neil Armstrong is a few feet ahead, kicking up lunar dust and proclaiming, "That's one small step for man . . ."

While it's not exactly a game, if you do find yourself trying Apollo 11 VR, there's a good chance it's because you are or know a video game aficionado who has invested in a headset and other equipment designed to get the most out of virtual reality. The company behind the project, Waterford, Ireland-based Immersive VR Education, calls it an "experience" or "a new type of documentary."

The project required extensive study on the part of developers, according to Immersive VR Education CEO David Whelan. "It was similar to the amount of research that goes into making a documentary," he says.

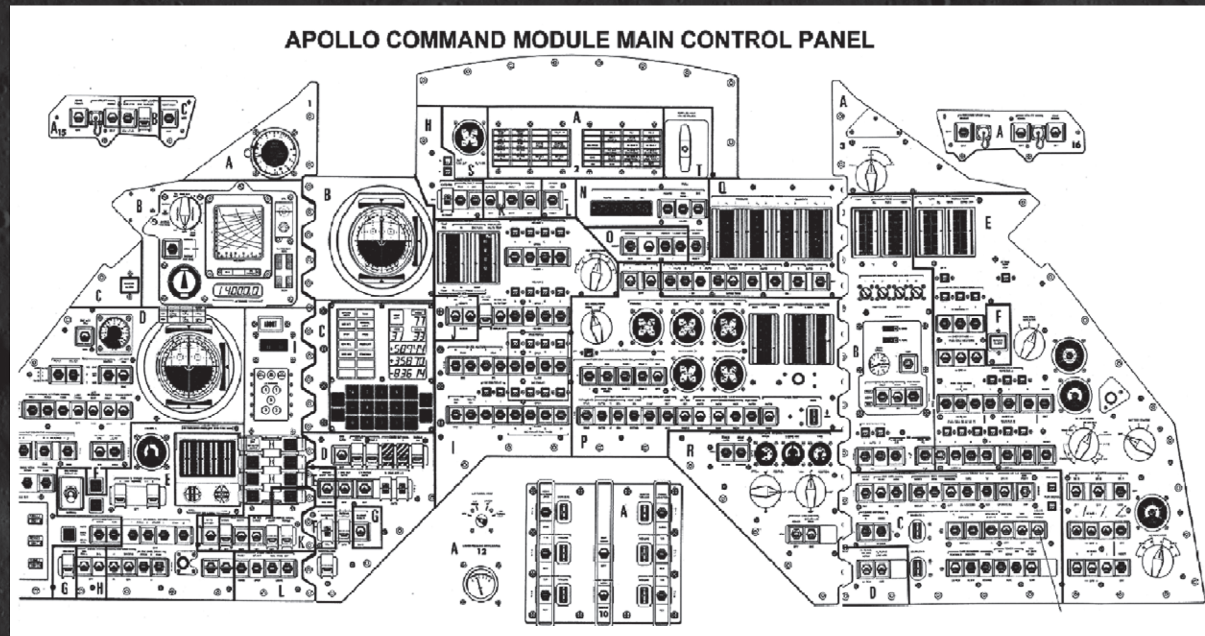
And it wouldn't have been possible without the vast amounts of information NASA posts on publicly accessible websites.

Technology Transfer

The National Aeronautics and Space Act of 1958, which created NASA, tasked the Space Agency not only with exploring and studying aeronautics and space but also with providing for the "widest practicable and appropriate dissemination of information concerning its activities."

"That phrase from the Space Act is at the root of what we do in the History Division," says Stephen Garber, one of two historians in the NASA Headquarters office that maintains the Agency's historical websites.

Garber coordinates with volunteers to offer information on a variety of large and small projects, but the Apollo mission pages—especially the Lunar Surface Journal—are among the most popular NASA archives online.



In developing a virtual reality experience and educational app, Immersive VR Education made extensive use of a treasure trove of data and resources NASA has made publicly available, such as this diagram of the Apollo capsule's control panel. This page's background shows a NASA lunar surface photo mosaic the company used to get every surface crater right in its rendering of the mission's landing site

Whelan said these repositories provided his company with extremely detailed design plans that illustrated the interiors of the spacecraft, the lander, and the command module. Apollo 16 astronaut Charlie Duke got to experience an early version of the software before its release, and his observations helped the developers improve the accuracy of the control panel for the final release.

"We put him back where he sat in the 1970s, and based on his feedback, we changed a few things," says Whelan, who believes every switch and dial on the control panel is now exactly accurate.

On NASA's website, the team found a spectacular photo mosaic of the initial landing site created from many photos taken on earlier Apollo flights stitched together. The Immersive VR Education developers essentially drew their virtual world on top of that image.

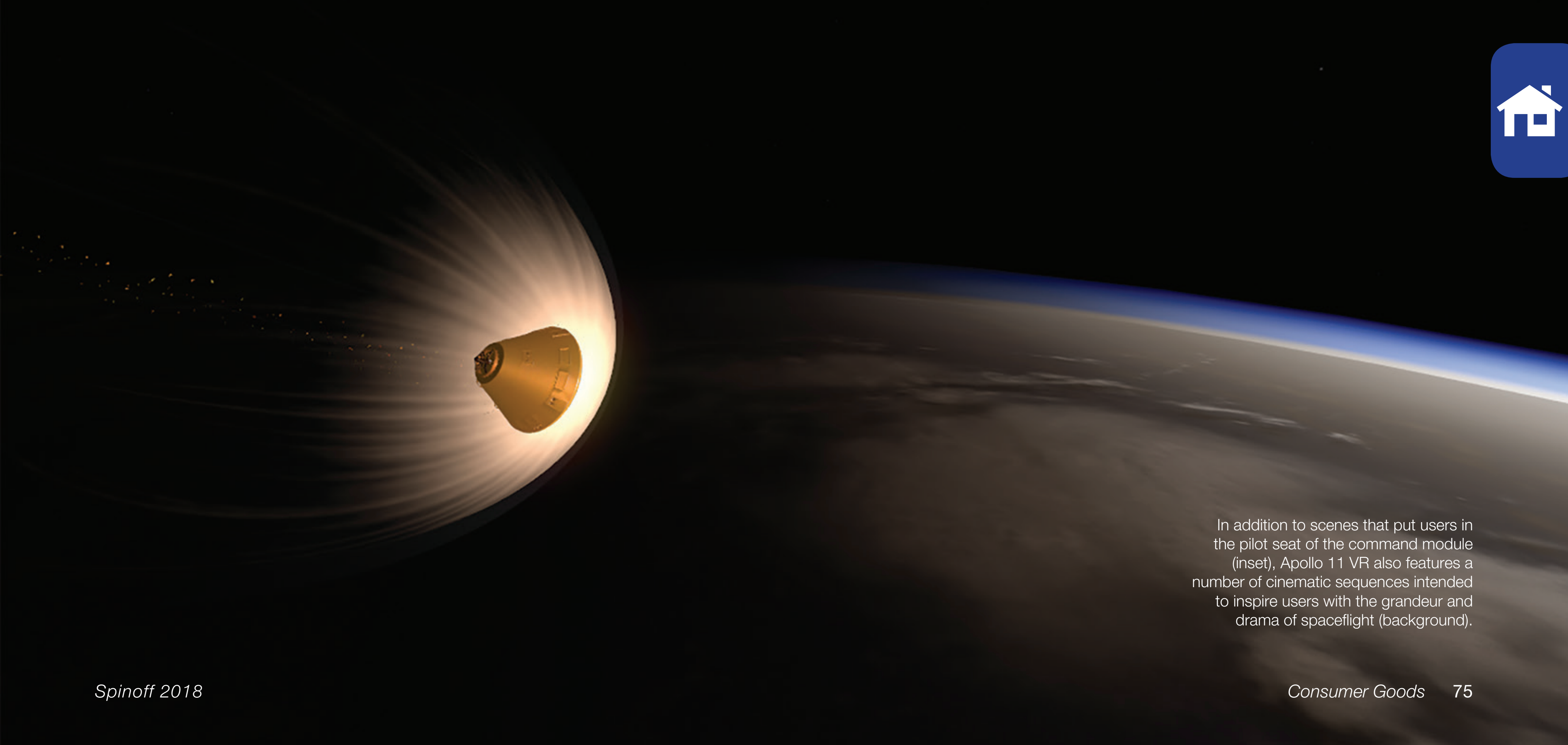
"When players look out of the lander, they see every crater and every valley exactly as the astronauts would have seen them back in the day," says Whelan, who was surprised by how much information was available.

"Everything is cataloged really well," he says of the Space Agency's websites. "I would have thought we'd have to contact NASA quite a lot more to get a lot of information that was actually freely available."

Apollo 11 VR also includes original audio heightened with stirring music that makes the experience feel more momentous. "We find that if you get an emotional reaction

“If you get an **emotional reaction** from somebody, **the experience sticks** with **them** a **lot more.”**

— David Whelan, Immersive VR Education



In addition to scenes that put users in the pilot seat of the command module (inset), Apollo 11 VR also features a number of cinematic sequences intended to inspire users with the grandeur and drama of spaceflight (background).

from somebody, the experience sticks with them a lot more," Whelan says.

Benefits

Immersive VR Education is in the business of creating virtual classrooms. The company's flagship product, Engage, lets up to 30 people participate in real time in a virtual lecture or meeting from anywhere in the world. Such events can then be posted online for later "experiencing."

The company built Apollo 11 VR to demonstrate a new way of teaching and learning history. "We're trying to show the general public that virtual reality isn't just for video games and entertainment," Whelan says. "It's also very useful for education."

Though popular as a paid app, the program is free for teachers wishing to show it to their students. Enthusiasts can buy it for the Oculus Rift, HTC Vive, and Sony PlayStation virtual reality headsets. It can also be viewed on a regular computer monitor, but much of the impact is lost without the more sophisticated equipment.

In its first year, Apollo 11 VR was purchased more than 40,000 times, and that was before it was available for PlayStation headsets. Immersive VR Education went on to develop an entirely free Mars Rover experience as a demonstration of their Engage platform and hopes to start projects about other Apollo missions, as well as a Space Shuttle series around deploying and then repairing the Hubble Space Telescope.

When NASA publishes images, designs, and information about its missions, it has no way of tracking where they go. Garber, the NASA historian, says he was surprised to learn that Apollo 11 VR was developed with information from websites he oversees, but the point in all those postings is precisely to inform school reports, news articles, curious web surfers, or developers of virtual reality worlds.

"We construe our mission broadly in that we try to cover the panoply of activities that NASA is involved in," Garber says. "Clearly people are still interested in the Apollo Program almost 50 years after it ended." ❖

The combination of a virtual reality environment and NASA data and media resources helped the company make its app a larger-than-life experience. It has received widespread critical and popular acclaim, including multiple awards, and has been purchased by more than 40,000 users.

Light-Induced Oxidation Cleans Air, Surfaces, Clothes


Image courtesy of Earthworks, CC BY 2.0

During a natural gas leak from this well in Aliso Canyon in late 2015 and early 2016, thousands of residents were relocated from the neighboring Los Angeles neighborhood of Porter Ranch. But thousands more were able to stay in place after Southern California Gas ordered 10,000 Air Scrubber Plus units and distributed them to residents. The devices are based on a more advanced form of an air purifier built for NASA in the 1990s, which breaks down organic contaminants in the air.

NASA Technology

In late 2015 and early 2016, while Southern California Gas workers struggled for months to stop a natural gas leak from a well at Aliso Canyon in Los Angeles, thousands of residents of the neighboring Porter Ranch community—and even two of its schools—were relocated. A device based on a NASA invention, however, allowed thousands more to stay in their homes.

A nearby heating and air conditioning company happened to be a distributor of Aerus Holdings' ActivePure products and introduced the gas company to the Aerus Air Scrubber Plus, a line of air- and surface-purifying devices. SoCalGas ended up ordering and installing more than 10,000 of the air purifiers in Porter Ranch homes.

"We didn't have the surge inventory to meet a demand like that," recalls Joe Urso, CEO of Aerus, which is headquartered in Dallas. "We had to expedite orders, fly stuff in, work overtime." In the end, though, he says, "It was a tremendous demonstration of the power of our technology. We were able to be their number-one solution and allow people to stay comfortably and safely in their homes."

Air Scrubber Plus (*Spinoff* 2015) is a family of devices that are typically installed in home ventilation systems, but the full line of ActivePure products comprises a broad range of about 60 models. These range from small, portable devices to industrial-sized units and are made for installation anywhere from ceiling tiles to automobiles. They even include laundry applications.

All of these are built on a discovery made in the 1990s at the Wisconsin Center for Space Automation and Robotics, a NASA Research Partnership Center at the University of Wisconsin-Madison. Researchers there, with the help of the Space Product Development Program at Marshall Space Flight Center, were trying to solve a specific problem when they hit upon a broad solution: photocatalytic oxidation.

When ultraviolet light strikes titanium dioxide, it frees electrons that turn oxygen and moisture into highly reactive hydroxyl radicals. These charged particles then oxidize air contaminants such as volatile organic compounds, turning them into carbon dioxide and water.

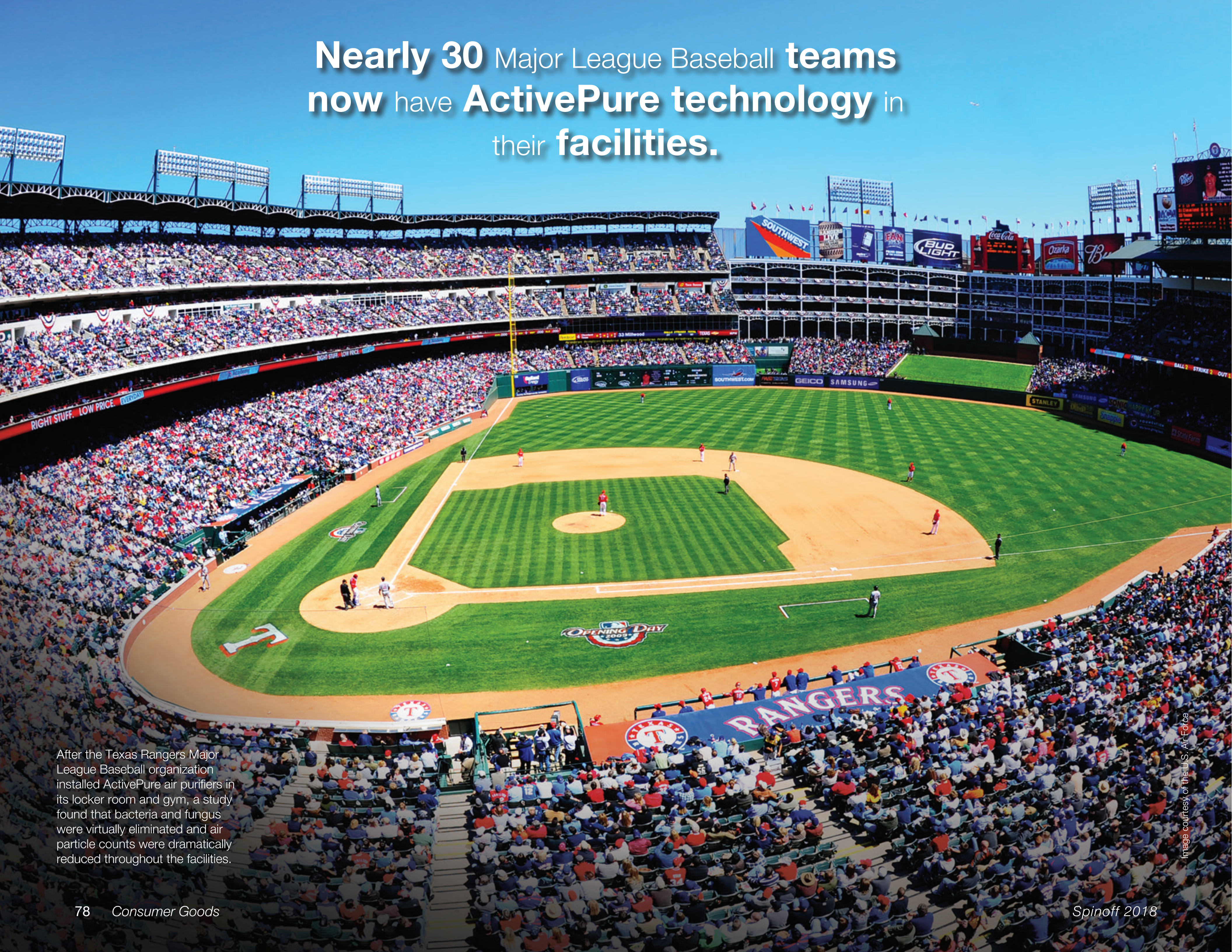
The university researchers were trying to eliminate ethylene that accumulates around plants growing in spacecraft, but they found that their ethylene "scrubber" also eliminated other airborne organic compounds and neutralized bacteria, viruses, and molds.

Technology Transfer

NASA has since considered photocatalytic oxidation for other uses in spacecraft, from revitalizing the atmosphere to disinfecting drinking water. Meanwhile, several companies have capitalized on the discovery, creating products for home, industrial, office, and outdoor use (*Spinoff* 2002, 2009, 2012, 2013).

In 2009, Aerus—formerly the famed Electrolux vacuum cleaner company—acquired a company called EcoQuest that had a proprietary form of the technology, known as ActivePure. It didn't just clean the air that passed through the system but sent oxidizers out into the surrounding environment, where they could not only neutralize airborne contaminants and pathogens but also settle on and clean surfaces.

Nearly 30 Major League Baseball **teams now** have **ActivePure technology** in their **facilities.**



After the Texas Rangers Major League Baseball organization installed ActivePure air purifiers in its locker room and gym, a study found that bacteria and fungus were virtually eliminated and air particle counts were dramatically reduced throughout the facilities.

Image courtesy of the U.S. Air Force

"It creates this blast of hydroxyl kill agents that we blow out into the atmosphere," as Urso puts it. "No other technology does that."

Aerus made further enhancements, altering the mix of metals in the photocatalyst and changing the way it interacts with the ultraviolet light to make it more effective.

The oxidizers ActivePure deploys include hydroxyls, hydrogen peroxide, and superoxides, all charged particles that clean air and surfaces but pose no threat to humans or pets. They naturally distribute themselves throughout the air, so the only question is the quantity needed to clean a given space, Urso says, noting that this is why the company offers the technology in different scales and also develops custom solutions for areas of any size.

Several of Aerus Holdings' subsidiary brands incorporate the technology into their products, including Beyond by Aerus, activTek, Vollara (formerly EcoQuest), and others. "That's what's allowed us to have such a big reach and a big impact," Urso says.

Benefits

When Aerus acquired them in 2009, ActivePure products had annual sales of about $10 million. By 2016, they were up to about $100 million, accounting for a third of Aerus Holdings' total sales. They're sold in 72 countries, and Urso estimates they support about 300 jobs directly and help support another 10,000 jobs through distribution points, of which there are about 1,300 in North America alone.

ActivePure has been validated in numerous third-party case studies. In several tests, Kansas State University and the University of Cincinnati found that an EcoQuest unit dramatically reduced concentrations of airborne aerosol contaminants, neutralized 90 percent of viruses and bacteria within an hour, and wiped out infectious germs and viruses in a matter of hours.

A 2013 study found that ActivePure virtually eliminated bacteria and fungus populations on various surfaces in three hotel rooms. After 30 days of exposure to both ActivePure and numerous hotel guests, no fungus was detected, and colony-forming bacteria counts were down to the single digits, even on surfaces with initial counts in the hundreds or thousands.

Aerus cites other, more anecdotal examples: the end of staph infections after ActivePure devices were installed in one school's sports facilities following a year that had seen 14 infections, and dramatic reductions in absenteeism and flu-related dismissals at schools that have installed the devices.

After four players in the Texas Rangers Major League Baseball organization contracted methicillin-resistant staphylococcus aureus (MRSA) infections in one year, the team installed ActivePure air purifiers in its stadium's locker room and gym. A study at the facilities again demonstrated that the purifiers virtually eliminated bacteria and fungus throughout the facility and dramatically reduced air particle counts continuously over the course of a year.

Nearly 30 Major League Baseball teams now have ActivePure technology in their facilities.

Even the most sterile environments can benefit from the devices. A 2015 study in an operating room at a Dallas hospital showed that after a week of ActivePure exposure, bacteria counts were down by more than 80 percent and air particles by 90 percent. "These places are scrubbed with chlorine and filled with ultraviolet lights and HEPA filters," Urso says. "They were really shocked when we came in and showed them the kind of impact we could have."

Cleaner air doesn't just reduce rates of illness but also helps with allergies and asthma and even improves sleep, he says.

Restaurant kitchens use ActivePure to clean their exhaust fumes. São Paulo, Brazil, is plagued with dense smog, and it's there that, in 2016, Aerus announced a partnership with Mitsubishi Brazil to mass-produce its first in-automobile air purifier, AutoPure.

ActivePure technology can also clean clothes. Units such as the Aerus Laundry Pro and Vollara LaundryPure can be hooked up to any washing machine to eliminate the need for detergent, bleach, and hot water. "We've taken photocatalytic oxidation and created oxidizers that work with water," Urso says.

The company estimates the devices could save a family up to $460 per year in detergent and electricity while keeping potentially allergenic detergent residue off clothes and phosphates out of the local water. Urso notes that the

Aerus has adapted its NASA-derived ActivePure technology to a variety of products. The Beyond Guardian Air unit (top) can purify the air in a 2,000 square-foot space at one air change per hour, while the Laundry Pro product line (bottom) makes unlikely use of this air-purification technology with units that hook up to clothes washing machines to eliminate the need for detergent, bleach, and hot water.

Texas Rangers, several of whom are sensitive to detergent, are also customers for this product line.

Photocatalytic oxidation may trace its roots to the Space Program—and could one day clean air and water for astronauts on deep-space exploration missions—but so far the technology has made its most important impact in everyday life on Earth.

"It's exciting to do something that makes a difference," Urso says. "People's health is really benefiting from the ultraclean air and surfaces ActivePure creates. There's just not another product like it." ❖

Ferrofluid Technology Becomes a Magnet for Pioneering Artists

Magnetic ferrofluids invented at Glenn Research Center have lately found their way into the art world. Nikola Ilic developed a suspension liquid that keeps ferrofluid from staining its container and founded Concept Zero, which sells products like Motion, pictured here.

NASA Technology

In 2008, when Nikola Ilic came across an online video of moving ferrofluid sculptures by Japanese artist Sachiko Kodama, with black liquid rising into swirling bristles that joined into quivering spikes, the artist-entrepreneur immediately wanted a ferrofluid display for his desk. "It looked like the T-1000 from *Terminator 2* come to life," he recalls.

But he couldn't find a display of the magnetized liquid available for sale anywhere online. So he decided to make his own—and soon learned why more people weren't doing it: "It stains everything," he says. In a typical display, a small amount of dark ferrofluid is placed in a clear glass chamber full of a clear suspension liquid. It's then manipulated by a magnet outside the chamber. But if the ferrofluid mixes with the suspension liquid, the dark fluid quickly stains the glass and makes a mess.

Perhaps it's not surprising that ferrofluid is not an ideal art material: after all, it wasn't invented for aesthetic purposes, but rather for space travel. In the early 1960s, Steve Papell, an engineer at Lewis Research Center, now Glenn Research Center, came up with the idea of magnetizing rocket fuel as a way to draw it from a storage tank into an engine in the absence of gravity. He discovered a way to stably disperse magnetic nanoparticles throughout a carrier fluid, making the first ferrofluid. A few years later, a company called Avco Space Systems won a NASA contract to further characterize and develop ferrofluid and managed to create a variety of liquids that ranged up to 10 times the magnetic strength of the initial Lewis invention.

The basic trick to creating a ferrofluid is to make the magnetic nanoparticles so tiny they naturally spread throughout the carrier fluid, rather than settling out of it, and to coat them with a surfactant that prevents them from clumping together.

Technology Transfer

Two Avco engineers licensed the technology from NASA to found Ferrofluidics Corporation, now Ferrotec. The material has come to be used in a variety of applications, from loudspeakers to petroleum refining and chemical processing facilities, to semiconductor chip manufacturing (*Spinoff* 1980, 1981, 1993, 2015).

Since around 2000, a small but growing number of artists around the world, including Ilic, have begun using ferrofluids to create striking visual displays. They have faced some technical hurdles, though, such as the problem of staining.

On that front, Ilic took what he calls "the Edison approach: try 10,000 things, and one of them works, and you build on it." He finally came up with a suspension solution that wouldn't mix with the educational-grade ferrofluid he buys from Ferrotec. He guards his recipe closely but hasn't patented it because he's wary of patenting and the effects it may have on ingenuity, he says. "If someone else figures it out, they can go for it."

In 2011, he started the online, Hamburg, New Jersey-based business Concept Zero. The site sells glass displays of various shapes and sizes, each filled with his clear suspension fluid and a small amount of black ferrofluid. When a magnet is placed close to a display, the dark fluid leaps into a hemisphere of spikes that follows the magnet around the glass.

Benefits

"People absolutely love it," Ilic says of the Concept Zero product line. "A lot of people use it as a fidget—it's sort of like a high-tech stress ball people play with while they think about other things."

He says sales are healthy. "I can barely handle what comes in on my end, but I do it."

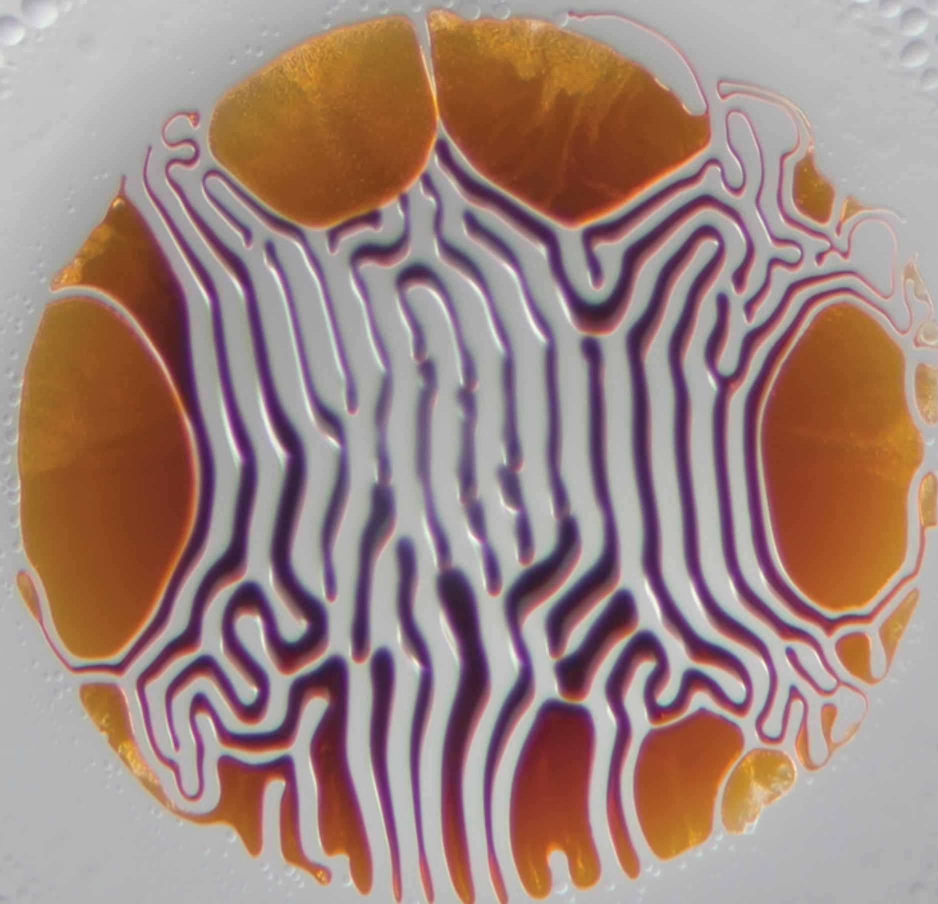
Ilic has also developed glass chambers for a number of other ferrofluid artists. "People doing this in the United States, most of them came here as a starting point," he says.

For example, he provided the chambers for artist Matt Robinson's automated, lava lamp-like Ferroflow displays. He also provides suspension fluid to artist Linden Gledhill, who uses ferrofluid to create intricate abstract images. He helped promote (and Gledhill helped photograph) Mike Pecci's horror film *12 Kilometers*, in which the black, animated fluid plays the villain—a malignant entity released by Russian miners.

He also provided flat-panel chambers to designer Zelf Koelman, who used them with ferrofluid and an array of electromagnets to create a digital clock. Ilic has been working on his own flat panel display, with the electromagnet arrangement to be programmed by the user. He notes that designer Martin Frey used a similar setup to recreate an early video game with ferrofluid pixels. Ilic says he's also experimenting with dried ferrofluid to create fixed sculptures.

Overall, though, the number of artists working with ferrofluid remains smaller than Ilic would like, he says. "The more talented people that get involved, the higher the quality of art." On his website, he promotes designers new to the medium, as well as some of the original vanguard. "If anyone comes up with something I think is interesting, I put it on my website," he says. "If it's cool, it's going up there, even if it's a competitor."

But Ilic says the scarcity of people repurposing this space-age substance for art is also part of its allure. "It draws people who want to pioneer something because the field isn't saturated," he says. "It's like finding a new continent. You don't know what's around the corner." ❖



Concept Zero recently partnered with artist Linden Gledhill to launch a line of Gledhill's art. He created the images by using a magnetic field to manipulate ferrofluids diluted with solvents and photographing the results.

"The more talented people that get involved, **the higher** the **quality of art."**

— Nikola Ilic, Concept Zero

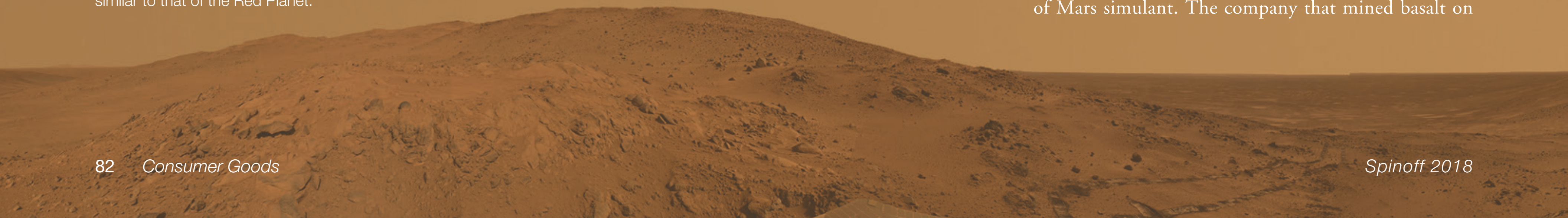
The Martian Garden Recreates Red Planet's Surface

NASA Technology

After the Phoenix lander settled into the northern polar region of Mars in 2008, its operators discovered that icy soil scraped from the planet's surface was too sticky to deliver from the probe's scoop to one of its instruments, forcing them to content themselves with only analyzing dry soil. A little over a year later, near the planet's equator, the Spirit rover got stuck in a deposit of soft iron sulfate hidden under a layer of normal-looking Martian soil, putting an end to more than five years of roaming.

These and other unexpected difficulties that have confronted rovers and landers on other worlds might be avoided in future missions if engineers building them have more accurate testing environments, including "simulants" imitating the dirt, dust, and rock of a given planet. As a 2012 paper out of NASA's Marshall Space Flight Center notes, technology sent to other planets and moons "is only as good as the simulants used to test it."

Unlike the Moon, no surface samples from Mars have been returned to Earth. But orbiters have recorded surface compositions across the entire planet, and robotic explorers have carried out deeper investigations at various sites. A major ingredient of much of the Martian surface is basalt, an iron-rich rock typically associated with volcanoes on Earth. So that's where NASA researchers go to look for appropriate Mars simulants.



Growing food on the desolate surface of Mars is a challenge NASA plans to take on one day. The Martian Garden lets buyers give it a try, with dirt that the Jet Propulsion Laboratory (JPL) tested and found to be similar to that of the Red Planet.

In the 1990s, NASA engineers developing terrestrial Mars probes tested them using a mixture known as JSC Mars-1, consisting of particles ejected from Pu'u Nene volcano in Hawaii. But these naturally round particles tended to attract moisture and become clay-like, so in the mid-2000s, NASA started looking elsewhere.

In 2006, Greg Peters of the Jet Propulsion Laboratory's (JPL) Extraterrestrial Materials Simulation Laboratory found what he was looking for on a mountain in the Mojave Desert of California. Saddleback Mountain is home to a basalt quarry, dug into flows about 20 million years old. "I actually grew up in that area, so I knew about that deposit," Peters says. "My dad worked at the adjacent borax mine."

Samples were brought back to JPL and examined. "Mineralogically and chemically, it looked like a pretty good match," Peters says, adding, "Also, this basalt was available in tons, already processed." The company operating the quarry was crushing the rocks onsite, and the process, more akin to the mechanical weathering process on Mars, produced rougher grains that didn't attract water and become muddy. The dominant minerals were also those with a large presence in Martian soil—feldspar, pyroxene, olivine, and magnetite.

Mars Mojave Simulant (MMS) was born, and by 2008, JPL had stored up 10 tons of crushed Saddleback Mountain basalt.

Technology Transfer

When Mark Cusimano and a friend decided to go into business in 2015, both were "passionate space enthusiasts," he says. As park rangers for the city of Austin, Texas, they had run a park astronomy program together.

They hit on the idea of a kit for gardening on Mars and discovered JSC Mars-1, which by then was being mined and sold to NASA and other customers by the space company Orbitec, but transportation from Hawaii made the simulant prohibitively expensive. It was only after learning of MMS that they founded The Martian Garden. The Austin-based company, where Cusimano is the chief technology officer, successfully completed its Kickstarter campaign in the fall of 2016, selling 50 Martian gardening kits based on the Mars simulant, complete with a desktop greenhouse, seeds, and fertilizer.

But the Mars-like dirt on its own has proven to be an even bigger seller, with customers ordering it in shipments of up to 200 pounds. "People have been very enthusiastic about the bulk material," Cusimano says.

The interest is not because the dirt is particularly good for gardening but rather because it presents the challenge of growing plants on Mars, where the surface is rich in inorganic nutrients but totally lacking in organic compounds. The company bakes the soil in an autoclave "so it's as dead as we can make it," Cusimano says. Fertilizer is a necessity.

In the spring of 2017, the company began offering MMS-2, which incorporates additives to more closely imitate the chemical composition of Mars' surface, with about 93 percent accuracy. The company is also working on another product—MMS-2+—that will also incorporate perchlorates, volatile chemicals that pose some health hazards but are now known to be pervasive on Mars. Cusimano plans to experiment with growing water hyacinths in the mixture, because they are often used to clean up perchlorates.

The Martian Garden kits currently come with a mix of cabbage, kale, arugula, and dill seeds, mainly because these plants germinate quickly and easily.

Benefits

The Martian Garden is now the sole commercial provider of Mars simulant. The company that mined basalt on

The Martian Garden's gardening kits include a desktop greenhouse, seeds, fertilizer, and the Mojave Mars Simulant JPL uses to test Mars landers and rovers.

While The Martian Garden sold enough gardening kits to meet its Kickstarter fundraising goal, the company has seen greater success with its individual bags of its Mars surface simulant, a mixture based on JPL testing that found crushed basalt from a quarry in the Mojave Desert to be similar to the surface of the Red Planet. It's marketed in packages of up to 10 pounds.

> "The more we work with educators, the more we realize that the thing we need the most to get to Mars is an educated and enthusiastic public."
>
> — Mark Cusimano, The Martian Garden

Saddleback Mountain went out of business years ago, and Cusimano's company struck an agreement with the entity mining borax nearby, which took over the basalt site, allowing The Martian Garden to harvest the material. Orbitec, recently purchased by Sierra Nevada, has stopped selling JSC Mars-1.

"It was good timing on our part," Cusimano says. "Right as they were leaving the market, we were able to step in."

By April of 2017, the company had sold more than 1,500 pounds of simulant and about 160 garden kits.

The primary markets are elementary through high school teachers and researchers at universities. The former are especially dear to Cusimano, who traces his interest in space back to early childhood. He's currently working with a teacher and customer to develop a classroom kit and curriculum.

"The more we work with educators, the more we realize that the thing we need the most to get to Mars is an educated and enthusiastic public," he says. "Instilling that passion in the generation that's going to go to Mars is a pride point for us."

Research, however, is still a major interest, and to that end the company is also working to develop an affordable Mars environment chamber that would also recreate the atmosphere, pressure, and temperature of Mars.

NASA may also end up being a customer. Peters notes that since the Saddleback Mountain basalt quarry shut down, the Space Agency no longer has a source for Martian simulant. NASA also continues to look for more accurate Mars soil analogs. After all, the surface varies across the planet. And the Phoenix lander's scoop instrument was tested with the original MMS and still didn't perform as expected.

Peters says he was pleasantly surprised to learn how the Martian Garden was selling the simulant he found. "The more people who buy it, they're either learning about Mars by doing experiments, or you're getting somebody interested." ❖

Aerogel Insulation Makes Thinner, Warmer Outerwear

NASA Technology

When Michael Markesbery, future cofounder of Oros, climbed the tallest mountain in the Swiss Alps with friends, he was bundled up with so many bulky layers he could barely move his arms.

"I remember thinking, it's the 21st century, but I still have to wear all this bulk and layers to stay warm?" recalls Markesbery. Actually, he didn't know it, but something already existed that could make incredibly warm outerwear with far less bulk, and it owes much of its development to NASA.

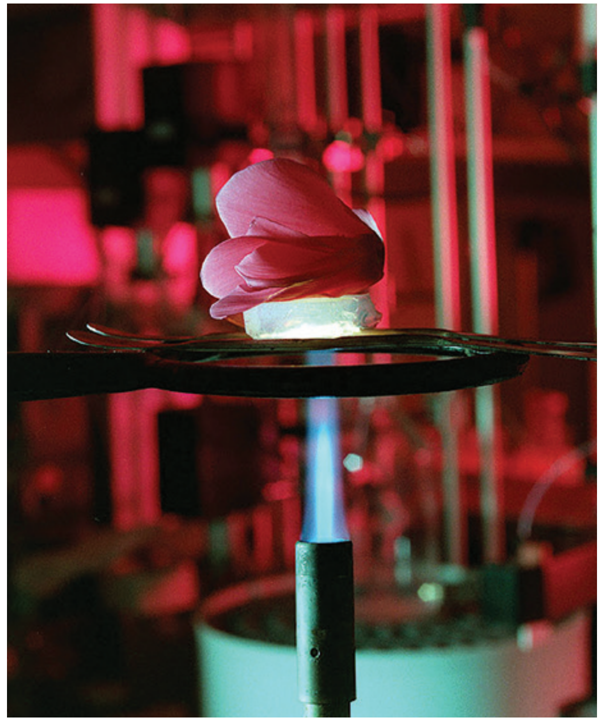
The material, silica aerogel, was first invented nearly 100 years ago, before the Space Agency was founded. Aerogels are a class of materials that are made by creating a kind of gel and then removing all the liquid through a process known as supercritical drying, leaving a porous solid filled with air.

When made out of silica, or fused quartz, the resulting material has pores less than one-ten thousandth the diameter of a human hair, or just a few nanometers. That nanoporous structure gives silica aerogel the lowest thermal conductivity of any known solid, which means it's an incredibly good insulator, and because the structure is 95 percent air, it is also extremely lightweight.

The possible applications for the material were obvious, but pure silica aerogel had a pretty major downside. Silica, one of the key ingredients in glass, is brittle: as an aerogel, it would crack under the slightest pressure. So for decades, silica aerogel was hardly ever used.

In the 1990s, NASA helped change that.

In 1992, Kennedy Space Center's James Fesmire, the mechanical engineer responsible for managing cryogenic propellant systems design at the launch pads, had an idea for a flexible aerogel insulator—a composite with the same ability to stop heat as traditional silica aerogel but one which would solve the brittleness problem. He wanted to use it to insulate the equipment that stored and transferred liquid fuel for the Space Shuttle, which needed to be kept at temperatures hundreds of degrees below zero.



Aerogel is one of the lightest known materials and one of the world's best insulators. Here a delicate flower is protected from the blue-hot flame by a small chunk of silica aerogel.

The following year, Kennedy awarded a Small Business Innovation Research (SBIR) contract to Aspen Systems Inc. to work on creating that flexible, durable, easy-to-use form of aerogel. The company soon developed aerogel composite blankets that fill the spaces of a fiber web with silica aerogel. Further SBIR contracts and partnerships helped prove the excellent insulating characteristics of the new composite material and improve manufacturing practices to make it cheaper and faster to produce.

Aspen saw that it had a marketable product and spun off a division called Aspen Aerogels Inc. to sell its flexible aerogel commercially. NASA used the material for its cryogenic fuel tanks and pipelines, and elsewhere in other formulations, but the material has also found a home in many applications outside the space industry, including building and construction, appliances and refrigeration equipment, and more.

Technology Transfer

All of this development happened well before Markesbery summited in Switzerland, but he didn't find out about aerogel until several years later, when he won a scholarship from the Astronaut Scholarship Foundation for his undergraduate research.

As part of the award, Markesbery got to meet NASA personnel, including astronaut Robert Gibson, from whom he finally learned about the material. "I started getting intrigued," he says, remembering his problem with bulky layers and wondering if this could help him make something better.

The astronaut scholarship also came with another perk that helped Markesbery and his collaborators: $10,000. Confident they had a good idea for a product, "we took the $10,000 from the scholarship and our own money, and dumped it into working with different aerogel manufacturers," he says.

They ultimately came across Aspen Aerogels, launched a Kickstarter campaign (featuring a video of Gibson), and started selling the brand-new company's first product: the Lukla jacket, insulated with Aspen's aerogel blankets. They quickly raised more than $300,000 and sold more than 1,100 jackets, all featuring the aerogel blankets developed with NASA funding.

Benefits

Oros, based in Cincinnati, Ohio, boasted customers could wear a Lukla jacket "with no layers and be perfectly warm in even the MOST EXTREME temperatures," thanks to its NASA-tested and approved aerogel insulation.

But the young company wasn't ready to rest on its laurels. "When we made the original jacket with these aerogel blankets, we learned that they were amazing insulators, and they were good for apparel—but not great," Markesbery recalled.

They noticed two main issues. First, the silica had a tendency to flake out of the fiber blanket with movement, a problem for a jacket intended for athletes. "Every time you move you're losing thermal performance you never get back," he said. The second problem was that the silica aerogel itself tends to suck out moisture on contact, "so if you touch it with your skin or your hand, it would dry out your skin. That meant we had to encapsulate the insulation, like a Ziploc baggie. That cut the breathability down to virtually zero.

"We said this is a really good first step and market validation for aerogel use. But it can still get better. We needed a flexible sheet that maintained its insulation, but that didn't shed with motion," Markesbery says.

The company continued its research and ultimately came up with a new, proprietary way to utilize aerogel in a flexible polymer composite, which it says provides more structure and stability than the fiber blanket. It also increases breathability for comfort and reduces the overall weight of the insulation. As a result, the next-generation jacket is at least 40 percent lighter than the original, weighing in at just 2.5 pounds or less.

Oros calls its new, proprietary insulation SolarCore and used it in its products in 2016 and 2017—a product line that has been extended to include gloves, leggings, snow pants, and base-layer shirts. Even the knit hats are insulated with SolarCore, which is knitted into the brim. The company brags the insulation is so warm, it has added zippered vents in the jacket and snow pants in case the wearer overheats—all with just 3 millimeters of insulation.

The company continues its research into aerogel upgrades, with more improvements planned in the next release of products in fall 2018. But the original product line and core and inspiration for development started with aerogel's NASA roots. As Markesbery says: "If it's good enough for space, shouldn't it be good enough for Earth?" ❖

"If it's good enough **for space, shouldn't it** be good enough **for Earth?"**

— Michael Markesbery, Oros

Oros makes extra-lightweight outwear lined with aerogel-infused insulation. NASA helped drive the innovations that made aerogel practical for apparel—in its original form, silica aerogel was extremely brittle, but it can be used in composites that are durable and flexible.

Space-Grade Insulation Keeps Beer Colder on Earth

NASA Technology

A class of insulation invented to help NASA with a range of daunting tasks, from storing liquid hydrogen or helium to insulating spacecraft and keeping astronauts comfortable in their spacesuits, is now keeping beer kegs cold at parties and barbecues around Philadelphia and beyond.

Most everyday insulation, such as traditional clothing, blankets, or rolls of fiberglass, is designed primarily to prevent the conduction of heat from one side to the other. Cloth and fiberglass are poor heat conductors, as are the pockets of air they trap. But NASA engineers calculated early in the Space Program that to insulate a spacesuit against the temperature extremes of space, conventional insulation would have to be several feet thick. They had to find another way.

By the time the Space Program got underway, engineers were already working with insulation that reflected radiated heat, rather than simply damping conduction. Reflective surfaces had been added to some building insulation and were used in Thermos bottles, for example. But NASA mastered reflective insulation, turning it into a versatile and extremely effective technology now known as radiant barrier.

A key innovation was layering lightweight, reflective materials to increase their insulating power. The first such multilayer reflective insulations were created under contract to Marshall Space Flight Center in the mid-1960s, when the Linde Division of Union Carbide Corporation delivered a series of insulations made with layers of thin aluminum foils and sheets of fiberglass, and the Metallized Products Division of National Research Corporation created an insulation made from sheets of crinkled, aluminized Mylar. The latter, known as NRC-2, became the model for a host of "superinsulation" materials that would find a multitude of uses in space and on Earth.

Mylar is a trade name for a remarkably thin, lightweight, and durable polyester film developed by DuPont in the mid-1950s. A line of similar materials followed. The first metallized polyester thin film was created in the late 1950s by depositing vaporized aluminum onto Mylar in a vacuum. One of its earliest uses was in NASA's Echo 1 satellite balloon, an early communications satellite that used the material's reflectiveness to bounce radio and radar signals back to Earth.

Metallized Mylar turned out to reflect heat just as well as it did radio transmissions, and NASA researchers found that when sheets were layered half an inch thick without touching each other, it created an insulation vastly more effective per pound than any other in the vacuum of space.

As the Space Agency began adapting this new class of insulation to various uses, NASA and its contractors made advances on virtually all fronts, including tensile strength, fabrication and application techniques, testing procedures, predictive modeling of performance, and fine-tuning of materials and configurations. Building on NASA's work, manufacturers began experimenting with different metals on a variety of polymer thin films.

The resulting materials came to be used not just in all spacecraft and spacesuits but in commercial spinoffs that include clothing, firefighting and camping gear, building insulation, cryogenic storage, magnetic resonance imaging machines, particle colliders, and commercial satellites, to name a few. Nearly half the issues of *Spinoff* since 1976 have featured products incorporating radiant barrier technology.

Technology Transfer

In June of 2015, the evening before the annual Philadelphia International Cycling Classic, Dan Gwiazdowski and friends

In Goddard Space Flight Center's Space Environment Simulator, an engineer lays radiant barrier insulation over wires on the floor, keeping the heat they generate from contaminating the chamber, which is used to mimic the environmental conditions of space.

Image courtesy of Chris Gunn, CC BY-NC-ND 2.0

were preparing for a backyard get-together at a home along the race route. They had already picked up a beer keg and were contemplating how to keep it cold overnight. Relying on ice alone would require the inconvenience of periodically refilling the tub of ice throughout the night.

"I was thinking, the keg is already cold, we just need to keep it from getting hot," Gwiazdowski recalls. "I was like, 'Aha!' I remembered having an emergency blanket in my car."

He wrapped the reflective Mylar blanket around the keg and ice bucket the best he could, and he and his friends were still drinking cold beer when the race ended the next day. "We realized we were onto something," he says.

Gwiazdowski had founded the design company JUNTO LLC in 2011, naming it after a group founded in his city by Benjamin Franklin, which met to drink and discuss politics, morals, and philosophy. Franklin's Junto is credited with the colonies' first lending library and the city's first fire department. "It was a creative collaborative that benefited the community around it," Gwiazdowski says.

Likewise, he says, he tries to involve others in collaborative thinking to "create simple products that consider environmental impact, are beneficial to users, and apply creativity to result in smart design"—sometimes around a keg of Philadelphia microbrew.

In that vein, following his improvised keg-cooling experiment, he started researching reflective insulation and testing prototype keg covers. While some materials were too thick and heavy for his liking, others were too flimsy to stand up to reuse. Then he came across a product line called HeatSheets (*Spinoff* 2006), manufactured by Advanced Flexible Materials Inc. (AFMInc).

That company was founded by David Deigan, a former employee of the National Metallizing Division of Standard Packaging Corporation, an early NASA supplier of reflective insulation. Before shutting down, National Metallizing had started spinning off commercial products, and Deigan founded AFMInc to continue doing so, manufacturing blankets, ponchos, and capes for emergencies, outdoor adventures, and, most famously, marathons and other athletic events.

Gwiazdowski contacted the company, got a sample, and did some testing. "It was lightweight, very strong, flexible, recyclable, and very effective," he says.

Based on the material, he came up with the design for his KegSheet product, which AFMInc agreed to manufacture for him.

In early 2016, the Space Foundation announced that the KegSheet had been officially space certified.

Benefits

When wrapped over a keg and ice bucket, a KegSheet keeps beer cold "pretty much all day," Gwiazdowski says, noting that he wrapped the keg for the 2016 bike race at about 5:00 the night before the event. "By five in the afternoon the next day, we still had beer that was drinkably cold."

In a test on a sunny, 90 °F day, he found that the beer actually got cooler over the first several hours. After five hours, a wrapped keg was almost 4 degrees cooler than its initial temperature, while an unwrapped control keg in ice had risen 17 degrees in temperature. At the end of eight hours, the unwrapped keg was more than 24 degrees hotter than its starting temperature, while the KegSheet-insulated one was just 9 degrees warmer.

Another option, he points out, is to wrap a keg without ice to avoid the mess and hassle. In a separate test on a cooler day, Gwiazdowski found an unwrapped keg on ice warmed 10 degrees after eight hours; an insulated keg without ice was just 7 degrees warmer.

He notes that the insulators are lightweight and easily portable, fitting in a pants pocket when folded. They're also strong and washable, allowing repeated reuse. And they can be recycled with plastic shopping bags.

Gwiazdowski has been working to make the insulators available where kegs are rented. "Recently, we've been making a concerted effort to get out to retailers and beer festivals," he says. KegSheets began showing up at retailers, mostly around Philadelphia, in late summer of 2016, going for anywhere from eight to 15 dollars.

He notes that they quickly pay for themselves through money saved on ice.

"It's incredible to be able to leverage a technology NASA's created and apply it to something that's fun and exciting—in this case, drinking beer." ❖

KegSheet beer keg insulators made with multilayer reflective thin-film insulation pioneered by NASA, are not just effective but also lightweight and low-mass, folding up small enough to fit in a back pocket.

High-Efficiency LEDs Grow Crops, Stimulate Alertness

NASA Technology

NASA harnesses the power of light for purposes as varied as laser communications, 3D mapping of land surfaces, and spectroscopy to determine the composition of distant stars. The Space Agency has also devoted significant research and development to using the visible spectrum to drive biological processes, and a number of former contractors have made that knowledge available in the commercial marketplace.

The most important light-driven organic process on Earth is photosynthesis, by which plants convert sunlight into chemical energy, driving the entire food chain.

Light also plays a crucial role in biological cycles related to sleeping and waking. In 2001, an advisor to NASA demonstrated the existence of a third type of light receptor in the mammalian eye. In addition to the rods and cones that enable vision, George “Bud” Brainard, Thomas Jefferson University researcher and frequent NASA consultant, showed that another photoreceptor in the retina, now known as the intrinsically photosensitive retinal ganglion cell, is responsible for regulating both pupil constriction and circadian rhythms.

By then, NASA had been experimenting for about a decade with using LED technology to help plants grow. The Agency has also worked with LEDs to help regulate astronauts’ sleep cycles on the International Space Station (ISS), where 16 sunrises and sunsets every 24 hours tend to throw off their internal clocks.

Now, Biological Innovation and Optimization Systems (BIOS) Lighting, a young company in Melbourne, Florida, is leveraging the know-how of two former NASA contractors who helped the Agency pioneer both these LED applications, as the company brings two different product lines to market.

Neil Yorio started working with NASA as a graduate student in 1989, when the Agency’s Life Sciences Support Facility was housed in a converted hangar at Cape Canaveral Air Force Station, adjacent to Kennedy Space Center.

Ray Wheeler, who still heads NASA’s Advanced Life Support Program today, checks on hydroponically grown lettuce in the Life Sciences Support Facility’s Biomass Production Chamber in the early 1990s. His team, including Neil Yorio, now vice president for lighting research for agriculture at Biological Innovation and Optimization Systems (BIOS) Lighting, became some of the first researchers to investigate the use of LED lighting for plant growth.

There, Yorio and colleagues retrofitted an old pressure chamber from the Gemini missions to create the Biomass Production Chamber for the Controlled Ecological Life Support System (CELSS) project, planned as a test bed to demonstrate and measure the self-regenerating life support system for long-term space exploration missions and even extraterrestrial colonization.

Plants were central to the system. NASA was—and remains—interested in technology for growing plants on long-duration space exploration missions, not just as a food source but also to perform all the roles they carry out on Earth: eliminating carbon dioxide, providing oxygen, purifying water, and processing waste.

At the time, Yorio says, the researchers primarily used high-pressure sodium lamps to provide light, a technology that still dominates indoor agriculture today. After some initial testing at a NASA Research Partnership Center at the University of Wisconsin-Madison, though, the CELSS team started experimenting with LEDs for plant lighting.

It was still a new technology, expensive and not yet efficient. Nonetheless, Yorio says, “there was interest in using them because they’re small, solid-state, lightweight, they had the potential to be energy-efficient, and they had no hazardous materials.” He coauthored some of the first papers published on LED-based grow lights in 1997 and ’98.

When the Space Life Sciences Lab was built next to Kennedy in 2003, he and fellow researchers moved there as part of the Advanced Life Support Program, and he oversaw a number of projects that continued experimenting with LEDs.

The lab is where he met Robert Soler, who Bionetics Corporation hired in 2007 to help finish the first LED module to provide lighting for astronauts on the ISS.

"We'd started seeing some issues with the general luminaire system on the ISS," says Howard "Bill" Wells, chief engineer at Bionetics. The fluorescent bulbs were frequently failing and had a relatively low light output. "Another problem was that fluorescent lights have mercury and glass, so you have two potential safety hazards you've got to deal with."

One LED replacement went up in 2008 as a demonstration and still helps light the space station's U.S. National Laboratory.

Not long after, NASA requested an update to replace all the lighting in the U.S. portion of the space station with LED fixtures, this time incorporating the ability to alter their spectra to help manage astronauts' sleep cycles.

Soler helped write the proposal that won Bionetics the contract to design and build the new LED-based lighting modules for the ISS. By then, both he and Yorio were working for the company Lighting Science, and Soler helped Bionetics build the modules as a part-time consultant.

The resulting lights have three modes of operation: general task lighting, a pre-sleep mode, and a wake-up mode. The wake-up mode imitates broad daylight, suppressing melatonin in the brain to increase alertness. "Melatonin is basically the night-night drug your body uses to sleep," Wells says. Pre-sleep mode, on the other hand, eliminates blue-green wavelengths to allow melatonin release.

The lighting in all three modes also needed to be energy-efficient, render true colors—meaning it wouldn't cast its own hue—and be pleasing to the eye, avoiding any harshness. "To bring all those things together, that's kind of what my area of expertise is," Soler says.

The work eventually led Lighting Science to release a commercial line of LED bulbs with similar capabilities (*Spinoff* 2015).

Technology Transfer

All the while, LEDs have been catching on for more and more applications. "We've had the benefit of capitalizing on technological development on the part of a lot of companies, to the point that the consumer market was driving that technology," Yorio says. This has meant ever-increasing efficiency at lower and lower costs.

LEDs have finally advanced to the point that they can match or surpass the performance of, for example, high-pressure sodium lamps in agricultural applications. "Now we find ourselves with the opportunity to replace high-energy-consuming, hazardous-waste-containing products with more efficient and sustainable alternatives."

Yorio, Soler, and a handful of others left Lighting Science in 2014 to create BIOS, where they've continued to develop LED technology and adapt it to human and agricultural biology.

Benefits

Photosynthesis requires light in roughly the same wavelengths that enable vision—about 400 to 700 nanometers. But most lamps for indoor agriculture emit radiation well beyond this spectrum, especially in the form of heat. LEDs, on the other hand, produce light only within a narrow spectrum determined by the material they're made of. Most of the energy put into an LED, therefore, can be used to produce what's known as photosynthetically active radiation (PAR)—the light that plants use.

"By eliminating photons that aren't included in PAR, you're able to reduce power and heat and still exceed the performance of high-pressure sodium lamps," Yorio says.

Wells points out that by reducing heat, LEDs also reduce the need for air conditioning, further saving energy. And they far outlast alternatives. So despite a higher initial cost, he says, they save money in the long run.

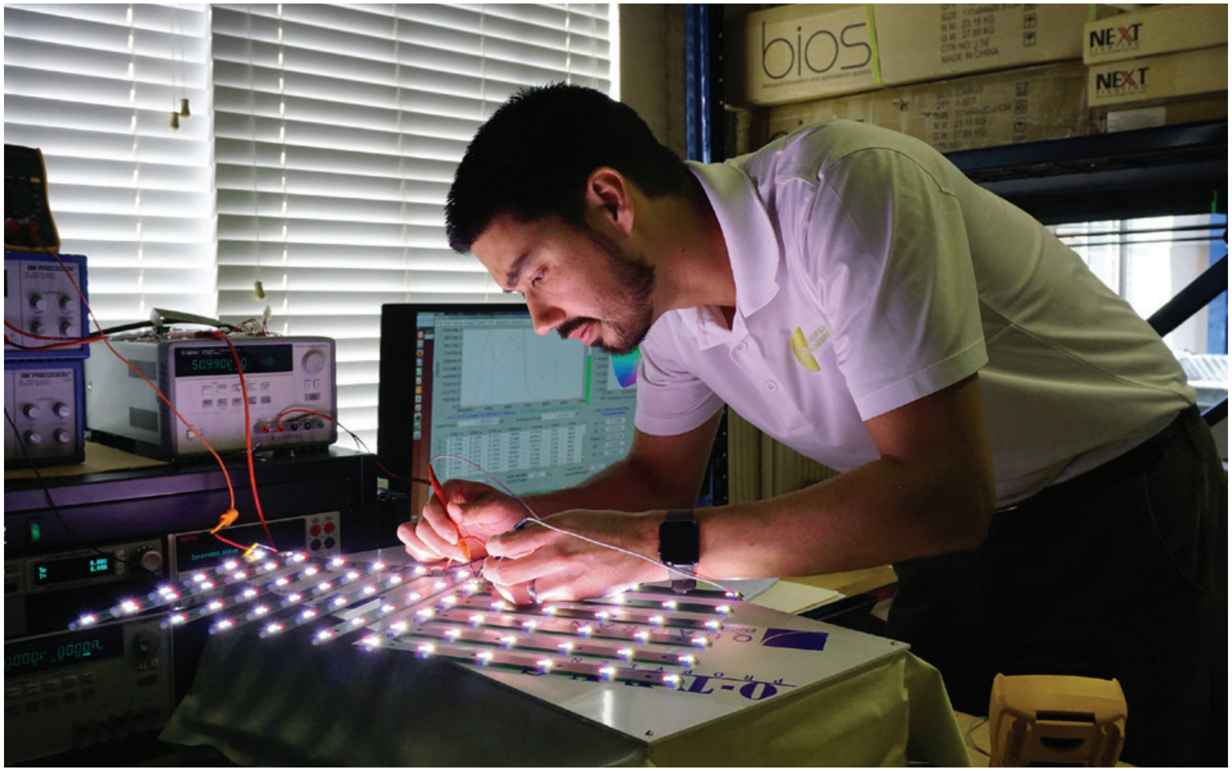
LED-based grow lights cost about $1,000 less over five years than comparable high-pressure sodium lamps,

Neil Yorio, vice president of lighting research for agriculture at BIOS Lighting, prepares to test one of the company's Icarus LED grow lights in a light chamber. Yorio started using LED lighting for agriculture as a NASA contractor in the 1990s.

“What BIOS does is use **LEDs** to **pinpoint peak sensitivity** and **infuse that** into the **traditional white-light LED.”**

— Robert Soler, BIOS Lighting

BIOS Lighting’s SkyBlue interior LED lighting technology mimics sunlight, including the melatonin-suppressing blue-green light that induces wakefulness, while producing true colors. BIOS partners with other companies to create both small-scale home lighting and systems for offices and retail space.



Robert Soler, vice president of human biological technologies and research at BIOS Lighting, works on an LED lighting array in his lab. Soler helped design LED lighting modules for the ISS as a NASA contractor.

which have to be replaced around every six months, Yorio estimates.

He notes that LEDs are also much safer than all other electric lighting alternatives.

As its first products became available in early 2015, BIOS found that the biggest agricultural market was in the cannabis farming industry that is gradually becoming legalized. An emerging movement to put food production closer to end consumers is also contributing to the demand for grow lights, Yorio says. "There's a very strong movement for indoor farming."

In human lighting, Soler says, the lighting industry has focused on deep blue frequencies to induce alertness. More recent research, however, he says, shows that light on the edge of blue and green is most effective at inducing both melatonin suppression and pupil constriction, and traditional LEDs have relatively low output in that range. Further research is showing that the deep blue frequencies commonly used in the industry may cause oxidative stress in the eye.

BIOS's SkyBlue lighting technology shifts peak outputs accordingly while producing true colors in a spectrum that closely imitates daylight, Soler says. "What BIOS does is use LEDs to pinpoint peak sensitivity and infuse that into the traditional white-light LED."

In a world where most people spend most of the day indoors with little exposure to melatonin-suppressing sunlight, the disoriented circadian rhythm is a common problem, which BIOS aims to address, Soler says.

The company isn't making its own human lighting products but is currently partnering with two other companies to put its technology in their products: Ledra Lighting specializes in small-scale decorative and recessed lighting for the home, while Pinnacle Architectural Lighting targets environments like offices, retail spaces, and hotel lobbies.

The technology has already made its way into the Pittsburgh Pirates' clubhouse and bullpen.

"There's a lot of interest in doing exactly what we're doing, but we're the first ones doing it," Soler says.

BIOS has released two of its own agricultural lighting models. One is a high-output fixture designed for vertical agriculture, where plants grow on stacked shelves. It surpasses the photosynthetically active output of a 1,000-watt high-pressure sodium lamp using just 40 to 50 percent of the energy, and it spreads light uniformly across a specific area so it can hang close to the plants. The other model is designed to supplement sunlight in a greenhouse.

Both are informed by Yorio's long experience with indoor farming at Kennedy during the time when NASA was making the switch to LED lighting. "Neil was there when all this was happening, but I think his real experience is in understanding plant lighting and horticulture, and really understanding plants as a whole and how to grow them," says Ray Wheeler, who headed—and still heads—Advanced Life Support.

Soler's work for NASA, meanwhile, provided him with a test bed for his technology and also stretched its limitations. The project required the LEDs to give off exactly the same colors of light from one module to the next and regardless of the angle from which they were viewed. Some of the techniques he developed to meet those specifications have helped him keep BIOS's lighting uniform, "so you can't tell one light from another, which is surprisingly hard to do," he says.

As the company's first products hit the market, the LED modules Soler helped design to support astronauts' sleep cycles finally began making their way to the ISS, where they are gradually replacing the original fluorescent lighting. He says he's interested to see the performance results.

"There's a lot of stuff we'll learn through what's going on at NASA," Soler says. "Those findings will definitely inform the next-generation LED lights. NASA is still going to be a conduit for a lot of that science." ❖

Paired Sleep Tracker, Light Therapy Tools Retrain Circadian Rhythms

NASA Technology

Lack of sleep could be costing the U.S. economy around $411 billion a year, according to a 2016 estimate by the RAND Corporation. That same year, a National Sleep Foundation survey found that 3 percent of American adults—amounting to more than 7 million drivers—had dozed off behind the wheel during the two weeks before the survey.

Many factors contribute to sleeplessness, but researchers are finding that a major one is light exposure—and not just the amount of light we're exposed to, but the color of the light.

Fares Siddiqui was surprised when an acquaintance mentioned this to him in late 2015. The recent mechanical engineering graduate was looking for a product to design and bring to market, and he immediately jumped online to do some research. One of the first items he found was a 2007 study demonstrating that, in addition to image-forming rods and cones, the human eye has a third type of photoreceptor that influences circadian rhythms, now known as the intrinsically photosensitive retinal ganglion cell.

Maintaining a regular sleep schedule is difficult for astronauts, who don't experience 24-hour daylight cycles, so the NASA-funded National Space Biomedical Research Institute has collaborated on several groundbreaking studies to understand how artificial light can be used to retrain circadian rhythms.

This particular study showed that even in blind subjects, exposure to short-wavelength blue light suppressed melatonin, causing alertness, while light at the longer wavelengths where visual sensitivity peaks did not. These blue wavelengths are abundant in daylight, and their suppression of melatonin causes a reset of the circadian rhythm that governs sleep and wakefulness.

The study was funded in part by the National Space Biomedical Research Institute (NSBRI), which is funded in turn by NASA's Johnson Space Center.

Researchers had had some idea about all this for some time. In 1990, before the NSBRI existed, NASA reached out to Charles Czeisler, then an associate professor at Harvard Medical School and a specialist in circadian rhythms, who had just demonstrated the ability to reset the circadian clocks of night-shift workers by systematically exposing them to light.

At the time, astronauts preparing for a nighttime Shuttle launch that kept getting postponed were having a hard time adjusting to their inverted schedule. Czeisler repeated his experiment on the crew with success. He would later serve for a decade as team leader of the NSBRI's Human Performance Factors, Sleep, and Chronobiology Team.

Technology Transfer

Since around 2000, the NASA-funded institute has collaborated with Harvard Medical School, Brigham and Women's Hospital, Thomas Jefferson University, and others in numerous studies to advance understanding of light's influence on circadian rhythms, culminating in the delivery of tunable LED lighting modules to the International Space Station (ISS) in late 2016. NASA has a keen interest in the subject because sleep is problematic for astronauts on the ISS, which sees 15 or 16 sunrises and sunsets every 24 hours, and no space travelers experience the normal 24-hour Earth day (although astronauts on Mars would come close).

All of this gave Siddiqui confidence that a product could be based on the research. "Once we realized this was validated and something NASA uses, we thought we really should look into this in more depth," he says.

Based on the research, Siddiqui knew when he founded Circadia, based in London and San Francisco, that his product would need a tunable LED lamp akin to the ones going to the space station. But he wanted to take the concept a step further, basing light exposure on individual sleeping patterns and on each user's responses to light exposure, in a sort of biofeedback loop. "Every human's exposure to light has a somewhat different effect on sleep," he explains.

To determine sleep patterns, he settled on contactless radar-based technology to create a device that mounts on the wall or ceiling in the vicinity of the user's bed and can detect the rise and fall of a sleeper's chest, as well as the intensity of movement during sleep, from up to eight feet away. With the help of Circadia's proprietary machine-learning algorithms, the sleep tracker can use this data to determine with 92 percent accuracy what stage of sleep the user is in.

Sleep-stage data is in turn fed into a smartphone app based on software that Harvard Medical School and Brigham and Women's Hospital created in part with funding both directly from NASA and from the NSBRI. The app provides the link between the sleep tracker and a portable light therapy device that sits on a desk to provide what Siddiqui calls "visual caffeine" throughout the day.

This is primarily light in the short, blue wavelengths that retinal ganglion cells respond to by suppressing melatonin production. The idea is to induce wakefulness during the day to promote sleepiness at night. Then, in the hours before bedtime, longer-wavelength reddish light simulates late evening light and stops preventing the hormone's production.

Benefits

What sets Circadia's system apart from any other light therapy or sleep tracker it that it combines diagnostics and treatment in one complete, closed-loop system. The app links the sleep tracking and light therapy devices, calculating and adjusting the wavelengths, intensities, and durations of light exposure throughout the day based on nighttime sleep patterns. “It’s circadian lighting based on biofeedback from sleep,” Siddiqui says. “It’s unique in that it connects both lighting science and sleep science together.”

The sleep tracker also takes into account environmental factors that can affect quality of sleep, such as temperature, humidity, and light.

Circadia took its product to Kickstarter in June of 2017, accepting orders for the paired sleep tracker and light therapy device, although Siddiqui says the devices will also be offered separately in the future. Those orders are scheduled to ship in early 2018.

“We live in an era of artificial darkness,” Siddiqui says, noting that most people in modern societies spend little time outdoors. Meanwhile, while the blue light of computer and smartphone screens isn’t a sufficient replacement for sunlight during the day, it’s enough to impede sleepiness in the hours before bedtime, when many people are scrolling through social media on their phones. “Always being able to reach out to our friends and family is harming us in a way,” he says.

Siddiqui also laments the common attitude that “sleep is for the weak,” he says, noting that lack of sleep not only results in short-term effects like stress, loss of concentration and short-term memory, and decreased productivity, but is also correlated with long-term health problems such as type 2 diabetes, obesity, and cancer.

He notes that, in addition to helping users to maintain a steady, healthy sleep cycle, Circadia’s system can also retrain circadian rhythms—much as Czeisler did for the Space Shuttle crew almost three decades ago—whether that’s to adjust to shift work, get to bed earlier, or overcome jet lag.

Through adjustments to light therapy informed by the sleep tracker, it also aims to improve users’ quality of sleep and work.

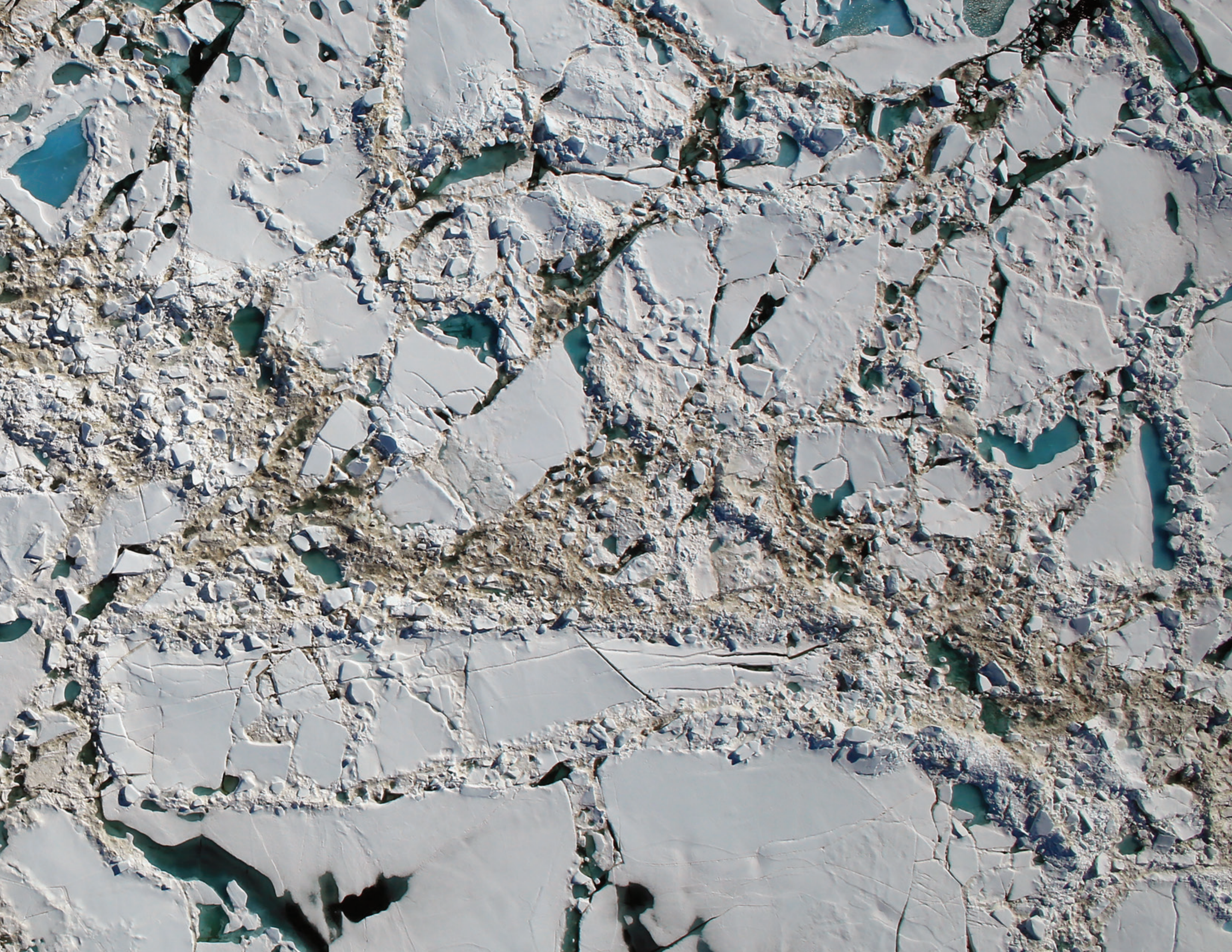
“Our goal is to help improve people’s quality of life,” Siddiqui says. “We believe the only way we live life to the fullest is with a good night’s sleep.” ❖

A tunable LED lamp, the portable Circadia light therapy device provides alertness-inducing short-wavelength light for much of the day, followed by redder light toward bedtime. Precise times and wavelengths are based on the user’s sleep patterns.

The Circadia sleep sensor mounts on a wall near the user’s bed and uses radar to monitor sleep stages based on breathing and intensity of movement. That data is fed into a smartphone app based on software developed in part with NASA funding, which determines daytime light therapy.

Energy and Environment

Many of the challenges of space missions—from keeping healthy to making the best use of scarce resources—apply here on Earth as well. NASA research into fields like agriculture and energy-efficient electronics is tailored for the long-duration missions to Mars and beyond that the Space Agency envisions, but it is already making life better here for us. The research has led to precision fertilizer, a solution that helps plants make better use of it, LED lighting that is safer and uses a fraction of the power of traditional lighting, and much more.



Organic Compound Turns Toxic Waste into Harmless Byproducts

NASA Technology

In 2004, a team of researchers at New Mexico Highlands University (NMHU) was trying to develop a substance that would glow to indicate the presence of hydrazine, a toxic, flammable, unstable compound often used as rocket fuel. To their surprise, the first attempt did more than they'd hoped. It didn't just react with hydrazine—it neutralized the hazardous chemical.

It took more than a dozen years and considerable investigation by NASA and others, however, before the resulting ZeenKleen product, now marketed by Marietta, Georgia-based Hydrazine Neutralizing Solutions Inc. (HNSI), began to make hydrazine cleanup and disposal cheap and easy for the Space Agency, the military, and a range of industries from power to plastics.

Since signing a 1997 Space Act Agreement with Johnson Space Center, the NMHU team, led by Professor Merritt Helvenston, had been working to improve a hydrazine-absorbing pad that Johnson's White Sands Test Facility originally developed. Now they had enlisted the help of Rudy Martinez, an organic chemist with the Los Alamos National Laboratory who had recently started teaching at the university, and it was Martinez who hit on the formula that would later be commercialized.

The key ingredient was alpha-ketoglutaric acid (AKGA), an organic compound essential to metabolism and often used as a dietary supplement and wound-healing agent. Martinez's interest, however, was in its molecular configuration, which appeared ideal for reacting with hydrazine. "We wanted to start with the basic structure of the AKGA molecule and modify it to make it glow," he says.

First the team had to see how well AKGA would react with hydrazine. "We found out the reaction takes pure hydrazine and neutralizes 99 percent of it within 15 minutes," Martinez says. "We just kind of stopped working on the detector because we had such a great neutralizer."

After some initial testing, the university contacted Chuck Davis, hydrazine specialist at Kennedy Space Center's Propellants and Life Support Branch.

Hydrazine compounds "are really awesome propellants but have a lot of operational restraints," Davis says, noting that, as hazardous materials, their disposal is complicated and costly.

NASA has used hydrazine and its derivatives since the Gemini missions of the 1960s, primarily in smaller thrusters that adjust a spacecraft's course or orientation. A monopropellant that combusts when exposed to a catalyst, hydrazine requires no ignition system and doesn't need to be oxidized to power a thruster.

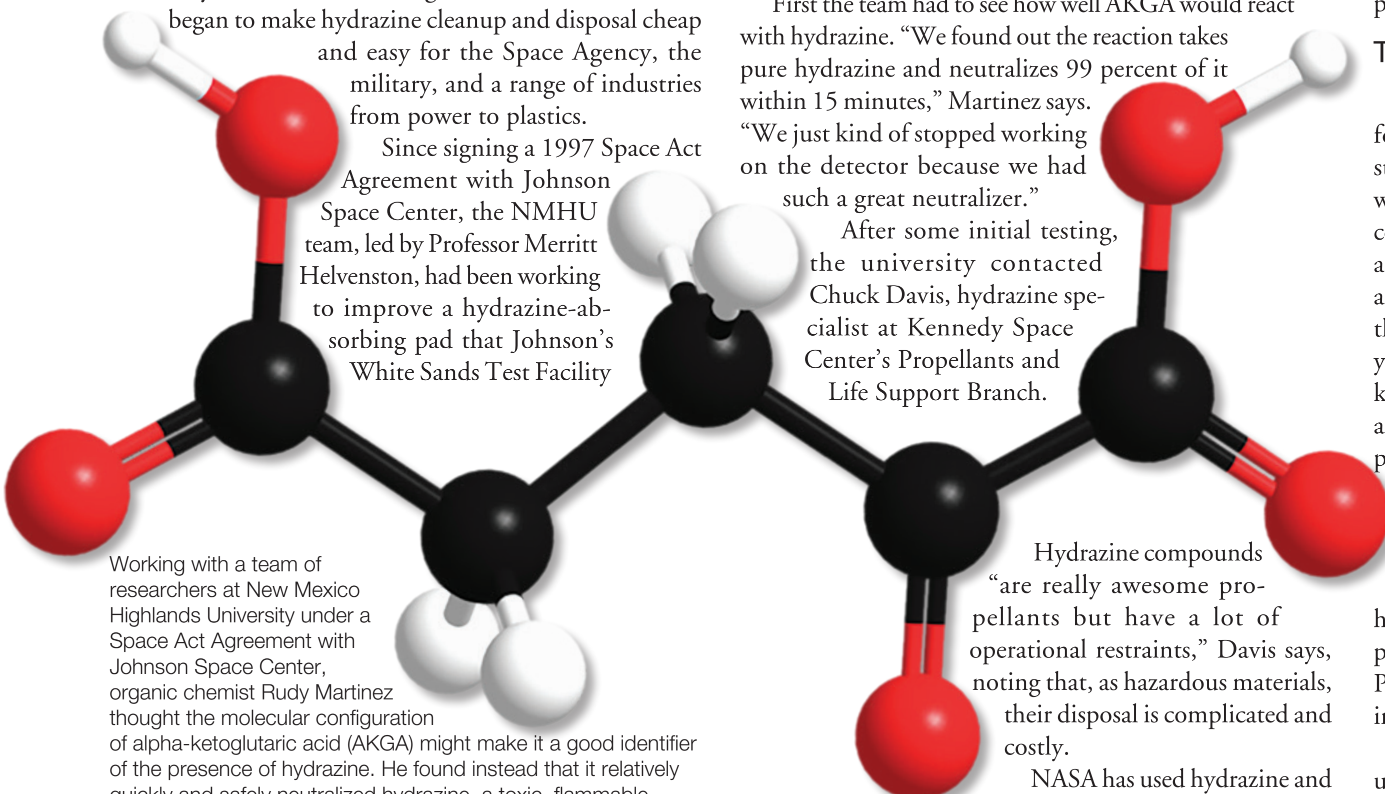
Kennedy, where NASA's spacecraft are fueled before launch, uses more hydrazine than any of the Agency's other centers, producing about 15,000 gallons of hydrazine waste per year. "We'll have some leftover fuel at the end of a job, and it may be watered down," Davis says. "We can't use it for flight anymore, so we've got to throw it away"—a complicated procedure for a substance considered hazardous to humans at concentrations of less than one part per million.

Technology Transfer

Davis' interest in AKGA as a promising alternative for hydrazine cleanup, from both safety and financial standpoints, prompted Kennedy to contact White Sands, where a round of testing was carried out in 2008. The study concluded that AKGA effectively neutralized both hydrazine and one of its derivatives, monomethylhydrazine (MMH), also commonly used for propulsion. Researchers confirmed that AKGA, when combined with hydrazine or MMH, yielded water and one of two pyridazinecarboxylic acids known as PCA and mPCA, respectively. These byproducts are relatively harmless and stable, and the reaction that produces them is irreversible.

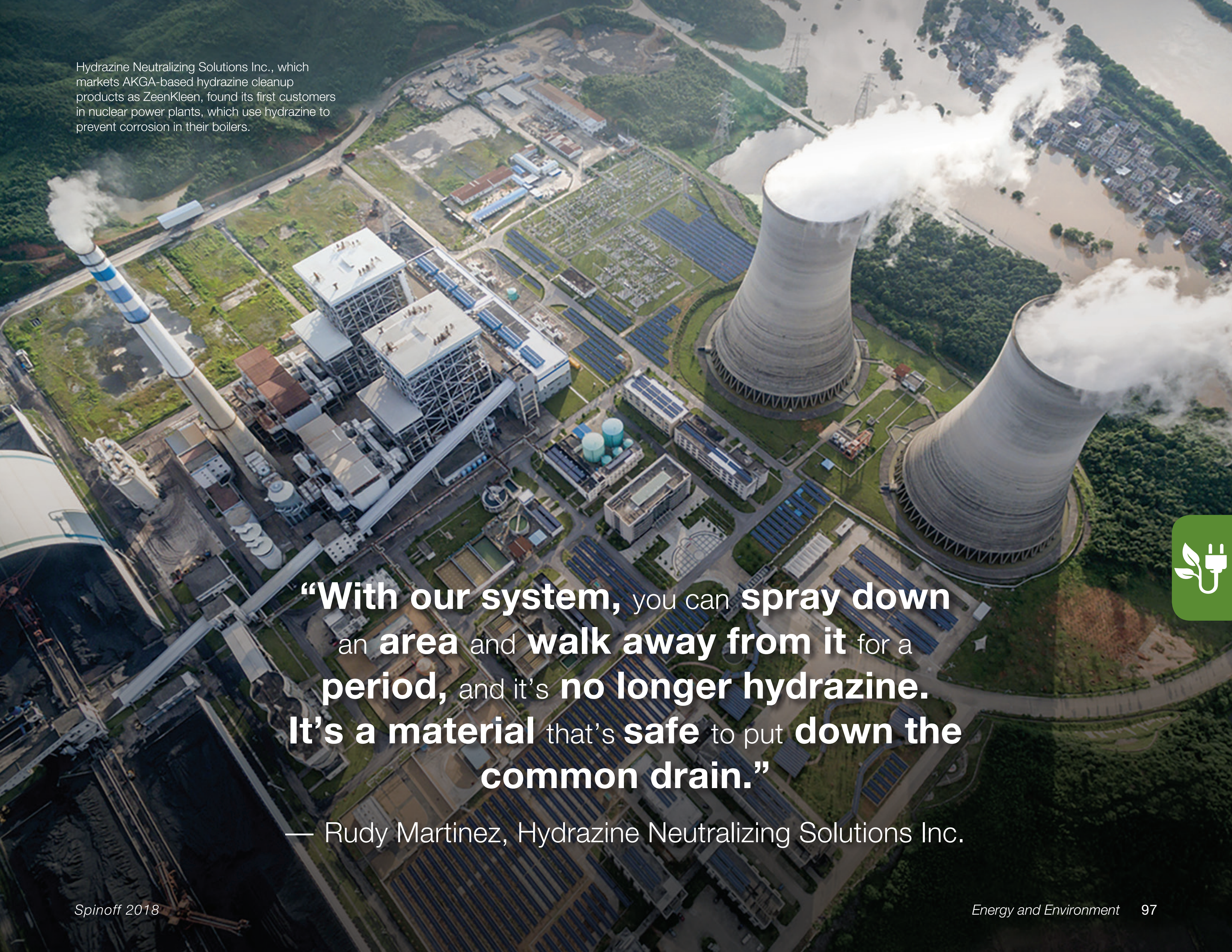
Following the White Sands study, Kennedy funded a series of experiments by its support contractors and the University of Central Florida (UCF) to determine the effectiveness and ideal procedures for neutralizing hydrazine and MMH with AKGA. Testing looked for any possible health or environmental impacts of the resulting PCA and mPCA and also determined that they would not inhibit sewage treatment if properly poured down a drain.

The work came to the attention of the Air Force, which uses hydrazine in the emergency power unit of its F-16 fighter jet, among other purposes. The Cape Canaveral Air Force Station Sewage Treatment Plant partnered with



Working with a team of researchers at New Mexico Highlands University under a Space Act Agreement with Johnson Space Center, organic chemist Rudy Martinez thought the molecular configuration of alpha-ketoglutaric acid (AKGA) might make it a good identifier of the presence of hydrazine. He found instead that it relatively quickly and safely neutralized hydrazine, a toxic, flammable compound used in small spacecraft thrusters and a number of industrial processes.

Image courtesy of Adam Redzikowski CC BY-SA 3.0



Hydrazine Neutralizing Solutions Inc., which markets AKGA-based hydrazine cleanup products as ZeenKleen, found its first customers in nuclear power plants, which use hydrazine to prevent corrosion in their boilers.

"With our system, you can **spray down** an **area** and **walk away from it** for a **period,** and it's **no longer hydrazine. It's a material** that's **safe** to put **down the common drain."**

— Rudy Martinez, Hydrazine Neutralizing Solutions Inc.

Kennedy and UCF researchers to evaluate the possible impacts of disposing of PCA and mPCA through the sewer system.

Following those tests and Kennedy's creation of procedures for disposal into the sewer, the Air Force station consulted with state and Federal environmental agencies and, in 2015, obtained permits for the center to treat hydrazine with AKGA and dump the end product down the drain.

Benefits

Davis says he expects NASA will alter its regulations and procedures to make AKGA the standard for hydrazine disposal. "Instead of diluting it down to about a hundred to one and shipping it off to a hazardous waste incinerator, we can just pour it down the sink into the local sewer system," he says. "We're eliminating a hazardous waste stream and not paying somebody to haul away toxic waste."

Not only are the end products safe, but PCA is marketable as a plant growth regulator, a business avenue Martinez and his colleagues plan to explore.

NASA's testing opened the way for other Federal agencies to change their procedures as well, and the Air Force is going through an approval process to switch to AKGA.

The favorable test results coming out of Kennedy and White Sands helped prove the product's commercial viability, and, in 2013, the university licensed its creation to Millennium Enterprises, which founded HNSI to market it, in various forms, under the name of ZeenKleen. Martinez is the business's director of chemistry.

The company is discovering a market well beyond NASA and the military.

When he started working on hydrazine remediation, Martinez says, "as far as I knew, NASA was the only one who used hydrazine." In reality, he says, "even when NASA was still flying the Shuttle, their use only accounted for about 5 percent of the hydrazine that's produced annually." The chemical is commonly used to make plastics, pesticides, and pharmaceuticals and is also essential to the power industry, where it prevents corrosion in power plant boilers.

So far, HNSI has found customers in about 10 nuclear power plants, where hydrazine is normally used in a 1 to 3 percent solution, Martinez says. In the case of a more

Image courtesy of Lockheed Martin

The Mars Atmosphere Volatility Evolution (MAVEN) propulsion system is powered by a 450-gallon tank of hydrazine. Although hazardous, hydrazine and its derivatives are efficient fuels that require no ignition or oxidation, so they are often used in secondary thrusters for large spacecraft and primary thrusters for probes and satellites.

concentrated spill, a standard industry treatment is to dilute hydrazine to about 3 percent by adding water and then use bleach to neutralize the diluted hydrazine. The treatment produces a reaction that significantly raises the temperature of the spill and still results in a hazardous materials.

"This is so much safer than using bleach to neutralize hydrazine," Martinez says. "With our system, you can spray down an area and walk away from it for a period, and it's no longer hydrazine. It's a material that's safe to put down the common drain."

HNSI sells ZeenKleen in liquid and powder forms, as well as in pillows and pads.

Martinez says the company is eyeing the plastic and pharmaceutical industries, although he knows all too well how much effort it takes to change procedures for dealing with dangerous chemicals. "Those are tough nuts to crack, but I think word of mouth is working in our favor," he says.

He notes that much of that favorable publicity—as well as HNSI's founding and the military's interest in its product—is the result of the Space Agency's extensive testing. "NASA's been a great partner," he says. "They were able to do a lot of testing, and that really gave people confidence that this works." ❖

LED Lighting Improves Efficiency, Imaging, Cuts Maintenance

NASA Technology

When Stennis Space Center officials wanted to try more energy-efficient lighting in the center's rocket engine test stands, they couldn't simply go out and buy the latest LED bulbs. Anything that's going to share a room with a live rocket engine generating half a million pounds of thrust, 120 decibels of vibration, and temperatures in the thousands of degrees by ejecting hot gases at more than a dozen times the speed of sound, in a process involving flammable liquids and gases, needs some special engineering.

Rocket engine testing requires a lot of light. This is because all tests are filmed with high-speed cameras to monitor performance, but those cameras have to adjust to the bright plume from a firing engine, which would black out the rest of the image, explains Tom Stanley, technical monitor and small business technical advisor at Stennis. "In order to image the engine, we put a whole lot of light on that engine deck." Traditionally that light has been provided by a host of metal halide bulbs.

Spurred by incentives for Federal installations to reduce energy use, Stennis decided in 2009 to try out LED lighting, which was new at the time but promised significant energy savings. The center issued two Small Business Technology Transfer contracts to Solon, Ohio-based LED lighting company Energy Focus.

With those contracts, the company developed floodlights able to withstand the hazardous conditions in test stands to illuminate engine testing, as well as general area lighting.

Technology Transfer

Although LEDs are relatively efficient in that they generate far more light than heat, they do still emit some heat, and the hermetically sealed design necessary in a potentially flammable environment made temperature management the biggest challenge to overcome. "You're putting a whole lot of LEDs into an enclosure and sealing it off and not allowing that heat to dissipate," Stanley says.

Under contracts with Stennis Space Center, Energy Focus designed LED floodlights that could withstand conditions inside a rocket engine test stand and would not pose a hazard themselves.

"We successfully overcame that by using an array of heat spreaders that contacted the LEDs directly and were able to extract heat properly," says John Davenport, who was the company's executive director and chief scientist at the time, and who remains a senior technical advisor to Energy Focus. The key was a thermally conductive aluminum alloy in a configuration that allowed internal conduction and convection to move heat out through a heat sink.

This advancement subsequently played out across the company's product line, including its popular LED tube for fluorescent replacements. "If you keep temperatures low enough, you can make these things last indefinitely," Davenport says.

For the floodlights, the company developed highly efficient optical cones that allowed for less stray light when focusing a beam. "In the commercial world, we now make products that can focus on a flagpole without losing light," Davenport says, noting that this also improves energy efficiency.

After completing the project, Energy Focus redesigned its general area lighting for lower cost and put out the LED HazGlobe for hazardous areas, as well as explosion-proof globe lights. The floodlight also evolved into a similar commercial product for use in hazardous areas. "It's not the same form factor or performance as the Stennis floodlights, but it's the same application," says Brian Danison, the company's director of engineering. "People wanted that product, and since we had the experience it wasn't a huge leap."

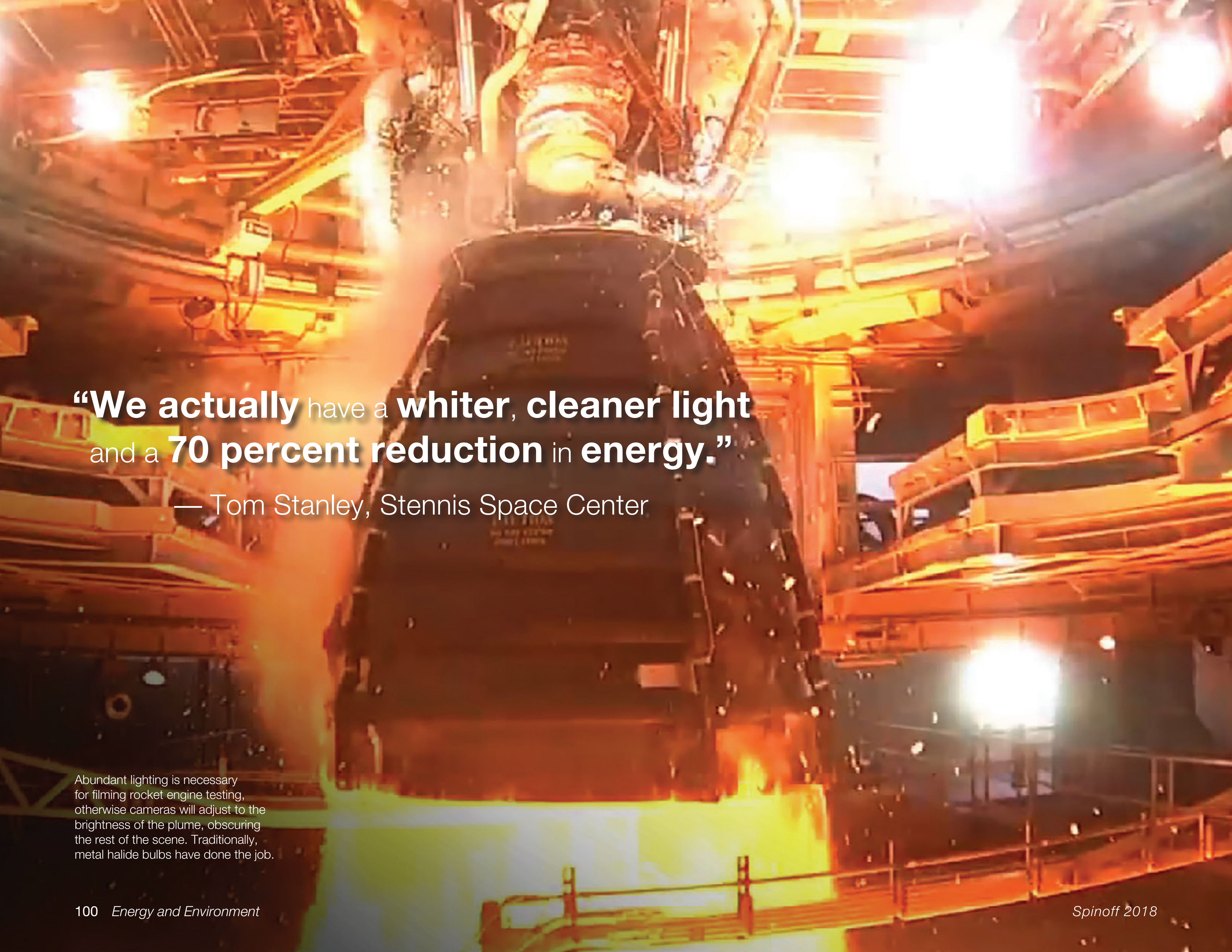
Meanwhile, the original eight LED floodlights have been installed in Stennis' A-1 test stand, where engines planned for NASA's Space Launch System have been tested in recent years, and 16 general area LED lights illuminate the center's E Complex, which is used for testing developmental rocket engine components.

Benefits

Energy Focus's LED floodlights produce the same amount of light as their 1,000-watt metal halide predecessors but use less than 300 watts, Stanley says. "We actually have a whiter, cleaner light and a 70 percent reduction in energy."

Davenport notes that LEDs can be tailored to emit light across the visible spectrum, making them more accurate for scientific imaging purposes and safer for human lighting. LED light resolves fluorescent lighting's issues of flicker and poor light quality.

LED technology now benefits the company's other customers. "The Intellitube now has almost twice the efficiency of the first Intellitube we made for the Navy, and part of that



“We actually have a **whiter**, **cleaner light** and a **70 percent reduction** in **energy.”**

— Tom Stanley, Stennis Space Center

Abundant lighting is necessary for filming rocket engine testing, otherwise cameras will adjust to the brightness of the plume, obscuring the rest of the scene. Traditionally, metal halide bulbs have done the job.

The LED HazGlobe hazardous area lamp grew out of work Energy Focus did for Stennis, including general lighting for hazardous areas in a test stand.

Some of the first lighting designed for hazardous areas was for use in coal mines. Energy Focus now offers more energy-efficient, long-lived LED lighting for hazardous areas, following work the company did to provide general area lighting in a rocket engine testing complex.

was getting the thermals right, so NASA played a role in that," Davenport says, referring to one of the company's most popular products.

But the biggest benefit, also partly resulting from better temperature management, is the products' lifespan, Danison says. While a fluorescent bulb, for example, needs to be changed every few years depending on use, Energy Focus became the first company to offer an unqualified 10-year warranty on its lights.

The hazardous area lights, given their application, carry a five-year warranty. These are being used in oil rigs, paint spray booths, elevator shafts, grain and steel mills, and munitions areas, among other uses.

About 60 percent of Energy Focus' business is with the military—particularly the Navy—with the rest coming from the commercial market, Danison says. He notes that the company recently replaced 78 units of 70-pound, 1,000-watt metal halide lights on the USS George Washington aircraft carrier with 24-pound, 250-watt lamps.

Energy Focus has retrofitted approximately 450,000 LED tubes across the fleet and on every surface ship in the Navy. In addition to light energy savings, there are also tangible cooling energy savings. Danison notes that a ship lit with LEDs likely dedicates less fuel to cooling because the lights generate less heat than the old fluorescent technology. And because of their long lifespan, a destroyer that had a maintenance crew of 24 sailors dedicated to replacing its 3,800 fluorescent lights is now down to a team of four, he says.

Davenport notes that an aircraft bearing factory not far from Energy Focus headquarters swapped out its old fluorescent lighting for the company's LEDs in August 2010 and has experienced less than a 1 percent failure rate while enjoying a sharp reduction in headaches among employees. "You would have to fight them to take those LEDs out," he says.

For all these reasons, Stanley says, "this is where lighting in general is going. We're getting away from Thomas Edison technology, and we're moving toward LEDs."

Davenport notes that it was early Government funding that advanced energy-saving LED technology, making possible a shift from legacy fluorescent lighting. "Having R&D help when you're in the formative stage, I can't tell you how important that is," he says. "These programs, like the [Small Business Innovation Research contracts] NASA and the Navy offer, they have tremendous benefit, tremendous payback." ❖

Plant Food for Space Grows Crops on Earth

U.S. astronaut and Expedition 46 Commander Scott Kelly shared this photograph of a blooming zinnia flower in the Veggie plant growth system aboard the space station in early 2016. This experiment in flowering plants precedes planned tests of growing tomatoes and peppers in space.

NASA Technology

The goal is a fresh and tasty salad on Mars. While other NASA programs are working on getting to the Red Planet, the Agency's Veggie team is figuring out how to grow salad ingredients in space, vegetable by vegetable, with an interim goal of a salad on the International Space Station (ISS).

"Right now the astronauts are only getting fresh produce when a new supply arrives," says Gioia Massa, NASA team lead for the Veggie project at Kennedy Space Center. Veggie—the NASA program named for modular growing units designed by Orbital Technologies Corporation—is designed "to be kind of an astronaut garden—and an opportunity for us to do research in space."

To grow red romaine lettuce on the ISS, NASA scientists teamed up with Sarasota, Florida-based Florikan (*Spinoff* 2017), a company that had already been working with the Agency to develop polymer-coated, controlled-release fertilizer systems.

"We worked very closely to develop a technology that would work for their hydroponic growing system in space," Florikan founder Ed Rosenthal says. They couldn't use the injectable liquid fertilizer that's typically used in hydroponic systems because water floats in microgravity, and those systems typically require numerous applications, which isn't practical for astronauts or efficient in general. "We had to be able to deliver single-application nutrients without mixing them in water," Rosenthal says.

The team developed a way to incorporate Florikan controlled-release fertilizer into the baked ceramic that holds the roots of NASA's Veggie plants instead of normal soil. The fertilizer released itself over the life of the plants so the astronauts didn't have to tinker with it. By August 2015, astronauts were eating red romaine lettuce grown in the space station—a significant step. But a real salad needs more than just lettuce.

Flowering vegetables like tomatoes and peppers are the true keys to excellent salads. Although NASA has been testing a Chinese cabbage in the interim, the next plan is to grow dwarf tomatoes.

The fertilizer Rosenthal adapted for NASA's lettuce crop was his Nutricote 18-6-8 formula, named for its ratio of nitrogen, phosphate, and potassium. Florikan has been selling Nutricote for decades, and Rosenthal has been tweaking it the whole time. But when Massa contacted him about growing tomatoes and peppers, Rosenthal was concerned. "The 18-6-8 ratio is not the right formulation for flowering plants," he said.

On Earth, farmers might just grow tomatoes and peppers with the 18-6-8 formula and manually add extra potassium. "But that's not practical in space," Rosenthal says. Although evidence suggests that gardening can relieve stress even in space, and astronauts have said they enjoy it, NASA's Veggie support back on Earth still aims to make the process as hands-off as possible.

"You could not possibly expect astronauts to put a little more potassium into the silica, as needed," Rosenthal says, referring to the silica ceramic that holds the plants in place. "These folks have a lot more important things to do than mixing fertilizer."

These Red Robin tomatoes, shown growing in vertical hydroponics at Sweetgrass Farms, benefited from a special fertilizer formula developed by Florikan for use in space.

Rosenthal and his team at Florikan came up with a new formula, specifically designed for hydroponically grown flowering plants. The product was similar to the fertilizer that successfully grew red romaine on the ISS, so it was mostly space-tested.

"At NASA, you can change maybe one thing, have one variable," Rosenthal says, describing the rigorous requirements for space experiments. "So we used the same polymer coating, the same release characteristics, the same nutrients. Now all we had to do was reduce the nitrogen and increase the potassium."

The result was a 14-4-14 NPK formulation—14 parts nitrogen, 4 parts phosphate, and 14 parts potassium. NASA began using this formula with success in Earth-based preparatory experiments and plans to have the astronauts try it on the space station with tomato seeds in 2018.

> "We got just about perfect yield on nearly every seed. . . . That's unheard of."
>
> — Ed Rosenthal, Florikan ESA LLC

Technology Transfer

Rosenthal has been innovating fertilizer for years. In 2004, he introduced what he called a staged nutrient-release process that won wide praise, including from the National Society of Professional Engineers. That recognition provided him with 40 hours of free consultation with NASA through the Space Alliance Technology Outreach Program.

It was under the guidance of Kennedy researchers that Rosenthal began developing fertilizer with the robust, "NASA-grade" polymer coating he still uses today. "If they're spraying a polymer on an astronaut suit, it's got to stand up to high heat and incredibly cold temperatures," says Rosenthal. "That's not unlike what we face in agriculture."

An early version of this fertilizer didn't hold up in heavy rain, which wasn't a consideration for space. For earthbound farmers, Rosenthal came up with a polyurethane wax undercoat that successfully resolved the issue. He got three patents out of that fertilizer product—one for the initial staged nutrient-release process, another for the polymer coating NASA researchers led him to, and a third for the wax undercoating that solved the rain problem.

In December 2016, he got another patent for the new 14-4-14 formula that he originally designed for NASA's flowering vegetables. The formula, which was already being used in Agency experiments and commercial hydroponics on Earth, is the first controlled-release fertilizer to work successfully in vertical hydroponic farming, replacing liquid feed and the need for multiple applications.

Benefits

"Farmers are finding that really anything that flowers has an opportunity with this formula," Rosenthal says. "We're over $1 million in sales and growing."

Among the earliest commercial adaptors of the 14-4-14 formula was Sarasota, Florida-based Sweetgrass Farm, a fully hydroponic operation that in 2016 began the process of converting to exclusive use of Rosenthal's fertilizer system. "The plants grown with Florikan controlled-release fertilizer, which was applied only once at the beginning of the growth cycle, were healthy, vibrant, productive, and of exceptional quality," Sweetgrass owner James Demler said in a statement submitted to the U.S. Patent and Trade Office supporting Rosenthal's application for the 14-4-14 formula.

Demler also noted that his system now consists of only the controlled-release 14-4-14 fertilizer, in addition to water, seedlings, and the fibrous husks of coconuts, which he uses instead of soil or the baked ceramic NASA requires to hold the plant roots.

Rosenthal worked with Demler to test seed-to-seedling yields using a nano-sized version of the 14-4-14 formula, which involves much smaller granules. "We got just about perfect yield on nearly every seed, including all the NASA varieties," Rosenthal says. "That's unheard of."

NASA has also started testing the nano-formula, which makes it possible to achieve nearly perfectly even fertilizer distribution.

Such precision applications have environmental benefits as well. Farmers don't have to buy as much fertilizer when they use Rosenthal's formula because less of it gets lost in runoff that contaminates rivers, streams, and entire watersheds. Florikan has been recognized by the U.S. Environmental Protection Agency (EPA) for its success in reducing excess fertilizing nutrients, twice winning the EPA's Gulf Guardian Award for reducing contamination of the Gulf of Mexico.

In February 2017, Florikan and Rosenthal were inducted into the Space Technology Hall of Fame, a program run by the Space Foundation to raise public awareness of the innovations arising from space exploration.

"This technology that we developed for NASA Veggie is a better way to grow all sorts of flowering plants on Earth, from strawberries to tomatoes, to peppers and beyond," Rosenthal says.

And NASA is a few steps closer to its salad on Mars, as well. ❖

Remote Sensing Technology Fights Forest Fires Smarter

NASA Technology

Fires were raging in Northern California in June 2008, at the height of one of the state's most destructive wildfire seasons in history, and one blaze was headed right toward the town of Paradise. Well, maybe.

It's not so easy to figure out the future path of a forest fire—a lot depends on wind and other constantly changing factors. But it's crucially important to be as accurate as possible when making predictions. The lives and homes of the tens of thousands of people living in towns like Paradise may depend on the reliability of those predictions.

Sensors mounted on an airplane or drone, which give a picture of the fire from above, are an important tool—and that's where NASA comes in. The Space Agency has a lot of experience with remote sensing technology and relaying the information quickly to scientists on the ground.

NASA isn't the Government agency officially tasked with monitoring forest fires, of course. The U.S. Forest Service, as well as local and state firefighting agencies and the Bureau of Land Management, all work together to battle the infernos and keep people out of harm's way.

For decades, NASA has worked in partnership with the Washington, DC-based Forest Service, sharing technical expertise that helps get better information to firefighting decision makers faster.

The collaboration stretches back to the 1980s, explains Vince Ambrosia, associate program manager for wildfires in the NASA Applied Sciences Program at Ames Research Center. At the time, NASA was working on sensor technology and asked "how we can transfer the information they gather in near real time to make it useful for the fire community."

"We wanted to be able to leverage the subject matter expertise and sensors and aircraft that NASA has and the Forest Service doesn't have," notes Everett Hinkley, National Remote Sensing Program manager for the Forest Service. "It's a positive feedback loop: we have the information needs, and NASA has the requisite expertise in those areas."

In the 1990s, NASA began a project to adapt uncrewed aircraft for environmental research, and the researchers at Ames wanted to ensure the technology would be useful to the broadest possible spectrum of potential end users.

One concept tested during the project was sending data in near real time to the ground via communications links installed directly on the aircraft.

For the Forest Service, this was a much-needed upgrade to the original system on their crewed jets: rolling up a printout of thermal sensor data into a plastic tube, attaching the tube to a parachute and dropping it out of the airplane. A later version—downloading digital sensor readouts onto a thumb drive and dropping the drive out of the airplane—wasn't much better.

A downlink connection would allow the data to arrive faster, and it could be sent to multiple recipients at once—not just the team on the fire front line, but the commanders organizing the teams, as well as decision makers looking at the big picture across the entire region throughout the fire season, explains Don Sullivan, who specializes in information technology design for NASA's Airborne Science Program at Ames.

Technology Transfer

When Sullivan and Ambrosia and the Airborne Science team at Ames were considering the best ways to get information from an aircraft to the ground they considered several methods, including relaying via geosynchronous or low-Earth orbiting satellites or connecting directly from aircraft to ground.

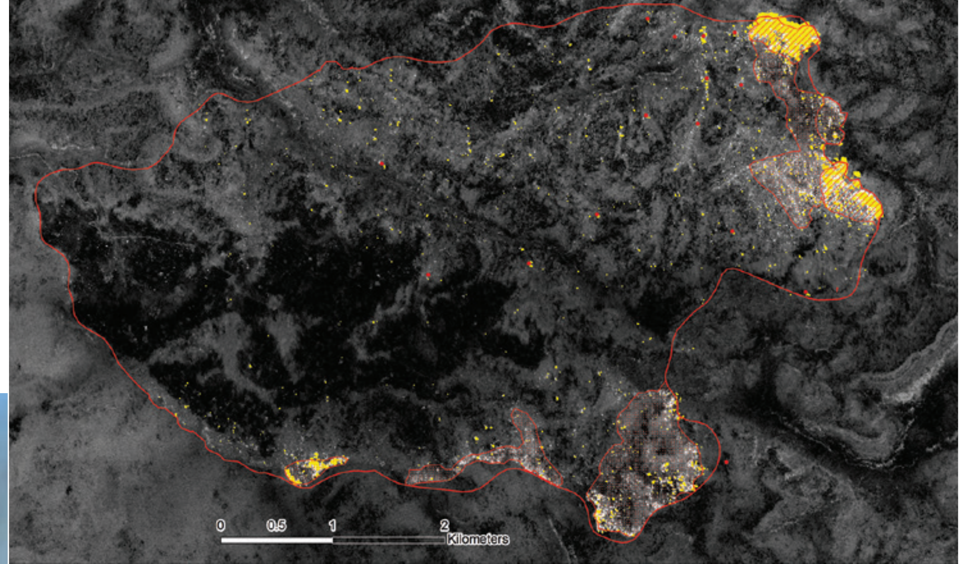
For NASA's larger project on environmental research with drones, a satellite relay made the most sense, because the research would be done over oceans, in the Arctic, and around the globe.

But since U.S. forest fires are on land, Sullivan and the Ames team determined an aircraft-to-ground system would work best—it was less expensive than relying on geosynchronous satellites and offered a much higher bandwidth than the existing network of low-Earth orbiting satellites.

NASA recommended a contract with Aircell, which recently rebranded as Gogo Business Aviation, a private company unaffiliated with NASA, explains the Forest Service's Hinkley, who adds that it's the same technology

NASA used its unmanned Ikhana aircraft to test technology it helped develop or recommended to the U.S. Forest Service, including a system to send sensor data to decision makers on the ground in near real time.

Remote sensing data helps ensure trucks like these are sent to the most effective points to battle wildfires. This map shows results from a night flight over a 2014 fire in New Mexico: the yellow represents fire spots detected by the autonomous modular sensor, and the red shows fire intensity (hot spots and intense burning, versus smoldering) as detected by an infrared sensor.



that's often used on commercial aircraft, "any time there's Internet."

NASA's expertise identified the merit of this airborne wireless networking technology for the Forest Service: "NASA helped us with the evaluation and testing of the various systems to see which one would work best for us," he emphasizes.

"NASA has Don Sullivan, who is a brilliant communications and networking person. We don't have anyone that has that particular set of skills in the Forest Service," Hinkley says. "People like Don can steer you away from things: 'You don't want to do this because of incompatibility issues or cost issues you don't see up front.' Having those kinds of skills is really invaluable.

"We ended up purchasing two Aircell systems," he adds.

Benefits

NASA's expert evaluation and recommendations have had significant benefits for the Forest Service and for the agencies that rely on the remote sensing data the Forest Service supplies.

NASA and the Forest Service continue to explore using uncrewed aircraft to expand data-gathering. NASA's uncrewed Ikhana test plane has demonstrated improved thermal sensors and provided helpful data in real fire situations. For the moment, however, the Forest Service continues to rely on the proven service of its two crewed aircraft.

With just two planes to cover the entire country, every minute of air time is in high demand. Using a network connection to send sensor data to decision makers makes the whole system safer and more efficient. "It means we can do more fires per night, 10 or more on busy nights," says Hinkley.

"And it means fewer takeoffs and landings, which increases safety for the pilot and crew on board," he adds.

Sending the sensor data to multiple recipients also saves time, ensuring decision makers get the information they need in near real time. As an added bonus, an onboard computer system can quickly process the raw data and send customized information to the various recipients as needed.

"On the fire line, they want a small file that finds where the fire is, and its intensity," explains Sullivan, whereas "other people, planners, wanted to be able to look at the entire thing and allocate resources," so they need larger image files.

"But then there are people who are doing instant commands for the entire incident, who want to know what nine crews are doing," so they need a rich image that combines a photographic snapshot with infrared imagery.

In California in 2008, all that paid off—big time—when a NASA test flight using a data downlink system was able to provide updated information to the incident managers that was crucial in determining where to send firefighting resources and whether a full evacuation of the town of Paradise was needed.

Without that timely information, says Sullivan, "there likely would have been injuries and certainly property damage that was worse than it turned out to be." ❖

Earth Images Enable Near-Perfect Crop Predictions

NASA Technology

NASA has been taking pictures of Earth from space for as long as the Space Agency has been around—and well before Boston-based startup TellusLabs began using these images to predict corn and soy yields with remarkable accuracy.

In fact, the earliest grainy pictures of Earth from space predate the Space Agency, going back as far as 1946, when a group of scientists and soldiers set a camera to snap a new frame every 1.5 seconds and then mounted it on a rocket they launched from the White Sands Missile Range in New Mexico.

NASA was established a dozen years later, in 1958, and almost immediately began snapping more photos of Earth. Astronauts on the first Mercury missions in the early 1960s got in a few quick shots in their free time, before the Earth-observing program became more formalized and they were trained in terrain photography and equipped with an 8mm Hasselblad camera.

Also in the early 1960s, test bed missions for Apollo—the program that ultimately put the first humans on the Moon in 1969—returned with increasingly complete images of Earth from space. Years before the famous Blue Marble photograph from Apollo 17 in 1972, these early images are said to have been the inspiration for the Landsat Program, which, for the first time, launched a satellite specifically to observe and collect data on Earth's landmasses.

Landsat 1—then known as the Earth Resources Technology Satellite—entered orbit on July 23, 1972, after some rigorous justification to budget skeptics. It was equipped with a multispectral scanner that captured more than 300,000 images before the spacecraft was decommissioned in 1978.

Landsat 1 was followed by numerous successors, including most recently Landsat 8, a NASA collaboration with the U.S. Geological Survey (USGS) that launched February 11, 2013, and is able to collect data in more spectral bands than ever before. That satellite, now operated by USGS, captures images of the entire planet every 16 days, offset eight days from Landsat 7, which has been in operation since its launch on April 15, 1999.

This image, taken by Landsat 8 and processed by TellusLabs, shows New Orleans as it sits along the Gulf of Mexico. Agriculture, largely sugar cane, can be seen along the banks of the Mississippi in light pink and blue. Also apparent are sediment swirls in Lake Pontchartrain to the north and the loss of coastal land south and east of the city.

The program itself holds the longest continuous record of space-based observations of Earth. Engineers at NASA's Goddard Space Flight Center are currently developing Landsat 9, which is scheduled to launch in 2023.

Landsat observations were joined in December 1999 by the Moderate-Resolution Imaging Spectroradiometer (MODIS) instruments, two of which now orbit Earth on separate satellites, covering the entire planet every one to two days and acquiring data in 36 spectral bands. Together, the satellite constellation provides some of the highest-quality Earth images available.

Technology Transfer

As a remote sensing scientist in Boston University's Earth and Environment Department, TellusLabs cofounder Mark Friedl has worked on the MODIS science team and has affiliate membership on the Landsat science team. His academic work—often involving or funded by NASA—has included mapping global land cover and seasonal variability in growth.

Using both MODIS and Landsat data, his Boston University teams have developed tools and techniques to map the timing of leaf emergence, fall, and color, as well as growing season intensity. This type of information can be used to understand how weather and climate affect vegetation growth, and it certainly informed the programs he went on to write for TellusLabs.

Through his academic work, Friedl has come to know the Landsat and MODIS datasets extremely well. When Amazon Web Services began offering significantly simplified access to them, making the NASA and USGS datasets widely available to researchers around the world, free of charge, Friedl wasn't surprised. "They're hosting the data because they know people will use it," he says.

"This is incredibly valuable data NASA has been collecting over the years, certainly for science but also for a whole range of applications," he says. "Increasingly, people are figuring that out."

For more than two decades, Friedl has been watching as conditions converged to create the unique opportunities of the moment. The quality and capabilities of NASA's space instruments have improved as historical records continue to get longer. Add to this the huge advancements in computing power and the maturation of data analytics, machine learning, and statistical analysis techniques.

"All that has kind of put us in a different place than we were even 5 or 10 years ago with respect to these types of data and the types of things we can do with them," he says.

It's why he and his TellusLabs cofounder David Potere decided several years ago to use space data for what they call geographical or spaceborne insights. During weekends, evenings, and vacation, they built a crop-prediction model that combines current NASA and USGS data streams with historical data and then blends them with a variety of other data sources, including weather models.

Benefits

In its first year, the beta version of TellusLabs' initial product, Kernel, consistently predicted final 2016 yields on U.S. corn and soy crops ahead of all publicly available in-season forecasts, the company says.

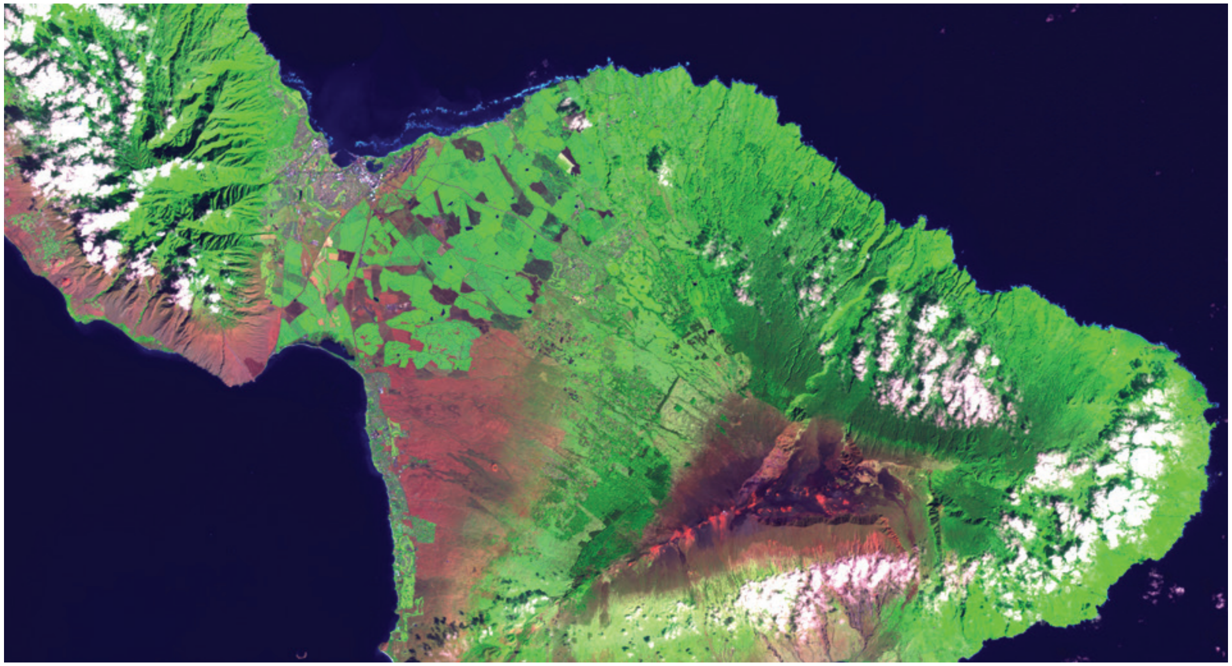
Kernel projected yields on 2016 U.S. soy crops within 1 percent of the final yields, nearly two months before the U.S. Department of Agriculture (USDA)—September 13, versus November 9. The platform's corn predictions also steadily converged with the USDA's final reported yield, ending off by less than 1 percent, at 173.1 bushels per acre, versus the actual 174.6 bushels per acre.

The company was at the top of the 2016 class at MassChallenge, a startup accelerator in Boston that awarded TellusLabs $100,000, in addition to office space, private-sector mentors, and computing resources. In early 2017, the company announced it had raised $3.1 million in seed funding from a partnership of several venture capital firms.

"What distinguishes us is we're taking the meteorological data and building models that are in some senses similar to more traditional crop forecasting models, but we're adding the additional dimension of the space-based observation," Friedl says.

Within a year, TellusLabs already had more than 600 subscribers from a wide range of fields. The key groups, the company says, are large institutional investors, individual investors and advisors, a variety of organizations engaged up and down the agricultural value chain, as well as individual farmers and farming consortia.

"Our thesis right now is that there's a lot of value in the really high-quality measurements that the Space Agency missions provide," Friedl says. His academic work with the Agency helped familiarize him with the satellite data that has made TellusLabs possible, he adds. ❖



In this false-color infrared view of Maui, the large sugar plantations that dominate the agriculture of that island are on view, wedged in the lowlands between the mountains of Pu'u Kukui on the east and Haleakala in the west.

Micronutrient Formula Strengthens Plants, Increasing Yields

NASA Technology

An apple a day keeps the doctor away—but how do you bring enough apples, and other fresh food, all the way to Mars and back? Given the limits on how much cargo can be brought on any space journey, NASA has been exploring solutions to pack maximum nutrition into each bite.

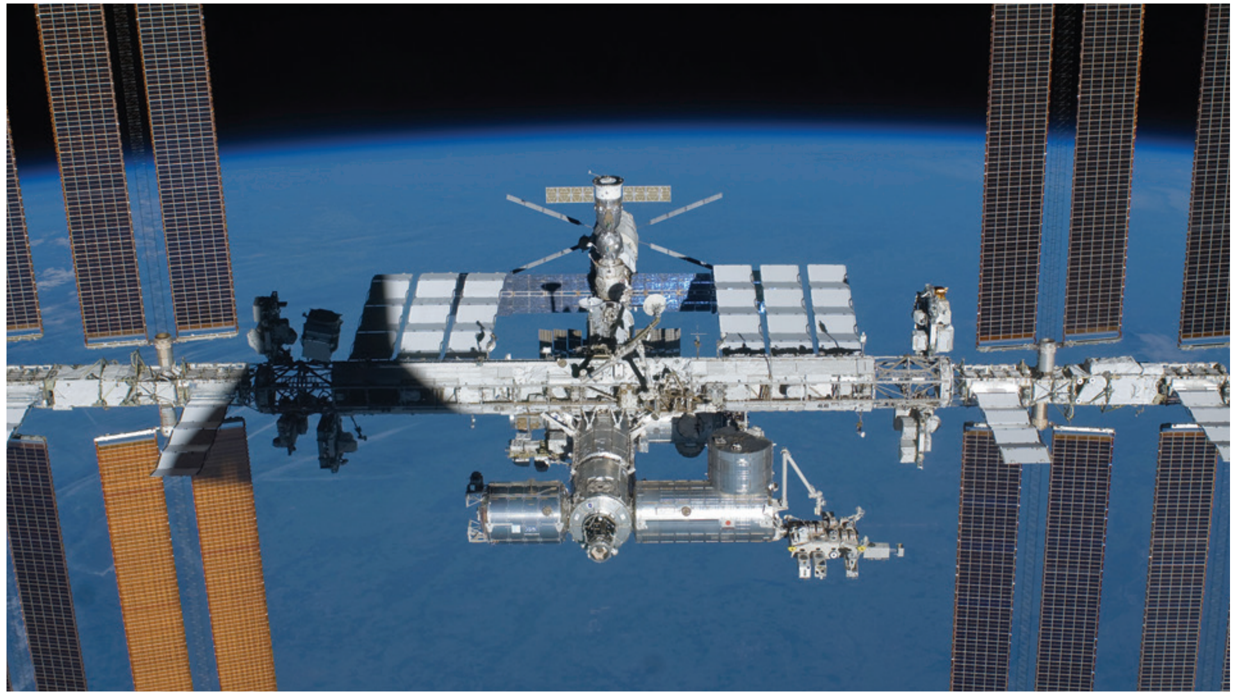
Astronauts already take vitamins and other nutritional supplements, but what if extra nutrients could be added to fruits and other plants as they grow? It's a solution that could have a huge impact on Earth as well, especially where food scarcity and poverty continue to make malnutrition a terrible problem.

The technology comes from Boca Raton, Florida-based Zero Gravity Solutions Inc. (ZGSI), founded by 19-year U.S. Department of Agriculture veteran John Wayne Kennedy. Kennedy was already working with NASA to explore cell replication and gene expression in microgravity when he began investigating the possibility of increasing the nutritional value of plants as they grow. The key, he theorized, was increasing the level of minerals like zinc and copper.

These micronutrients, explains Ames Research Center plant scientist John Freeman, are crucial for human health and are often lacking in sufficient quantities in the food we eat. Most essential are the "big four," he says, referring to zinc, selenium, iron, and iodine. "Deficiencies in these four minerals cause illnesses and disease in billions of people worldwide."

Scientists call it "hidden hunger," because these deficiencies often appear in people who otherwise appear to have enough food to eat. "The world's staples are rice and corn and potatoes and wheat," Freeman explains, "but those crops are often very deficient in these micronutrients." Moreover, even plants that are traditionally rich in minerals can end up with lower concentrations of them after years of harvests have depleted the soil.

Kennedy wanted to increase the level of micronutrients, on a cellular level, in plants as they grow. "That creates a highly nutritious plant by itself, by bringing the zinc and copper into the food," explains ZGSI CEO Harvey Kaye, "but it also makes the plant much healthier, by virtue of enhancing the overall stress responses and photosynthesis. This can result in higher yields and quality, including greater sugar content."



With longer-duration voyages envisioned, research is ongoing to ensure astronauts will be able to maximize nutrition while minimizing cargo volume. In 2017, NASA delivered to the ISS broccoli seeds to be grown with a micronutrient formula developed under Space Act Agreements.

That would mean a double benefit for long-duration space voyages, by increasing nutrition for astronauts while also helping to make any crops they grow hardier and more likely to thrive under adverse conditions.

Technology Transfer

In 2016, Ames Research Center and ZGSI signed a new reimbursable Space Act Agreement, with Ames senior research scientist David Bubenheim as principal investigator, to evaluate the nutrient delivery system for commercial agriculture and space applications. A trial based on a batch of broccoli was sent to the International Space Station in early 2017. "We're hoping to not only improve growth of roots and shoots but also to biofortify and increase levels of zinc in edible portions—the shoots of the broccoli," Freeman says.

Although this crop will merely be for evaluation purposes, he says he hopes future iterations will be given to astronauts to eat.

But in the meantime, says Kaye, the positive results from the various ground- and space-based tests have convinced ZGSI to sell their product for agriculture here on Earth.

> “You can keep piling on all the fertilizer in the world, but if you don’t have sufficient micronutrients, a plant can’t work at its full capacity.”
>
> — Andrew Koopman, Zero Gravity Solutions Inc.

The company has provided the technology for academic trials as well as to commercial farmers for testing, and is now manufacturing and selling it commercially to growers in the United States and overseas.

Benefits

ZGSI calls its product BAM-FX, which stands for Bio-Available Minerals, Formula X. Growers can either apply it as a soil drench at the time of planting or spritz the formula onto the leaves as the plant grows, Kaye explains. Because cells carry a negative charge, and BAM-FX has a positive charge, it is attracted to plants. And because the zinc and copper are in the right cationic bioavailable forms, they are able to pass through the cellular membrane transporters “and efficiently deliver nutrients into the cells of the plant.”

The goal is not to replace fertilizer, says Andrew Koopman, CEO of Zero Gravity Life Sciences Inc., a subsidiary of ZGSI, but to help the plant use the fertilizer and other nutrients more efficiently. “The reason you need minerals is because they’re cofactors: enzymes need them to operate.” The enzymes enable metabolism by breaking down nutrients. The more efficient a plant’s metabolism, the better it grows and regulates reactions to external stressors, like drought and heat.

If you only have a small supply of a mineral, that limits enzyme activity, so increasing mineral levels “increases the plant’s efficiency and lowers its energy requirements.”

In other words, says Koopman, “You can keep piling on all the fertilizer in the world, but if you don’t have sufficient micronutrients, a plant can’t work at its full capacity.”

When treated with BAM-FX, crop yields increase on average by 25 percent, in some cases even when growers used 25 percent less fertilizer, ZGSI says, which could mean lower costs for farmers and less pollution from nitrogen and phosphorous runoff. In a study in California’s wine country, BAM-FX increased vineyard yield by 50 percent under drought conditions while also increasing total phenolic and sugar content, which determines the potential quality and alcohol level in the finished product.

The reduced need for fertilizers could have an especially big impact in the developing world, Koopman notes, where many low-income farmers can’t afford effective fertilizer inputs. Following pilot studies in Asia, ZGSI says, the company is now getting orders from Malaysia, India, and Indonesia, with new studies being conducted in South America to test the efficacy of the formula on crops there with differing soil and growing conditions.

Rice plants grown with the micronutrient formula, called BAM-FX, are bigger and healthier than ones grown with traditional methods alone, as seen in this picture from Pakistan. The formula can be applied to the seed at planting time or, as this helicopter is doing in California, sprayed over the leaves as they grow.

“Everybody talks about the need to feed 9 billion people in the coming years with the same acreage. The notion of continuing to do the same thing we’ve done for 50 years is not the answer. What needs to be done is the application of technology to deal with the major issues relating to humanity,” Kaye says.

“NASA has always played a leading role in that kind of work,” Freeman says. “Here’s another example of a product designed for some of the extremes in space that has found clear application in Earth’s agricultural environments.” ❖

Chemical Simulation Software Predicts Climate Change, Air Quality

NASA Technology

For climate scientists, the whole Earth is a laboratory. They need to observe what is happening across the entire planet over long swaths of time.

To do that, NASA operates numerous Earth-observing satellites, flies instrumented aircraft to take localized measurements, and grabs data from instruments on the ground. But these observations are intermittent: they offer many points of data but not a complete and continuous picture.

Researchers fill those gaps using complex computer models, which smooth out the data for factors like temperature, wind direction, and, one of the more complex dynamics, chemical reactions.

"The chemicals in the atmosphere all interact with each other and with light from the sun. A commonly known example is chlorofluorocarbons, which harm the ozone layer in the presence of ultraviolet light," explains Tom Clune, a senior computational scientist at Goddard Space Flight Center. Clune used to head the Advanced Software Technology Group, which collaborates on a number of computer modeling projects, including the Goddard Earth Observing System Model, Version 5 (GEOS-5), which studies climate and weather.

Chemical reactions happen continuously—everywhere. So researchers break the atmosphere into small boxes, and, for GEOS-5, model each of around 300 reactions of around 100 different chemicals within each box, repeating the calculations with the resulting chemicals, over and over, Clune explains.

"It solves for a short period of time in each box, ignoring spatial variation, just saying, 'If you start with these concentrations, what concentrations do you end up with at the end of that time step?'" he says.

"At the resolution we're running, it's about a billion of these boxes in a grid. So we have to do a billion of those, solving 100 equations in 30-minute time steps," often until the model has data for a 30-year span.

That is very expensive in terms of processing power. NASA began using computers to help back in the 1970s, but with new microprocessors increasingly powerful and cheap, the software was due for an upgrade. The old software was not designed to take advantage of a new generation of hardware accelerators.

Technology Transfer

Clune had begun trying to work up a new solver for chemical reactions when he found out that a private company already had taken it on—and received a Small Business Innovation Research (SBIR) contract from NASA to help fund the project.

The company was Baltimore-based ParaTools Inc., and the software was Kppa, developed by John Linford. The two men met at a conference in 2014.

"Talking to him, I quickly realized that all of the things I had been planning to do, he had done already—and then some," Clune says.

ParaTools' SBIR contract was funded out of Ames Research Center in 2014, but Linford had been working on the problem of simulating chemical reactions with advanced computer processors for many years before that. "I started working in chemical kinetics in grad school in 2006, and I developed a prototype for Kppa," he recalls. "After I joined ParaTools, I could see there was a real need for a co-generator for these types of problems that just wasn't being met."

"A lot of the tools used in weather or air quality forecasts are written in-house, at NASA or elsewhere, by domain scientists: chemists or environmental scientists who don't have a strong background in computer science," Linford says. But the high-end microprocessors that have come out in recent years, and which are significantly faster, are harder to program for.

"The new generation of computers are just ludicrously complicated, and it's really asking too much for a chemist to program one."

Linford, whose background is in computer programming with some chemistry mixed in, says he thinks researchers and programmers should work together to make the most out of the advanced computing power available.

"The real key is that Kppa provides an intermediate layer between the scientist and that architecture," he says. "The scientist can give the inputs and the outputs for their chemical equations, and Kppa translates to the computer

Simulating the many chemical reactions that occur constantly across the atmosphere is a complex task. New software designed with NASA funding is helping scientists study climate and weather.

code. That's where the performance really comes from. You don't have to be an expert in programming computers, you just have to be a chemist."

Clune notes that his team at Goddard does include extremely talented software designers, but, in this case, "they didn't write this layer. So either we get them to rewrite a layer and have them compete with a product that's perfectly good down the road or we get them to adopt the product that's good."

Benefits

There are at least three projects at NASA that could benefit from Kppa, Clune says. One is the GEOS-5 model he works on, which needs to solve the chemical reactions to model climate and weather. A second is the Global Modeling Initiative, which has a model to forecast air quality.

The third is at the Goddard Institute for Space Studies, which could use the software for climate studies on Earth but also is interested in adapting it to study exoplanets. "The chemistry can be quite different from one planet to the next, so they want a tool that just makes it easy to say, here's a different set of reactions, just plug that into the model," Clune says.

The Agency is exploring whether to license Kppa from ParaTools—and NASA isn't the only entity interested.

"The Swiss National Supercomputing Centre has used Kppa to run their national air quality reports," Linford says. The government uses a large supercomputer to run its air quality studies, which, among other issues, runs up a hefty power bill. "So the sooner they can turn it off, the better, which means they're very interested in a program that can reduce the run time."

With Kppa, "they can get answers in hours instead of days," Linford says. That's because Kppa takes advantage of the multi-core design of modern microprocessors, which allows many operations to be carried out in tandem.

"The way it's done traditionally, with the old tools, you have your atmosphere and you would chop it into little pieces, and each one would line up and go one at a time. And with Kppa, we can do many pieces at once."

Paratools Inc., which built the Kppa chemical modeling software, now sells it to clients around the world. Switzerland, where this picture was taken, is using it to run their national air quality reports.

What's more, "if I can simulate in an hour what I used to simulate in a day, I can make the problem bigger, make it more descriptive or the grid resolution higher, get a much better scientific answer than I could before," Linford says.

Clune notes that NASA already had chemical kinetics software that allowed for parallel processing, but Kppa lets researchers take advantage of the most cutting-edge hardware as well as ensuring the software uses the latest mathematical solvers available.

ParaTools' clients for Kppa include universities as well as the air quality research division of Environment and Climate Change Canada, but, says Linford, "what we're really interested in is developing relationships where we work together to build a better technology," customized to their particular needs.

"These systems and science become so complicated, it really takes a team to accomplish. We need chemists and engineers coupled with computer scientists to move forward." ❖

NASA Kite Invention Spurs Ever-Growing Educational Program

NASA Technology

When an educational agency contacted NASA engineer Geoff Bland in 2010, wondering about a way to monitor ponds and streams where water samples were being collected, he gave what may have seemed an unconventional answer: "I said, 'Would you be interested in flying kites?'" he recalls.

Wayne Regional Educational Service Agency (RESA), which supports schools in Wayne County, just outside Detroit, had students comparing water quality in Michigan's Upper Peninsula with the rest of the state. It had occurred to someone, though, that conditions at the water collection sites weren't being monitored. "We wondered, is there some way to put up cameras and take pictures of the study sites?" says David Bydlowski, science consultant for Wayne RESA.

So the group had applied for and been granted a small NASA Cooperative Agreement Notice (CAN) award to explore options. Organizers had no idea Wayne RESA was about to be at the center of a project involving a multitude of organizations across the country, from Fairbanks, Alaska, to the Chesapeake Bay.

Through a series of contacts, the group ended up in touch with Bland, who works in the Earth Science Field Support Office at Goddard Space Flight Center's Wallops Flight Facility. Bland had worked on other educational programs that incorporated remote sensing and Earth-observation data, and he had also recently invented a new, low-cost, easy-to-use device for keeping cameras and other sensors in the air.

The Investigating Climate Change and Remote Sensing project, which came to involve schools and organizations across the country, began with one educational agency serving a county in Michigan and its interest in aerial imaging to monitor conditions at ponds and streams where water samples were being collected.

Bland has been involved with aerial imaging since the 1990s, when he led the creation of the first small electrically propelled drone to be outfitted with scientific research sensors. Interested in simpler, cheaper solutions, he looked to kites but found that the traditional tool to stabilize a camera on a windblown kite didn't provide the stability he needed and tended to get tangled. So he and NASA technician Ted Miles built something better.

Their AeroPod device is aerodynamically stabilized and is not attached directly to the kite but to a line that hangs from a ring suspended between ball bearing swivels on two segments of kite string. It was patented in 2012.

AeroPods can be equipped with the same sensors commonly flown on drones and require far less training. "You can take somebody who's never flown anything and have them taking data with a set of sensors after a day of training," Bland says. They also never run out of power.

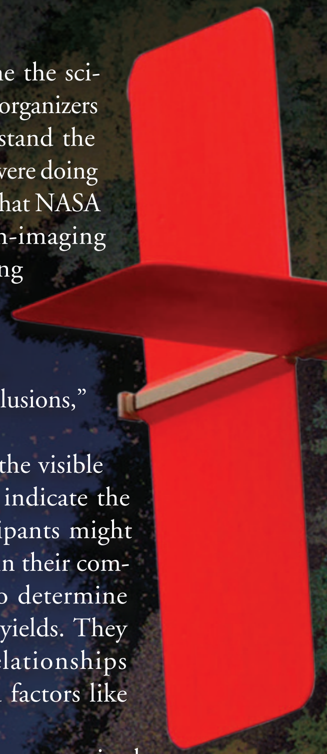
Technology Transfer

Wayne RESA's leadership, with Bland's collaboration, ultimately came up with the Investigating Climate Change and Remote Sensing (ICCARS) Project, which was piloted in 2010. It was much more ambitious than the original plan to monitor water quality test sites.

The team developed 60 lesson plans for middle and high school students, some intended as classroom course material and some as extracurricular activities. The program uses AeroPod-gathered Earth-imaging data to understand the science of climate change and its relationship to changes in land use and land cover.

To license the AeroPod technology at no cost, the Goddard Strategic Partnerships Office created a new educational license that requires feedback rather than monetary payment. "If end users want to develop their own AeroPod, that's absolutely all right, as long as they tell us what they like and don't like about it," Bland says. Licensers also must share any data that's of interest to NASA and any of their own advancements to the technology.

Benefits

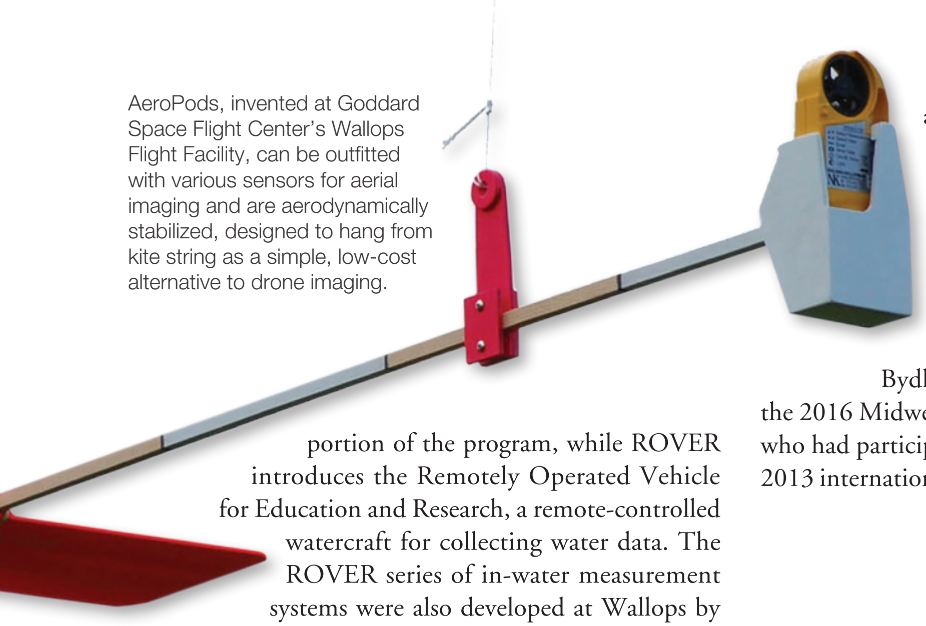


Bydlowski, who became the science lead for ICCARS, says organizers wanted students to understand the parallel between what they were doing with imagers on kites and what NASA does with its many Earth-imaging satellites. "We're collecting data from the ground, and if we collect data day after day like a satellite does, we can start to draw some conclusions," he says.

Aerial images taken in the visible and near-infrared spectra indicate the health of crops, so participants might analyze imagery collected in their community with AeroPods to determine biomass and predict crop yields. They could then look for relationships between crop growth and factors like temperature changes.

The program provides customized handheld field data collectors with a software package for processing images, pinpointing locations with GPS, and transmitting data back to the classroom. Students share data with the ICCARS community through the project's online portal, and they share it with the world through the Global Learning and Observations to Benefit the Environment (GLOBE) Program, an international school-based science and education program.

After the two-year CAN funding expired, Wayne RESA continued its ICCARS work, and in 2016, NASA granted the agency a five-year CAN award to expand the program into what's now known as the AEROKATS and ROVER Education Network (AREN). AEROKATS, or Advanced Earth Research Observation Kites and Atmospheric and Terrestrial Sensors, refers mainly to the kite-based AeroPod



AeroPods, invented at Goddard Space Flight Center's Wallops Flight Facility, can be outfitted with various sensors for aerial imaging and are aerodynamically stabilized, designed to hang from kite string as a simple, low-cost alternative to drone imaging.

portion of the program, while ROVER introduces the Remotely Operated Vehicle for Education and Research, a remote-controlled watercraft for collecting water data. The ROVER series of in-water measurement systems were also developed at Wallops by Bland and Miles, in collaboration with the University of Maryland Eastern Shore (UMES).

Along the way, several partners have joined in as co-investigators or collaborators on AREN, with Wayne RESA as the lead institution. The University of South Florida has developed an engineering mentoring program for middle school students, designing and building ROVERs, while the University of Alaska, Fairbanks, is rolling aspects of the project into an educational program studying the warming Arctic. The Chesapeake Bay Environmental Center is helping to develop equipment and operations. Goddard and UMES continue to work together on developing and implementing these educational tools, and new partnerships also include Anasphere Inc., Montana State University, Public Lab, and Washington College.

What has made ICCARS and now AREN so popular and effective is that students are getting out in the field, collecting real-world data, and coming up with their own questions to answer with that data, rather than having information and questions fed to them in the classroom, Bydlowski says.

All the while, Bland says, he's made sure the Space Agency's rigorous operations procedures are part of the curriculum. Like a rocket launch, each flight or mission is a team effort in which all participants have specific roles, checklists are developed and followed, risks are assessed and mitigated, and operations are preceded and followed by comprehensive briefings.

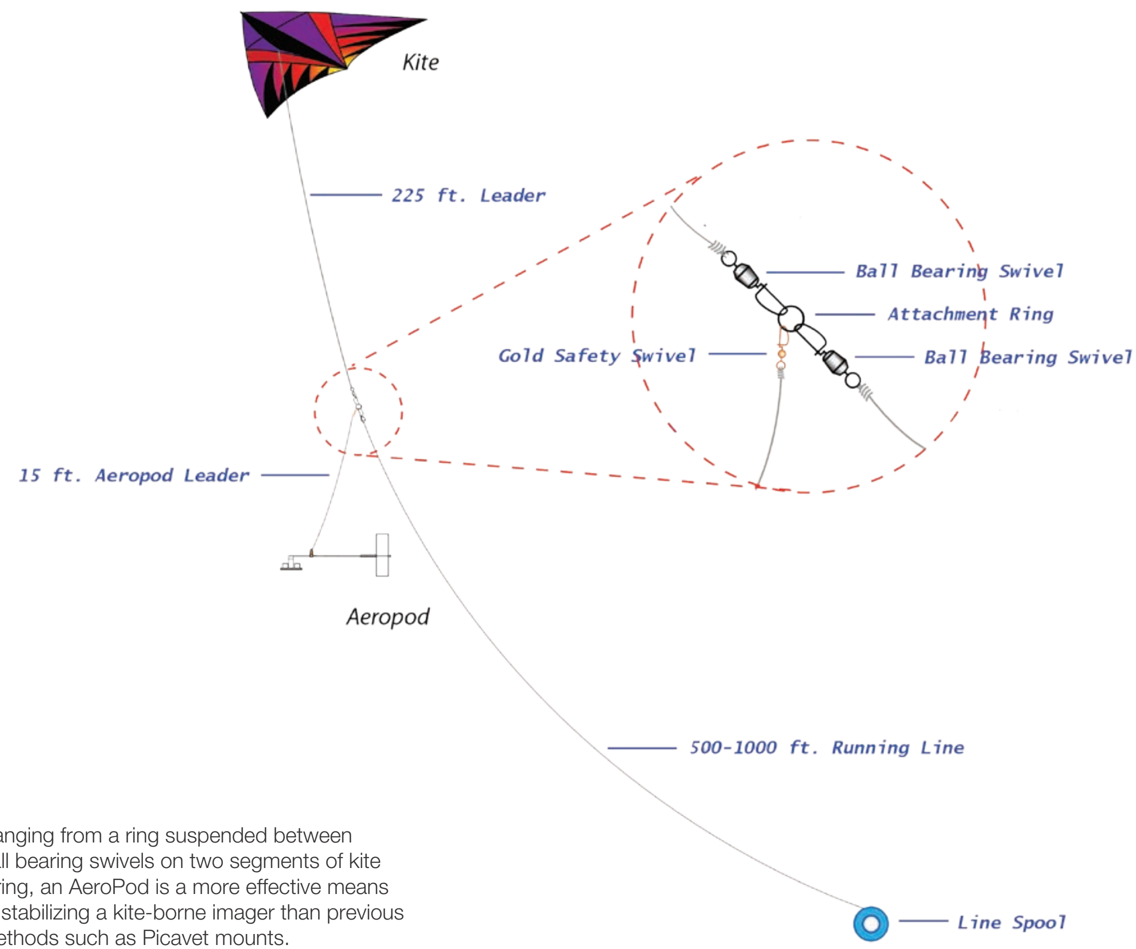
Bland says students who participate in the programs end up better equipped to work with aviation and develop scientific research projects.

Project leaders are still gathering data to quantify the programs' success, but Bydlowski notes that first and second place in the 2016 Midwest Regional Science Fair went to students who had participated in ICCARS, as did first place in the 2013 international GLOBE Student Research Exhibition.

It's impossible to know how many students have learned new skills from the programs, but 31 schools in Wayne County participate, while countless students and teachers from coast to coast have also gotten involved.

Bland says he wants the program to improve the quality of future science and bolster NASA's ranks. "I hope the young people participating today turn into the next generation of NASA engineers, scientists, professionals, and support staff, people who will help us continue to understand our own planet and explore the universe," he says.

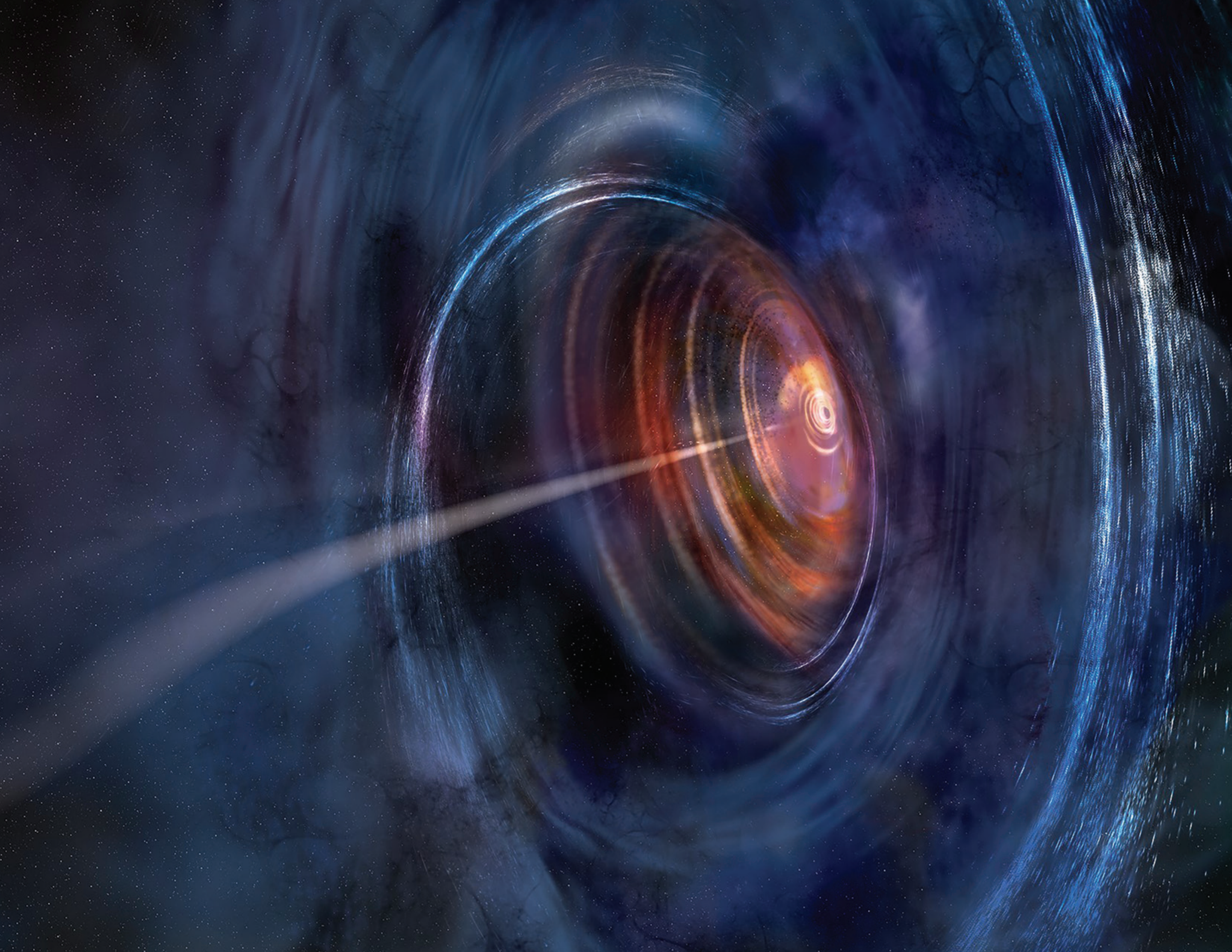
"And, hopefully, the program is fun, too." ❖



Hanging from a ring suspended between ball bearing swivels on two segments of kite string, an AeroPod is a more effective means of stabilizing a kite-borne imager than previous methods such as Picavet mounts.

Information Technology

When NASA wants to design a self-learning Mars robot, predict how a rocket will react to pressure, or pick up fainter clues in images of deep space, it relies on high-powered software and information technology. But these innovations don't just appear—to meet these needs, NASA partners with industry and tasks its own computer scientists to build them. That benefits all of us, because the same codes end up with wide-ranging applications, including helping cars avoid collisions and image analysis that can map storms and detect inflamed cells.



Planet-Navigating AI “Brain” Helps Drones and Cars Avoid Collisions

NASA Technology

Once you’ve designed a robot that can autonomously explore planetary terrains, putting the same technology in cars, toys, and drones seems almost easy. That’s why conducting NASA-funded research on deep-space computing was a natural fit for Boston-based startup Neurala.

“The use case was ideal for our long-term vision, which is that every device should have a brain,” says Massimiliano Versace, who founded Neurala with colleagues in the Cognitive and Neural Systems Department at Boston University. “The best way to do this is to force yourself into the most difficult situation and use the most ubiquitous and inexpensive processors and sensor packages on the market.”

The company’s core technology is an artificial intelligence (AI) “brain”—neural network software modeled on the human brain that can interact with and learn from its environment using ordinary cameras and sensors. The Neurala Brain can process its surroundings locally, so it doesn’t require a cloud-based supercomputer like other AI systems. That’s where the NASA research was especially crucial.

To put a self-learning robot on Mars, for instance, where communication with Earth can be delayed by as much as 25 minutes, “you need to rely only on the compute power that you have on board,” Versace explains. “You cannot ping a server. You don’t have GPS. You don’t want to send to Mars something that can break or fail or needs a lot of communication and exchanges with Earth.”

A system that can work under these most demanding conditions has far fewer hurdles on Earth.

The idea for Neurala came in 2005, when Versace and his colleagues Anatoly Gorshechnikov and Heather Ames realized that major developments in the latest graphics processing units weren’t just good for video game displays—they also had game-changing potential for artificial intelligence.

“The intuition we had back then was: what if each pixel that the graphic processor processes is treated like a neuron?” Versace recalls. The colleagues started using graphic cards to develop programs that operated more like brains, which can slowly compute a large amount of information in parallel—that is at one time—versus a traditional central processing unit, which can process many small pieces of information very fast but only serially, or one after the other.

From left to right: Matt Luciw (Neurala), Mark Motter (Langley Research Center), and Massimiliano Versace (Neurala). Neurala developed and commercialized its neural-network software thanks in part to a series of STTR contracts with Langley.

An initial signal that this research could have more than a theoretical impact came in early 2009, when the team started working on the Defense Advanced Research Projects Agency (DARPA) SyNAPSE Project, which aimed to develop low-power computers inspired by biological neural systems—specifically, brains.

NASA got wind of the work in 2010, when Versace wrote about the DARPA research in *IEEE Spectrum*, a magazine published by the Institute of Electrical and Electronics Engineers. Mark Motter, an engineer at NASA’s Langley Research Center, read the article and immediately saw broad potential applications for the brain-inspired system.

“The high-level aspirational goal was to have computational capability and memory collocated so you don’t use up all the energy in the device by shipping data back and forth over a data bus,” recalls Motter. “That caught my interest.”

Technology Transfer

Motter reached out to the Neurala founders and eventually became the technical representative on the company’s Small Business Technology Transfer (STTR) contracts with Langley.

“The first phase of the STTR award was really focused on showing how a rover on Mars would learn to navigate within an unsupervised neuromorphic computing paradigm and find its way in an unfamiliar environment,” Motter says—neuromorphic meaning neural-like in operation.

At the time, exploring planetary surfaces still required a good deal of human control and power-hungry sensors for even basic functions. There was a sense that AI was the way forward, but it was still largely unproven. In fact, the technology was at a turning point. Less than a decade later, neural networks and deep learning appear ready to transform industries and replace old algorithms in tasks like object recognition and speech recognition.

Back in 2011, working with academic partners in Boston University’s Neuromorphics Lab, Neurala completed its STTR Phase I research before winning the larger Phase II contract, for which the company developed another key to what would soon become its commercial offerings: visual processors based on passive sensors to enable robots to identify and interact with objects and learn new terrain.

This screenshot shows a self-driving car's view when powered by Neurala's software. The vehicle can automatically identify pedestrians, cars, cyclists, trucks, and more on a Boston street in real time.

Motter, whose own PhD work also involved unsupervised learning and could be applied to unpiloted aerial vehicles, or drones, took particular interest in Neurala's Phase II STTR research, because the visual processors had clear potential benefits on Earth. Yet another award from a NASA Center Innovation Fund allowed the Neurala team to help Motter develop technology to avert drone collisions.

Benefits

Following all that NASA work, Neurala was able in 2014 to raise $750,000 in private capital. The company then applied for and was awarded an additional $250,000 from NASA in STTR Phase II Enhancement money—a program that matches private funds to help commercialize STTR technology.

"This was very important for us, because it gave us a substantial amount of cash to pay for our development costs," Versace says.

Neurala created several iOS and Android apps for consumer robots and drones like the Parrot Jumping Sumo ground robot and the DJI Phantom and Parrot Bebop drones. The company is also licensing the technology to consumer drone manufacturers Parrot and Teal, Versace says.

"We used these initial apps as proof of concept and almost as marketing materials," Versace says. "In essence, they gave us the chance to do the real stuff by demonstrating with this low-cost application that we can deliver technology to the end user."

The products have helped the company reach its real market: designers and manufacturers. By the time Neurala announced in December 2016 that it had raised $14 million in its series A financing round—on top of $2 million in seed funding—it already had contracts with several drone companies, industrial robot manufacturers, and a major automaker looking toward self-driving cars, where the ability to make calculations locally is vital.

"If you're a drone flying 50 miles an hour, by the time you send video to the cloud where a program identifies a bird in your path and sends back information to steer, you've already hit the bird," Versace says. "You want to be able to compute quickly on the device for safety reasons. Our technology enables us to cut the umbilical cord to the external world."

The company's main product, its Brains for Bots software development kit, enables app developers to incorporate the Neurala Brain into programs created for a variety of computing platforms used in drones, self-driving cars, industrial robots, smart cameras, toys, gadgets, mobile phones, and computers. The software can learn to identify, find, and track objects. Later iterations of the software will incorporate navigation and advanced collision avoidance.

In the case of smart household devices and toys, local computing prevents security and privacy problems, too. "It's sort of an Internet of things without the Internet," Versace says. "With the Internet of things, everything has to be connected with everything else. In reality, sometimes you don't really need the Internet. Or you don't want it. Or you can't have it."

Recent projects for Neurala include a partnership with Motorola to incorporate facial recognition into cameras worn by police and technology for drones used to detect poachers in Africa.

The Neurala Brain's ability to function locally owes much to the Space Agency's early support, Versace says.

"They gave us the money to do it, but also, they forced us to do it the right way," he says. "They put very high and stringent demands on the project. It's like they made us go to the gym and get strong in this project before we faced the real world.

"Without NASA, Neurala would not be the company that it is," Versace says. ❖

Early NASA “Dream Computer Program” Still Optimizes Designs

NASA Technology

At the top of the food chain, an apex predator hunts without fear of being hunted. That’s why MSC Software Corporation branded its latest software line MSC Apex and dubbed the original, 2014 release “Arctic Wolf,” confident the computer-aided engineering program would soon, like its namesake, dominate the landscape.

Computer-aided engineering uses software to model, test, and analyze structures and parts before they’re ever built. It’s a tool that has come to be embraced by industries from aeronautics and auto manufacturing to farm machinery and medical equipment.

NASA, always trying to stay atop the engineering curve, quickly became an Apex customer and found its nomenclature to be justified.

“With Apex, what normally can take you days or weeks can be done in a couple of hours,” says Scott Taylor, a senior mechanical engineer at NASA’s Marshall Space Flight Center. Taylor uses the software to analyze the Agency’s next-generation rocket, the Space Launch System. “It is just stunning, and I’ve been here at NASA as a contractor since ’89. I’ve used all of the packages. This is just simply something else.”

But a lot of the computer coding that enables Apex, as well as a number of other related programs, was first found in the product of a long-ago partnership between Newport Beach, California-based MSC and NASA: NASTRAN.

Half a century after its creation, NASTRAN remains at the cutting edge of its field, both in the internal workings of programs like Apex and as an industry standard in its own right. To this day it is one of NASA’s most widely used software programs, and its influence has changed the design process for a number of industries.

NASTRAN owes its existence perhaps first and foremost to Thomas G. Butler, who, as an engineer at Goddard Space Flight Center in the 1960s, championed the creation of a general-purpose finite element analysis (FEA) program.

Thomas G. Butler, right, an engineer at Goddard Space Flight Center in the 1960s, is credited as the father of NASTRAN, perhaps NASA’s most successful software spinoff. Butler recruited supporters from various NASA field centers for the creation of general-purpose finite element analysis software, forming a committee that outlined their “dream computer program.”

FEA is a now-common computerized numerical method for modeling structures and predicting how they will react to outside forces such as pressure, vibration, and temperature.

But back then, the field was in its infancy, and when Butler hired Reg Mitchell, then an engineering student at George Washington University, as a summer engineering aide in 1964, “I had to go to the library to find out what finite elements were,” Mitchell recalls.

Butler had previously worked at the Baltimore division of the Martin Company, which developed an early, basic finite element modeling program, Mitchell explains. “He arranged to have a copy brought down to Goddard, and I was to try to figure out how to use it that summer.”

Meanwhile, Butler recruited supporters from the various NASA field centers and several Department of Defense agencies, and a committee was formed with him at the head. “These fellows all got together and came up with their dream computer program, all the things it should do—a lot of which weren’t doable in 1964, but they described what they wanted, not necessarily what they had,” Mitchell says.

Following a competitive process, a team of three companies—Computer Sciences Corporation (CSC), the Martin Company, and MSC—was selected to build this dream program. Richard MacNeal and others from MSC, better known then as the MacNeal-Schwendler Corporation, handled the theoretical mathematics behind the software’s design, while CSC created much of the architecture and programming, and Martin produced the structure-plotting capability, Mitchell says.

He describes the basic idea of the program as “a virtual Tinkertoy set.”

A model was defined using coordinates for grid points, connected by virtual plates, beams, rods, and other finite element building blocks that were assigned the properties of various materials. “Then the computer takes all this description of geometry and the material the elements are made of and builds a huge matrix equation set that describes this theoretical model.” Hypothetical loads of pressure or vibration, for example, are applied, and the software figures out how these loads move through the model.

Engineers built the program as a series of functional modules. “NASTRAN was one of the first programs that was highly modular in its approach, which is probably why it’s still around now, all these years later,” Mitchell says.

While NASA had an obvious interest in predicting the behavior of aeronautic and space vehicles, NASTRAN was always intended to work just as well for any other structure, he says. “NASTRAN was to be a general-purpose structural analyzer. It didn’t matter what you were analyzing. It hasn’t mattered to this day.”

This flexibility earned the program wide appeal, and its extensive documentation also eased its adoption by industry, says Mitchell, who was the chief reviewer for the programming manual. He describes it as “about two phone books thick.” In addition, a user’s manual and a theoretical manual were also created.

“Butler was big on documentation, not only on how to use the software but also how to fix it, how to add to it—all this was extensively documented, much better than the average program in the late 1960s,” he says.

NASTRAN was first demonstrated to modest fanfare in a Goddard auditorium in May of 1967, and the program was fully functional a year later.

Technology Transfer

In the early 1970s, NASA released NASTRAN to the public through its Computer Software Management and Information Center (COSMIC) at the University of Georgia, which managed the Agency’s public software programs at the time, offering them at low prices.

MSC and other companies soon began marketing their own versions of the program.

“As soon as we started distributing it, industry saw a good thing and pounced right on it, with the automobile companies being the biggest pouncers,” Mitchell says. “Using NASTRAN in the process that’s now called virtual product design, you can do a lot of trial-and-error in your structures on the computer instead of going out and building stuff and driving it around the track. It significantly shortened the development time for their automobiles.”

The automotive industry has remained the biggest user, but companies and Government agencies have used NASTRAN to design everything from steam turbines to tractors, floppy disks to computer printers, oil platforms to buildings, and manufacturing equipment to roller coasters, as well as ships, submarines, planes, helicopters, and space shuttles (*Spinoff* 1976-1982, 1986, 1988, 1990, 1991, 1998). The program has been used for such disparate purposes as earthquake analysis and predicting thermal activity in poultry houses and plant nurseries.

Meanwhile, NASTRAN has grown from about 300,000 lines of code to nearly a million as it has been refined and new modules have been added. The Space Agency remains a regular user.

“If you’re going to qualify anything for flight, especially manned flight, NASTRAN is the software that’s been relied on,” Taylor says. “For us, it’s a daily experience, running NASTRAN.”

Benefits

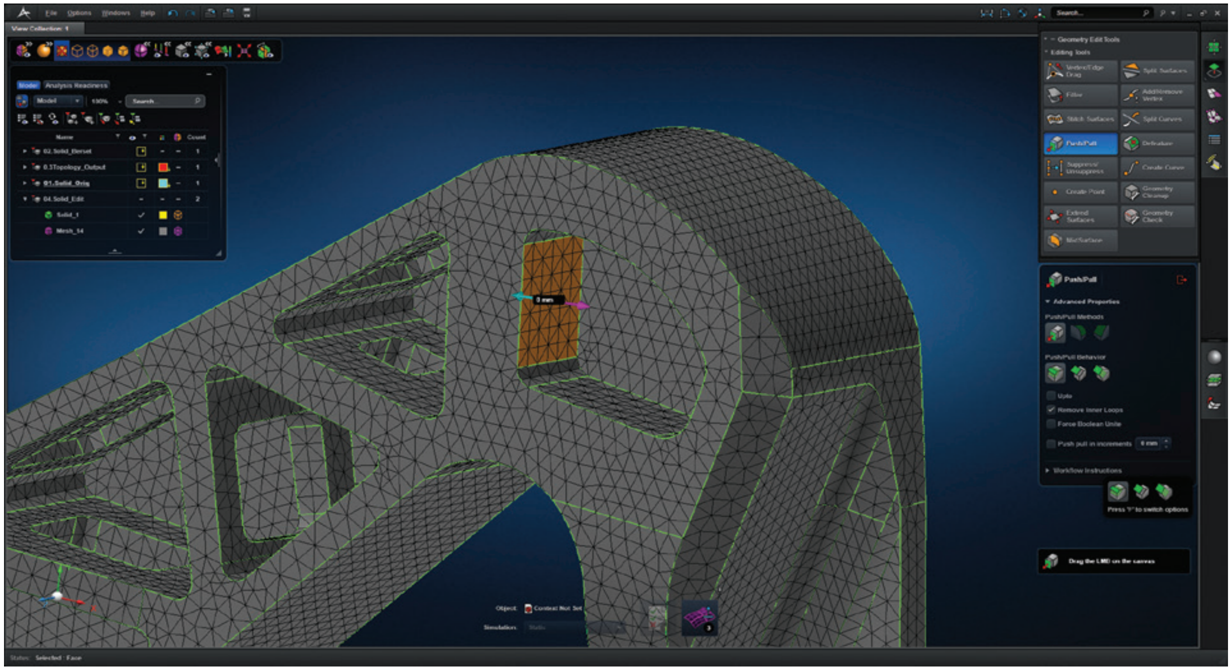
NASTRAN’s code has turned up in other software—Apex is one of several MSC programs that incorporate it, for example—and its successes, both in the marketplace and in the design lab, inspired the widespread adoption and further refinement of FEA software. Such software has since become an everyday engineering tool that has decreased the time and cost of design, raised engineering standards, and led to better understandings of the behavior of materials and systems.

“NASTRAN is used by most aerospace and automotive manufacturers out there,” says Hugues Jeancolas, senior product manager at MSC, noting that it was important for the company to build its latest software on the NASTRAN foundation that customers have come to trust for its accuracy and reliability. “Apex is reusing all the same NASTRAN element and material formulations that have proven themselves over the past decades and will continue to give our users the same level of accuracy.”

“Apex is reusing all the same NASTRAN element and material formulations that have proven themselves over the past decades.”

— Hugues Jeancolas, MSC Software

The NASTRAN program, created at Goddard and released to the public in the 1970s, has since been used to design everything from roller coasters to cars, steam turbines, oil platforms, buildings, aircraft, and much more.



MSC Software's Apex series of computer-aided engineering (CAE) programs are at the cutting edge of their industry, with an ease of use that opens up CAE to amateurs and saves professional engineers untold time and tedium. At its heart, though, is coding from NASTRAN, created by NASA half a century ago.

The difference is that, as MSC's next-generation computer-aided engineering platform, Apex integrates NASTRAN's solver capabilities with a modern, easy-to-use graphical user interface. The platform now has six releases and is quickly gaining a hold on the market.

Until now, computer-aided engineering's complexity has restricted its use to a small group of experts who usually use it to run simulations late in the design process, says Jeancolas. As a result, much of the insight gained from simulation is not leveraged to the extent it could be. "MSC's new platform intends to enable non-experts to harness the power of simulation earlier in the design cycle by delivering a seamless integration of both modeling and simulation tools," Jeancolas says.

Even in other modern software, he says, converting computer-aided design models into simplified, FEA-ready models is extremely time-consuming. A majority of the engineers MSC surveyed before creating Apex said they spent more than a third of their time preparing models. For example, the necessary process of breaking up models into a mesh of tiny elements is long, tedious, and error-prone. "Sixty-seven percent of FEA experts we interviewed need two to four solver runs to obtain a converged solution," Jeancolas says.

Apex eliminates much of that manual work. Meshes regenerate automatically as the engineer makes changes to the geometry, and the program continually checks to see that all elements of a model are viable, color-coding those that have problems like a lack of part connectivity or a possible over-constraint. "Our integration eliminates this incremental, iterative process, where you pass entire datasets from a pre-processor to the solver, and try, try, try until you get it right," says Jeancolas. "Solver checks are now fully synchronous with modeling."

Another evolution in Apex comes from its parts-based architecture. A designer often optimizes a model by running multiple simulations with only slight modifications to a single part. Apex speeds up this process by storing and reusing the mathematical representation of the parts that have not been modified, while traditional software requires all parts to be processed at every solver execution. "This gives users the opportunity to incrementally build, validate, and execute simulations," says Jeancolas. "After the complete assembly is built, small changes are fast to execute."

Finally, Apex's capabilities for processing the results of simulations are also intimately integrated with its solver. This integration has been most fully realized in the latest release, Fossa, where users can now artificially shift vibration frequencies, add damping, or recompute a structure's frequency response, skipping many steps of traditional finite element programs.

In the end, Jeancolas says, a model and simulation can be completed in as little as one-tenth the time it would take with other FEA software.

Taylor says he's seen the evidence himself, recalling one project that took an expert the better part of a month. "We got ahold of it with Apex, and I promise you, we were able to do in a morning what took him a month," he reports.

The integration of an intuitive new user interface with time-tested solver methods not only offers major productivity gains for FEA experts but also makes this previously esoteric technology accessible to any engineer, says Jeancolas. He says Apex represents the next step in a process MSC began decades ago when it first repackaged NASTRAN—"commercializing extremely complex technology and putting it in the hands of everybody."

The new software also reflects the intentions of the committee that dreamed up NASTRAN at Goddard, wanting to leverage the latest computing power to design better structures faster and more economically.

Given the reach this early software has had across years and industries, Mitchell says, "If Tom Butler were still alive, he would say his vision has been fulfilled. He envisioned it as a general-purpose program that could be used for anything, anywhere." ❖

"With Apex, what normally **can take you days** or weeks **can be done** in a **couple of hours."**

— Scott Taylor, Marshall Space Flight Center

Image courtesy of Giant Magellan Telescope Organization

Engineers chose the MSC Apex Fossa program to design and analyze the structures of the planned Giant Magellan Telescope and the 22-story-tall building that will house it, pictured in this artist's rendering. It was a daunting task, as the telescope will sit on a mountaintop in Chile, where it will endure high winds and earthquakes of up to 8.0 on the Richter scale.

2D Analysis Software Clarifies Medical, Weather, Intelligence Images

NASA Technology

NASA engineer Semion Kizhner spent an entire week trying to understand the Hilbert-Huang Transform with the colleague who had developed it, but to no avail. He hoped to develop a software that would get people using this powerful but complex new algorithm, he says, because he saw great potential in it that might require decades of development.

Fortunately, no one needs to fully understand a transform to use it. “I have no clue how intestines work, but that doesn’t prevent me from eating,” says Kizhner, now recently retired from Goddard Space Flight Center’s Instrument Electronics Development Branch.

A transform—essentially, a particular type of mathematical formula—helps scientists gather information from complex data. For example, Kizhner says, he might not be able to interpret the raw data from an electrocardiogram reading, but transforming the data into the frequency domain might show that something is happening about once a second, which is the normal respiration rate—a clue suggesting the phenomenon is probably associated with breathing.

“You try to apply some known transform, and if you’re lucky, it will give you something you understand,” Kizhner says.

One of the most commonly used transforms is the century-old Fourier Transform, originally devised to study heat transfer but now used in applications as diverse as quantum mechanics and digital image compression. The Fourier Transform, however, has severe limitations when it comes to analyzing natural phenomena. Kizhner had been looking for an alternative, and the Hilbert-Huang Transform (HHT), created by Goddard chief scientist for oceanography Norden Huang, seemed like a promising option.

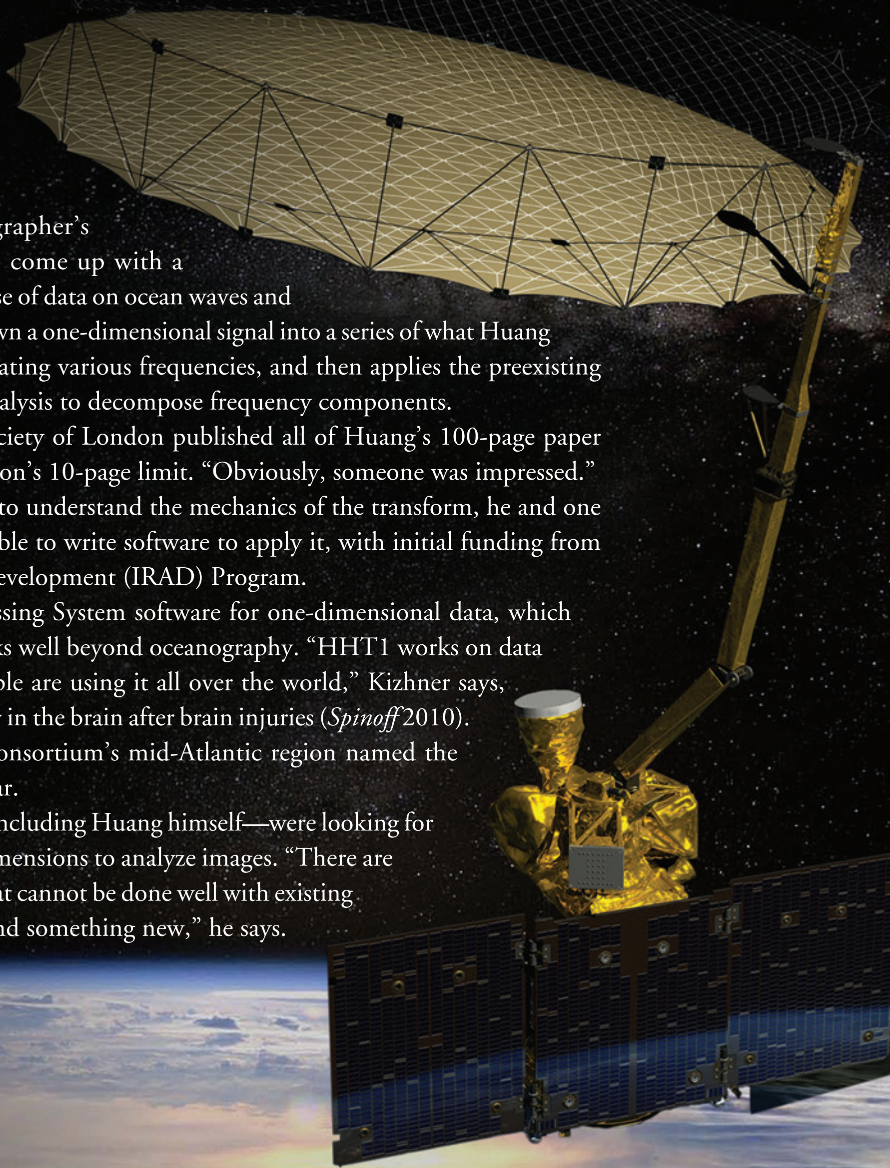
It’s the product of the oceanographer’s nearly four decades of attempts to come up with a transform that could make more sense of data on ocean waves and atmospheric turbulence. It breaks down a one-dimensional signal into a series of what Huang called intrinsic mode functions, isolating various frequencies, and then applies the preexisting one-dimensional Hilbert spectral analysis to decompose frequency components.

Kizhner notes that the Royal Society of London published all of Huang’s 100-page paper on the subject despite the organization’s 10-page limit. “Obviously, someone was impressed.”

Although Kizhner still struggled to understand the mechanics of the transform, he and one of his students, Karin Blank, were able to write software to apply it, with initial funding from Goddard’s Internal Research and Development (IRAD) Program.

The resulting HHT Data Processing System software for one-dimensional data, which can be licensed from Goddard, works well beyond oceanography. “HHT1 works on data like nothing else before it, and people are using it all over the world,” Kizhner says, including to help monitor blood flow in the brain after brain injuries (*Spinoff* 2010). In 2006, the Federal Laboratory Consortium’s mid-Atlantic region named the software Best Technology of the Year.

But Kizhner—and many others, including Huang himself—were looking for a way to use the transform in two dimensions to analyze images. “There are certain things in image processing that cannot be done well with existing techniques, so we always strive to find something new,” he says.



Goddard engineer Semion Kizhner’s two-dimensional version of the Hilbert-Huang Transform was first tried out on the radiometer for NASA’s Soil Moisture Active Passive (SMAP) satellite, where it eliminates radio interference from imagery.

Such a tool could help detect and eliminate stray light and other extraneous data in, say, long-exposure images of deep space. But it might also be able to extract even deeper, more specific information, Kizhner says. He likens it to using an image of illegible handwritten notes to make determinations about the writer's character. "It's very difficult to do."

Following years of attempts, on a camping trip, Kizhner was finally struck by an idea that would let him apply the Hilbert Transform across two dimensions, paving the way for Huang's technique to also analyze frequencies across a plane—a near real-time HHT2 algorithm.

It worked. With a little more IRAD funding and some help from coworkers, Kizhner developed and patented a prototype in the MATLAB programming language. To do so, he developed a way to also extend Huang's empirical mode decomposition to two dimensions—and he sped up the whole thing by writing it as an algorithm that could run on many processing units simultaneously, in near real time. He also implemented a novel Hilbert Transform for two-dimensional spectral analysis.

One of his assignments for his day job was to help design a data processing system for a radiometer to fly on the Soil Moisture Active Passive (SMAP) satellite, which launched in 2015. The radiometer operates in the L1 microwave band, a wavelength that is unaffected by the atmosphere. That same characteristic, however, makes the L1 bandwidth popular for other uses, such as cell phones, which could interfere with the instrument's signals. Goddard decided to try out the two-dimensional Hilbert-Huang software prototype, using it to remove radio interference from the satellite's imagery and recover the data that had been contaminated, rather than simply deleting all contaminated data, as state-of-the-art systems did at the time.

Arlington, Virginia-based Syneren Technologies Corporation collaborated on the effort, and after a year of working together closely, the company expressed interest in commercializing the prototype HHT2 program. Syneren currently holds an exclusive field-of-use license.

One purpose of NASA's SMAP satellite, whose radiometer applies the Hilbert-Huang Transform in two dimensions to filter out radio interference, is to assist with flood prediction.

Image courtesy of the U.S. Air Force

Technology Transfer

It was clear the software's image-processing capability could theoretically be applied to a wide swath of industries, but figuring out the details was better suited to the private sector, Kizhner says.

"I thought it was a great idea for us to continue the research and actually make a commercial product, because if we didn't, this would just evaporate," recalls Meg Vootukuru, Syneren's owner and CEO.

Syneren signed a Space Act Agreement, and Kizhner has consulted with the company weekly ever since.

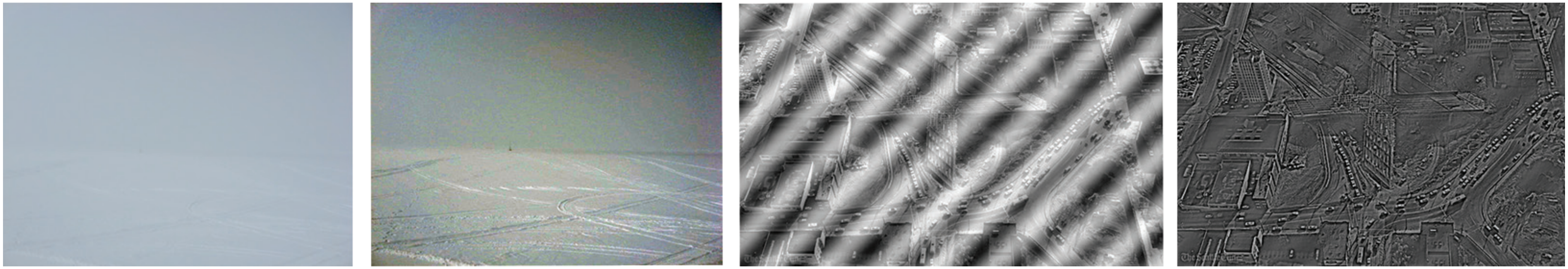
"They extended the software, enriched it, fixed bugs, and put in a lot of work, and they came up with SIETech," Kizhner says, or Syneren Image Enhancement Technology.

To begin with, the company rewrote the software in C++, as MATLAB can be difficult to install and use. "We developed an algorithm and software that makes it easy to commercialize," says Vootukuru, noting that the program can be installed on any hardware platform and leverages multiprocessing to run fast and efficiently.

By the end of 2016, Syneren was in talks with a number of companies and Government agencies about how the software could be tailored to each of their needs. Different clients would need different products, geared toward the solutions they're looking for, says SIETech product manager Richard Williams. "The product is tailorable—we've got to determine what question you're trying to answer. We're open to whatever our clients need."

Benefits

SIETech uses the Hilbert-Huang Transform to sift through different frequencies in an image, starting out by analyzing high frequencies from the entire image and



SIETech image-processing software, based on a two-dimensional version of the Hilbert-Huang Transform created at Goddard Space Flight Center, eliminates "noise" such as haze (left) or radio interference (right). It has possible applications in fields as diverse as medical imaging, weather forecasting, and defense.

> "The whole process removes periodic noise and other obscurants and lets you see edges, features, and patterns you couldn't see otherwise."
>
> — Mark Christman, Syneren

moving to lower and lower frequencies, to identify different features, explains Mark Christman, a senior program manager at Syneren. For example, higher frequencies are often useful for edge detection, and lower frequencies might help distinguish healthy cells from unhealthy ones in a medical application.

"The whole process removes periodic noise and other obscurants and lets you see edges, features, and patterns you couldn't see otherwise," Christman says.

In one demonstration, the software was used to analyze radar images from a storm, and it identified more features and characteristics than the National Weather Service's own image analysis system. Both identified the storm's hook pattern, its debris ball, and some hail, but SIETech also found hail in areas where the weather service didn't, and it was better able to determine the intensity of precipitation and debris throughout the images. "They certainly believed our product had the potential to improve forecast accuracy," Williams says.

When Syneren turned the technology on an inflamed kidney, lower-frequency analysis was able to differentiate between normal and abnormal cells and color-code areas to assist with pattern recognition.

In defense applications, he says, the software can analyze aerial images to distinguish manmade features among foliage, spot footprints or tire tracks, and remove fog or other visual noise.

In the oil and gas industry, SIETech could be used to identify surface and subterranean patterns indicating features that might contain oil. And in oil spill crisis management, it could be used to pinpoint and prioritize areas where the oil is most concentrated, helping to assign resources for oil removal.

The Naval Oceanographic Office is considering using the program in support of its monitoring of sea surface temperatures to distinguish ocean currents, and Williams notes that forest services could use it for monitoring anything from forest fires to vegetation health.

"Just about every industry uses imagery in some way, and this software has the potential to make that more efficient for all those industries," Williams says. "We're just scratching the surface of what this software is capable of."

Kizhner notes that the near real-time speed of his original software design has allowed improvements to the program to be verified quickly, enabling rapid development for new commercial applications.

He thinks the transforms have revolutionary potential that will require decades of work to fully realize—after all, no one even understands yet why they work the way they do. A lot of that work, he says, will come from others. "You have a breakthrough in engineering and science of very general proportions, and eventually people will find applications for it."

Kizhner recalls his own motivation for struggling to apply the Hilbert-Huang Transform to two dimensions: "I tried, and it didn't work. You know what happens with a NASA engineer when he tries something and cannot do it, and people tell him it cannot be done—the next day he starts trying to do it again," he says. "That's what NASA does. It finds things that weren't known before." ❖

"Just about every **industry** uses **imagery** in some way**, and this software** has the **potential to make** that more **efficient** for all **those industries."**

— Richard Williams, Syneren

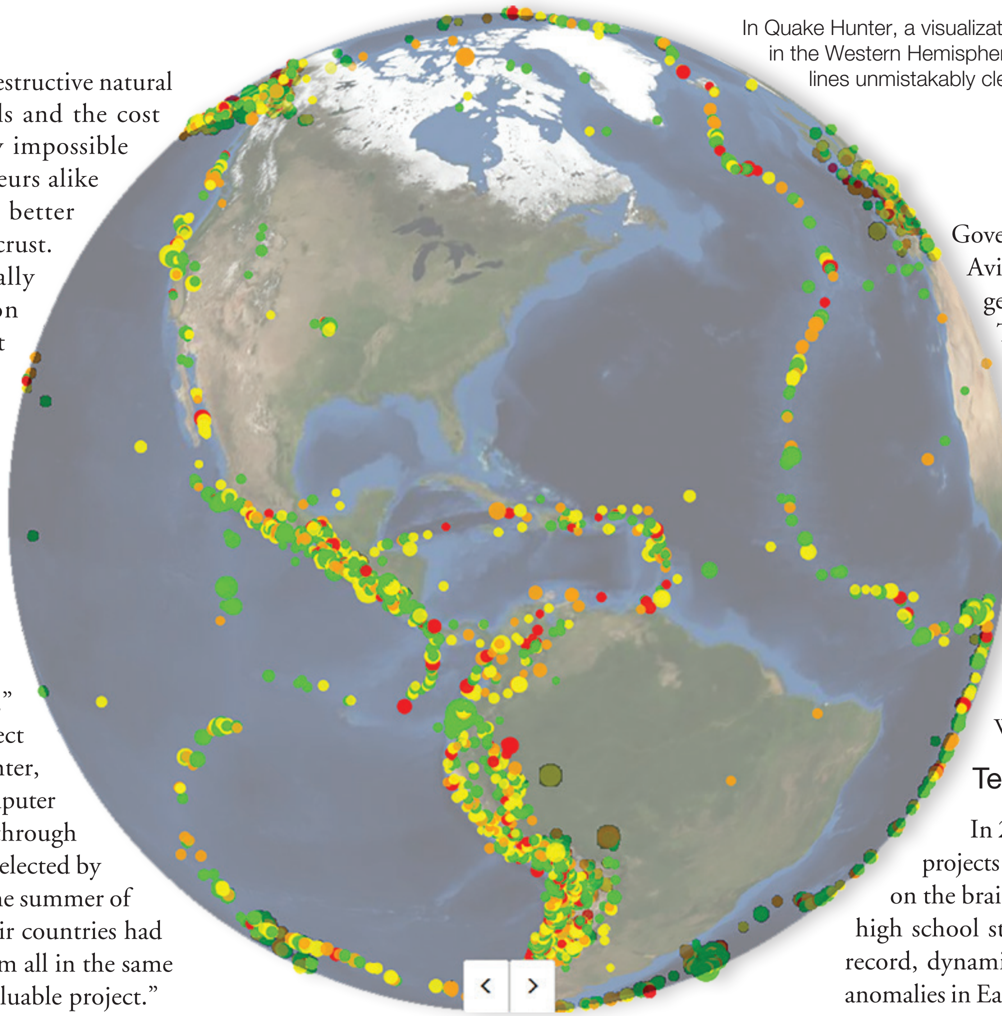
One possible use of SIETech image-processing software is in oil spill cleanups, where it could pinpoint the areas of highest oil concentration and prioritize them for remediation.

Image courtesy of the Federal Emergency Management Agency

Quake Hunter Maps a Century of Quakes Worldwide

NASA Technology

Earthquakes are among the most destructive natural disasters, in terms of death tolls and the cost of recovery. They're also nearly impossible to predict, but seismologists and amateurs alike now have another tool to help them better understand the behavior of the planet's crust. An open source virtual globe originally developed by NASA as an education tool and used by countless government agencies, nonprofit organizations, and commercial entities around the world now provides the ability to track and visualize 100 years' worth of global earthquake data.



In Quake Hunter, a visualization of about a year's worth of earthquakes in the Western Hemisphere, between 2016 and 2017, makes the fault lines unmistakably clear.

Like many capabilities added to World Wind since it was introduced in 2003, Quake Hunter wasn't created by NASA engineers. In this case, NASA interns developed the application.

"I had access to extraordinary talent," says Patrick Hogan, World Wind project manager at NASA's Ames Research Center, referring to the international group of computer science students who were nominated through the NASA I2 Project and competitively selected by NASA to support World Wind during the summer of 2016. "These were the best students their countries had to offer. I was very fortunate to have them all in the same place at the same time to support this valuable project."

The original World Wind, created under NASA's Learning Technologies Program, was a standalone application much like Google Earth, except it preceded the tech giant's product by a couple of years.

It was released under the NASA Open Source Agreement in 2004 and, after moving to SourceForge the next year because NASA's servers couldn't handle all the traffic it generated, the app saw days of almost 100,000 downloads.

With access to the source code, users created hundreds of add-ons to let others explore other planets and moons, follow the Tour de France, track disease outbreaks, or find the locations of castles.

In 2006, a Java-based World Wind software development kit funded by the U.S. Department of Energy made it easier for users to base their own apps on the software. Government agencies snapped it up. The Federal Aviation Administration is building its next-generation air traffic control system with it. The United Nations uses it to track locusts. The Department of Defense is perhaps the biggest user, with many of its branches and agencies using it to manage operations. The European Space Agency recently embedded a group of software developers on the Ames World Wind team to drive further improvements to the web version of World Wind. Major corporations have provided funding over the years, either for features to be added to the kit's core or for assistance in developing their own World Wind-based apps.

Technology Transfer

In 2016, Hogan was considering World Wind projects his interns could pursue. He had seismology on the brain because he'd recently been working with high school students in Alaska to use World Wind to record, dynamically visualize, and archive data for local anomalies in Earth's magnetic field preceding seismic activity, in hope of being able to forecast earthquakes.

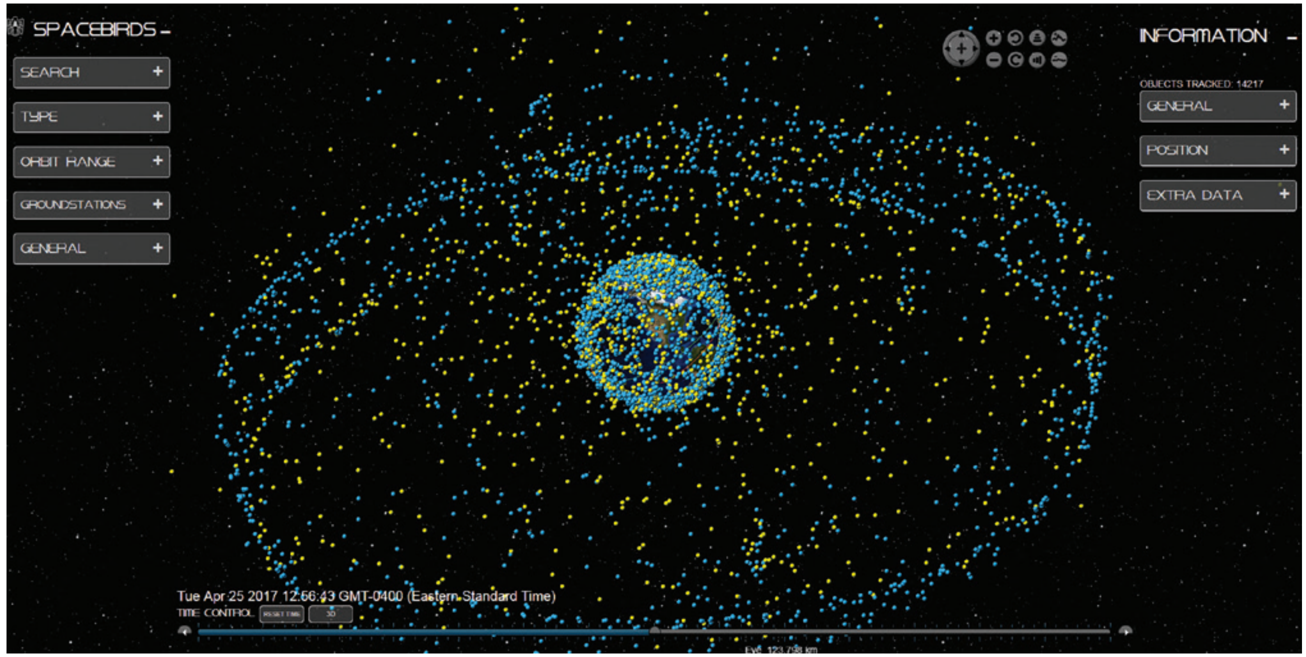
"There's this rich seismic data, and I thought, man, let's do something with that," he recalls.

Hogan also had recently received support from the U.S. Geological Survey (USGS), where that historical earthquake data resides, to allow subsurface data to be visualized in World Wind. The Geological Survey was interested in mapping underground features like wells, fault lines, and aquifers, but this capability would also let the earthquake-mapping application pinpoint not just a quake's epicenter but its hypocenter—the spot within the earth where the rupture occurs. "We only went inside the earth because we could, and we only could because of the USGS," he says.

Starting with this newly enabled model of Earth, the students used USGS data to map every quake in the last century. The Quake Hunter web app is available for download, with source code or not. The user can filter quakes based on a geographic area and ranges of dates, magnitudes, and depths. Quakes are represented by dots of different sizes and colors depending on their magnitude and the date range they fall into. By viewing the planet at an angle, the user can see the depths of quakes' hypocenters.

Hogan notes that his interns succeeded despite this being their first time writing in JavaScript, which he called a testimony to both their ability and World Wind's ease of use.

They also managed to build two other World Wind-based apps that summer—SpaceBirds, which tracks the location of 15,000 or so satellites in Earth's orbit, and WorldWeather, which maps historical, current, and forecasted weather for the entire globe in three dimensions using multiple globes. All three are available as web apps, along with source code.



A visualization of all the satellites in space, as seen with SpaceBirds, another application built on World Wind, reveals dense rings in geostationary orbit and an even denser satellite population just off the planet's surface in low-Earth orbit. The satellite representations move in real time, and their orbits can be tracked.

Benefits

After Quake Hunter was completed, Hogan shared the work with the director of USGS's Innovation Center for Earth Science. Observing color-coded dots representing earthquakes in Italy, he noticed the pattern appeared to be moving northward and correctly predicted the location of the next quake, Hogan recalls. Not all earthquakes are so predictable, but the episode demonstrates some of the value of a visual representation of the planet's seismic history.

"No one has ever had this degree of immediate access to the data," Hogan says, noting that, while the data was publicly available, looking at numbers and coordinates on a spreadsheet is not at all like looking at an image of the data in the context of the real world.

From this, patterns emerge. Observing the depths of quakes in a small area over a long period gives a picture of the nature of the fault line. Hogan notes that a user considering buying a home in an area like California can see how active the area is or whether a quake is overdue. And for anyone who studies geology and seismic data, he says, "it's an extraordinary window into the science. It helps us understand not only Earth processes but also where areas of concern are."

As for SpaceBirds, which pulls satellite location data from the Department of Defense's SpaceTrack server and visualizes it, Hogan says, "I thought it was just a natural for NASA."

For the WorldWeather app, he says, team members pulled data from every publicly available weather-related server they could find. The program allows the user to visualize any number of data layers or place two, three, or four globes side-by-side to look for correlations between different aspects of weather, as well as terrestrial data like soil moisture or vegetation classification.

"What's more interesting than climate change and weather?" Hogan asks, noting that one idea is to help farmers plan watering programs and know what sort of weather they'll be up against. "It's just bringing all the free, public sources of that data into one program."

Some of the interns won funding to go on to create an upcoming CitySmart app, a suite of tools built on World Wind for urban management. One of several partners in the project, which is still under development, is the city of Springfield, Oregon, which asked the team to map its underground infrastructure, and, Hogan notes, this is now possible due to the same upgrades that let Quake Hunter pinpoint earthquakes' hypocenters underground. "If we have an open source program in place that allows cities of the world to work together, that would be amazing," he adds.

"We're doing things for the world that I think really are for the benefit of all." ❖

Free Aerodynamic Simulation Code Supports Industry, Education

NASA Technology

In the mid-1990s, NASA, the Air Force, and McDonnell Douglas Corporation realized they were duplicating each other's efforts to make better software simulating interactions between air and aircraft. So they decided to team up.

Computational fluid dynamics (CFD) software, which simulates the interaction of fluid—including air—with surfaces, was relatively new at the time, and it was not well trusted by many flight engineers, who preferred physical wind tunnel testing to predict aircraft performance. NASA's Lewis Research Center, now Glenn Research Center, and the Air Force's Arnold Engineering Development Complex were each working on their own version of CFD software for spacecraft and formed the National Program for Applications-Oriented Research in CFD (NPARC) Alliance in 1993. The group's first code was called NPARC.

A few years later, McDonnell Douglas, which became part of Boeing, got involved, offering its own CFD program, which ended up becoming the basis for NPARC's Wind code, incorporating features of the other two programs.

"Boeing offered their code technology for us to use but said we had to release it publicly and support it," says Nick Georgiadis, Glenn's technology lead for Wind.

Available for free to any U.S. entity or individual, it was one of the first public, supported, documented, and validated CFD codes for aerospace flow problems and quickly caught on among Government agencies, aircraft and aerospace companies, and universities. The program was primarily geared toward supersonic flight but is also useful in simulating subsonic aircraft.

In all CFD software, the model requires the area occupied by fluid to be broken up into a mesh of cells, and a set of equations are solved within each cell. In the late 1990s, Wind engineers added new capability to model flow problems with an unstructured grid, allowing the mesh to conform more easily to complex geometries, and Wind became Wind-US, which is still available today, even if it's not as widely used as it once was.

"The early 2000s were probably the peak, when there may have been 150 organizations across the country that were using it," Georgiadis says. "It was definitely one of the most widely used codes of any aerospace CFD solver in the U.S."

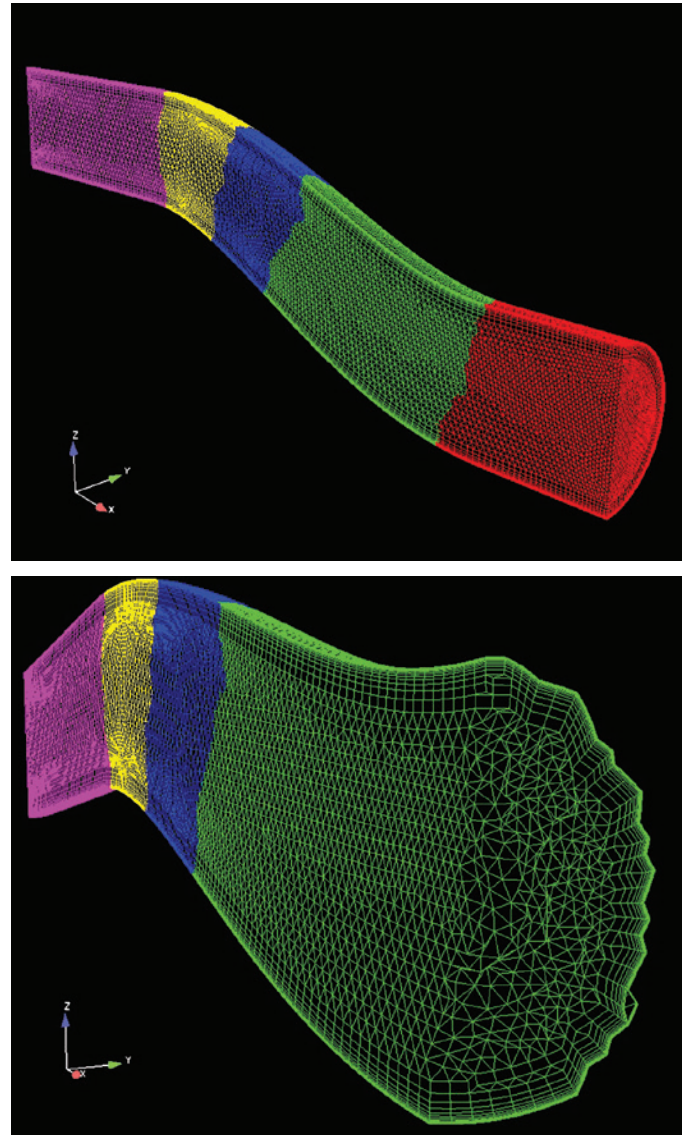
Technology Transfer

One company that still uses the program is Innovative Technology Applications Company (ITAC) LLC, based in Chesterfield, Missouri. President Alan Cain, who founded the company in 1999, began working with the original code at McDonnell Douglas, and chief scientist Chris Nelson, formerly of Arnold Engineering Development Center, got involved around the time Wind was born.

"Maybe 70 percent of the basis for starting the business was access to and understanding of Wind-US," says Cain, who estimates that in ITAC's first decade about half of its work was based on the program, whether using it for consulting or helping clients make their own modifications to it. Those customers have included the Air Force, universities, private companies, NASA, and others. "Having knowledge of the problems that could be solved with the code allowed me to found the business," Cain says.

The company has also made its mark on the software. Part of NPARC's approach is that, while most of the development has been done in-house, outside innovators who use the program, such as ITAC, can also contribute improvements. "Chris would make changes, and then they would be evaluated and tested and become part of the permanent capability available to others later," Cain says.

Boeing has also continued to add to the program, whether through contracts or uncompensated contributions. "They've given us a lot more technology than they've been paid for," Georgiadis says. "We've asked why they stay on, and they say they value our contributions, in particular how we do detailed validation, documentation, and support."



These images from Wind-US show how a jet engine intake duct can be broken into a handful of zones and thousands of tiny cells for analysis. The cells can take on a variety of shapes.

One of many projects in which Innovative Technology Applications Company has relied on Wind-US software was a Navy contract to explore the use of a wavy leading edge, similar to that of a humpback whale fin, on the tower-like "sail" of a submarine.

Benefits

While the use of commercial software for unstructured CFD has grown in recent years, and Wind-US usage is no longer at the levels of years past, the continued meticulous validation of Wind-US's code and its extensive documentation, including the online user manual, still offer advantages over many alternatives, Georgiadis says.

Another advantage is the program's versatility, Nelson says. "The idea was to make this code be a kind of Swiss Army knife for flight CFD."

"There's a lot of flexibility and capability to address a very broad range of problems," says Cain. He notes that Wind-US can be used for steady-state CFD, which provides a sort of snapshot of interactions between fluids and surfaces, or unsteady simulation, which models those behaviors over time. Unsteady CFD is necessary to understand irregular air flows or details of the combustion process, or to calculate time-averaged equations of motion, and it requires "almost unlimited amounts of information," he says.

The program is also able to account for a fluid's compressibility, which has allowed ITAC to carry out contract work in aero-optics, simulating laser behavior in which fluctuations in air density affect the speed of light. The same feature let the company investigate the use of a wavy leading edge—imitating the fins of a humpback whale—on the tower-like "sails" on submarines. Whereas air is compressible, water is not. "By knowing all the ins and outs of the code and having complete control, you can work with the model of equation of state to get water behavior," Cain says.

Several years ago, ITAC did extensive Wind-US-based work for a company called Ramgen Power Systems, which applies supersonic aircraft technology to green energy. As part of the work, Nelson enabled the program to use inputs of known variables like temperature, pressure, and density to calculate unknown variables for different gases. While some other CFD programs have this capability, Cain says, most don't make it quite as easy to recalculate for different gases.

"With a lot of applications, it's not that there are no other codes out there that could do pieces of it," Nelson says. "But this code can do all these things."

Recently, ITAC has used Wind-US to analyze the wind tunnel at the Illinois Institute of Technology to inform changes that would improve control of unsteady flows.

Cain says Wind-US may have had as large an impact through universities as it's had directly on private and Government users. It has been popular with educational institutions, which not only can get the program for free but can access the source code and let students make changes. "Students can get experience and take a job in the industry and continue using Wind-US or now have a good enough understanding of the problems and what they're doing to use other codes," he says.

"We haven't kept track of how many papers have been written by users of Wind-US, but that number is certainly in the order of several hundred over 20 years," Georgiadis says.

In the years since Wind was first built, wind tunnel testing has become more expensive, and CFD has come to be increasingly trusted and relied on, in conjunction with testing. "I think it's one of many codes that helped advance CFD and trust in CFD technology for aerospace problems," Georgiadis says. "It's enabled a lot of successful Government programs and industry efforts as well." ❖

Software Models Atmosphere for Spacecraft

NASA Technology

When the Curiosity rover made its spectacular landing on Mars, most of the attention was focused on the revolutionary "sky-crane maneuver" that helped slow the spacecraft down. But behind the scenes, NASA atmospheric modeling software helped with another make-or-break factor: choosing the landing site. This same software is used for commercial spacecraft to ensure they can fly—and land—safely.

The code is part of the Global Reference Atmospheric Model (GRAM) family of software. The first, Earth-GRAM, was originally developed in 1972, with codes developed later for Mars, Venus, Neptune, and Saturn's moon, Titan.

Boeing says it uses Earth-GRAM on many projects, including to help design the Starliner, a spacecraft intended to shuttle astronauts to the ISS, and to help train the craft's future crew.

"Engineers will input a geographic position and time, and they can also change the input parameters to specify atmospheric conditions, such as the atmospheric dust level on Mars," explains Marshall Space Flight Center's Hilary Justh, a planetary scientist in the Natural Environments Branch who oversees updates and development for the planetary GRAMs. "GRAM outputs include density, temperature, pressure, winds, and selected atmospheric constituents.

"This assists engineers as they design the spacecraft and choose landing sites," Justh says.

Other atmospheric models exist and can give more details, but they take longer. The GRAMs are "an easy way to get a snapshot of what's occurring in the atmosphere," says Justh.

For Curiosity, the entry, descent, and landing team developed a set of acceptable parameters under which the rover could land safely. The mission's Council of Atmospheres, of which Justh was a member, then evaluated the candidate landing sites. "Mars-GRAM was utilized as part of the process to determine which sites met the parameters," Justh explains. Mars-GRAM helped to rule out sites that were unacceptable and allowed the team to focus on the best contenders.

Technology Transfer

As a benefit to the public, NASA offers many of its software packages for free, and the GRAM family is one of them. All the versions are used by researchers, and recently, SpaceX has also become one of the Mars-GRAM users for the Red Dragon spacecraft it plans to send to Mars.

However, the most commonly used version outside NASA is Earth-GRAM, especially among commercial aerospace companies. For example, Boeing, whose aerospace business is based in Berkeley, Missouri, began using the software to work on the Starliner, a commercial crew spacecraft intended to shuttle astronauts to the International Space Station.

The team chose to use the software for the NASA project in part because a database already known and approved by the Agency would help ease approval of the proposal, explains Boeing engineer Thomas Tanita, but now "we use GRAM on many other projects, simply because it's becoming an industry standard."

> "[It's] an easy way to get a snapshot of what's occurring in the atmosphere."
>
> — Hilary Justh, Marshall Space Flight Center

Benefits

"The good thing about GRAM—and the reason why we moved over to it—is that there's a wealth of statistical data that stands behind GRAM, and it's also applicable to many locations around the globe," says Tanita.

Tanita has been working with NASA since the days of the Space Shuttle. Back then, he says, Boeing used detailed models for common landing sites, but they weren't able to generate profiles just anywhere. "With GRAM, we're able to go to any location, any time of the year and have relatively solid statistical information as to what kind of atmosphere on that day for that type of entry for that type of trajectory."

Also, the model can generate thousands of likely potential atmospheres at a given altitude on a given day, he adds. "It allows us to build an operational envelope in which we are confident the vehicle will perform as expected."

GRAM also helps predict how the winds will impact the spacecraft's reentry. "On any given day we have to say we can meet our stipulated touchdown footprint, and having knowledge of the winds allows us to tune our guidance and select the proper flight control that will enable us to meet the requirements," Tanita says.

And because the models are so accurate, Boeing is also using GRAM to simulate the atmospheres for crew members training to fly the Starliner. ❖

Software Takes Cost Estimating to the Stars

NASA Technology

When imagining what it takes to design a spacecraft, few people think about the engineering work that goes into getting an accurate cost estimate before the building begins. And yet, software designed at NASA's Marshall Space Flight Center to do just that has become one of the center's most-downloaded codes.

Every industry relies on cost estimates when taking on a project, whether it's a new car model or planning a menu at a new restaurant. But few estimates are more complicated than those for aerospace, where the industrial base is small and specialized and everything is typically custom-made for its application.

"We use historical data to estimate the cost of a future system," explains Marshall cost engineer Andy Prince, "because in the space arena, you don't have a production-type environment that you can rely on for data to feed your estimates."

A team led by Marshall's Engineering Cost Office has built NASA's latest cost-estimating model, called the Project Cost Estimating Capability, or PCEC. "When you run the model, it will guide you through a process of building a work breakdown structure for your project," Prince says. "Then you can select the cost-estimating relationships, or algorithms, you want to use to estimate the project." For example, the cost-estimating relationships used for a Mars lander would be different than ones for a human spaceflight project or for a deep space telescope.

PCEC was first released in 2014 and has been updated yearly since. It replaces an earlier cost-estimating model designed in the 1990s, the NASA/Air Force Cost Model (NAFCOM)—and it adds a lot of helpful features. The biggest change is that NAFCOM was a stand-alone program, while PCEC works as an Excel add-in, which allows for more flexibility. Users can see all the formulas and even edit them if they want—and, since most offices already have Excel, PCEC is easy to install and use. It is also less expensive to develop and maintain that NAFCOM was.

Technology Transfer

PCEC is available under a general software usage agreement, which means it can be downloaded for free in the United States and internationally.

Dozens of companies, universities, Government agencies, and international organizations have already taken advantage, both because it can be used for any type of space mission and because there are no other publicly available competitors.

"Big companies like Boeing develop their own in-house models, but they're not going to share those because they are considered proprietary and competition-sensitive," Prince says. Likewise, military agencies have similar cost-estimating models, but those are withheld for national security reasons.

Estimating the cost of new spacecraft, like the Space Launch System that aims to bring the first humans to Mars, is a complicated feat. Software designed at Marshall Space Flight Center incorporates the many algorithms needed to do it into an easy-to-use and fully customizable Excel add-in—and has become one of the center's most-downloaded codes.

Benefits

At universities, the software tends to be used in design classes. "Good engineers want to make the most efficient, effective system possible," Prince says, "and this software helps them see that there's a cost dimension that has to be factored into the efficiency and effectiveness of their design."

"Good engineers want to make the most efficient, effective system possible, and this software helps."

— Andy Prince, Marshall Space Flight Center

In the commercial world, Lockheed Martin has found PCEC useful as a cross-check for its own cost-estimating models, especially in proposals for NASA. The company also uses the software as an industry baseline more generally, explains parametrics estimating manager Nichole Renda. "We have a strong in-house parametric and data analytics database of our own history, but there are times we want to get a cross-reference to see how that is trending or compares with industry. We use PCEC as that cross-check or validation tool."

Lockheed Martin had previously used NAFCOM in similar ways, but Renda says the new version will be "used more than NAFCOM, for sure," because of improvements including a better historical dataset and better algorithms.

The increased user flexibility also helps, says Lockheed Martin senior staff engineer Steve Graybeal. "NAFCOM was a little more of a black box. PCEC is a lot more transparent in terms of the data points and the statistics and estimating relationships. It's more apparent what you're doing now with the data." ❖

Communication Devices Ease Contact with Commercial Spacecraft

NASA Technology

Scientific experimentation is the central purpose of the International Space Station (ISS), where astronauts work toward answers that will be crucial to the future of space travel, such as the effects of microgravity on physiology and how exposure to space alters materials. While we've all seen the videos, photos, and tweets astronauts send from orbit, most of the information transmitted between the ISS and Earth is experiment data. As early as 2010, however, the system for downlinking this data was operating at full capacity, limiting the station's ability to carry out its primary mission. Upgrades were in order.

AMERGINT Technologies Inc., a new company at the time, was already making a name for itself, bringing in customers like the Department of Defense and Honeywell. So the Colorado Springs-based startup was ready when it got its biggest break yet: a contract to provide Johnson Space Center with a new data processor to handle a major increase in communications with the space station.

"When we saw that request for proposals, it looked like a really big challenge for us," says company president Rob Andzik. "This was by far the biggest work of our early years."

AMERGINT engineers thought space-to-Earth transmissions could benefit from more flexibility. Spacecraft communications "used to be done with customized hardware and firmware in rigid systems," Andzik explains. Each function would be carried out by one of a suite of complex and costly devices installed in a rack. Instead, AMERGINT came up with its SOFTLINK architecture, consisting of what it calls Software Devices. Each of these is focused on an atomic function—a specific task, such as inverting bits. These software modules can be virtually chained together in various configurations to meet the needs of any given application.

It was this customizable software architecture that won AMERGINT the job with NASA. The company already had a small library of Software Devices in its toolbox when it took the project on, but to finish it, the engineers would have to design many more. In particular, adding CCSDS (Consultative Committee for Space Data Systems) telemetry and telecommand support was critical to meeting the needs of the space community.

Johnson's new Communications Data Processer (CDP), installed and operational in 2013, was part of an overhaul of the entire communications system for the ISS. Upgrades to several components aboard the space station dramatically increased its capacity to relay data to Earth. "The K-band CDP is the most complex communication system we've ever put into the control center," says Jeff Boxell of Lockheed Martin, lead engineer for the Mission Control Center communication system at Johnson, noting that it comprised more than 800 Software Device instances.

The data processor handles about 30 distinct, real-time data streams, receiving, untangling, and distributing an ISS signal that includes video, voice, payload data, and other streams. Meanwhile, it combines command data streams from the control center to send a signal back to the space station. When it was delivered, it had a total data transfer rate of more than 430 megabits per second, about 120 times the speed required for streaming high-definition video. With recently added software, this is now in excess of 600 megabits per second.

The data processor's success led AMERGINT to further NASA work. For example, the company has since built a data processor for NASA's White Sands Test Facility, as well as serial conversion processors for White Sands and Kennedy Space Center, both of which interface with Mission Control.

These are all built using the same architecture and framework and many of the same Software Devices found in the data processor the company built for Johnson, much the way the same LEGO blocks can be used to create an endless variety of constructions, Andzik says.

Russian cosmonaut Dmitri Kondratyev and Italian astronaut Paolo Nespoli take pictures of Earth from the ISS Cupola. Astronaut photography is just one small example of the massive amount of data that streams from the space station to the Communications Data Processer AMERGINT built for Johnson Space Center with its flexible SOFTLINK architecture.

Technology Transfer

By now, AMERGINT's customer base has moved well beyond NASA and the Department of Defense, with clients in space agencies abroad and the private satellite and spacecraft industries, all of whom are benefiting from advances the company made to meet NASA's needs.

"Many of the individual building blocks and the high-performance throughput were developed and tested under the original NASA contract," Andzik says. "This was no small task and proved our architecture is as scalable as we say. These technologies are now part of our commercial

“We’re constantly developing new capabilities for the space station, which we’re always rolling into our commercial line.”

— Rob Andzik, AMERGINT

off-the-shelf products, and we’re leveraging them across the board.”

For the United Launch Alliance (ULA)—a joint venture between Lockheed Martin and Boeing—the company provides data acquisition on the launch pad and boosters for Atlas and Delta rockets. It created modems for the GPS satellite constellation. And AMERGINT supports Boeing’s CST-100 spacecraft. The company also provides technology—mainly software modems—for commercial satellite companies in the United States and abroad.

“From an architecture standpoint, these are all the same in the way the devices communicate, the way we deploy them, and how we manage them,” Andzik says. “The space station work was really our first stress test of the architecture, and meeting those requirements made SOFTLINK a rock-solid architecture.”

It’s also an ongoing process, he says. “We’re constantly developing new capabilities for the space station, which we’re always rolling into our commercial line.”

Benefits

At Johnson, Boxell is already seeing the advantages of AMERGINT’s modular software approach. With previous, more hardware-based data processors, “any slight tweak you had to make to that processor, you had to go back to the vendor,” he says, a process that cost both time and money.

With the new processor, “we’re not only able to modify their processor, but also can introduce our own software on it,” he says, adding that most vendors are reluctant to let clients introduce any software onto their product. Boxell, too, likens AMERGINT’s Software Devices to a LEGO set, and he says the company will build a final model for the client or just offer the pieces with assembly instructions.

After expanding and refining its SOFTLINK architecture to meet NASA’s needs for space station communication, AMERGINT has gone on to provide space communications systems and devices for numerous other Government and commercial clients.

AMERGINT even provides a code template to help users build their own software modules.

Andzik says the company benefited from the rigorous testing and security requirements associated with crewed spaceflight, as well as the prestige that comes with successfully supporting a project as high-profile, complex, and stringent as space station communications. “Our customers are now benefiting from a highly tested and robust system that was developed under this project,” he says.

He notes that products like the modem the company provided for GPS communications and the data acquisition system it built for ULA are completely different types of technology than the data processor at NASA Mission Control, but they benefit from the same flexible architecture that was expanded and tested under the work for Johnson. This both reduces costs and allows users to create their own graphical user interfaces and easily add components and software applications. It was the ISS work that determined the company’s systems were robust and reliable enough for the crewed spaceflight planned for ULA.

“When we started building this architecture we envisioned it working on small systems,” Andzik says. “The CDP changed our target. It showed us how robust our architecture is and enabled us to go after these bigger projects and bigger customers.”

As a small company that had to earn its credibility, Andzik says, “this project in particular has been a major feather in our cap that’s led us into some very prominent programs.”

AMERGINT remains a small company, but with its head count—less than 20 when it undertook its first NASA work—now over 50, it continues to grow, providing mission-critical applications that take advantage of the technology it honed for NASA. ❖

Mission Control Software Manages Commercial Satellite Fleets

NASA Technology

The task of monitoring and diagnosing spacecraft health is getting out of hand.

As satellites and other spacecraft have become more complex, the amount of data they send back, including information about the performance of nearly every component, has mushroomed. Meanwhile, more and more operators are launching not just single satellites but entire constellations that may include dozens of orbiters. Ground crews are left to confront this deluge of data through text-based interfaces on several different computer programs at the same time.

"Most people just plot each data stream they think is abnormal—'This is getting hot at the same time that this is getting hot, so here's what's wrong,'" says Jason Held, CEO of Saber Astronautics, which is based in Sydney, Australia, and Denver, Colorado. "But it's difficult to be conclusive with that evidence. You've got to look at all the different combinations of effects, which no human can do."

By 2012, he and his colleagues had a likely solution to the problem—user-friendly data-mining software capable of modeling and predicting a complex system's behavior. For a spacecraft, Held says, "it takes the data that's coming off these sensors and finds all the relationships between them autonomously."

But the company needed to validate the program against data from an actual spacecraft.

That's where Goddard Space Flight Center's Advanced Composition Explorer (ACE) came in. ACE was launched in 1997 to observe charged particles from the sun, the stars, and other origins, and NASA decided early on that its data would be available to the public.

The spacecraft, which orbits a point between Earth and the sun, has found its most practical use as the workhorse of the space weather community: it warns of solar flares before they cause geomagnetic storms that can disrupt electrical and communications systems on the ground. Warned of an impending solar storm, power companies diminish network loads to prevent damage to transformers, airlines redirect polar flights to avoid radiation exposure, and the military postpones space launches to prevent communications problems.

"One of the reasons why ACE is still funded after 20 years is that so many people rely on the solar wind data," says ACE project scientist Eric Christian.

Information on ACE's system health and performance is also made public, but much of the data is averaged or partial, so Saber Astronautics asked Goddard for the entire archive—15 years' worth—and NASA obliged.

ACE was an ideal test subject because it was of similar size and complexity to most of the day's commercial satellites, Held says. It had also seen some serious action that would allow the company to find correlations between disturbances in the space environment and system performance, and to see how components interact under stress.

Technology Transfer

Saber Astronautics had already successfully used its data-mining software in a number of nonspace applications, such as detecting leaks in a water grid, modeling the stock market, and predicting behavior in bank cash flows.

To prove its applicability to spacecraft, the company trained the program using ACE data from two weeks around the 2003 solar flare that remains the most hazardous space weather event ever recorded, building what Held calls a system map—a model of the relationships between everything that affects anything else on the spacecraft. The engineers then used the model to predict performances for three later periods, including three weeks around another solar flare in 2011.

The company found that a few of its metrics needed to be adjusted, but estimations were nonetheless about 97 percent accurate, even for a period eight years after the training window.

Goddard Space Flight Center's Advanced Composition Explorer (ACE) has been in space since 1997, observing charged particles from the sun, the stars, and other origins. In 2012, Goddard provided Saber Astronautics with the spacecraft's entire data archive, which the company used to validate its data-mining software for use in modeling and predicting spacecraft health and behavior. Following successful validation against the ACE archive, the company set about creating its Predictive Interactive Groundstation Interface software.

> "You've got to look at all the different combinations of effects, which no human can do."
>
> — Jason Held, Saber Astronautics

With that proof of concept in hand, Saber Astronautics started building its Predictive Interactive Groundstation Interface (PIGI) mission control software, which also includes spacecraft monitoring and command functions.

Benefits

To create a user-friendly interface, the company brought a video game designer on board. Instead of spreadsheets, PIGI (the company pronounces it "piggy") has the look of a first-person shooter, with users able to zoom out, see their entire satellite fleet, click on a craft to zoom in on it, and explode the satellite to see its various components. In the case of any abnormal readings, the spacecraft in question turns red, and with a couple of clicks, the malfunctioning parts turn red.

Held notes that many space startup companies are better entrepreneurs than space engineers, and they tend to make mistakes when it comes to operations. The task is made harder when multiple programs are needed for various operations, such as radiation tracking, dish control, and health telemetry, and data streams are displayed as hundreds of lines of text. For constellations the size of some being proposed, up to 50 or 100 satellites, the task would become virtually impossible even for seasoned space engineers.

PIGI consolidates all these functions in one program with an intuitive interface.

"Operational overhead comes down dramatically when you don't need 20 PhDs in the room," Held says, adding that high school students have been able to use the program.

For now, the company is focused on supporting satellite missions. Its first commercial offerings became available in late 2016, in the form of a "casual" license for students and hobbyists, as well as mission control services for satellite companies. The casual license enables mission planning, with software tools to import spacecraft designs, calculate orbits, and model environmental factors like space weather and magnetic fields.

Saber Astronautics' Predictive Interactive Groundstation Interface software can monitor and predict the behavior of systems and countless individual components on entire constellations of satellites, a task that would overwhelm even a team of engineers.

Mission control services can be far more sophisticated, depending on the level of service a company wants. Saber Astronautics can build a high-fidelity system map of a satellite or constellation for the client to use in its own mission control operations, or the company can provide full, real-time cause-and-effect modeling of spacecraft for prelaunch testing and on-orbit operations. Saber can receive and forward a client's satellite telemetry data, or it can use its full diagnostic capabilities to run a customer's satellite operations from ground stations it's planning in northern Canada, Australia, London, and the United States.

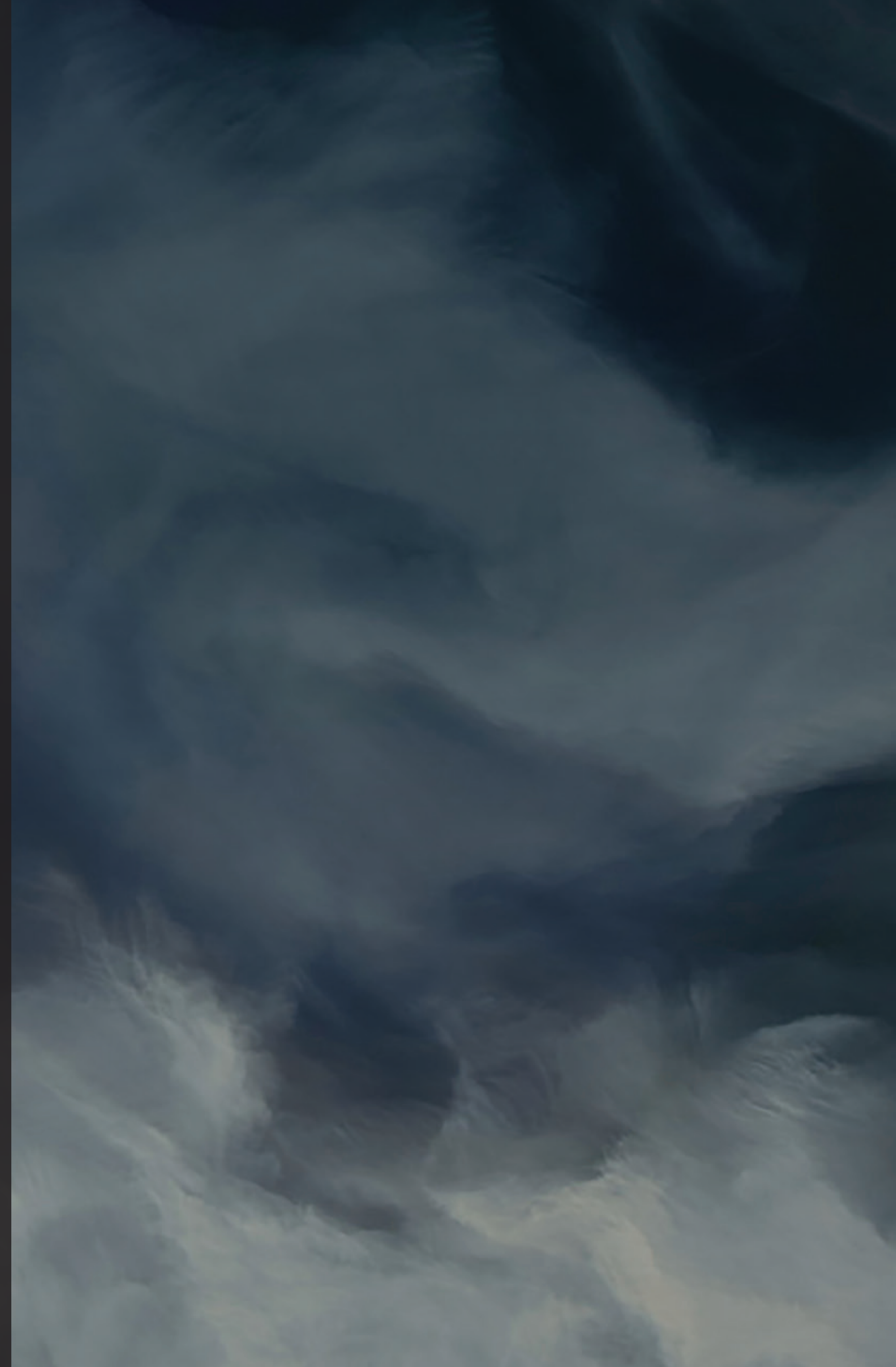
The company plans to start selling a license for small business use by early 2018, which would include most of PIGI's functions short of fully automated diagnostic capabilities. A full, enterprise-level license is expected to be available shortly after that.

In the long term, the company hopes to address the problem of deep-space astronaut missions, such as sending humans to Mars. It takes about 20 minutes for a signal to reach Mars, depending on the positioning of the planets, meaning it could take up to 40 minutes for a malfunction to be noticed by ground crews and addressed back to the astronaut crew.

Normally, Held says, NASA has responded to increasingly complex telemetry datasets by adding more people to Mission Control. "The question we need to ask ourselves is, if the spacecraft is going to Mars, does that really work? And the answer is no," he says. "They're going to need PIGI onboard the spacecraft to keep them alive." ❖

Industrial Productivity

To ensure everything goes right in space—and to fix any problems that arise—NASA pioneers cutting-edge technology that then finds uses in every industry, in every phase of manufacturing. These innovations make our lives safer and even enable research that will power future medical advances, including a tunable light filter designed to facilitate remote sensing that now enables biologists to manipulate microscopic genetic material. They also turn up in unexpected places, like a gold-plating technique improved for space that puts the shine on the Oscars.



High-Speed Cameras Test Material Performances on Impact

NASA Technology

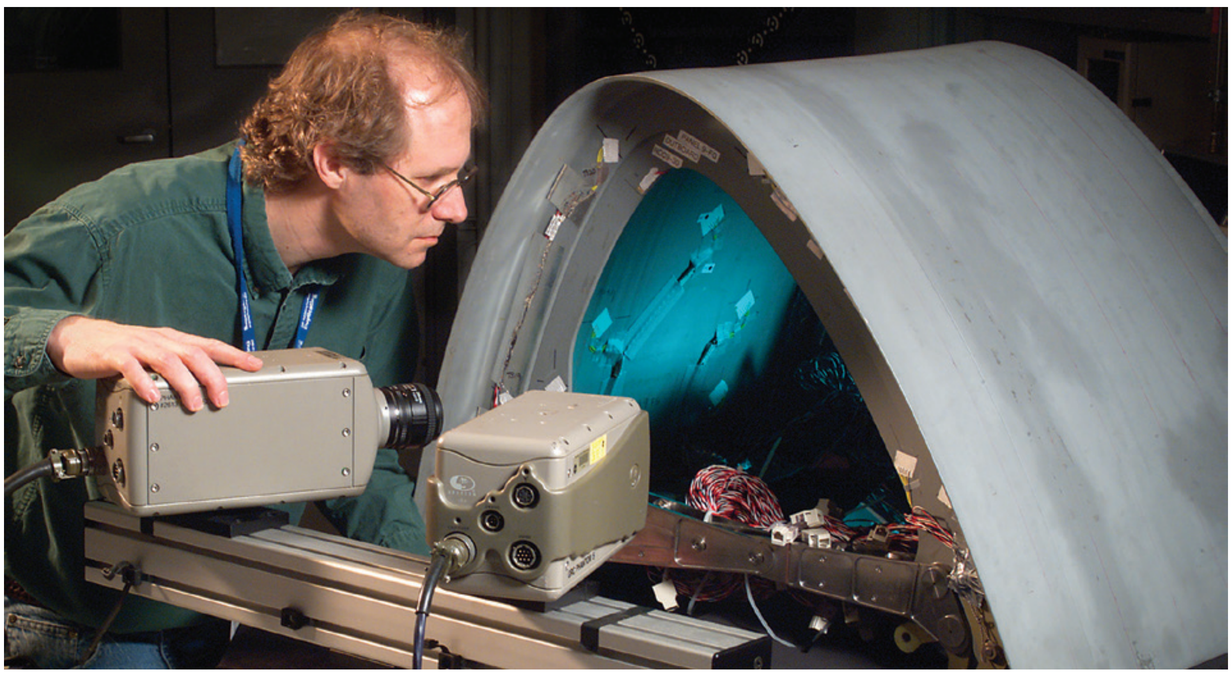
When something goes wrong in space, the results can be tragic. NASA takes the responsibility of testing to understand past accidents and prevent future ones seriously—and one of the tools it helped develop is used to make cars and airplanes safer, and much more.

On February 1, 2003, just minutes before Space Shuttle Columbia was due to touch down, the spacecraft suffered a catastrophic failure—all because of a piece of foam that broke off and knocked into the leading edge of the wing during launch 17 days earlier.

NASA spent months investigating the incident to get the complete picture of what went wrong that day, and Glenn Research Center's Matthew Melis, a ballistics expert who was responsible for part of the investigation, explains that much of the problem came down to a basic tenet of physics: "It's not just how much something weighs, it's how fast it's moving."

The foam was feather-light, and the reinforced carbon-carbon composite on the leading edge was "tough as nails," Melis explains, but the kinetic energy of the moving foam was powerful enough to cause critical damage to the Shuttle's thermal protection system.

Melis and the other investigators went to the lab to recreate the conditions of the accident and studied it carefully, including measuring the foam impact using stereo photogrammetry. The technique uses two synchronized cameras to film an impact, and then software to analyze how the materials deform during the event. Those movements translate to stress and strain.



To investigate the tragic 2003 Space Shuttle Columbia accident and understand how to prevent a future one, a team at Glenn Research Center used high-speed cameras and stereo photogrammetry software to analyze impact. The system, used here in 2004 to test a fiberglass surface on Space Shuttle Enterprise, had to be custom-built to meet NASA's needs.

"It's like using your two eyes to know where something is in 3D space," explains John Tyson, president of the company that built the stereo photogrammetry system NASA used. "With two cameras, we can precisely measure if something comes closer to you or goes further away, and can estimate the distances it's traveling."

The Columbia investigation team was able to not only show what happened to the reinforced carbon-carbon leading edge when the foam hit, but also predict what would happen in other circumstances if debris hit the Shuttle. They coordinated with the Debris Assessment Team at Johnson Space Center to come up with a list of different materials that might come off the Shuttle exterior, from foam to ice to tile putty, and what might happen if it hit.

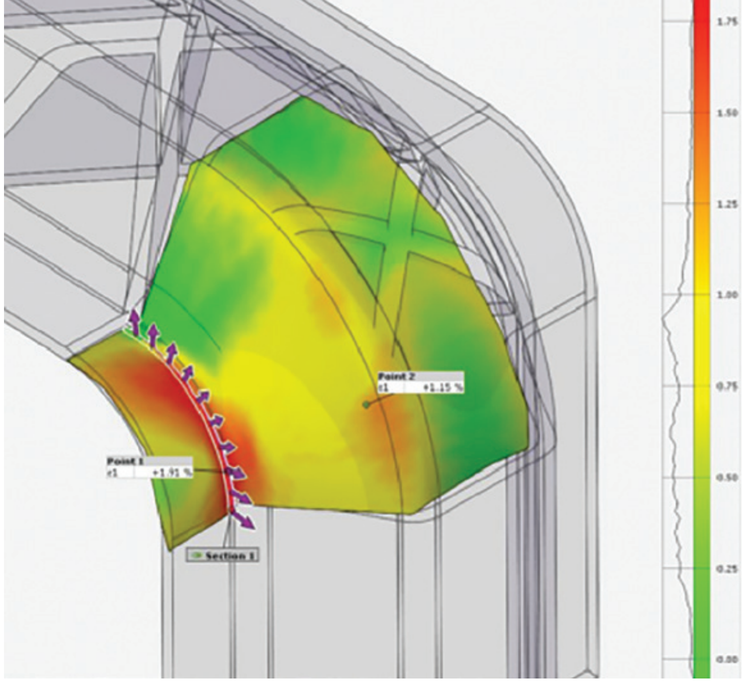
Using stereo photogrammetry, computer models, and other tools, they tested to see which impacts could cause critical damage and then recommended changes to the Shuttle structure to decrease the risk. "So if we said, 'That's too big a piece of foam,' they'd make changes: make that location of foam thinner or eliminate the piece altogether," Melis says. In one case, engineers had to increase the thickness of two windows by an eighth of an inch to ensure they wouldn't fail if they were struck by foam debris.

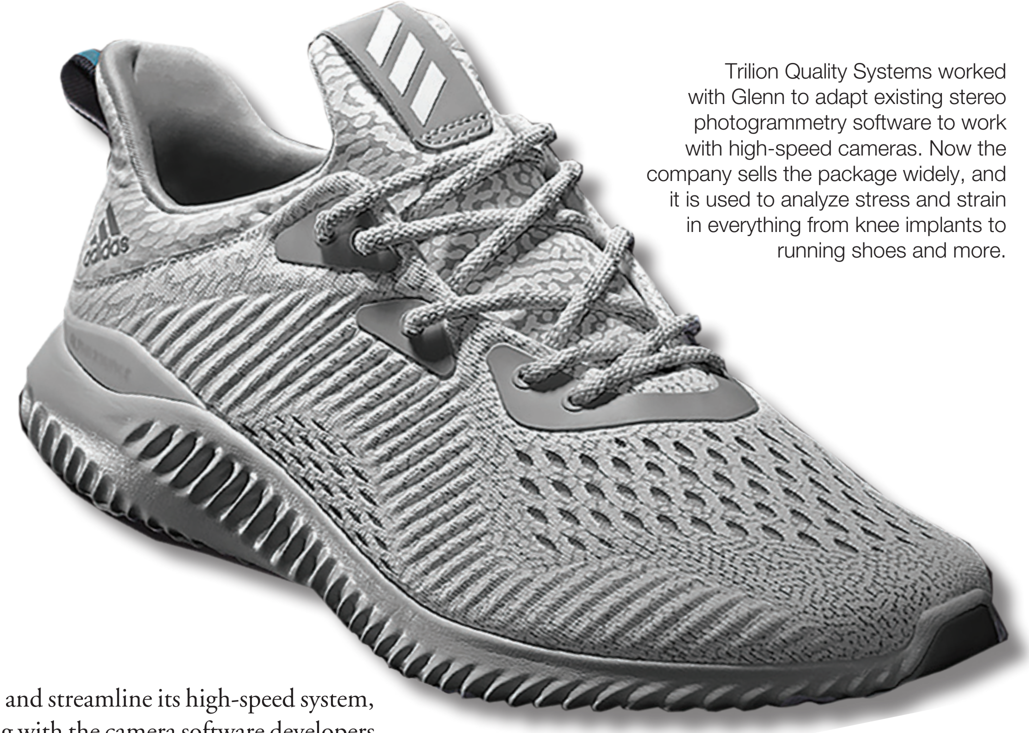
Finally, after two years of testing and analysis, NASA felt confident it could safely resume Shuttle flights.

Technology Transfer

Stereo photogrammetry was not a new technique in 2003, when the Columbia investigation began, Melis says. In fact, NASA had already been using it for a variety of purposes—but the existing technology wasn't going to cut it for the ballistics investigation.

ARAMIS, the photogrammetry software NASA uses, was able to analyze video of about 15 frames per second (fps). "That's relatively quick," says Melis. "But it didn't have the ability to work at 30,000 fps," which is the speed





Trilion Quality Systems worked with Glenn to adapt existing stereo photogrammetry software to work with high-speed cameras. Now the company sells the package widely, and it is used to analyze stress and strain in everything from knee implants to running shoes and more.

needed for “a ballistic event on par with what Columbia experienced.”

To get to a high enough frame rate, Melis says, there were two problems to solve: one, they needed a technique for calibrating and synchronizing the high-speed cameras, and two, they needed an efficient way to transfer the images from the high-speed cameras into the software so it could perform the calculations. Typically, cameras would save the video directly to the computer, but high-speed cameras downloaded the video to an onboard memory drive.

Melis began talking with Philadelphia-based Trilion Quality Systems, the sole U.S. distributor of the German-developed ARAMIS, asking them, “What can you guys do to get us hooked up to high speed?” The timeline was short, because NASA was eager to get answers and make the changes needed to return the Shuttle safely to flight.

Trilion set up shop at Glenn and got started. “It was a lot of little issues,” Tyson recalls. For example, “we had to get the high-speed camera companies to modify their software so it worked with our software.”

“We spent about two months getting it working,” Tyson says, including initially building intermediary software, “and then we kept fine-tuning it.” Since then, Trilion has continued to improve and streamline its high-speed system, including coordinating with the camera software developers and the company that developed ARAMIS so that the two components work together seamlessly.

Now, Tyson says, high-speed ARAMIS systems represent about 20 percent of Trilion’s business, and “it all started with NASA Glenn.”

Benefits

One of the most important uses of high-speed stereo photogrammetry, or as Trilion calls its system, high-speed digital image correlation, is for materials testing. “In all industries, you take a piece of a material and you stick it in a machine that pulls it apart, and when you pull it apart you understand how it stretches and fails,” Tyson explains.

To measure that very precisely, engineers typically would place strain gauges and other sensors directly on the surface during the testing. However, those sensors can only provide discrete measurements at a finite set of points. The results are put into computer models that can extrapolate the impact across the sample as a whole, but the results are only as good as the computer models and can miss something entirely if a sensor is not placed at the right spot. In contrast, using stereo photogrammetry, the software can take measurements across the entire surface all at once. “Instead of looking at a single point, you look at 10,000 points and get a much better understanding of what’s really occurring,” Tyson says.

Those measurements can be used to verify the computer model used with the physical sensors, or it can replace them entirely.

By understanding the materials better, Tyson says, manufacturers are able to improve performance and safety. For example, “years ago, cars were all just made of steel,” Tyson says. “Today there might be 50 different materials inside your car, each doing something different. That’s increased the safety of vehicles significantly, just by changing the materials.”

Trilion sells its systems to a wide range of industries, from car companies to orthopedic implant manufacturers to military contractors.

When Adidas wanted to design a new high-performance running shoe, it used the high-speed ARAMIS system to analyze Olympic marathoners’ feet as they hit the ground at full speed—first in bare feet and then in shoes. "One of the things they saw was that a normal shoe constrains the ball of your foot and your Achilles tendon—as you're running, your shoe is pushing against that tendon," Tyson says. "So they made a v-shaped opening at the back of their shoe so the tendon is free to move."

The shoe company also tested different materials to choose one that would allow the ball of the foot to expand with impact. "They studied the actual foot and then designed a shoe that would match the true motions of the athletes."

After the wing broke at the root during simulated flying to test at 120 percent strain, Boeing used Trilion's systems to confirm its Dreamliner 787 was structurally sound. Ford used the system to test the materials for its F-150 trucks when it wanted to switch the body from steel to aluminum—the lighter material saved money and increased fuel efficiency, but the company wanted to ensure it wouldn't compromise the toughness of its signature trucks.

In addition to providing detailed and accurate measurements across a surface, Tyson says, the high-speed ARAMIS system saves money. A strain gauge might cost \$1,500, he explains, which is less than the \$100,000 startup cost of an ARAMIS system, including the software, cameras, and setup. But over time, it ends up costing less; both in the labor costs of running the system and the cost of sensors. According to an estimate from Boeing, he says, they found an ARAMIS was 10 times cheaper than buying and replacing sensors, and required a fiftieth of the labor.

It has sometimes been challenging to convince a new customer that a pair of cameras can measure tiny movements as accurately as sensors, Tyson says, but that's where the company's NASA bona fides have been a big help.

"There's no question that that's a big gold star on what we do: that we helped the Space Shuttle fly again." ❖

Ford used Trilion's impact-testing system when it wanted to change the F-150 truck body from steel to aluminum. The lighter material saved on cost and fuel, but Ford wanted to ensure it wouldn't sacrifice toughness.

External Platform Enables Space Research

NASA Technology

Not all the research on the space station happens on the inside. A good portion of the investigations take advantage of the orbiting outpost's perch some 250 miles above Earth's surface, testing how materials perform outside our atmosphere or just taking in the view. As the commercial space industry grows, more and more companies need that platform—and a new module that deployed in 2016 is expanding the options for all.

NASA has been conducting external space research nearly as long as it's been sending objects into space. George Nelson, who manages the International Space Station (ISS) Technology and Science Research Office at Johnson Space Center, likens the method to how road builders test materials: "They learn just by putting the materials in the relevant environment," he says, "and look to see how they hold up to road traffic, heat, cold, and so on."

In the same way, new materials or materials that have never been used in space are placed on a research platform on the outside of a spacecraft for a given period of time and then observed for the effects from radiation, vacuum, and extreme heat or cold. Electrical and other components are also tested to ensure the wiring and other features are rugged enough to survive harsh radiation.

And external platforms on the space station are a good perch for Earth-, sun-, and star-observing instruments, which, unlike on a satellite, can be replaced with different instruments or, in some cases, brought back to the ground and repaired.

Technology Transfer

Airbus DS Space Systems Inc. has plenty of experience building external payload platforms. Originally established in Washington, DC, in 1973, the company moved to Houston to support the Shuttle program in the late 1980s, where it built much of its payload platform experience working for NASA. "We have a long history of external carriers going up in Shuttles," recalls Carl Kuehnel, technical programs director for Airbus DS. "We have two already attached to ISS," he adds, External Stowage Platforms 2 and 3.

Their latest external platform is also designed to attach to the space station, but this time the money didn't come from NASA.

"This was basically conceptualized in 2012, between our company and NanoRacks. We were contracted to design and develop it," Kuehnel says. NanoRacks did have a Space Act Agreement with NASA, which provided some resources, but the project was funded, and is now being operated, commercially.

Nevertheless, the company's previous NASA work was helpful: thanks to that experience, "we understand external environments, and how to build electronics for an external environment," Kuehnel says.

This external payload platform, built by Airbus DS Space Systems Inc., is small enough to be assembled on the ISS, sent in and out through an airlock, and maneuvered by a robotic arm, making it less expensive and easier than ever to send samples for testing or mount imagers in space.

Benefits

The new NanoRacks External Platform, or NREP, which became operational in August 2016, works a little differently than its predecessors. In particular, the platform was small enough to be assembled inside the space station, sent through an airlock, and installed using a robotic arm controlled from the ground. After the test period ends, the platform will be brought back inside the station the same way, to gather test samples and load the next batch.

That's a huge cost savings, because it means astronauts don't need to suit up for spacewalks to set up or retrieve the device. "We're looking at 15-week-type missions," Kuehnel says, adding they "expect to have two airlock cycles a year."

NanoRacks manages the platform and seeks out clients, but Airbus DS collaborates to help with interface testing and development of the payloads. That's an important part of the process, because the external platform is much more than a spot to park material, Kuehnel says. "NREP is quite a sophisticated unit. It's able to communicate with the payloads, get data from them, command them, stream data back," all using the external Wi-Fi installed on the ISS—the first platform to use that Wi-Fi.

NREP has nine slots, each 10 by 10 by 40 centimeters, and they can be configured to handle payloads of different combinations and sizes.

The first set of commercial payloads was brought back inside in spring of 2017, and Kuehnel said another three would be ready for the second cycle.

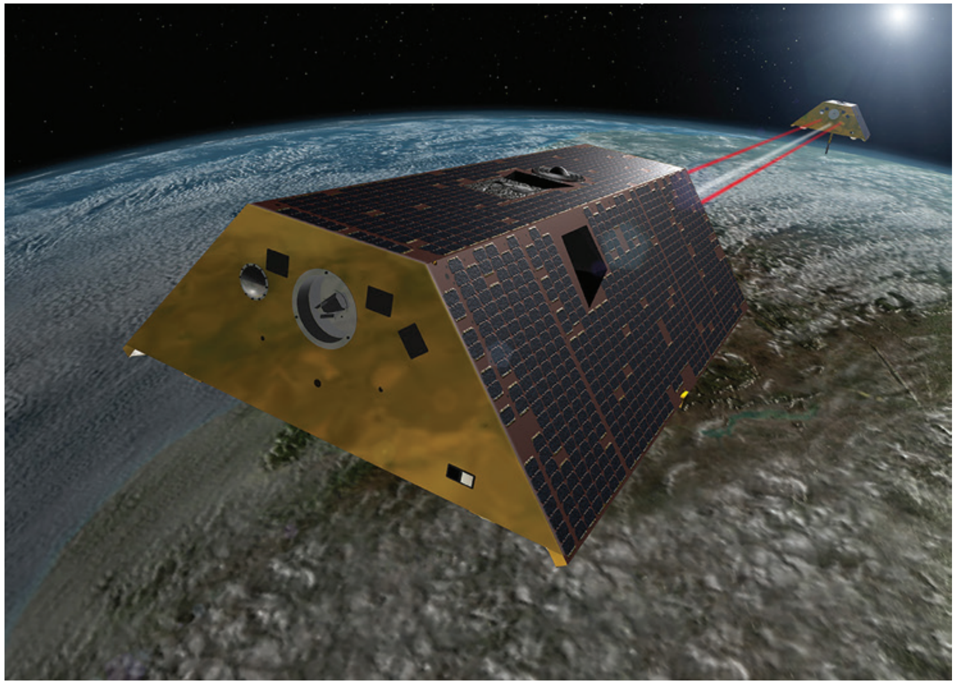
"I think for this size payload, people are starting to understand this is an easy, cost-effective way to get up onto orbit and be operated in the outer environment." ❖

All-in-One Lab Device Gets New Instruments via Software Update

NASA Technology

Devices for testing electronics haven't changed much in decades, and this presents an inconvenience not just for the engineers using them but for the electronics industry, says Daniel Shaddock, CEO of the startup Liquid Instruments. He thinks clunky equipment may also drive down recruiting. "Kids grow up using iPads, and then they get into the lab in college and it's like the Soviet era," Shaddock says, describing ungainly user interfaces with multitudes of knobs and buttons. "They get turned off and move on to other things."

So his company set out to improve test and measurement equipment and ended up with its Moku:Lab, a device that can reconfigure itself to be several different instruments and even use an iPad as its interface.



The engineers at Liquid Instruments gained much of their experience designing instruments for the Jet Propulsion Laboratory's Gravity Recovery and Climate Experiment Follow-On mission, which maps Earth's gravity field by using a laser interferometer to register tiny changes in the distance between two orbiting satellites.

Shaddock started his career as a postdoctoral researcher at NASA's Jet Propulsion Laboratory (JPL) in 2002, working on the Laser Interferometer Space Antenna (LISA), a joint project between NASA and the European Space Agency. Shortly, he says, he was made the project's interferometer architect.

LISA's task was daunting: three spacecraft more than 3 million miles apart were to detect gravitational waves that might affect their positions relative to each other by distances smaller than the width of the atoms that made up their instruments. To do this, they would have to correct for any extraneous "noise," including more than 30,000 miles of drift among them annually. "When I first heard about it, I thought it was crazy," Shaddock says. "Nobody could do this."

But it wasn't impossible. NASA substantially reduced the scope of its involvement in LISA in 2011, but the European Space Agency continues to work on it and hopes it will launch in the early 2030s. (In September of 2015, meanwhile, the National Science Foundation's ground-based Laser Interferometer Gravitational-Wave Observatory, using similar technology, became the first instrument to detect gravitational waves.)

At the heart of LISA's instrumentation is a phasemeter that measures the difference in phase of two incoming light signals down to a millionth of a wavelength. A phasemeter is also an instrument used in electronics testing and measurement and one of the instruments Moku:Lab can transform into.

After funding for LISA was cut, a number of the project's engineers were assigned to the Gravity Recovery and Climate Experiment (GRACE) Follow-On mission, also run out of JPL, which uses a similar technique to map Earth's gravity field. Shaddock was among them, although he moved back to Australia. There, through a partnership between NASA and the newly formed Australian Space Research Program, he led a team of about a dozen researchers at the Australian National University's Centre for Gravitational Physics, adapting the LISA phasemeter's field-programmable gate array (FPGA) processor for the GRACE Follow-On.

The Australian space program, however, was short-lived and ended in 2014. "I was left with all these very talented engineers," Shaddock recalls. "We looked at the technology we had and thought, 'Is this useful to anyone else?'"

Technology Transfer

Shaddock's team had gained extensive expertise in signal processing and chip programming under the GRACE Follow-On, and many of them under LISA as well, but the turning point came when one team member figured out how to remotely make an FPGA reconfigure itself for different purposes. FPGAs are computer chips that are not preprogrammed but designed to be configured by the customer. "She could run an entire experiment from her office," Shaddock says. "Eventually, she could run it from bed."

With funding from a couple of venture capital firms, the team founded Liquid Instruments, based in Canberra, Australia, and set about building a commercial product. Shaddock says the switch from academia to the commer-

> “It’s like the difference between a typewriter and a computer.”
>
> — Daniel Shaddock, Liquid Instruments

cial market was a challenge, but experience in designing instruments to survive in space went a long way to help the engineers develop a device that was small and sturdy.

The university exchanged the intellectual property that went into the devices for a small amount of company equity. The company promised investors to get a product to market within a year and sell an initial run of 60 devices, which it did in 2016—even though, Shaddock says, “we found out later they didn’t think we had a chance” of meeting the deadline.

The initial Moku:Lab devices could reconfigure into three instruments: an oscilloscope, a spectrum analyzer, and a waveform generator. Each of these devices would normally require its own circuit board and programming.

Because Moku:Lab’s hardware is reconfigurable, though, as the company develops configurations for more instruments, users can simply download them. And the company offers them for free, to the annoyance of some investors, Shaddock says. “But the benefit to us is that customers love us so much they recommend us to others, rather than us trying to nickel-and-dime them.”

Moku:Lab can now switch between eight common electronics test and measurement instruments, including a phasemeter, a data logger, and a lock-in amplifier, and the company hopes to make it a 20-instrument device by the end of 2018.

Shaddock recalls a recent technology event he attended, where he met a competitor who sells lock-in amplifiers for around $50,000. “And we just gave one away for free for our $5,000 device,” he says. “Those guys looked kind of worried.”

Benefits

“It’s like the difference between a typewriter and a computer,” Shaddock says, comparing his company’s all-in-one device to its predecessors.

By combining several expensive instruments in one affordable package, Moku:Lab offers enormous cost savings, but Shaddock notes that it also saves the time it would take to change out instruments and to install the software to support them. “We want to almost be like an appliance, where you just plug it in and turn it on,” he says. A slick, iPad-based user interface and Wi-Fi capability are also advantages.

The Moku:Lab replaces stacks of electronics test and measurement instruments with a single, small device that uses an iPad for its user-friendly interface. The device reconfigures its computer chip to essentially transform itself from one instrument to another.

The company has identified four target markets, the first being “people like us,” Shaddock says. These are engineers and physicists in research and development divisions, federally funded labs, and universities.

The next intended market is education, where Shaddock, a physics professor himself, hopes to help attract the interest of more students and enrich science, technology, engineering, and math curricula around the world. He envisions high school students using the device for debugging and trouble-shooting electronics, and the company is developing college lab experiments, which it plans to offer on its website for free.

In the industrial market, electronics manufacturers use various devices to test and measure products coming off the line, with workers switching between instruments at each workstation. Shaddock imagines a Moku:Lab at each of hundreds of workstations instead, all carrying out the functions of several instruments and recording test results at the commands of a central computer.

Finally, Liquid Instruments would like to get back into the aerospace industry, where remote testing is often necessary and any weight savings from reducing the number of devices on a spacecraft would be highly prized.

Having sold out its initial product run, the company found a larger manufacturer and hoped to sell about 600 new and improved units in 2017 and then 6,000 in 2018.

Shaddock told investors he expects tens of millions of dollars in revenue over the next few years. Given that the company is threatening to disrupt an industry that represents about $10 billion in annual sales, he has reason to be optimistic. “And if we hit $1 billion,” he says half-jokingly, “I’m going to come back and fund LISA myself.” ❖

Gold Coating Keeps Oscars Bright

NASA Technology

The Academy Awards ceremony is probably the last place most people would look for NASA technology, but it turns out the Space Agency has had an impact even on the glammest of Hollywood red carpets: the coveted Oscar trophy is coated in the same gold that helps telescopes glimpse distant galaxies.

For space missions, gold has a few qualities that make it particularly useful. For one, it's good at reflecting infrared wavelengths of light, which help to detect celestial objects from very far away. Even better, says Goddard Space Flight Center physicist Jim Tuttle, "gold is really inert. It doesn't oxidize at all." That means it won't tarnish or change over time, unlike aluminum or most other metals.

Because of both of those properties, gold is also a good way to block the absorption of radiant heat, which can be a problem in space: "the shinier and more reflective something is, the less heat it absorbs from its surroundings," Tuttle notes.

For all those reasons, the James Webb Space Telescope, the successor to the Hubble telescope, due to launch in 2019, uses a lot of gold, and not just on the spectacular main mirrors. The telescope's designers also called on gold to coat a 32-foot refrigerant tube that cools the Mid-Infrared Instrument, or MIRI.

The instrument houses an infrared camera and medium-resolution spectrograph that will help astronomers detect and reveal physical details of newly forming stars, comets, and objects in the Kuiper Belt. But to do all that, MIRI must be kept extremely cold: just six degrees above absolute zero. That's because heat also shows up as infrared light, explains Goddard engineer Kimberly Banks, who worked with John Gygax and Shaun Thomson on Webb's thermal systems. To detect faint light signatures from far away, the detector needs to eliminate all the stronger heat signals around it.

Most of Webb will already be operating at a chilly -387 °F, or 40 Kelvin. To get MIRI down to 6 K, the refrigerant tube circulates gas through heat exchangers. The tube's gold coating helps to keep the gas from absorbing heat from the rest of the telescope.

The most common method for gold coating is by vapor deposit—when the metal is heated in a vacuum until it becomes a gas, which then condenses in a thin layer across a surface. The process is effective but does have drawbacks. For one, gold loses some of its reflectivity during vapor deposition—meaning the resulting coating would absorb an unacceptable amount of heat.

Beyond that, the gold becomes extremely delicate. "We've seen many times over the years, that somebody will put a nice gold coating on something, but as soon as you bend it, all of a sudden a whole layer of gold will peel up and flake off," says Gygax. Not only does that lower reflectivity, but the flakes can interfere with sensitive instruments.

Technology Transfer

Long-time NASA partner Epner Technology, a Brooklyn-based family business that has been gold-plating everything from jewelry to missile components for three generations, seemed to be the best option, Gygax says.

Gold is highly reflective and doesn't tarnish—great for the James Webb Space Telescope's main mirror but also to block radiant heat from instruments in the telescope's interior. Longtime NASA partner Epner Technology didn't coat the main mirror, but its extremely durable and shiny plating was perfect for a cooling tube in the interior.

Some Oscar winners found the gold coating wore off over time. In 2016, Epner Technology began gold-plating the statuettes, using a technique improved in part for the Mars Orbiter Laser Altimeter. Epner guarantees the coating for life.

The company claimed its gold would never flake off, but, says Gygax, "we were hesitant. That's why we made him prove it to us—and he did." The company also boasted its gold plating was significantly more reflective than vapor-deposited gold. Again, the Goddard team wanted to be sure, so this time they turned to Tuttle, a cryogenics researcher who designed an experiment that showed the reflectance would be sufficient at its extremely low operating temperatures aboard Webb.

In fact, the plating achieved its hardness and reflectivity in part thanks to work Epner did for NASA more than two decades before.

Epner uses an electroplating process it calls LaserGold, because it first used the technique to coat laser components. The company has been gold-plating NASA spacecraft components at least since the first GOES (Geostationary Operational Environmental Satellite) weather satellite in the 1970s.

"In our system, we have a tank with an electrolyte solution of gold cyanide, an anode, and the part to be gold-plated, the cathode. A direct current power source 'drives' the positively charged gold ions to the negatively charged cathode where they collect an electron and return to their pure gold state," explains company President David Epner. The resulting coating was already harder and more reflective than vapor-deposited gold, but both attributes have been improved through the years. One key improvement came in the early 1990s, when NASA needed to gold-plate a mirror for the Mars Orbiter Laser Altimeter (MOLA) and told Epner it needed better reflectivity without losing strength (*Spinoff* 1997).

At around the same time, the team building the Keck Observatory, a pair of powerful land-based telescopes, was planning to gold-plate its secondary infrared mirror and needed additional hardness to ensure it was cleanable without any scratching. (Keck was not a NASA mission, though the Space Agency later joined as a partner.)

To meet the needs of both aerospace projects, Epner tweaked its proprietary processes to ensure the highest possible reflectivity while also achieving a hardness triple that of pure gold.

"Normally when you want to harden a gold, you add nickel or cobalt, and it becomes an alloy," Epner explains. "It's hard as hell, but the reflectivity plunges. The problem is creating a pure gold that is also hard."

The trick, Epner explains, was in modifying the electric current to get a more tightly packed atom. Because the gold remains pure, the reflectivity remains extremely high.

Benefits

The improved technique convinced both the MOLA and Keck teams, and Epner has been using it for its varied commercial clients ever since.

In the medical industry, Epner coated light pipes for Braun ear thermometers and for a turning mirror on the end of a catheter used to laser-ablate enlarged prostates.

In public health, Epner uses electroforming to create infrared carbon dioxide detectors. Epner also plates an infrared mirror on missile guidance systems and an infrared jammer on Apache and Cobra helicopters, among other defense applications. And the company continues to work on sculptures and jewelry, including working with a designer who crafts unique creations using gold-plated lace.

In 2016, Epner's reputation for durable and brilliant gold coatings, built in part through its many years working for NASA, brought a new client: the Academy of Motion Picture Arts and Sciences. "They were awestruck that we were going to give them a gold that had been in space for 30, 35 years," Epner recalls.

For more than three decades, a trophy manufacturer cast the Oscars in a tin alloy and then plated them with gold. They shone—but the coating wore off. "They were seeing a steady stream of winners returning their Oscars for replating," Epner says. "My company replated three of them directly for the recipients."

When the Academy came to Epner, "we guaranteed that our gold coating will never come off." In fact, Epner has offered a lifetime guarantee to replate, for free, any Oscar that starts to show wear. "That's something I'll never have to make good on," he says. ❖

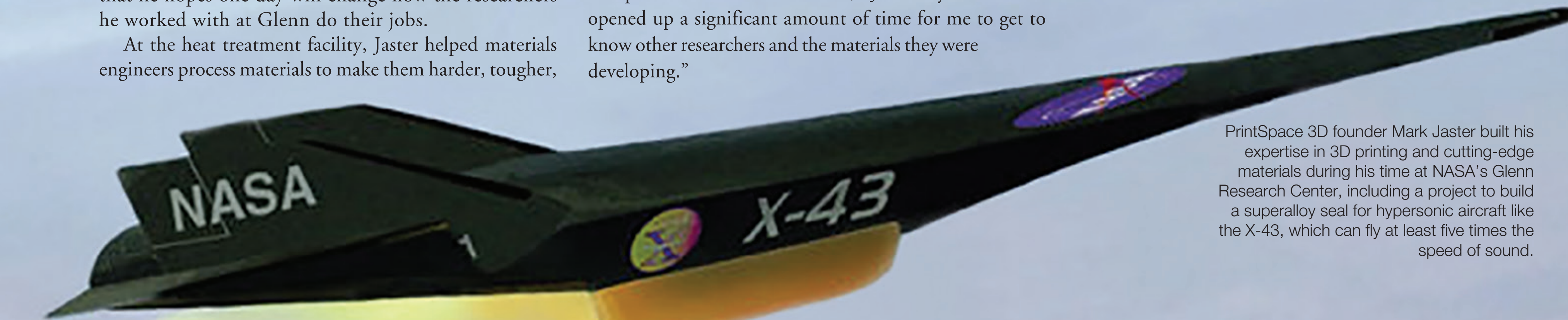
3D Printer Aims to Accelerate Materials Development

NASA Technology

When Mark Jaster was a brand-new graduate, he landed a coveted job at NASA's Glenn Research Center after two summer internships there, in the heat treatment facility. A decade or so later, Jaster continues putting the skills and knowledge he learned to good use, building a high-end 3D printer that he hopes one day will change how the researchers he worked with at Glenn do their jobs.

At the heat treatment facility, Jaster helped materials engineers process materials to make them harder, tougher, and stronger as needed. "It sounds like a mundane thing, heat treatment facility, but a material's microstructure influences how the material performs, and heat treatment can change the microstructure," says Frank Ritzert, a senior materials research engineer at Glenn, who first selected Jaster as an intern and also recommended him for the full-time position.

"Mark, with his high aptitude, mastered that job pretty quickly," Ritzert recalls, so he encouraged him to look for opportunities to learn from and engage with the research being done around him once he fulfilled his core responsibilities.



PrintSpace 3D founder Mark Jaster built his expertise in 3D printing and cutting-edge materials during his time at NASA's Glenn Research Center, including a project to build a superalloy seal for hypersonic aircraft like the X-43, which can fly at least five times the speed of sound.

It was an opportunity Jaster relished—and one that, in part, motivated him to push for automating some of the more routine parts of his job in the heat treatment facility.

Jaster helped the team adopt touch screens and data acquisition systems for tools like the furnace that controls pressure and temperature. "By automating these systems we were able to do things more quickly and efficiently and provide more accurate data," Jaster says. "And this opened up a significant amount of time for me to get to know other researchers and the materials they were developing."

One of the many side projects he got involved in was an effort to build a complex seal for a hypersonic aircraft, which required a coil spring made from a superalloy metal, able to withstand extreme heat.

The researchers determined that the best way to facilitate casting the part was with a 3D printer. Printers can only fabricate in a limited range of materials, and there wasn't much research on what the printing process does to the performance of high-end metals. In other words, even if it could be printed in the right metal, it was not clear the final product would work in the same way as traditionally cast materials. Instead, the researchers printed a plastic model, which they used to build a mold for the final product: a nickel-based superalloy coil.

"After working on this project and seeing the possibilities, I caught fire. I knew I wanted to be involved in designing better 3D printers that could actually print with more of these exotic materials that were being developed by my colleagues at NASA."

Not only could an advanced 3D printer eliminate many steps in fabricating complex parts with proven materials, Jaster says, but it could help speed up the process to prove new materials, a process he was also familiar with from his time at Glenn.

Technology Transfer

In 2014, after a year of working on 3D printing at another company, Jaster founded PrintSpace 3D in Rexburg, Idaho, and began building the Altair 3D printer.

"The Altair is designed for engineers, for people who are pushing the limits. It prints with over 25 different materials," Jaster says. "A lot of these are higher-end materials that weren't generally known by industry. It helped having those materials in the back of my mind, and knowing they exist, because I worked with researchers who developed them."

"Our goal is to keep bringing more materials to the printer, so users can actually make end-use products and not just prototypes," he adds, including both materials developed at PrintSpace3D and ones under development elsewhere.

> "The Altair is designed for engineers, for people who are pushing the limits."
>
> — Mark Jaster, PrintSpace 3D

It's the first big step toward the fulfillment of the idea he had at NASA, when he was working on building the nickel-based superalloy coil.

Benefits

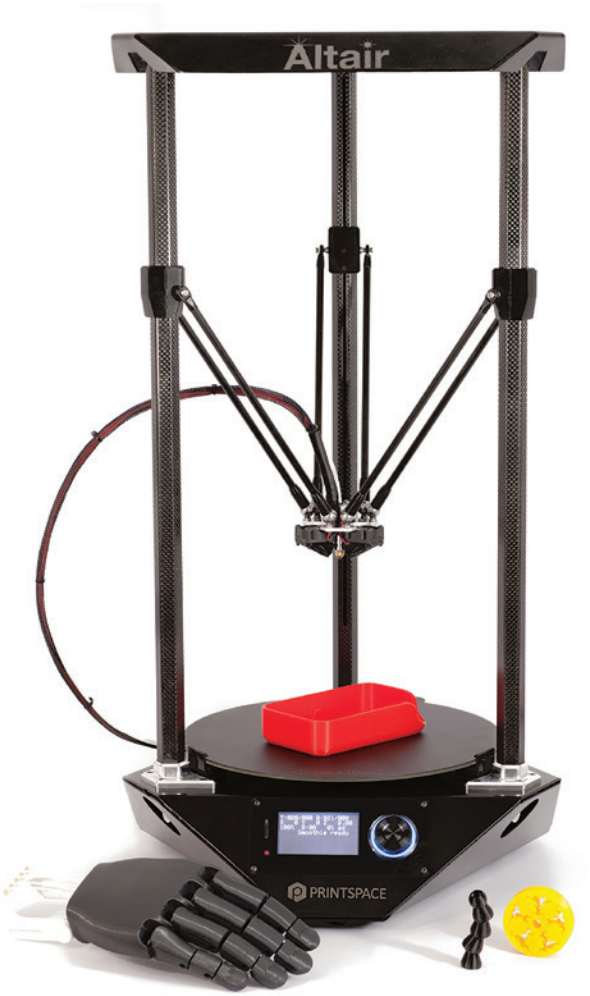
Beyond the extensive range of materials the Altair can use, it is extremely fast and has a user-friendly interface, Jaster says, both features which benefited from his NASA experience.

For example, one of the limiting factors in a 3D printer's speed is the hot end, which heats the printing material into a molten liquid just prior to it being deposited and then cooled to a solid state.

Making a better hot end "requires having a good understanding of each material's properties and their thermal characteristics—something I learned at NASA on the Venus flight project," Jaster says, where he and his colleagues tested different materials for a hot-side adapter flange that was part of a larger Thermal Management System and learned about controlling where the heat goes and avoiding excess waste heat.

The Altair hot end heats up within seconds—compared to a 5- or even 10-minute delay among competitors, he says—and can work at very high temperatures, which is essential for many higher-end materials and makes the printer faster overall. The hot end is also very accurate in reaching the specific melting point of various materials, which requires control systems that automatically and accurately measure temperatures and pressures.

"If you're not measuring those well enough, you can always just increase temperature to make up for it. But if you increase temperature too much, other things start to happen," Jaster says, noting his experience automating the heat treatment facility translated directly to these challenges in improving the Altair's hot end. Likewise, the development benefited from his knowledge of human-machine interfaces, which he was able to integrate into the Altair.



The Altair printer, which comes in base and pro models, can print with more than 25 materials, and PrintSpace 3D is working on incorporating more. The company hopes the printer will help users make end-use products and not just prototypes.

Soon after PrintSpace3D launched, it won a local business contest, earning the startup $5,000 and increased local recognition. "Being on the news has brought people into the lab who have purchased the Altair 3D printer," Jaster says.

The company's customers extend well beyond Idaho, however. Printers have been sold to universities, businesses, and research labs across the United States and overseas.

The base model starts at $3,400. A more advanced "pro" model was released in late 2016, and Jaster says he doesn't plan to stop there. "We eventually want to be selling printers to industry and to NASA that will solve very specific needs. These will cost closer to half a million."

Recently this vision has led to a partnership with the Department of Energy's Oak Ridge National Laboratory. In September 2016, PrintSpace 3D signed an exclusive license agreement to pair an Oak Ridge technology with the PrintSpace 3D printer.

The result will be a printer capable of printing in PEEK (polyetheretherketone), an engineering-grade thermoplastic used in aerospace, medical, and other demanding industrial applications because of its lightweight, non-conductive and shock absorbent properties.

Although it is in high demand, PEEK has proven difficult for 3D printing—to date, very few 3D printers can print with the material, Jaster says.

"This is only the beginning," he adds. "After the development of the PEEK printer, a metal printer will be our next version. PrintSpace 3D printers will continue to be the printers of choice for engineers who need these types of advanced material 3D printing." ❖

Silicon Diode Sensor Tracks Extreme Temperatures

NASA Technology

When people feel sick, they can just grab a drugstore thermometer and pop it in their mouth. But it's a different story for engineers looking to get an accurate read on the temperature of rocket fuel, which must be kept at hundreds of degrees below zero.

Why so cold for something that's eventually going to launch in a fiery explosion? NASA needs to keep the fuel, which consists of hydrogen and oxygen, in liquid form because it takes up less space than gas and is easier to contain—and that requires keeping both substances well below typical Earth ambient temperatures.

The Space Agency has worked out systems to cool, and keep cool, fuel in storage tanks and along the pipelines that transport it to the rockets. But it's important to monitor that temperature constantly, because with warm air all around, it's not hard for the fuel to start heating up.

"There's always going to be some kind of boil-off, but the idea is to maintain those temperatures to the optimal range so you don't get gas mixed with liquid," explains Jose Perotti, who was an instrumentation engineer for the Space Shuttle Program at Kennedy Space Center.

Once the fuel starts warming up, gas bubbles can form, which degrades the flow along the pipeline, Perotti says. "We wanted to read in fractions of degrees at those lower temperatures to better know whether the quality of the fluid was good."

Technology Transfer

To build the sensors for the Space Shuttle fuel system, Kennedy turned to Scientific Instruments Inc., the West Palm Beach, Florida-based company it had been relying on for temperature sensors since the Apollo era. "Kennedy was one of the first customers we ever had as a company," explains Austin Capers, who oversees cryogenic thermometry sales for the company.

"They ended up using our sensors on the oxygen tanks during the Apollo missions, which was the biggest first step that our founders took in this business, what got the company to the next level."

The sensors Scientific Instruments had been providing more recently, based on platinum resistance thermometers, had a problem, Perotti says. "At the temperatures we were trying to measure, the response signal from the sensor was fairly low. It was hard to obtain the resolution at these lower temperatures needed for cryogenic operations."

Scientific Instruments already had a better technology, using silicon diode sensors, but the instruments needed some modifications to work for NASA.

"They are semiconductor-based sensors that are very, very responsive to the lower temperature we need to measure," Perotti says. "Scientific Instruments worked to characterize those silicon diodes and package them in the format and fit form required under NASA specifications for applications in the Space Shuttle, and also to develop an associated signal conditioner to translate into signals we could use."

Among other modifications, Capers says, the sensor needed a more robust package, because "it needs to withstand harsher conditions." NASA's specifications also included accuracy levels, probe lengths, and that the probes could withstand a certain pressure rating, he explains. To achieve all that, Scientific Instruments designed a hermetically sealed stainless-steel enclosure, with the sensor mounted inside at one end and a connector on the exterior.

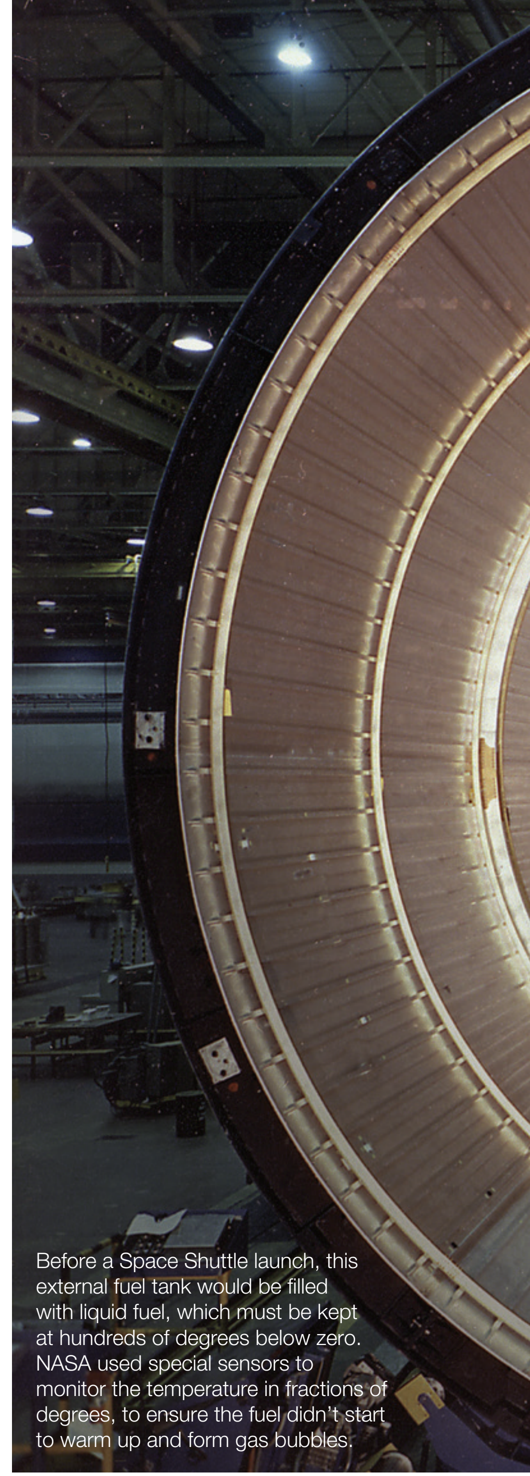
The probe is either directly immersed in the liquid or mounted in a thermowell, which is a tube closed at one end that is placed inside the fluid stream. To get a temperature reading, current is supplied to the probe, typically 10 microamps or 100 microamps, and the diode sends back a voltage reading, which is correlated to a temperature.

"After we made it, NASA engineers tested and qualified it," Capers says. "It's a product we still make for them today."

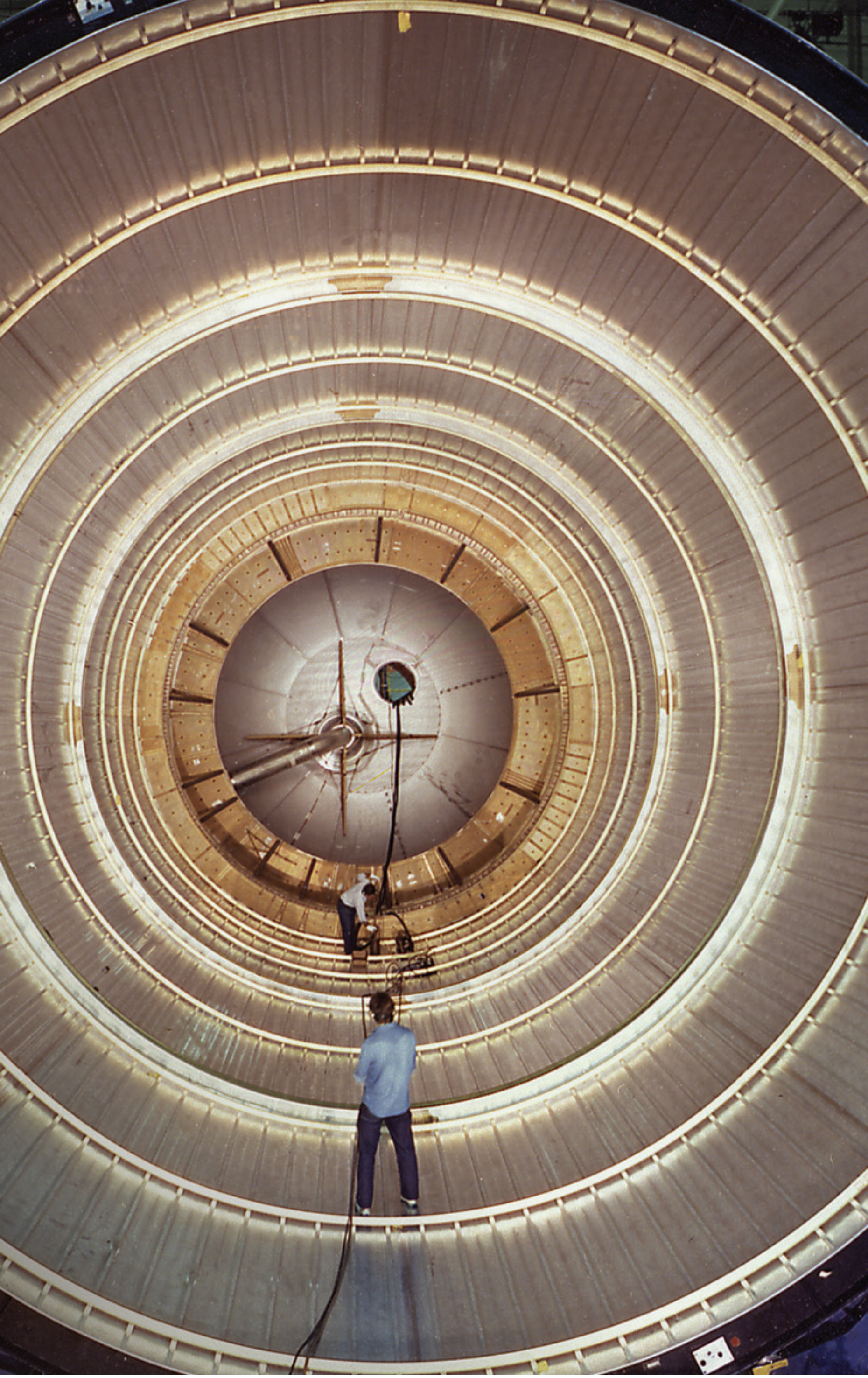
Benefits

One of the big advantages of silicon diode sensors over their predecessors is that they're interchangeable: if one fails, you can just take it out and replace it with another one. In contrast, many high-tech temperature sensors require individual calibration, so it can take a lot more effort to get them up and running.

The sensors are also accurate down to a tenth of a degree, over an extremely wide temperature range. While a typical thermometer at a drug store has a temperature range of around 90–105 °F, Capers says, "our silicon diodes work



Before a Space Shuttle launch, this external fuel tank would be filled with liquid fuel, which must be kept at hundreds of degrees below zero. NASA used special sensors to monitor the temperature in fractions of degrees, to ensure the fuel didn't start to warm up and form gas bubbles.



well all the way down to 1.5 Kelvin, or roughly -460 °F, and the maximum temperature they can read is 450 Kelvin, equivalent to 350 °F." They are most accurate, however, at the lower end of the range.

NASA continues to use the silicon diode sensors for its fuel systems and has also used them on other projects, including the Hubble Space Telescope. And the Space Agency isn't the only buyer, Capers says.

"We sell a similar model today to several private space exploration companies. It's a similar design, similar concept," he says, though "the actual design of the probe is a little different." Like NASA, these private companies are also using the sensors for their liquid oxygen and liquid hydrogen tanks, as well as to measure inlet temperatures from fuel pumps. In the mid-1990s, Scientific Instruments also supplied silicon diodes for the production of MRI magnets.

Although Scientific Instruments is under contract to only produce sensor packages with the exact NASA specifications for the Space Agency, these other sensors have benefited from the development and quality control testing done at NASA—and the connection also helps during sales pitches.

"Absolutely," Capers says. "I mention a lot how we were the sole source provider of these temperature transducers during the entire Shuttle program." ❖

> "After we made it, NASA engineers tested and qualified it. It's a product we still make for them today."
>
> — Austin Capers, Scientific Instruments Inc.

Scientific Instruments Inc. has been making temperature sensors for NASA since the Apollo era. For the Shuttle program, it improved an existing silicon diode sensor, which it now sells to private aerospace companies and the medical industry.

Tunable Liquid Crystals Grab Particles and Cells Using Only Light

NASA Technology

Images taken from high in the sky can offer clues to how well a plant is growing and whether its water needs are being met. The key is in filtering the light—infrared wavelengths can reveal chlorophyll content, for example, which dips when plants are starting to fail.

NASA helped develop a light filter that could be tuned to different wavelengths with a flip of a switch, hoping it could be useful on its many Earth-observing missions, but the result turned out to have wide-ranging applications far beyond plant stress, from nuclear fusion to brain research.

The work began in the early 1990s, explains Meadowlark Optics Chairman Tom Baur. "We were trying to develop a filter that passes one color of light, and we wanted to be able to adjust the color without any mechanical motions." That way, a single remotely controlled instrument could be used to observe any portion of the light spectrum, instead of needing to swap out filters or have separate devices for different wavelengths.

They came up with a device that uses a thin layer of liquid crystal—on the order of 5 or 10 microns thick—between two windows with a transparent conductive coating. The electricity varies the alignment of the liquid molecules, which allows different wavelengths of light to pass through when the device is used between polarizers.

"The polarization change is dependent on the voltage," Baur explains, and the result is that "without any mechanics you can change the optical performance electrically."

Technology Transfer

Meadowlark developed its first tunable light filter using these "liquid crystal variable retarders"—with funding from two Small Business Innovation Research (SBIR) contracts, the first from the Air Force and the second, in 1996, from NASA's Jet Propulsion Laboratory (JPL).

The Air Force intended to use the filters to study magnetic fields—and the magnetic storms they cause—on the sun, which can have a powerful impact on electronics and communications systems on Earth. "It's estimated that once every 100 or 200 years, a magnetic storm on the sun is strong enough that it would knock out all the electric transformers on Earth," Baur says. "So, clearly, being able to predict these storms is important, and tunable filters are one tool for studying them."

The tunable filters are useful because to study magnetic fields on the sun, researchers look at different heights in its atmosphere, and "different colors of light are emitted at different altitudes."

The Space Agency also studies solar magnetic fields, but, says Baur, JPL's interest was in remote sensing more generally, and included Earth-observation missions that study crops and minerals from the air.

"For example, you can use tunable filters to look at water stress in plants," Baur says, "so if you're in a place where irrigation is being used, if you look at the crop in different colors of light you can tell whether or not those plants are thirsty."

Liquid crystal variable retarders have resulted in some $5 million in business for the company. The Frederick, Colorado-based company was also honored with the Photonics Circle of Excellence award from *Photonics Spectra* magazine for the innovation.

The innovation has since proliferated throughout the optics industry, Baur says. "They are now sold by a number of companies—but we were the first."

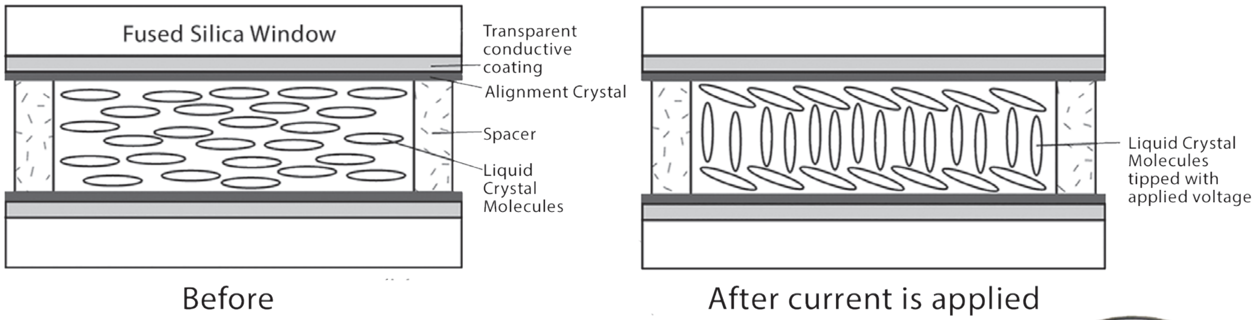
Benefits

Although the tunable filters were initially created for astronomers and remote sensing, it was quickly clear that these devices would have far wider applications. "It's like saying, 'Well, we invented a lens, what category would you put that in?' Could be used in a microscope, telescope, a laser system," Baur says.

Currently, the largest market Meadowlark has for liquid crystal variable retarders is in biology research. "They are a real handy tool if you want to work with really tiny little things. It's a non-mechanical way of grabbing hold of tiny things and moving them about," Baur explains.

He's talking about optical tweezers, which are essentially a laser fed through a microscope to create a highly focused

This image of the U.S.-Mexico border from 2000, combining visible and infrared bands, shows lushly growing, gridded fields (in red) on the U.S. side, compared to more sparse and irregular growth in Mexico. Tunable liquid crystal filters help focus in on different light wavelengths, which can reveal insights like which plants need more water or which might be diseased.



Liquid crystal variable retarders are light filters that can be tuned to different colors of light with electricity. The current causes the liquid molecules to change their alignment, allowing different wavelengths to pass through.

> "In some way, 30-40 percent of all the products we sell use the technology that was developed in those SBIRs. They absolutely helped grow the company."
>
> — Tom Baur, Meadowlark Optics

beam, which can attract and hold tiny particles with a slight electrical charge. When the researcher moves this optical trap, the particle goes with it. Researchers direct the laser through thousands of liquid crystal variable retarders built into a tool called a spatial light modulator.

Meadowlark has an extensive line of spatial light modulators, but all work on basically the same principle: the liquid crystal variable retarders are built into an array, maybe 1,000 by 1,000, and each one can be manipulated individually with a different electric voltage, which allows the operator to shape the light however it's needed. For optical tweezers, the laser beams can be shaped and split "to create holographic light patterns that can actually trap a living cell and move it around," Baur says.

Spatial light modulators can also create light patterns to stimulate brain tissue in very precise ways to study how the brain works. Another spatial light modulator the company built is installed in Livermore National Laboratory's National Ignition Facility, the world's largest laser system. To ensure that the incredibly powerful laser only hits exactly where it is supposed to, the lab needed a spatial light modulator to pattern the beam before it is amplified. That allowed the researchers to use much higher power levels, because they knew no sensitive instruments would be zapped as collateral damage.

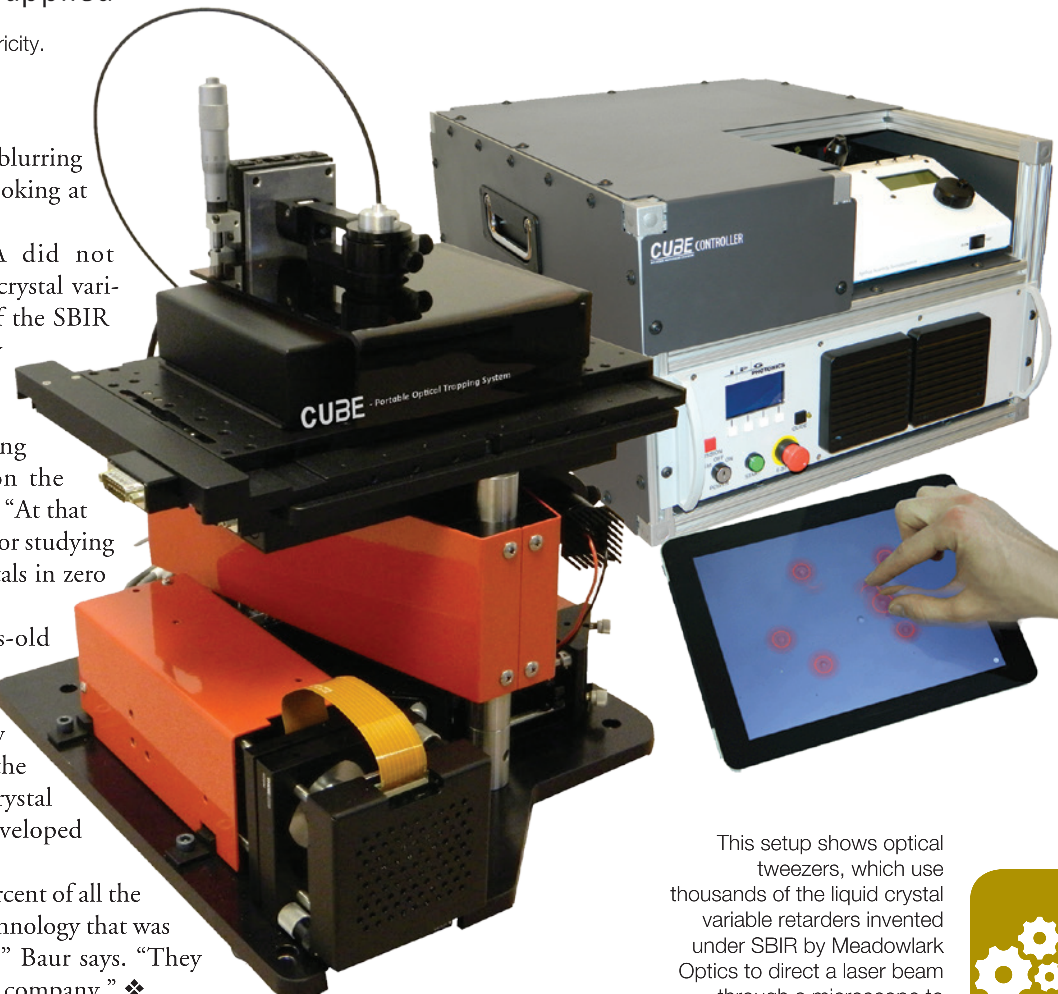
"We won an R&D 100 award for that spatial light modulator, about three or four years ago," Baur recalls.

Spatial light modulators are also used in optical communications, as well as in adaptive optics, which allows astronomers to remove the blurring of the atmosphere when looking at faraway stars or planets.

And although NASA did not immediately adopt liquid crystal variable retarders at the end of the SBIR contract, the Space Agency has since become a customer of Meadowlark's spatial light modulators, including for research conducted on the Space Shuttle, Baur recalls. "At that time they were being used for studying the growth of protein crystals in zero gravity."

Overall, those decades-old SBIR contracts have continued to pay off hugely for the company, which grew from 10 or 15 people at the time the original liquid crystal variable retarders were developed to some 40 people today.

"In some way, 30-40 percent of all the products we sell use the technology that was developed in those SBIRs," Baur says. "They absolutely helped grow the company." ❖



This setup shows optical tweezers, which use thousands of the liquid crystal variable retarders invented under SBIR by Meadowlark Optics to direct a laser beam through a microscope to "grab" tiny particles.

Spinoffs of Tomorrow

Want more spinoffs? Make it so. NASA is constantly innovating, but it relies on American businesses and entrepreneurs to ensure its inventions see widespread use on Earth. This section features 20 technologies ready to be licensed and turned into commercial successes.

Ames

The OMEGA System

An algae photobioreactor using floating enclosures with semi-permeable membranes

The OMEGA system is an innovative method for growing algae, cleaning wastewater, capturing carbon dioxide, and producing biofuel and other useful products. Algae grows in floating flexible plastic enclosures with semi-permeable membranes, while the surrounding waters provide infrastructure, cooling, and some mixing from wave action.

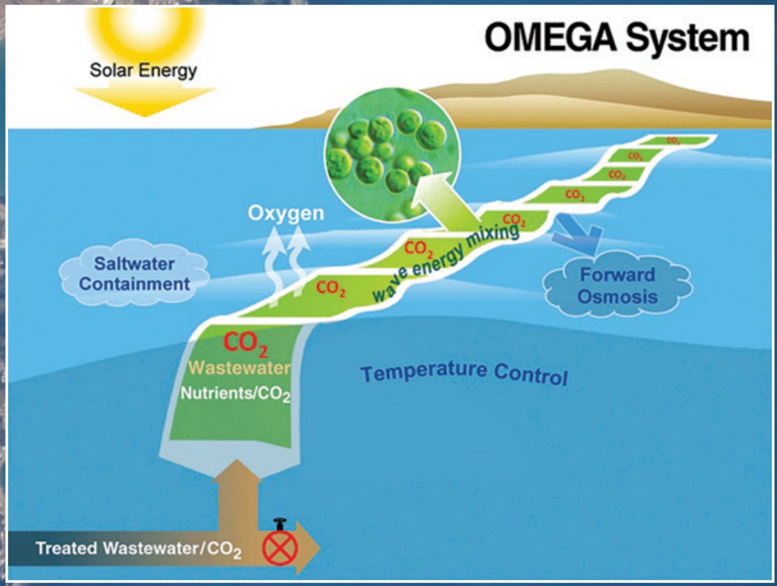
Deployed in the marine environment, the gradient between the freshwater inside the system and the saltwater outside drives forward osmosis, cleaning the water as it is released into the surrounding environment. In addition, this process concentrates nutrients in the algae medium to stimulate growth and concentrates the algae to facilitate harvesting. The system is ideal for nutrient-rich domestic wastewater environments. Harvested algae can be used to make biofuels, fertilizer, animal food, and other products.

Benefits

- Expanded use of protected bays for biomass production
- Doesn't compete with agricultural land use
- Advanced wastewater treatment
- Captures carbon dioxide from the atmosphere

Applications

- Diesel fuel production
- Lipid-based chemical production
- High-value products (e.g., cosmetics, nutraceuticals, food additives)
- Fertilizer and animal food products
- Advanced sewage treatment
- Pharmaceutical products
- Renewable energy



Supercapacitors with High Energy Density

Graphene composite materials for supercapacitor electrodes

Supercapacitors have received intense interest as an alternative to traditional energy storage devices in recent years. Applications for supercapacitors range from plug-in hybrid electric vehicles to backup power sources. However, while the power density of supercapacitors surpasses that of batteries, commercially available batteries have a significantly higher specific energy density. This innovation develops electrode composite materials that combine graphene with a metal oxide nanocomposite of manganese oxide and cobalt oxide. It comprises a scalable, integrated materials synthesis and device fabrication process to optimize specific capacitance and cycling lifetime and device reliability. Both the energy density and the power density of the materials are exceptionally high.

Benefits

- Enables a scalable, low-cost fabrication scheme
- Increased energy density and power density
- Optimizes cycle life and reliability
- Lower cost than a traditional battery

Applications

- Electric vehicle power sources
- Sustainable and renewable energy markets
- Energy and environmental design

Armstrong

High-Resolution Terrain Information Algorithms

Software for aeronautics collision avoidance and a range of research areas

These data-adaptive algorithms provide an extensive and highly efficient encoding process for global-scale digital terrain maps along with a real-time decoding process to locally render map data. The software is efficient and powerful, with a capability to integrate more than 250 billion separate pieces of terrain information into a single terrain map, and the resulting imagery is a thousand times more detailed than that provided by current aircraft mapping systems.

Users can easily integrate the algorithms into an aircraft's existing onboard computing environment or into an electronic flight bag or mobile device application. In addition to its use within next-generation collision avoidance systems, the software can be adapted for use in a wide variety of applications, including aerospace satellites, automobiles, scientific research, marine charting systems, video games, and medical device software.

Applications

- Collision avoidance
- Aerial firefighting
- Crop dusting
- Unmanned aerial vehicle navigation and research
- Automotive GPS
- Medical software
- Gaming systems

Benefits

- Provides very high encoding process ratios
- Highly configurable
- Works on portable platforms
- Affordable and accessible

Real-Time 3D Shape Rendering

Ultrafast algorithms enable smart structures with unparalleled self-monitoring capabilities

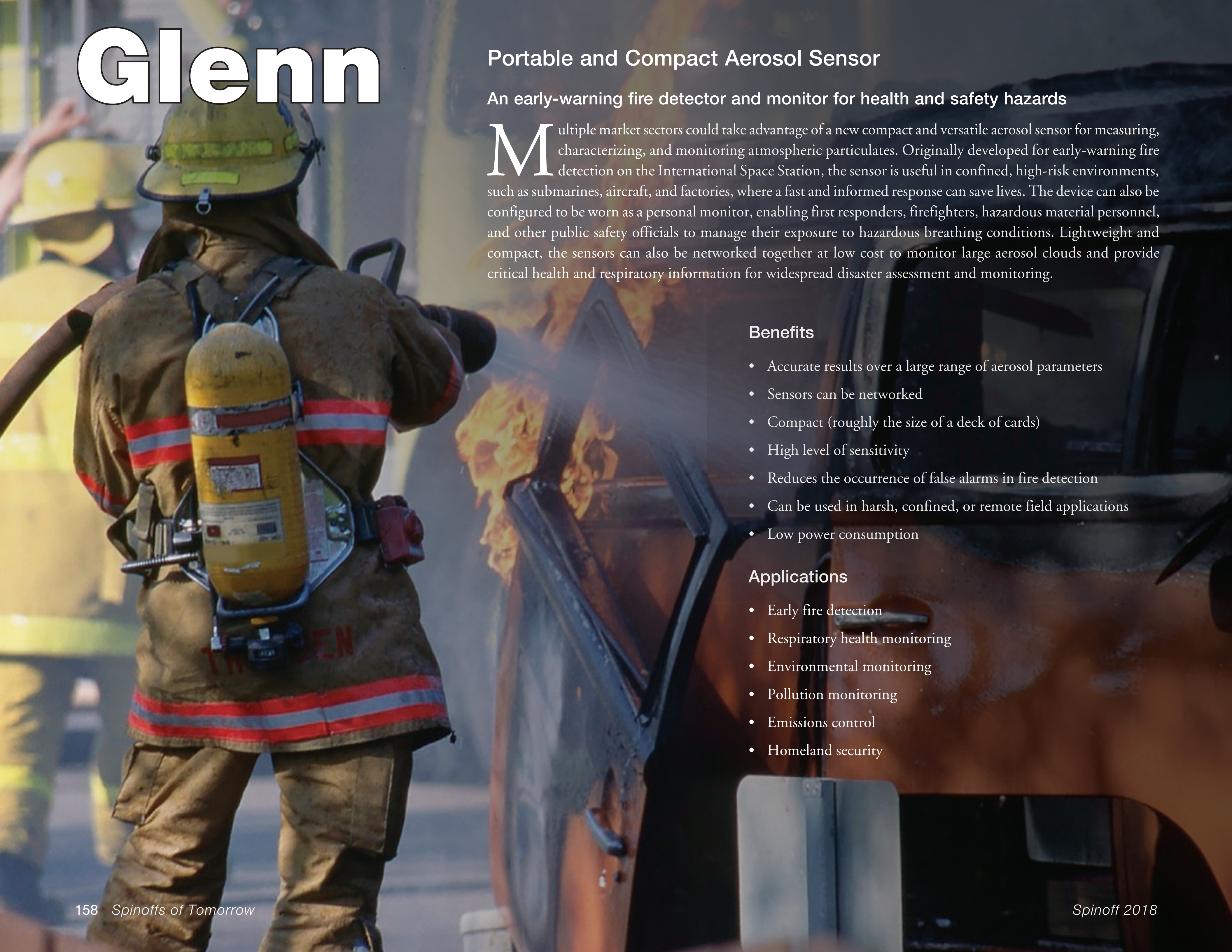
Researchers at NASA's Armstrong Flight Research Center have developed an innovative method for rendering the bending shape of an optical fiber cable in real time. Unlike current methods used to calculate shape rendering, which are complex and time-intensive and which may have lag time, this technology's streamlined algorithms require no post-processing. Armstrong's system scans at a rate of 100 times per second, providing instantaneous 3D shape rendering. The sensors, along with NASA's sophisticated algorithms, can be used to calculate a variety of critical parameters including shape, stress, temperature, pressure, strength, and operational load. The sensing system can be used for aerospace, civil structures, oil and gas drilling, renewable energy, and much more.

Benefits

- Unparalleled speed that permits real-time monitoring with no lag
- No post-processing required
- Small size and light weight

Applications

- Endoscopes, catheters, and robotic surgery
- Oil and gas drilling and exploration
- Structural monitoring for aircraft, wind turbines, and automobiles
- Position control of robotic arms and tools



Glenn

Portable and Compact Aerosol Sensor

An early-warning fire detector and monitor for health and safety hazards

Multiple market sectors could take advantage of a new compact and versatile aerosol sensor for measuring, characterizing, and monitoring atmospheric particulates. Originally developed for early-warning fire detection on the International Space Station, the sensor is useful in confined, high-risk environments, such as submarines, aircraft, and factories, where a fast and informed response can save lives. The device can also be configured to be worn as a personal monitor, enabling first responders, firefighters, hazardous material personnel, and other public safety officials to manage their exposure to hazardous breathing conditions. Lightweight and compact, the sensors can also be networked together at low cost to monitor large aerosol clouds and provide critical health and respiratory information for widespread disaster assessment and monitoring.

Benefits

- Accurate results over a large range of aerosol parameters
- Sensors can be networked
- Compact (roughly the size of a deck of cards)
- High level of sensitivity
- Reduces the occurrence of false alarms in fire detection
- Can be used in harsh, confined, or remote field applications
- Low power consumption

Applications

- Early fire detection
- Respiratory health monitoring
- Environmental monitoring
- Pollution monitoring
- Emissions control
- Homeland security

Shape Memory Alloy Rock Splitters

Provides a compact, powerful, non-explosive method for fracturing rocklike materials

A groundbreaking method uses shape memory alloys (SMAs) to split apart rock formations without the need for explosives or hydraulics. Conventional approaches present difficulties in transportation and operation and can badly damage underlying samples during use. Glenn's innovation exploits cutting-edge SMA compositions to deliver controllable stresses in excess of 1500 megapascals, which is up to four times greater than the force exerted by commercial SMAs. The SMA compositions are also tunable to multiple activation temperatures up to 750 °F, depending on the usage environments. Glenn's Shape Memory Alloy Rock Splitter device generates this power without any demolition damage to the surrounding environment, and in a package that combines reliability, ease of setup and activation, and cost-effectiveness. This technology could prove invaluable to enterprises as varied as oil drilling, mining, civil engineering, fossil collection, and search-and-rescue operations—any field that requires compact but large static forces.

Benefits

- Stresses are four to five times more powerful than similar alloys
- Causes no demolition or vibration damage to surrounding environment
- Convenient setup and activation
- Simple and safe, requiring only heat to activate
- Compact, small volume, and extremely low weight
- Useful in spaces that heavy equipment cannot access
- Reusable

Applications

- Oil drilling and offshore exploration
- Hydraulic fracturing
- Gemstone and precious metal mining
- Civil engineering
- Archaeological digs
- Commercial space

Goddard

Miniaturized Laser Heterodyne Radiometer

A novel and compact system for measuring greenhouse gases in the environment

Goddard Space Flight Center has developed a passive monitor for measuring greenhouse gases in the atmosphere, including carbon dioxide, methane, and carbon monoxide. Further, trace gas concentrations can be correlated with altitude, providing further delineation of composition. This is an autonomous instrument with a uniquely small footprint—it's about the size of carry-on luggage. This instrument uses a variation of laser heterodyne radiometer (LHR) to measure the concentration of trace gases in the atmosphere by measuring their absorption of infrared sunlight.

Benefits

- Small size (carry-on luggage-sized)
- Can correlate trace concentrations with altitude

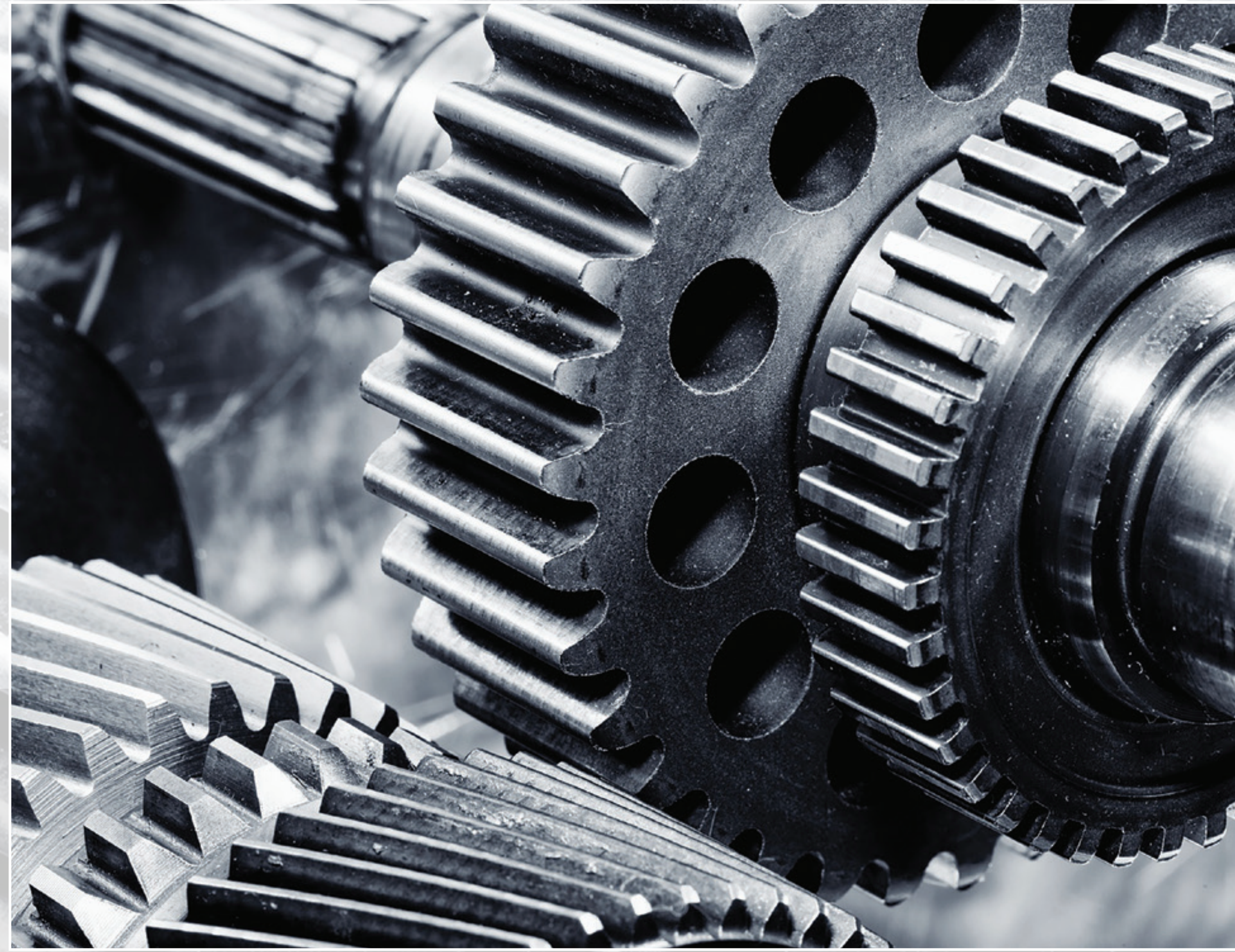
Applications

- Environmental monitoring
- Meteorology
- Gas line monitoring for methane

Gear Bearings

Increased capacity and performance with reduced size, weight, and cost

This potentially revolutionary gear bearing technology represents a mechanical architecture breakthrough: it combines gear and bearing functions into a single unit that significantly improves gear drives across the board for electrical, internal combustion, and turbine motors. Because it combines gear and bearing functions, it reduces weight, number of parts, size, and cost, while also increasing load capacity and performance. The technology is compatible with most gear types, including spur, helical, elliptical, and bevel gears. By selecting the appropriate manufacturing method and materials, gear bearings can be tailored to benefit any application, from toys to aircraft.



Benefits

- Zero backlash results in smoother operation and superior control
- Improved thrust bearing
- Unprecedented speed reduction
- Less noise and vibration
- Fewer fatigue failures
- Low cost, simple design
- Can be applied to many types of motions including linear, rotary, or motion hybrids
- Enables all-electric actuator systems, eliminating hydraulics in many applications

Applications

- Transportation, including automotive, aircraft, marine, and rail
- Power tools, automotive tools, and garden equipment
- Industrial machinery
- Farm equipment
- Robots, cars, and motorized toys

JPL

Automated Scheduling and Planning Environment

Artificial intelligence powers framework for scheduling and planning applications

Automated planning and scheduling technologies have great promise in reducing operations costs and increasing the autonomy of systems in aerospace and other industries. Based on artificial intelligence techniques, the Automated Scheduling and Planning Environment (ASPEN) is a modular, reconfigurable application framework capable of supporting a wide variety of planning and scheduling applications. ASPEN provides a set of reusable software components that implement the elements commonly found in complex planning and scheduling systems, including an expressive modeling language, a resource management system, a temporal reasoning system, and a graphical interface.

Benefits

- Modeling language requires no user knowledge in the areas of computer programming, planning, or scheduling
- Generic architecture allows users to choose from several search engines and propagation algorithms to optimize the planning process
- Allows re-planning during plan execution, enabling continuous real-time planning for embedded applications
- Plans can be optimized for a specific set of goals, such as maximizing science data or minimizing power consumption

Applications

- Make-to-order manufacturing
- Capital-intensive production with constrained plant capacity
- Production in facilities where many different products are manufactured
- Products requiring a high number of components or tasks
- Production requiring frequent, unpredictable schedule changes

Ultrasonic, Percussive Drill

Drilling with low power, low noise

Engineers at the Jet Propulsion Laboratory have developed the technology for drills that operate in the ultrasonic range and incorporate an augmenter that puts the drilling capacity of large, heavy rotary drills into smaller, rotary hammering drills. These drills require low torque power and, by operating at ultrasonic frequencies, reduce noise. They are based on technology developed to enable sampling in low-gravity and extreme environments.

Generally, hammering fractures media, while rotation of fluted bits removes cuttings. To benefit from these two actions, a novel configuration of the percussive mechanism was developed to produce an augmenter of rotary drills. The drills are driven by piezoelectric-actuated percussive mechanisms that can be operated using low average power. They were demonstrated to penetrate rocks as hard as basalt, and one design was made as light as 400 grams. Piezoelectric actuators have only two moving parts and no gears or motors. The drill can be adapted easily to operations in an extreme range of temperatures.

Benefits

- Noise reduction
- Low average power requirement
- Compact and lightweight

Applications

- Construction industry
- Shallow mining
- Demolition
- Medical applications, such as extracting pacemaker leads, drilling bone, and ablating gallbladder and kidney stones

Johnson

Robonaut 2: Medical Opportunities

The future of robotics and medical care

Researchers at Johnson Space Center, in collaboration with General Motors and Oceaneering, have designed a state-of-the-art, highly dexterous, humanoid robot: Robonaut 2 (R2). R2 is made up of multiple component technologies and systems making up nearly 50 patented and patent pending technologies with the potential to be game-changers in multiple industries including the medical industry. R2 technologies can aid in a variety of medical applications, ranging from telemedicine to handling the logistics of medical procedures. These activities can be done in autonomous mode or in teleoperation mode, where the robot is controlled by a technician or physician. This type of operation would be advantageous during situations where a biomedical hazard poses risks to humans, such as a contagious outbreak or a combat situation. For more routine daily use, R2 could function as an assistant to hospital staff.

Benefits

- Can be controlled by direct teleoperations
- Safe for working side-by-side with humans
- Multiple cameras provide stereo vision and depth perception
- Dexterous hands can use many of the tools created for human use

Applications

- Telemedicine
- Surgical robotics
- Home medical service robotics
- Medical rehabilitation
- Hospital service robotics

Improved Infrared Contrast Analysis and Imaging

Nondestructive evaluation of advanced nonmetallic structural composites

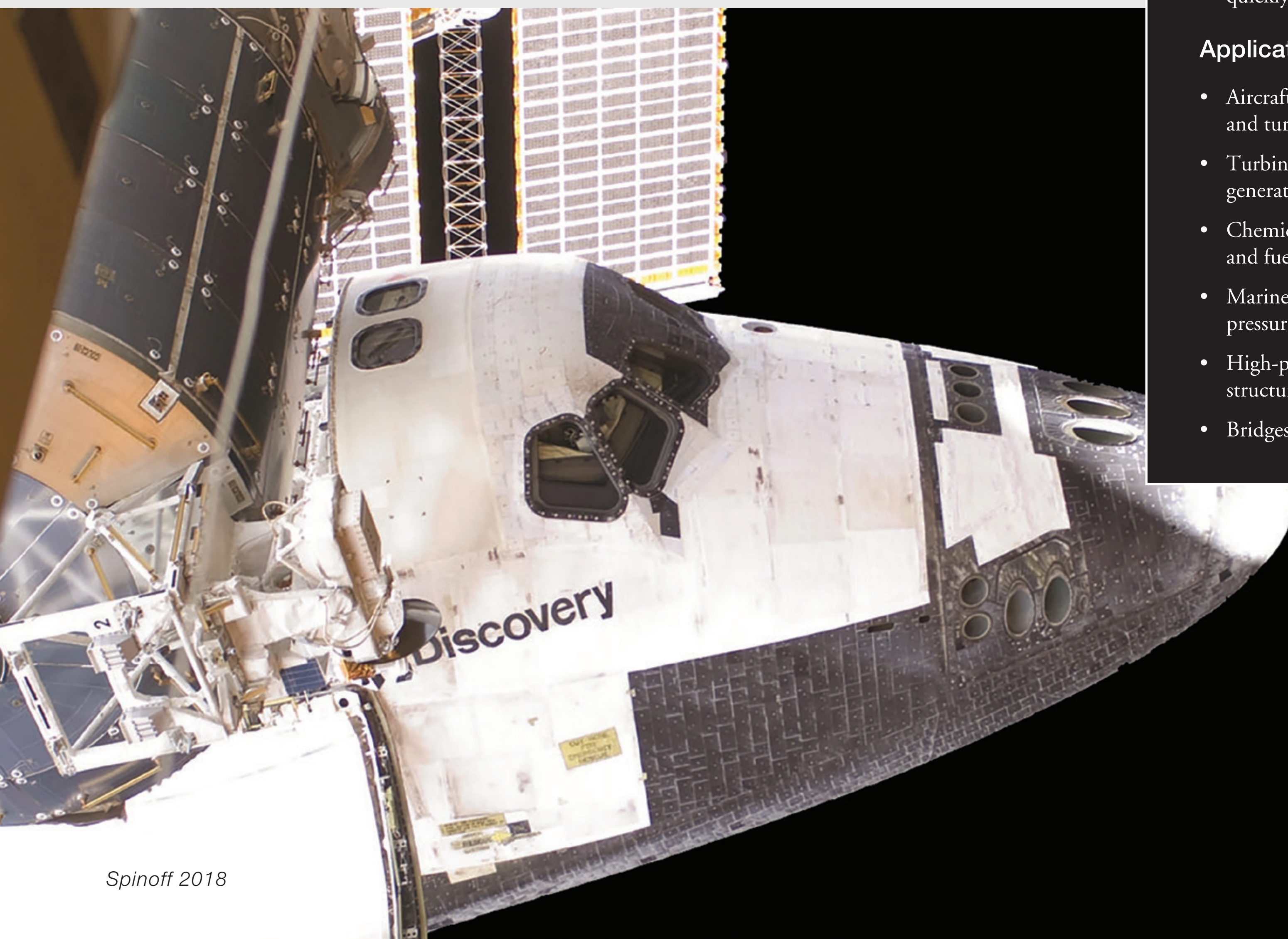
Novel techniques for post-processing flash infrared thermography data, developed at Johnson Space Center, provide numerous enhancements to nondestructive evaluation (NDE) of structures for a myriad of applications. Compatible with commercial infrared thermography products, this suite of tools provides both quantitative and qualitative data analysis capabilities and reliable detection and characterization of anomalies in composite structures. Calibration techniques provide detailed, systematic analysis of flash thermography data comparable to that used in advanced pulse-echo ultrasonic testing, offering accuracy not currently available for NDE of composite materials.

Benefits

- Comprehensive, efficient, and cost-effective
- Precise characterization of flaws in nonmetallic composites
- Compatible with existing flash thermography hardware systems
- Improves signal-to-noise ratio and flaw detection sensitivity
- Extracts and constructs images automatically, quickly, and simply

Applications

- Aircraft and fuselage structures, airfoils, and turbine blades
- Turbine blades and pipelines for power generation
- Chemical and petrochemical pipelines and fuel tanks
- Marine vehicle bodies, fuel tanks, pressure vessels
- High-performace automotive bodies and structures
- Bridges



Kennedy

Self-Healing Wire Insulation

Microcapsules release healant that repairs minor cuts, nicks, and abrasions

A new high-performance, flexible, low-melt polyimide film gives wire coatings self-healing properties. When a wire is damaged, microcapsules release a soluble polyimide that dissolves and heals the damaged area. Aerospace and ground vehicles often contain miles of high-performance electrical wire insulation that is prone to damage from abrasion and cuts during vehicle operation and maintenance. Large portions of this wire are often buried within the vehicle framework, making it very difficult and time-consuming to locate and repair damage. Incorporation of a self-healing capability in the insulation of this wire would provide self-repair of minor nicks, cuts, and abrasions without intervention and help reduce the danger of electrical shorts that can lead to sparking and fires.

Benefits

- Reduces maintenance requirements for wiring
- Can greatly reduce the cost of materials and labor required for the repairs
- Helps prevent shorts, increasing safety

Applications

- Aerospace, including aircraft, helicopters, and rockets
- Missiles, ground vehicles, ships, submarines, and unmanned aerial vehicles
- Automotive wiring

Benefits

- Reduces the need for ground-based assets
- Global coverage—vehicle does not have to be launched from a range
- Multiple vehicles (such as fly-back boosters) can be launched and tracked at the same time
- Increases responsiveness

Applications

- Government space missions
- Commercial space missions

Autonomous Flight Termination System

Redundant systems to autonomously make flight termination or destruct decisions

The Autonomous Flight Termination System (AFTS) is a joint NASA, U.S. Air Force, and DARPA project to develop an autonomous range safety system aboard a launch vehicle that can augment or replace the functions of the traditional human-in-the-loop system. Redundant AFTS processors evaluate data from onboard navigation sensors such as GPS and inertial measurement unit navigation sensors, and configurable rule-based algorithms are used to make flight termination decisions. The mission rules are developed by the local range safety authorities using the inventory of rule types taken from current human-in-the-loop operational flight safety practices.

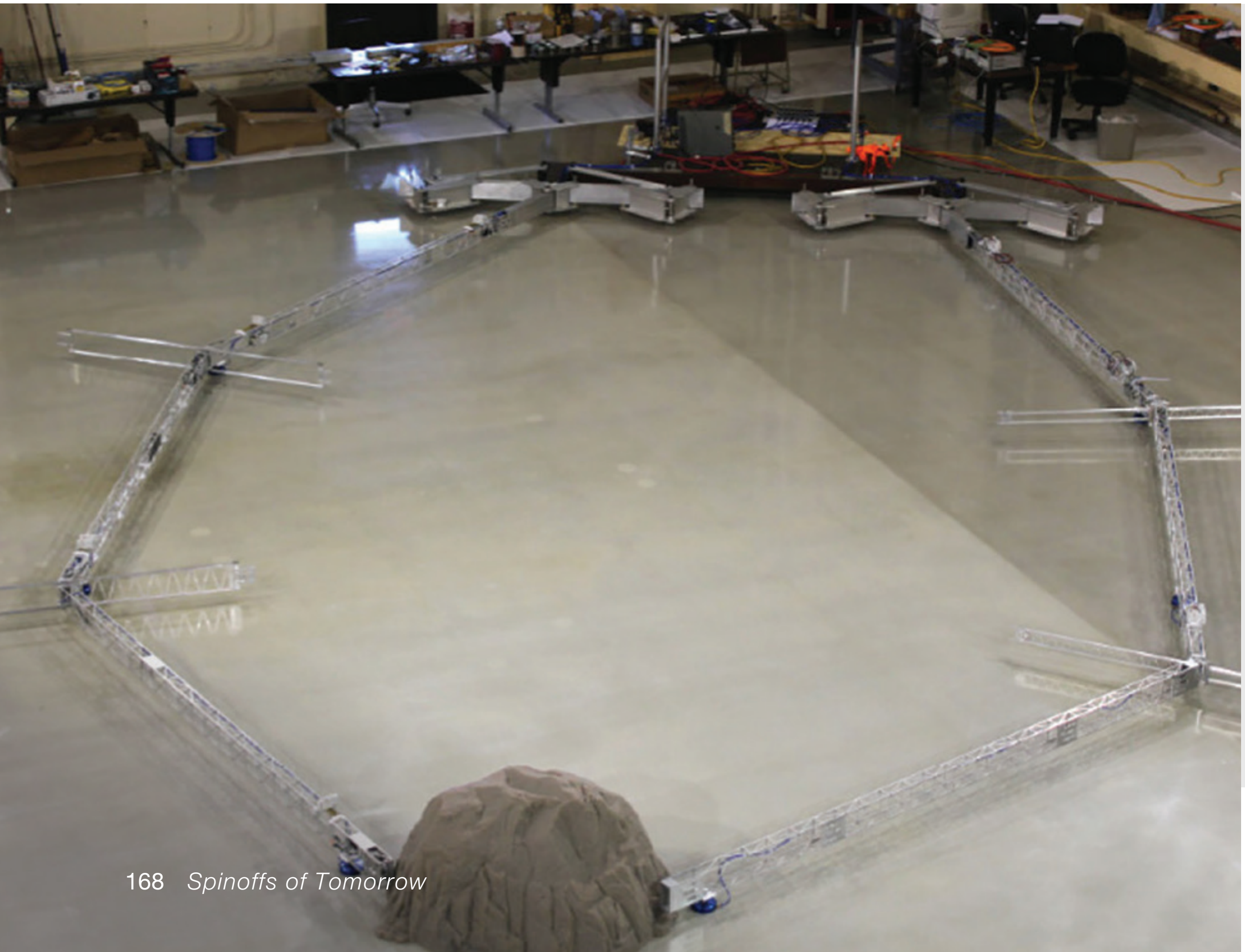
NASA is making this reference design hardware, software, and technical package available as a royalty-free technology transfer to other U.S. Government agencies and ITAR-qualified companies.

Langley

Compact Long-Reach Robotic Arm

Lightweight and compact arm with long reach and wide range of motion

Langley Research Center is developing a robotic arm with lightweight joints that provide a wide range of motion. The envisioned design provides users with a long reach and numerous degrees of freedom. Ideal for use in aquatic environments or for manipulation of light terrestrial loads, the arm consists of articulating booms connected by antagonistic cable tension elements. The arm elements are structurally efficient and lightweight and support compact packaging. The inherent mechanical advantage provided by the tendon articulation allows the use of small, efficient motor systems. The manipulator can be scaled over a large range, from 10 to more than 1,000 meters. Current efforts are focusing on a 15-meter prototype and a 300-meter subsystem to test the unique robotic architecture. NASA is seeking partners to assist with the development of its concept system for specific applications.



Benefits

- Provides a long reach for remote inspection or manipulation in inhospitable environments
- Tension stiffening improves structural efficiency
- Requires minimal storage space when packaged and is easily transported
- Design can be highly customized
- Capability to actively change component geometry during operation (e.g., extending or relocating links and spreader arms)

Applications

- Ship-to-harbor, harbor-to-ship, and ship-to-ship docking
- Retractable covers and awnings
- Camera booms for filming operations
- Floating barrier deployment and maneuvering
- Subsea cable inspection and placement
- Space operations

Electric Field Imaging System

Low-cost, noncontact imaging through electrical properties

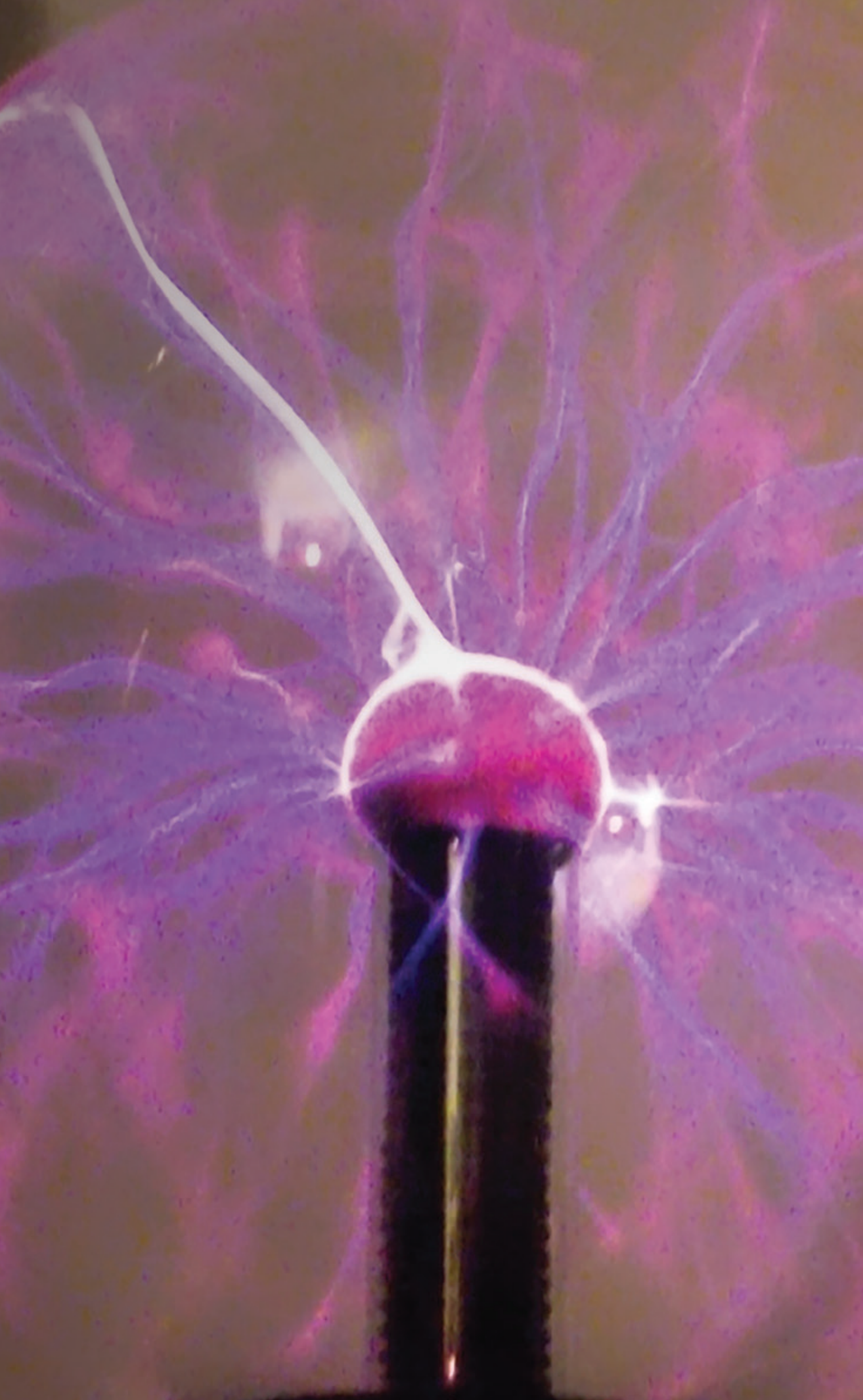
NASA's Electric Field Imaging (EFI) system is the only noncontact method capable of quantitatively measuring the magnitude and direction of electrostatic fields in near- and far-field applications. Based on low-cost, commercially available components, the EFI system uses measurement of very low-current, human-safe electric fields to construct a 3D image of objects and people based on their dielectric properties. This platform technology, originally developed for measurement of the efficacy of electrical shielding around cables, could be optimized for a variety of applications, and it has the potential to offer a lower-cost, portable, and safer alternative to image systems currently in use.

Benefits

- Can be optimized for localized or remote applications
- Shows potential for high-resolution imaging (tens of microns or better resolution for centimeter-scale to millimeter-scale objects)
- Displays potential for near real-time imaging with gigahertz data sampling rates
- Does not require exposure to radiation, magnetic fields, heat, or light
- Demonstrates potential for low-cost, portable construction
- Can distinguish between nonconductive materials with high precision (potential capability to detect a 0.01 percent change in dielectric properties between measurements)
- Has easy-to-use, point-and-scan workflow design

Applications

- Remote, noncontact respiratory and vascular system monitoring
- Brain imaging, cancer detection, and cardiac polarization wave imaging
- Nondestructive evaluation of composites, insulators, and electrical shielding
- Homeland security baggage and personnel screening
- Crime scene forensic evaluation
- Lightning strike detection and prediction

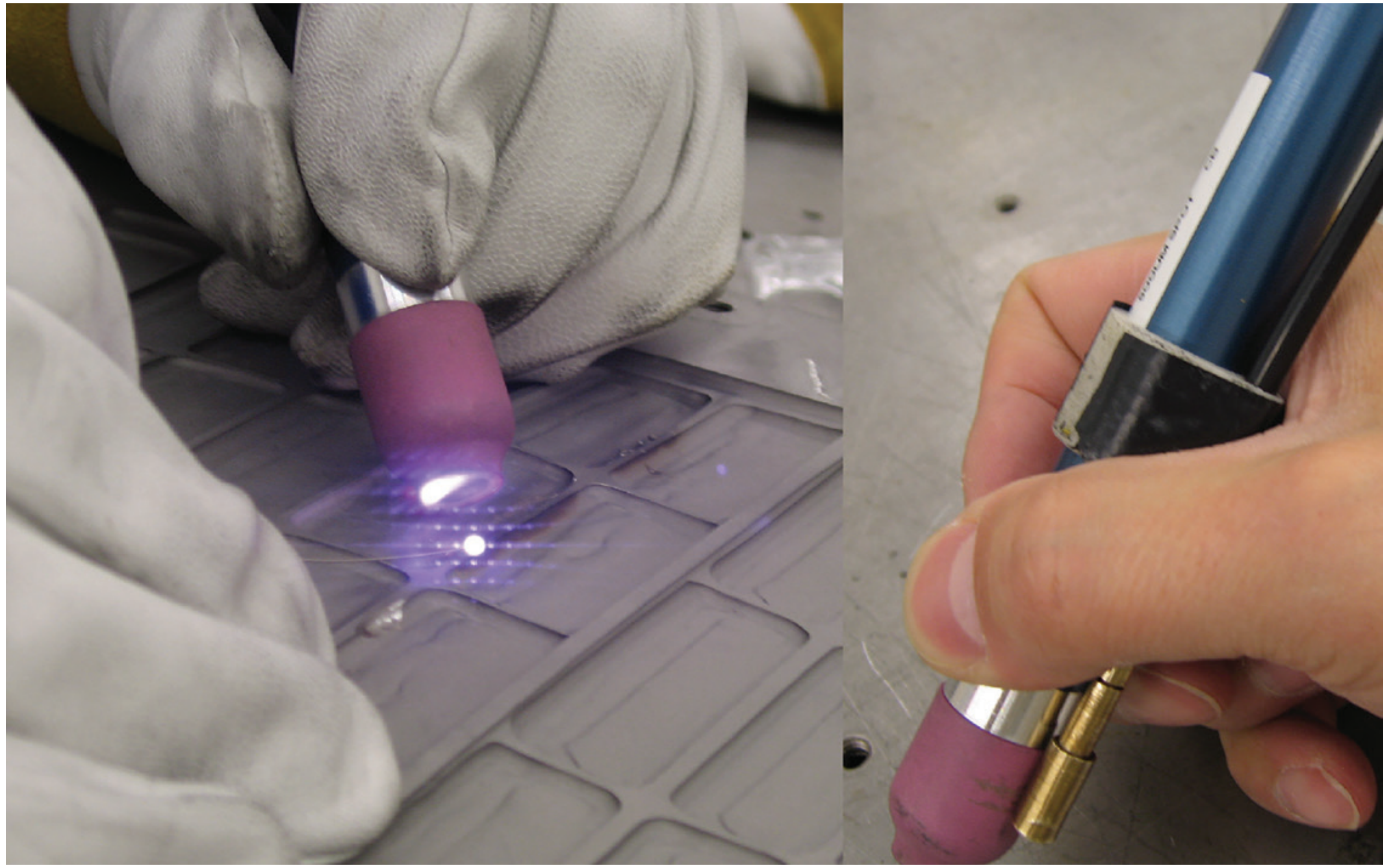


Marshall

High-Power Pulsed Electrical Switch

Mercury-free ignitron for fast switching under high voltage and current

Ignitron electrical switches have traditionally been used in a number of industrial applications in which the high-speed switching of electrical current under high voltage is needed. Today, many of these applications are served by solid-state, semiconductor-type switches, in part due to the toxicity of the mercury used in ignitrons and the lack of suitable alternative designs. On the whole, however, ignitrons can offer much greater durability and reliability over solid-state switch designs, and can handle even higher speeds and higher voltages. NASA scientists have developed a novel ignitron design that uses nontoxic gallium and gallium alloys. The design circumvents plating problems typically experienced with these metals that could lead to short-circuit reliability and durability problems. The result of the NASA innovation is an electrical switch that is ideally suited to the ultrafast switching of high currents under very high voltages.



Benefits

- Operates at very high switching speed and high current while withstanding extremely high voltages
- High reliability and durability and can be readily serviced or disposed
- Nontoxic and environmentally friendly

Applications

- Circuit protection systems in the electric power grid
- High-power and pulsed-power military applications
- Materials processing

Variable-Power Handheld Laser Torch

Accurate, portable tool for joining processes

Marshall Space Flight Center developed the handheld laser torch, designed for welding and brazing metals, to repair hard-to-reach Space Shuttle engine nozzles. It incorporates various manual controls and changing lenses to allow the operator to adjust the laser's power output in real time. The controls and lenses are designed to increase precision, portability, and maneuverability as compared to existing automated lasers and traditional welding techniques such as tungsten inert gas, metal inert gas, or gas-tungsten arc welding systems. Variable lenses allow the user to adjust power in real time, depending on circumstantial welding needs, while proximity sensors with automated shut-off switches also ensure a high level of safety for the user.

Benefits

- Enhanced accuracy
- Increased portability and maneuverability
- Improved user safety via added sensors and emergency switches
- Decreased heat-affected zone, preventing damage to the welding surface

Applications

- Aerospace engine repair
- Medical hardware manufacturing
- Plastic mold and die restoration
- Jewelry manufacturing and repair
- Eyeglass frame welding

Stennis

Cryogenic Butterfly Cam Valve

No-leak valve performs in broad range of temperatures

The main disadvantage of currently available butterfly valves is that more energy can't be added to reduce leakage, as with globe valves. The disc has to create a tight seal with the seat around it exactly when the disc hits 90 degrees. If additional torque is added, the disc will just rotate past 90 degrees, and the valve will open again, allowing fluid or gas to flow through the valve. Typical butterfly valves also fail leakage tests in liquid nitrogen.

The Cryogenic Butterfly Cam Valve design allows additional rotation of the shaft so the disc can slide toward the valve body until it seals tightly. This high-performance design enables a bubble-tight seal at both ambient and cryogenic temperatures, allowing it to prevent leakage no matter how drastic the dimensional changes are due to changing temperatures.

Benefits

- Improves performance over a wide range of temperatures
- Disc can rotate and translate
- Holds a bubble-tight seal regardless of dimensional changes due to changing temperatures
- Zero leakage
- Simple design with larger machining tolerances

Applications

- Aerospace industry
- Liquefied natural gas industries
- Air-gas separation industries
- Cryogenic plants
- Food hydrogenation

Forest and Vegetation Tracking System

Advance warning of risks for public authorities and land managers

Stennis Space Center is offering a powerful suite of software tools that have a proven track record in processing and analyzing satellite data to create maps detailing risks and damage to forests, agricultural crops, and grazing land. The software can be used to detect, identify, and track a variety of disturbances, such as damage from river flooding, severe hurricanes, drought, wildfires, wind, ice, hail, and frost. It can also track defoliation and mortality caused by insect pests or disease. This can be a useful tool for public authorities; land managers, whether forest rangers or farmers, for whom it can provide an early-warning system; and for university and government researchers.

Benefits

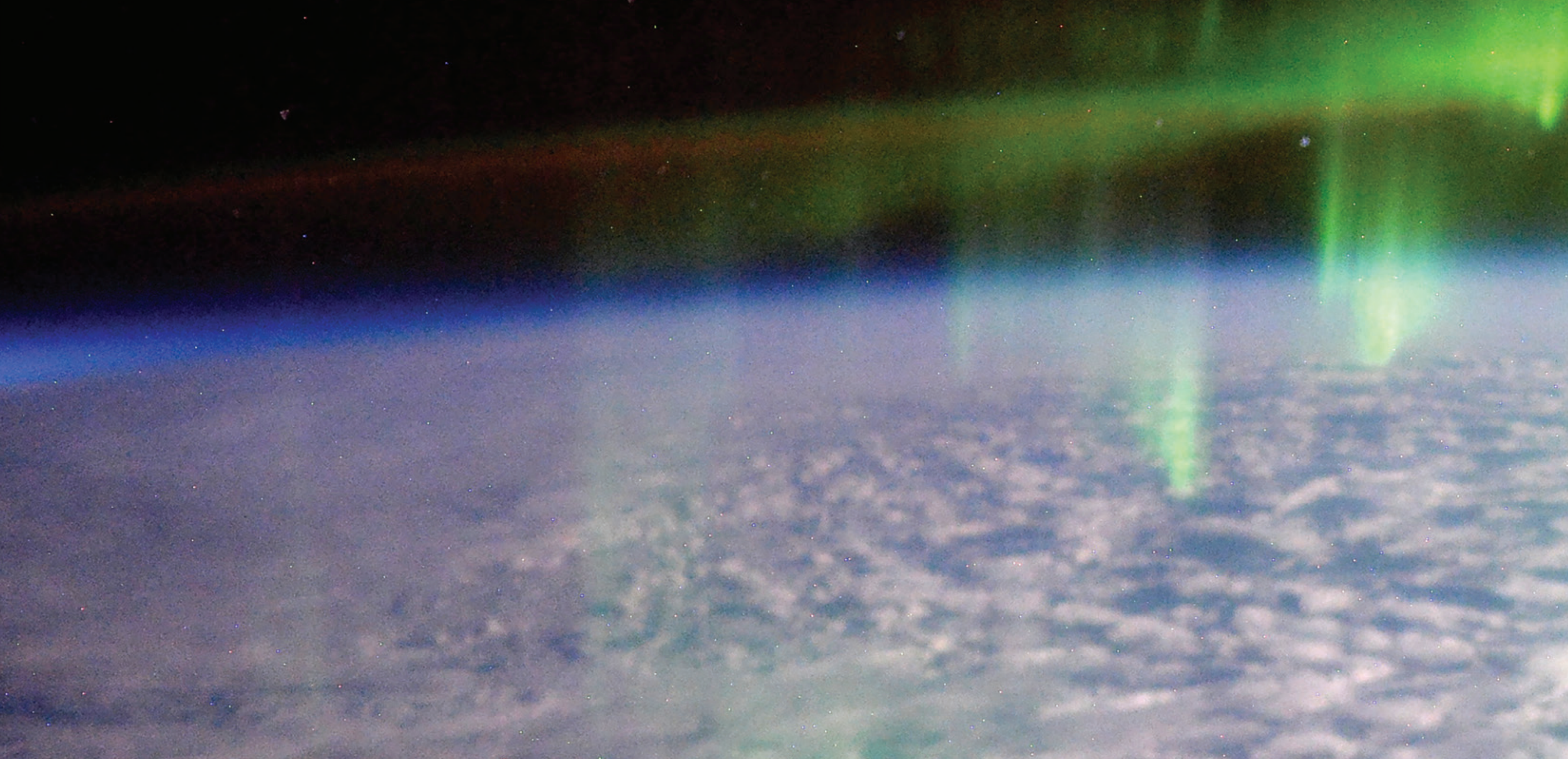
- Observation of patterns difficult or impossible to see from the ground
- Capable of near real-time monitoring
- Ability to rapidly identify and interpret risks and threats
- Cost and time savings for land managers
- Ability to create and share custom maps

Applications

- Forest monitoring and management
- Agricultural management
- Grazing rangeland management
- Academic and scientific research

NASA's Technology Transfer Program

Behind the scenes, NASA's Technology Transfer Program is the engine that ensures spinoffs keep spinning. Since 1962, the program, NASA's longest-running mission, has been powering the Agency's effort to inject research, technology, and inventions into American industry as much as possible.



NASA's Technology Transfer Program

Bringing NASA Technology Down to Earth

Even revolutionary technology can face a long road on its way to commercial success. The unparalleled efficiency of LEDs, for example, has only recently translated into market dominance in lighting and electronic screens, though the technology itself is a half-century old. It often takes multiple generations of inventors, engineers, and entrepreneurs to get promising technology from the lab to the store shelf. (In the case of LEDs, the key breakthrough came in 1994 with the development of blue LEDs, required to make white light, followed by billions of dollars of industry and government investment to make them practical in light bulbs and televisions.)

NASA innovators produce more than a thousand new technologies every year, including some with revolutionary potential. In keeping with the 1958 Space Act's directive to share the benefits of aeronautics and space research with the public, NASA's Technology Transfer Program assesses each technology's commercial potential and does its best to move these innovations toward commercialization. That includes patenting particularly promising innovations, managing a technology portfolio containing thousands of inventions and software programs, marketing technologies to industry, and overseeing licenses and other distribution agreements.

The commercial results—many of which you can read about in *Spinoff*—are sometimes decades in the making.

Thanks in large part to recent program initiatives, NASA technology has never been more easily accessible. Today, for example, the public can browse a central repository for NASA software (http://software.nasa.gov) that contains the Agency's publicly released codes—all of which are available free of charge and can be downloaded from the site. This catalog, first released in 2014, was the first of its kind among all agencies of the Federal Government, which is the world's largest creator of custom code.

A patent portfolio of Agency inventions, ranging from sensors and robotics to green energy innovations, is likewise managed through a single public-facing repository (http://technology.nasa.gov/patents). As of 2017, individuals and businesses interested in using these NASA technologies can apply for a license through a simple and automated online application system known as ATLAS. Commercial licenses are negotiated on a case-by-case basis, but NASA also offers a few licenses that have low or no up-front costs for startup companies or businesses interested in evaluating a technology before committing to it.

Members of NASA's Technology Transfer Program pose in front of the program's information booth at TechConnect in Washington, D.C., May 2016.

There are also thousands of formerly patented technologies that NASA has gifted into the public domain—again, with a central, searchable database developed by the Technology Transfer Program within the last few years (https://technology.nasa.gov/publicdomain). Anyone can pursue product development using these technologies for free, with no requirement to contact NASA.

The Technology Transfer Program's increased marketing and promotion of NASA's various technology portfolios has led to a dramatic spike in interest in NASA technology for commercial applications. Since the release of a single catalog, requests for Agency software have multiplied, leading to many thousands of transfers to the public each year. Meanwhile, there are about 450 active licenses for NASA-patented technologies, with roughly 100 new licenses being executed each year.

Managing this increased interest requires constant and continuous process improvements across all areas of the technology transfer pipeline—from new internal tools to help NASA innovators publish their discoveries and

inventions to websites and mobile applications the public can use to discover and acquire NASA technology. The Technology Transfer Program develops and maintains these tools while also conducting public outreach through media, conferences, and consultations with government, university, and commercial organizations.

All of these efforts haven't changed the nature of invention and product development: it can still take technology decades to mature from an initial idea or prototype into something consumers can use every day. NASA spinoffs profiled in its annual *Spinoff* publication still routinely feature products that have their origins in the Space Shuttle or even as far back as the Apollo Program. Much has changed since then, of course—not least the technologies themselves, as they wove their way into practical applications.

Some of these spinoffs from NASA aeronautics and space technology change the way we live—such as the NASA-developed aerodynamic truck and aircraft designs that dominate the roads and sky, or the international search and rescue system designed by the Agency. Others stay confined to their niche technical markets or are useful for only a short time and thus aren't as well known.

But all of these commercial successes, and the long process it took to make them happen, have helped establish NASA as the leader among Federal technology transfer programs, showing by example the ways in which public investments in science and technology yield practical benefits through commercial products. ❖

Top left: Technology Transfer Program Executive Dan Lockney speaks to University of Alabama students in the school's STEM Path to the MBA Program. Top right: In May 2017, NASA Langley inventors pitched their technologies to a panel of industry experts as part of a pilot competition using the same format as the television show Shark Tank. Bottom: Students attending a conference gather at NASA's technology transfer booth.

Technology Transfer Program Network Directory

MAP KEY

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

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.

To learn more about licensing NASA technology, visit http://technology.nasa.gov. General inquiries may be directed to the Spinoff Program Office at spinoff@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 Agencywide.

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.

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