National Aeronautics and Space Administration

spinoff

2015

Introduction

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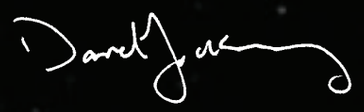

Hi, I'm Dan Lockney, Technology Transfer Program Executive at NASA Headquarters.

Here at NASA, we're preparing to look farther into our universe than ever before. We're creating the next generation of satellites and rovers for deep space and planetary missions. And we're building new vehicles that will soon take human beings to other worlds for the first time.

To power these missions, the latest era of innovation is underway here at the Space Agency. And while that means unique advances in science and technology for space applications, it also means remarkable new benefits for daily life, right here on Earth.

As a part of my job, I bring together NASA's best problem-solvers with the Nation's brightest commercial and entrepreneurial leaders, forming partnerships that transfer groundbreaking NASA technologies to the public — and providing solutions for challenges in the fields of health and medicine, transportation, consumer goods, public safety, and more.

Each year, NASA's Spinoff publication features the best recent examples of how NASA innovations now benefit our national and global communities. In this year's book, you'll find water bottles that use NASA-created filters to purify water from lakes and streams on the go; wind turbines, designed to withstand conditions on Mars, that are now powering communities across the world; and a heat shield developed by NASA that is helping the emerging commercial space industry soar to new heights.

Every day, I get to see how technologies created by the Space Agency to explore the universe end up saving lives, creating jobs, and even launching new industries.

Visit us at spinoff.nasa.gov to explore *Spinoff* 2015 and see for yourself. There's more space in your life than you think.

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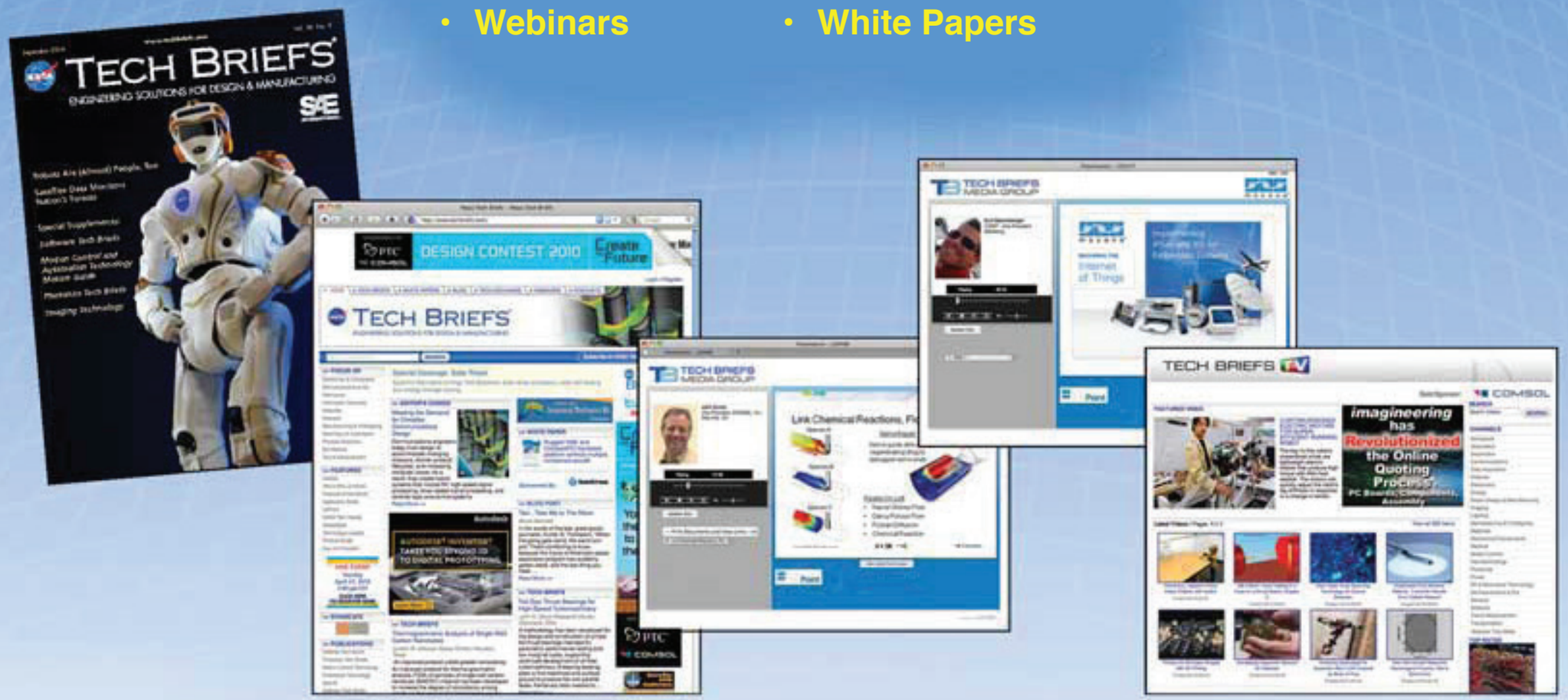

NASA Spinoff Technology Across the Nation

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Health and Medicine

NASA is continually developing new ways to keep its astronauts comfortable and in peak condition, always with an eye on sustainable systems that will enable deep-space missions in the future. The resulting technologies have found numerous applications for the general population, including devices that help patients to exercise more efficiently, rehabilitate more quickly, eat healthier, or get a better night's sleep.

Connect with NASA Spinoff

3D Endoscope Boosts Safety, Cuts Costs of Surgery

A joint effort between NASA's Jet Propulsion Lab and the Skull Base Institute in Los Angeles produced the Multi-Angle Rear-Viewing Endoscopic Tool (MARVEL), the first endoscope suitable for brain surgery that is capable of producing three dimensional imagery.

"A lot of things are not easy to solve when you're trying to break through a new technology right from the get-go," says Harish Manohara, supervisor of the Nano and Micro Systems Group and principal member of the technical staff at NASA's Jet Propulsion Laboratory (JPL).

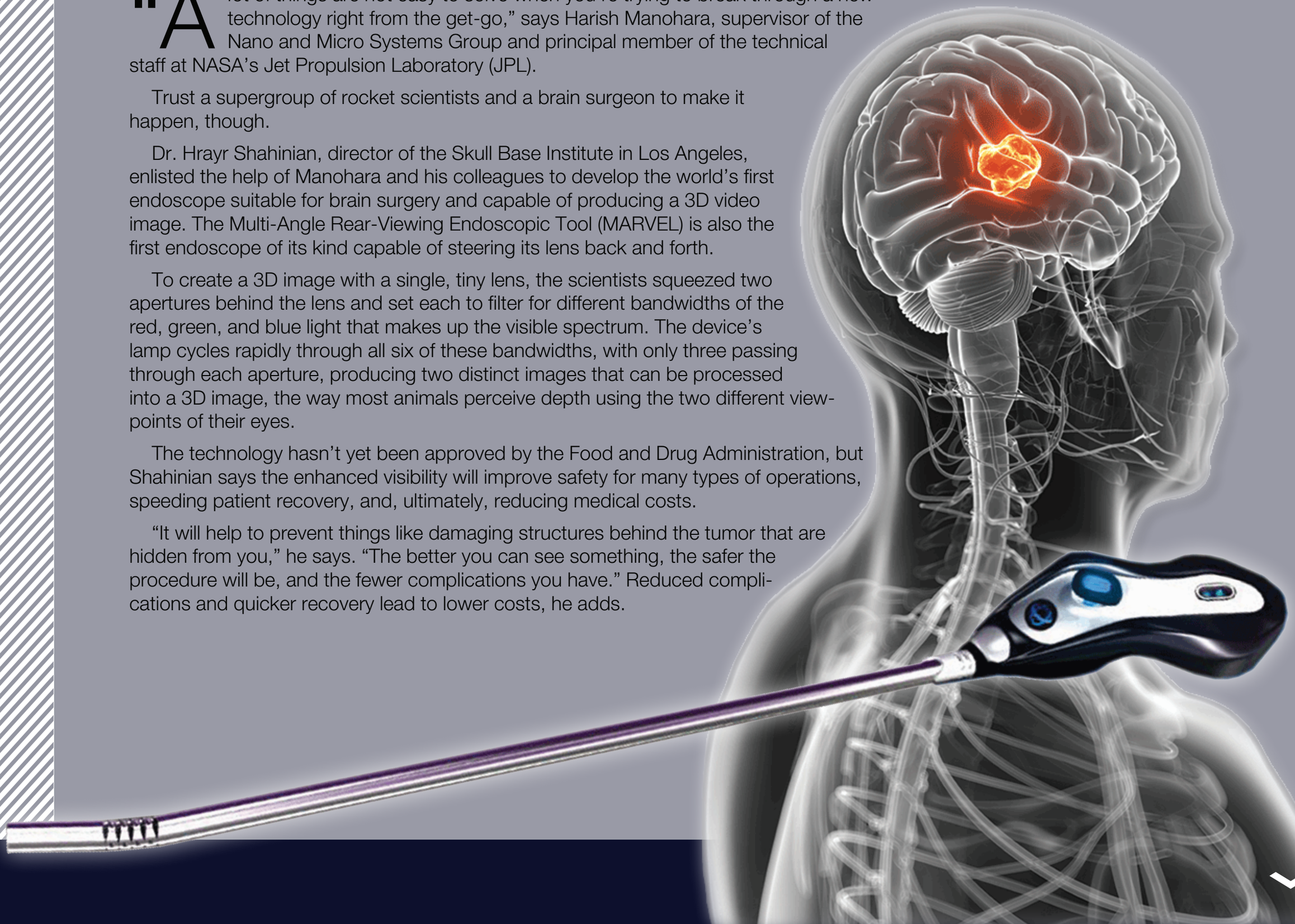
Trust a supergroup of rocket scientists and a brain surgeon to make it happen, though.

Dr. Hrayr Shahinian, director of the Skull Base Institute in Los Angeles, enlisted the help of Manohara and his colleagues to develop the world's first endoscope suitable for brain surgery and capable of producing a 3D video image. The Multi-Angle Rear-Viewing Endoscopic Tool (MARVEL) is also the first endoscope of its kind capable of steering its lens back and forth.

To create a 3D image with a single, tiny lens, the scientists squeezed two apertures behind the lens and set each to filter for different bandwidths of the red, green, and blue light that makes up the visible spectrum. The device's lamp cycles rapidly through all six of these bandwidths, with only three passing through each aperture, producing two distinct images that can be processed into a 3D image, the way most animals perceive depth using the two different viewpoints of their eyes.

The technology hasn't yet been approved by the Food and Drug Administration, but Shahinian says the enhanced visibility will improve safety for many types of operations, speeding patient recovery, and, ultimately, reducing medical costs.

"It will help to prevent things like damaging structures behind the tumor that are hidden from you," he says. "The better you can see something, the safer the procedure will be, and the fewer complications you have." Reduced complications and quicker recovery lead to lower costs, he adds.



NEUROSENSORY ALGORITHMS

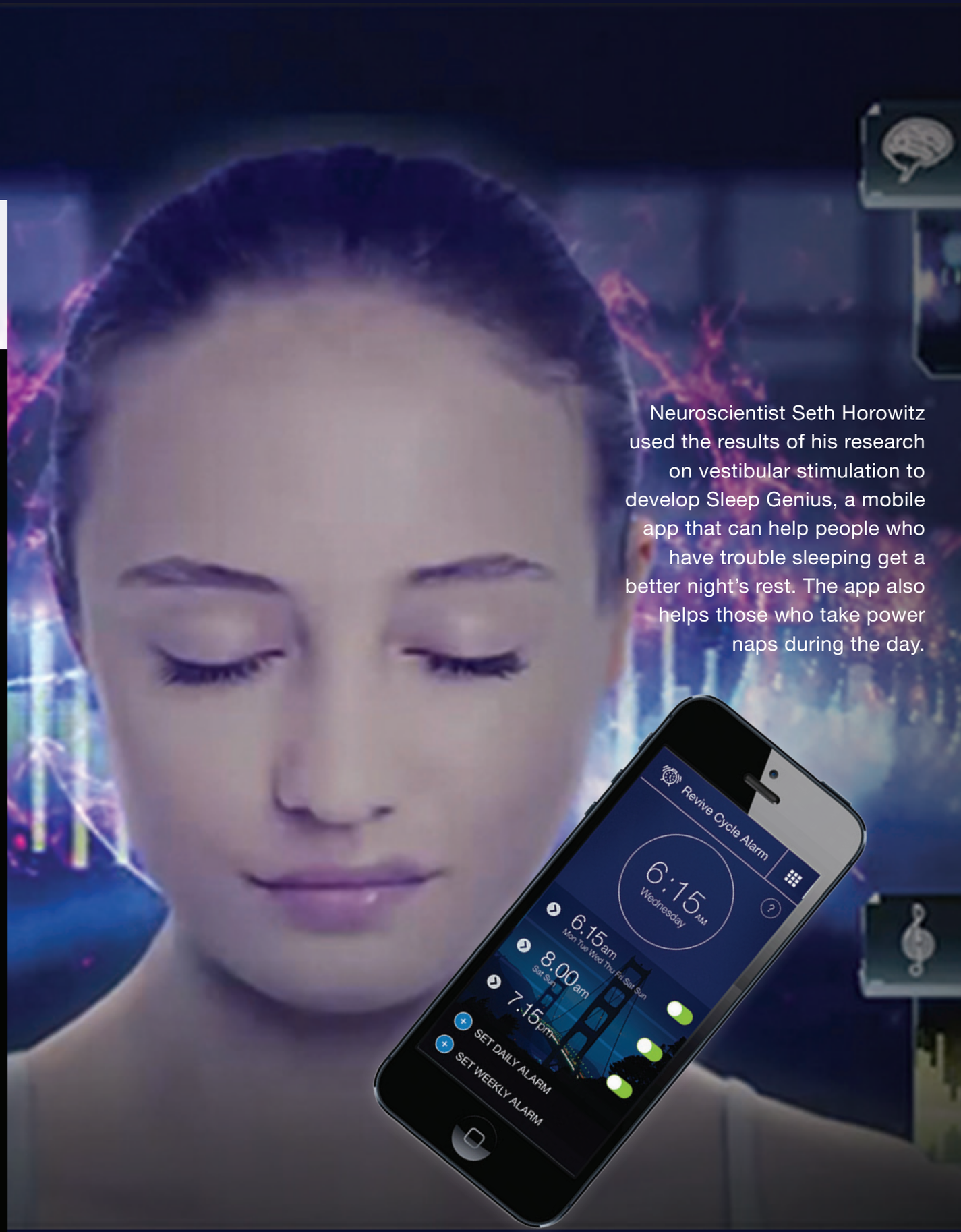
Audio App Brings a Better Night's Sleep

Into insomnia. In 2001 NASA's medical research arm, the National Space Biomedical Research Institute, provided funding for State University of New York at Stony Brook neuroscience professors to examine the impacts of the body's vestibular system on sleep, the ultimate goal being to help astronauts adjust their sleep schedules more effectively. Their research revealed that, beyond contributing to our sense of balance, the vestibular system, when activated by low-amplitude vibration, also triggers neurons in the brain that promote sleep.

One of the researchers, Seth Horowitz, also came to realize there is "crosstalk" between the auditory and vestibular systems, so much so, in fact, that low-frequency, moderate-amplitude sound can also foster sleep. As a result, he founded Park City, Utah-based Sleep Genius and developed an audio program of the same name to help people with sleeping problems.

Using the Sleep Genius app, Horowitz says, requires only a stereo system or sleep-safe headphones. Next is simply choosing one of three music selections—Renewed Universe, Dreamscapes, or Tranquility—setting the alarm (or the timer, if you only need help falling asleep), and then turning out the lights. The technology is designed to benefit people of all ages. "We've found a balance of frequencies that seems to address most of those factors for a wide group of people," he says.

In the short time the app has been on the market, more than 400,000 customers who suffer from chronic sleep ailments have downloaded it.



Neuroscientist Seth Horowitz used the results of his research on vestibular stimulation to develop Sleep Genius, a mobile app that can help people who have trouble sleeping get a better night's rest. The app also helps those who take power naps during the day.

Liquid Cooling Technology Increases Exercise Efficiency

In the mid-1960s, NASA adopted for spacesuits a concept originally developed by the British Royal Air Force to provide cooling for aircraft pilots in hot environments. It utilized a battery-operated miniature pump that cycled chilled water through a series of tubes lining the garment, which pressed against the skin, absorbing heat.

A team of scientists and engineers at NASA Ames Research Center have since investigated the physiological effects of such artificial cooling technologies, and, as a result, a number of spinoffs have emerged. One company, CoolSystems (now Game Ready), sells a device, consisting of ergonomic wraps connected to a control unit, which delivers pressure and cold to speed up recovery time for injuries (*Spinoff* 2004). Peter Wasowski, a co-founder of CoolSystems, is now utilizing a similar technology to help people of all ages and abilities improve their fitness and overall health.

In the late 1990s Wasowski became interested in vascular compression: a method of exercise whereby compression is added to arm and leg muscles to hasten the buildup of lactic acid, signaling the brain to release anabolic hormones responsible for rebuilding and strengthening damaged muscle tissue. He knew that colder temperatures also improved exercise efficiency as well as comfort.

With Vasper Systems, headquartered in San Jose, California, Wasowski incorporated the NASA liquid cooling technology into compressive cuffs, which are applied to the arms, thighs, and chests of clients as they complete a low-impact, 30-minute exercise routine on a recumbent bike. The brisk workout produces similar results to other exercises that take longer than an hour. Other benefits include less wear and tear on the body and reduced soreness after exercise.

"The technology's made quite a journey," Wasowski says. "It's wonderful how it's found a critical use back on Earth in helping people lead healthier lives while helping others compete at the highest levels in sports."

Peter Wasowski's Vasper exercise regimen uses the NASA-derived liquid cooling technology to concentrate lactic acid in the muscles, which he says improves workout efficiency and reduces recovery time.

Algae-Derived Dietary Ingredients Nourish Animals

In an era of dog spas and pet health insurance, DHAgold has come to be marketed as a health supplement to be added to pet food.

In the mid-1990s, Columbia, Maryland-based Martek Biosciences Corporation took the infant formula industry by storm with Formulaid, one of the most successful NASA spinoffs in the agency's history (*Spinoff* 1996, 2008). Based on work the company's founders did with Ames Research Center on the Closed Environment Life Support System project in the early 1980s, the formula supplement consisted of long-chain omega-3 fatty acids extracted from microalgae and a species of fungus.

One of those fatty acids—docosahexaenoic acid, or DHA, taken from crypthecodinium cohnii algae—is now incorporated into DHAgold, a dietary supplement for animal feed, whether it's for livestock, fish farms, or pets. DHA is essential for proper neuron functioning and makes up most of the fat in the brain and retina, and DHA supplements have been credited with positive effects on maladies from hypertension and arthritis to cancer and adult-onset diabetes, in addition to more neuron-related complications, such as Alzheimer's disease, attention deficit disorder, and depression.

When DHAgold is incorporated into chicken feed, the nutrient is delivered to humans via DHA-enriched eggs. When it's fed to pigs or fish, it accumulates in the animals' flesh, which consumers then eat. Fish are a well-known source of DHA, but this is because they feed on an algae-based food chain. Fish farms, however, often incorporate fish oil, rather than algae, into their feed. As concerns about overfishing become more acute, algae-based fish feed becomes more attractive. When incorporated into pet food, DHA confers the same benefits on pets that it does on humans, for example, boosting trainability in puppies and eyesight in older animals.

In 2011 Dutch-based Royal DSM spent more than $1 billion to purchase Martek, which, as the DSM Nutritional Products Division, continues to manufacture many of the same products, including DHAgold.

DHAgold can replace fish oil in aquaculture feed. A goal of fish farming is to slow the depletion of the seas' fish populations, but using fish oil in the feed undermines that aim.

Space Grant Research Launches Rehabilitation Chair

On the International Space Station, astronauts' bodies do not have to work like they do on Earth to move and accomplish normal daily tasks. Without the force of gravity acting on their bodies every moment of the day, astronauts' bones lose density in space at a rate 10 times faster than those who suffer from osteoporosis. To stay healthy and keep their bones strong, astronauts spend a considerable amount of time working out while in orbit.

In 2000, a biomedical engineering student at Michigan Technological University, Jeff Leismer, became particularly interested in this issue of bone loss in microgravity. One of Leismer's professors had an idea to develop something to simulate impact to the body so the bone wouldn't decrease as much in space. Working with funding from the National Space Grant College and Fellowship Program—which was implemented by NASA headquarters to fund research, education, and public service projects—a team at the school created a vibration-based system that could combat bone loss from prolonged trips to space.

Leismer continued working on the concept through a PhD program, and he now sells a rehabilitation chair incorporating the technology through his company, Sheboygan, Wisconsin-based VibeTech Inc. "Exercise is the number-one thing you should do," he says, "but patients don't do it because of barriers including exertion, pain, and flexibility. I am hoping this will help people lead a much higher quality of life—and hopefully live longer as well."

The VibeTech One rehabilitation chair can be used by people who have little or no physical strength or function in their lower body. Users can sit and relax as the therapy progresses.

Japan Aerospace Exploration Agency astronaut Koichi Wakata, Expedition 38 flight engineer, gets a workout on the advanced Resistive Exercise Device in the Tranquility node oftheInternational Space Station. Intense exercise regimens area necessary part of life in microgravity to maintain bone and muscle mass.

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>
> —Jeff Leismer, VibeTech

Vision Trainer Teaches Focusing Techniques at Home

When NASA's Ames Research Center contracted Stanford Research Institute in the 1960s to develop a means of measuring pilots' ability to adapt their vision to different distances, the agency was not considering a biofeedback device that could teach users to control their eye focus—much less a system that could improve sensory and motor processes, as well as attention, creativity, and learning, by inducing an "alpha brain-wave state."

Thirty years after the release of his Accommotrac Vision Trainer, Joseph Trachtman, pictured here, released a home version of the device, called the Zone-Trac. Advances in technology made it possible for Trachtman to build a much smaller, wearable, and more affordable device.

However, as Robert Randle, NASA's technical monitor of the Stanford contract, ran experiments on pilots using the optometer the institute developed, he discovered that his subjects were often able to control their normally involuntary eye focus. To help them, he incorporated auditory biofeedback, whereby the machine produced different tones depending on the contraction or relaxation of the eye's focusing mechanism.

He considered the device a potential means to overcome "empty-field myopia," the tendency for a pilot's focus, in empty skies, to rest at a distance around a meter away.

After studying the reports from the NASA work, optometrist Joseph Trachtman built a similar optometer with an audio biofeedback mechanism. He released the Accommotrac Vision Trainer in 1984 (*Spinoff* 1990). He found that, in addition to gaining control over visual focus, users reported unexpected benefits: widening of the field of vision, seeing in slow motion, intensified color perception, and increased hand-eye coordination and reaction times, which lingered after the treatment.

He began measuring quantifiable data, including brain waves, and found the reported effects appeared to be real, accompanied by an increase in alpha brain waves, the same emitted by Zen practitioners during meditation. Other forms of biofeedback have been reported to induce similar responses.

Taking advantage of the technological advances of the last 30 years, in early 2014, Trachtman released a smaller, more affordable home version of the device, called the Zone-Trac.

Transportation

NASA is best known for its audacious forays into the void beyond Earth's atmosphere, but "aeronautics" comes before "space" in the agency's name, and from its inception NASA has worked continuously to advance air travel for all Americans. Its endeavors have contributed directly to aircraft fuel efficiency, noise reduction, and safety and have also improved air traffic control.

Connect with NASA Spinoff

Aircraft Geared Architecture Reduces Fuel Cost and Noise

NASA has always worked hand in hand with industry to improve commercial flight efficiency. One such program is the Subsonic Fixed Wing Project, tasked with helping the private sector advance fuel efficiency and noise-reduction technologies. To that end, the agency teamed up with East Hartford, Connecticut-based engine manufacturer Pratt & Whitney to overcome a long-known inefficiency in turbofan engines, which power virtually all commercial aircraft today.

Turbofans have traditionally been designed so that a central shaft drives two separate engine parts: the turbine, which, as it spins, drives a compressor that pressurizes incoming air before it mixes with fuel for combustion; and the fan, which provides additional thrust. The problem is that fans are more efficient the slower they spin, whereas turbines work better the faster they spin.

Through a Space Act Agreement, the company was granted access to NASA's aeronautical experts and to various engine-testing facilities at Glenn Research Center. With additional funding from other agency programs, Pratt & Whitney developed and tested a geared box wherein the turbine and fan spin at their optimal speeds. The result is a more than 15 percent increase in fuel-burn efficiency and a nearly 75 percent reduction in noise pollution.

Since debuting its PurePower Geared Turbofan family of engines for regional and single-aisle aircraft in February 2013, the company has reported more than 5,500 PurePower engine orders and commitments from airlines worldwide. Pratt & Whitney chief engineer Michael Winter says by using the engines, airlines stand to save $1.5 million in fuel costs per aircraft annually. That also translates to releasing 3,000 fewer tons of carbon dioxide into the atmosphere.

"The first A in NASA stands for aeronautics, and the agency brings world-class researchers and facilities to the table," Winter says. "It's a tremendous resource for the industry and the nation."

In collaboration with NASA, Pratt & Whitney developed its PurePower family of turbofan engines, which are more fuel-efficient and quieter than other commercial models. Here, the PurePower 1217G engine, developed for Mitsubishi Regional Jet aircraft, undergoes ground testing in West Palm Beach, Florida.

Pratt & Whitney's PurePower PW1217G engine on its first test flight over Montreal, Canada. Engines in the PurePower family release 3,000 fewer tons of carbon dioxide into the atmosphere each year while saving airlines roughly $1.5 million in annual fuel costs.

Ubiquitous Supercritical Wing Design Cuts Billions in Fuel Costs

Dubbed “the man who could see air” by the Smithsonian’s Air & Space Magazine, Langley Research Center aeronautics engineer Richard Whitcomb took an unconventional approach to aerodynamics, eschewing calculations in preference of visualization and intuition. Among his major contributions to aeronautics was the supercritical wing, designed to help planes more easily break through the “sound barrier.”

“As an object moves through air, it collides with the air molecules, creating a disturbance that propagates away from the object by means of weak pressure waves—essentially sound waves,” explains Robert Gregg, chief aerodynamicist for Boeing Commercial Airplanes. As the object approaches the speed of sound, these disturbances cannot work their way forward and instead coalesce to form a shock wave, which tends to stand on the aircraft’s wing, creating drag. This was the sound barrier that aeronautical engineers had struggled to breach.

What Whitcomb and colleagues created almost looked upside-down compared with wings of the day. It was also thicker than the norm, especially on its leading edge. “The low upper-surface curvature weakens the shock wave and, in many cases, moves the location of the shock wave farther aft,” Gregg explains.

It turned out the wings were more efficient at subsonic speeds as well. Because the thicker wing forms a sturdier attachment to the fuselage, it requires less reinforcing structure. The resulting weight savings allows more weight to be spent on widening wing span, and a wider span brings greater fuel efficiency. A test wing was shown to create up to 30 percent more lift than the conventional wing.

Today, nearly all commercial, military, and business planes made by Renton, Washington-based Boeing Commercial Airplanes and other manufacturers use the technology, saving billions in fuel every year and cutting down on engine emissions.

The supercritical wing was one of three major contributions Langley Research Center engineer Richard Whitcomb made to aeronautics. An eccentric who seemed most at home in the center’s wind tunnel facilities, where he was known to sometimes sleep between double shifts, Whitcomb tended to prefer intuition to calculation when working out designs.

Using MUSYN's LPVTools software toolkit, NASA is synthesizing flight control algorithms for an unmanned, lightweight flexible aircraft called the X-56A Multi-Use Technology Testbed (MUTT). The agency's work with MUTT is an important step toward making such aircraft, which are prone to flutter, technically feasible.

Flight Controller Software Protects Lightweight Flexible Aircraft

In the late 1980s, NASA participated in the development of Robust Control theory. Put simply, the theory helps to provide automated stability to structures such as aircraft in response to various external forces. A resulting application is called gain scheduling, whereby electronic controllers are programmed to apply those split-second changes.

Recent research into lightweight flexible aircraft, whose bodies and wings are made of lighter materials, will bring about greater fuel efficiency and longer possible flight distances. But reducing a wing's heft also increases susceptibility to a dangerous condition called flutter: uncontrollable vibrations that can cause a wing to break apart. For lightweight flexible aircraft technology to become viable, NASA advanced what's called Linear Parameter-Varying Control (LPV) theory—a more vigorous version of Robust Control Theory—to account for the aeroelastic conditions that bring about flutter.

The agency then needed augmented gain scheduling tools so controllers could be programmed to prevent the dangerous occurrence. For that task, NASA's Armstrong Flight Research Center granted Small Business Innovation Research funding to Minneapolis, Minnesota-based MUSYN, a company that had developed commercial gain scheduling software tools in the early 1990s. The firm incorporated the agency's LPV theory into a new software program called LPVTools.

With LPVTools, both NASA and airplane manufacturers can now experiment with flutter suppression algorithms for prototype aircraft. Made commercially available in 2014, other applications for the technology include setting controls for a variety of automated machines, including unmanned aerial vehicles used in gathering scientific data and tractors set with controls for grading and digging work.

Two pilots operate the X-56A MUTT from a ground control station.

Cabin Pressure Monitors Notify Pilots to Save Lives

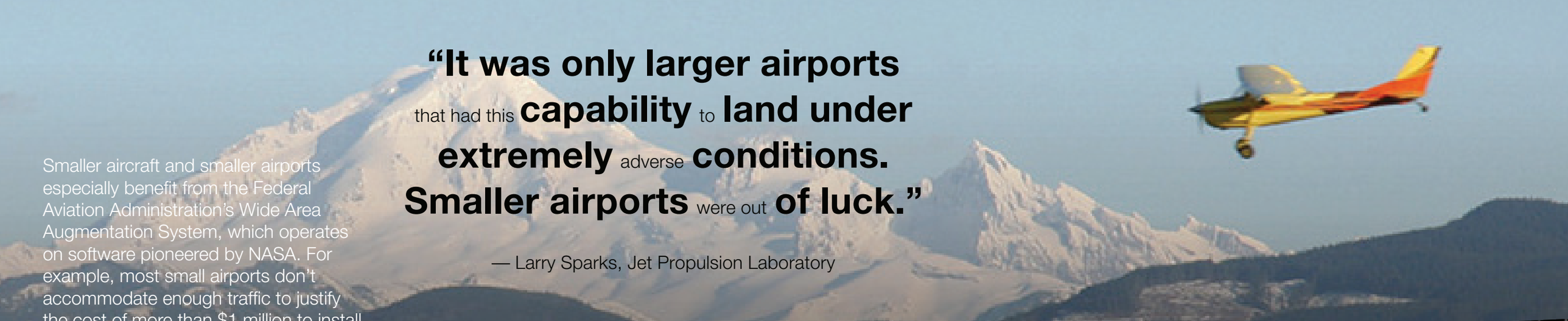
Typical cruising altitudes for business and commercial aircraft are up to 50,000 feet or more. Occupants could not survive in this environment without pressure in the aircraft being controlled to maintain oxygen concentrations consistent with those nearer the ground. A cabin pressure warning system typically lets pilots and crews know when pressure becomes dangerously low, but these can malfunction or be accidentally switched off. The result can be insidious and deadly, as those on the plane become slowly incapacitated by hypoxia—oxygen deprivation—without being aware
of it.

In the early 2000s Jan Zysko, an engineer at NASA's Kennedy Space Center, invented a cabin pressure monitor (CPM) to provide early warning of hypoxic conditions. In 2002, a company licensed the technology from NASA and started selling it (*Spinoff* 2003). The following year, the CPM won both NASA's government and commercial Invention of the Year awards in recognition of its value not only on planes and in space, but potentially for skydivers, balloonists, mountain climbers, and others.

A decade later the company went out of business. That was when Stacy Pappas, founder and owner of San Diego-based Aviation Technology Inc., heard about the CPM. She called NASA, obtained an exclusive license for the technology, and, working with her team of engineers and designers, built a new product from start to finish, based on the original NASA concept. Launched in 2014, AV Tech's Alt Alert is a personal altitude pressurization monitor that is smaller and lighter than most cell phones.

"Oftentimes, pilots don't realize their pressurization system has failed. If it does fail, or simply was not turned on prior to flight, and the pilots have adequate notification, they will have ample time to take action," says Pappas. "It could save lives."

Aviation Technology Inc.'s Alt Alert cabin pressure monitor uses a flashing, red light combined with either advisory chirps or sustained alarms, depending on the seriousness of the situation, to alert pilots and crewmembers to a loss of cabin pressure. The device can be secured to a visor with a clip, but it can also use a suction cup to attach to a window, or Velcro for mounting on an instrument panel.



“It was only larger airports that had this capability to land under extremely adverse conditions. Smaller airports were out of luck.”

— Larry Sparks, Jet Propulsion Laboratory

Smaller aircraft and smaller airports especially benefit from the Federal Aviation Administration’s Wide Area Augmentation System, which operates on software pioneered by NASA. For example, most small airports don’t accommodate enough traffic to justify the cost of more than $1 million to install an instrumented landing system, but the cost to inspect and commission an approach procedure that can be navigated with the help of GPS is about 90 percent less.

Global Positioning System (GPS) satellites, such as one from the Block IIR series, not only transmit data to and from GPS units on earth, but they are also used to determine the extent to which those signals are being delayed by activity in Earth’s ionosphere.

Ionospheric Mapping Software Ensures Accuracy of Pilots’ GPS

The software that enables navigation with the Global Positioning System (GPS), developed at NASA’s Jet Propulsion Laboratory (JPL), has been licensed by hundreds of commercial and noncommercial organizations (*Spinoff* 1999 and 2010), but companion software that allows the system to pinpoint locations accurately enough to guide airplane landings without radar assistance has existed more under the radar, so to speak.

In the early 2000s, Raytheon started using the GPS-Inferred Positioning System (GIPSY) that allows GPS navigation, along with accompanying software that was also developed at JPL, to enable the Federal Aviation Administration’s Wide Area Augmentation System (WAAS), which provides almost pinpoint accuracy in an airplane’s GPS.

The software does this by calculating the signal delay being caused by activity in Earth’s ionosphere at any given time and also coming up with a margin of error for its own calculations. The Ionospheric Slant TEC Analysis using GNSS-based Estimation (IonoSTAGE) software, which is primarily used for that last function, found its first commercial license in late 2013, when NEC, an international company based in Japan, with US headquarters in Irving, Texas, licensed the entire package of WAAS-enabling software.

Since WAAS went live in 2003, more than 73,000 planes have been outfitted with the capability to use it. Most of these are individually owned aircraft, business jets, emergency transporters, and an increasing number of regional airlines.

Before WAAS, these small planes required an airport with an instrument landing system to land under low-visibility conditions, says Larry Sparks, technologist with the Ionospheric and Atmospheric Remote Sensing Group at JPL, who wrote the original code for IonoSTAGE. “It was only larger airports that had this capability to land planes under extremely adverse conditions. Smaller airports were out of luck.”

›

Public Safety

From technologies meant to safeguard astronauts to crucial Earth-observation data, much of what NASA does has applications in keeping the general public safe and in helping people find or monitor resources such as drinking water, agricultural products, and forest cover. The agency also partners with industry to pioneer safety solutions, from preventing oil spills to assessing potential structural damages or increasing visibility under hazy conditions.

Connect with NASA Spinoff

Water Mapping Technology Rebuilds Lives in Arid Regions

> “Discovering a little water brings war, but discovering a lot of water can bring peace, because everyone can share it.”
>
> —Alain Gachet, Radar Technologies International

Turkana County in northwest Kenya has been reeling from several years of crippling drought. But a new story was written over this hardened landscape in September 2013, following the announcement of an incredible find: at least 66 trillion gallons of water deep beneath the surface of Turkana in the Lotikipi and Lodwar basins. The previously untapped catchment system has the potential to improve Kenyans’ lives for generations.

The find was made possible in part by NASA archive data. French geologist and geophysicist Alain Gachet had been discovering oil for companies when he started his own oil, mineral, and gas exploration company in the mid-1990s called Radar Technologies International (RTI), which has an office in New Braunfels, Texas. Utilizing images taken by NASA’s Spaceborne Imaging Radar (SIR), which uses radio waves to map Earth’s topography, he was probing for oil in the Libyan desert when he inadvertently discovered leaks in a subsurface pipeline that supplied water to coastal towns.

“The experience gave me the idea that I could use radar frequencies to find underground water that could be used to help people,” he says, “because people don’t drink oil—they drink water.”

Gachet used the SIR data in collaboration with Landsat satellite datasets and information from the Shuttle Radar Topography Mission (which NASA used to measure global land elevations) to develop his proprietary WATEX system, which is able to remove surface features and reveal underground reserves of water and map them for drillers.

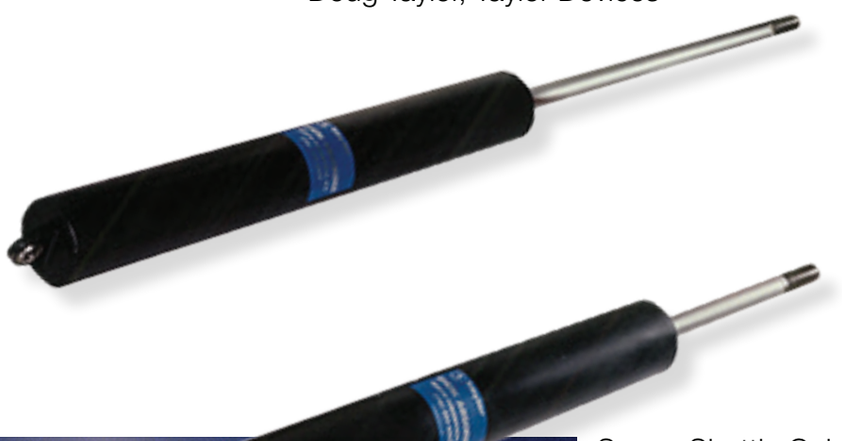
In addition to his work in Kenya, Gachet has been able to locate water for refugees in Darfur, in Western Sudan, and for others in war-torn countries such as Afghanistan and Iraq. A lot of the credit, he says, should go to the space agency. “NASA’s Landsat and Shuttle Radar Topography Mission [data] are my eyes on the ground. Without them I am totally blind. They are great gifts to humanity.”

The largest of the African Great Lakes, Victoria is situated across Tanzania, Uganda, and Kenya. Radar Technologies International’s (RTI) WATEX System uses Landsat data, which contains information on surface topography and rock chemistry, to help locate underground water.

Shock Absorbers Save Structures and Lives during Earthquakes

“It’s a simple device that lasts a really long time with no maintenance.”

—Doug Taylor, Taylor Devices



Space Shuttle Columbia just before its inaugural launch on April 12, 1981. Taylor Devices developed fluidics-based shock absorbers (above), derived from NASA funding for advancing computers, to safely remove the shuttle’s umbilicals during launch. Depending on their positions, the shock absorbers ranged from two to eight feet long and five to eight inches in diameter.

In the early 1960s, NASA was preparing the Apollo spacecraft to launch the first man on the moon. One of the issues the agency dealt with was making sure the umbilicals—bundles of fuel- and electricity-carrying cords and tubes connected to different parts of the rocket—were removed from the spacecraft quickly but safely during launch. Taylor Devices, headquartered in North Tonawanda, New York, provided the dampers for the swing arms that carried the umbilicals so they were pulled back into their cradles gently and didn’t break from overexertion or collide with the vehicle.

The company also had a hand in another NASA project: utilizing oil-based hydraulics to run a computer. Taylor Devices was hired as a sub-contractor to work on some of the engineering elements, and during that time it made headway in the science of fluidics, so much so that the firm would later develop its fluidics-based dampers, which are more compact and powerful compared to conventional technologies.

The dampers would go on to be used to control the gantry’s swing arms for the Space Shuttle Program, and since the 1990s the company has been using the technology for its seismic dampers, which stabilize buildings in the event of an earthquake.

More than 550 buildings and bridges are now protected by Taylor Device’s fluidic, seismic dampers (accounting for about 60 percent of sales), many of them located in the world’s most seismically active areas such as San Francisco, Tokyo, and Taiwan, among others. “Not a single building outfitted with our dampers has fallen or had even minor damage after a quake,” he says, “and because of that, a substantial number of human lives have been saved.”

One of Taylor Devices’ chevron brace dampers is embedded in a building’s frame at the Portland, Oregon Galleria shopping mall. The company is using its NASAderived dampers to secure structures during earthquakes.

Software Facilitates Sharing of Water Quality Data Worldwide

Canadian astronaut Robert Thirsk shows the coliform bacteria test kit that is used onboard the International Space Station. The test is designed to be lightweight and simple yet accurate.

Onboard the International Space Station, or ISS, reclaimed water must be checked periodically for any traces of contamination, such as *E. coli*, which could make astronauts sick in space.

Throughout the late 1990s and early 2000s, there was no way of knowing what kinds of bacteria were present without having samples flown back to Earth. But the Space Shuttle Columbia disaster in 2003 temporarily discontinued US flights to and from the station, hampering the agency's ability to transport water samples and supplies As a result, NASA scientists simplified a common coliform bacteria test that didn't require bulky lab equipment so it could be carried out on the ISS. To put it simply, a water sample, mixed with a growth indicator powder, is stored in a plastic bag and left out at room temperature for approximately 44 hours, at which time a dependable reading can be made based on a color change.

John Feighery, an environmental engineer at Johnson Space Center who was involved in developing the test, went on to work in rural communities abroad, helping to test water for contamination.

Maurice Kanzala collects a water sample from a shallow dug well for The Water Trust, one of mWater's clients working to provide safe water in rural Uganda. The mWater app allows field workers to record and share water quality or other data on how the water source is functioning over time.

Realizing such communities need simpler ways to test for coliform bacteria, in August 2012 Feighery introduced a smartphone app called mWater, which offers instructions on how to perform the NASA water contamination analysis. Afterward, through the app, users can share results with the public.

Through his New York City-based mWater Foundation, Feighery and his wife Annie, along with fellow cofounder Clayton Grassick, are implementing the technology on a larger scale. In 2013 the US Agency for International Development awarded the organization funding to work with the Tanzanian government. The goal is to get public employees, such as water utility workers, public health workers, and community health workers, to use the app on a consistent basis.

Underwater Adhesives Retrofit Pipelines with Advanced Sensors

By the time the gas you fill your car with hits the engine, it's been through quite a journey. An oil platform in the Gulf of Mexico, for example, might need to be built over water with a depth of 10,000 feet or more. Extending from the platform, which floats on the sea, are tension legs stretching nearly two miles to connect the operation to the sea bed. Then comes the drilling, which in some cases might need to go another 35,000 feet beneath the ocean floor before hitting its target.

"That oil is traveling a long distance under extreme conditions," says David Brower, president of Astro Technology Inc. (ATI), a Houston-based company that provides safety and monitoring services to the oil and gas industry. "Temperatures range from very cold to very hot. The pressures can be extreme. And the distance that you have to flow the crude oil can sometimes reach 50–60 miles—that's a really long pipeline."

ATI entered a partnership with Johnson Space Center to pioneer an advanced fiber-optic monitoring system for offshore oil pipelines. The company's underwater adhesives allow it to retrofit older deep-water systems in order to measure pressure, temperature, strain, and flow properties, giving energy companies crucial data in real time and significantly decreasing the risk of a catastrophe.

"Even if you can prevent just one incident like British Petroleum had with *Deepwater Horizon* spill—which has run up about an $80 billion price tag—the value technology is obvious," says Brower.

Pictured here are two tests of ATI's clamps in a NASA lab at Johnson Space Center. On the left, a proprietary coating uses friction to keep the clamp in place. On the right, a special adhesive works even underwater to bind clamps to pipes.

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Image courtesy of Agência Brasil, CC-BY 3.0

Laser Imaging Video Camera Sees through Fire, Fog, Smoke

Starting from the left, three pictures of a pair of church towers, all taken at 500 meters, demonstrate the LITO technology. Image 1 is a pair of church towers, as seen with regular, visible light. Image 2 is those same towers barely discernable through rain and drizzle by a regular camera. Image three is of the towers as seen with the LITO device through the same rain and drizzle.

In November of 2012, Bob Foraker was strolling through the NASA Technology Days expo in Cleveland when he stumbled on something he'd never seen before: a video camera capable of seeing through flames, fog, dust, and virtually any other obscurant, even at night. The entrepreneur made a proposition to enter into a collaborative agreement with the inventor, Richard Billmers, whereby Foraker would round up investors and help to develop a business model for what would become Canton, Ohio-based Laser Imaging through Obscurants (LITO) Technologies Inc.

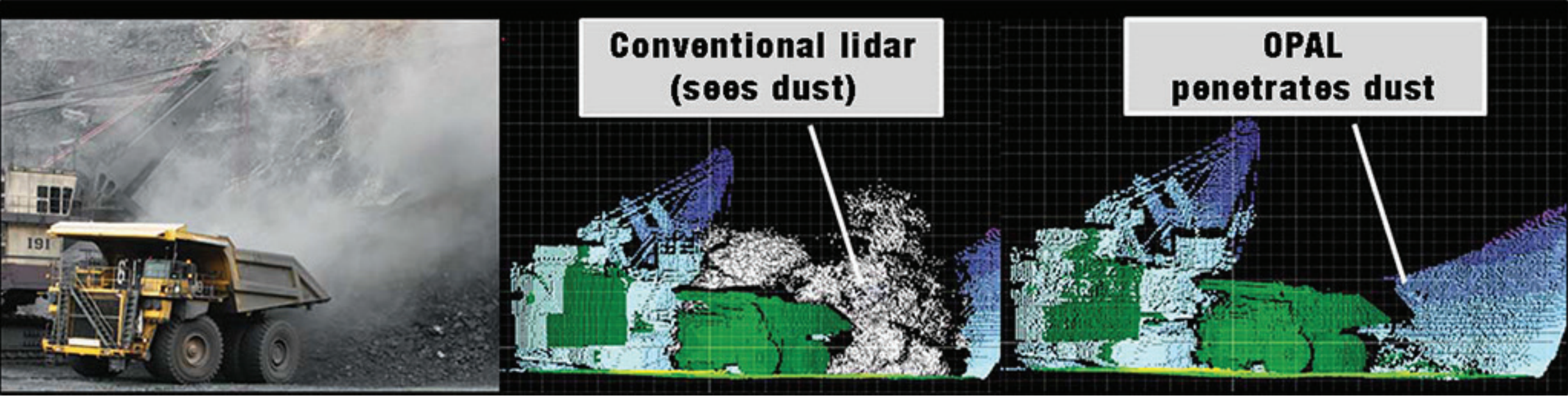
After developing the initial technology with US Navy funding, Billmers had refined the prototype under Phase I and II Small Business Innovation Research contracts with Langley Research Center in 2007 and 2008. The device couples a pulsed laser light with a time-gated aperture to capture light reflected from objects while screening out light reflected from any intervening obscurants. The reflected laser pulses also overpower what little light a fire emits during the brief aperture openings, enabling the camera to see through flames.

It was the device's potential to improve visibility for pilots that interested NASA, but the prototype is currently being demonstrated at Glenn Research Center as part of the center's perimeter security system. LITO is currently marketing the technology for perimeter security, but the company hopes to adapt the device for use in aviation, shipping, fire and rescue, and other fields in the future.

"There is no **other system** out there **that can** see through a **flame sheet."**

—Richard Billmers, LITO Technologies

The LITO technology was originally conceived of as a "fire lidar" capable of seeing through flames. The technology was proven effective early on, and the company still envisions a device that would prevent firefighters and other first responders from being blinded by smoke and flames.



Neptec Technologies' Obscurant Penetrating Auto-Synchronous Lidar, or OPAL, family of 3D laser sensors, unlike conventional lidar technology, is able to penetrate dust, operate in total darkness, and withstand considerable vibration and shock.

3D Lasers Increase Efficiency, Safety of Moving Machines

Neptec Design Group, based in Ottawa, Canada, and with offices in Houston, began its collaboration with NASA in the early 1990s when it created a camera-based tracking technology called the Space Vision System, which was used as the "eyes" for connecting the modules of the International Space Station. Following the Columbia Space Shuttle disaster in 2003, the company supplied its Laser Camera System (LCS), which uses triangulation to render a three-dimensional map of the shuttle's hull for inspection at Johnson Space Center.

Funded by NASA and the Canadian Space Agency, the company also developed the TriDAR 3D sensor, which combines LCS technology with a long-range LiDAR system to help spacecraft to rendezvous and dock with each other. The technology automatically acquires and tracks the target spacecraft without the use of any markers and can operate in total darkness.

In 2011 the company founded Neptec Technologies to commercialize its technologies for use on Earth. Its main commercial entrée is the Obscurant Penetrating Auto-Synchronous LiDAR, or OPAL, family of 3D laser scanners, which is largely derived from its work on TriDAR and LCS. Working in unison with its 3DRi software development toolkit, OPAL is designed to help machines operate in challenging environments where safety and efficiency are key.

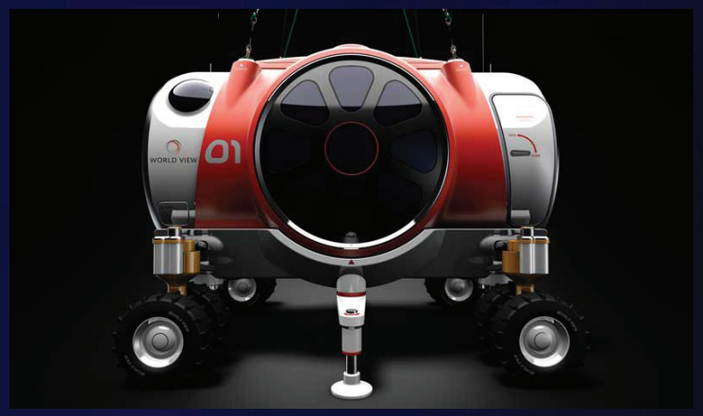
The company has already started collaborating with two global mining companies by installing OPAL scanners on their excavators and haul trucks. The size of these machines, combined with the often limited light and space in which they operate, makes it difficult for operators to maneuver to desired locations on the first attempt. OPAL will help facilitate both goals by allowing operators clear visual access to their targets, saving precious time and money as a result.

"If this technology shaves one or two seconds off the average spot time, that translates to millions of dollars a year in increased revenues," company CEO Mike Sekerka says.

Consumer Goods

NASA's innovations and partnerships have steadily found their way into the commercial market in countless consumer products, ranging from the obvious—such as technology and training that will one day enable civilian trips to space—to the unexpected, such as inventionsb that turn up in speakers, skin cream, lighting systems, and air purifiers. They even include devices to monitor personal ultraviolet exposure or to improve your golf swing.

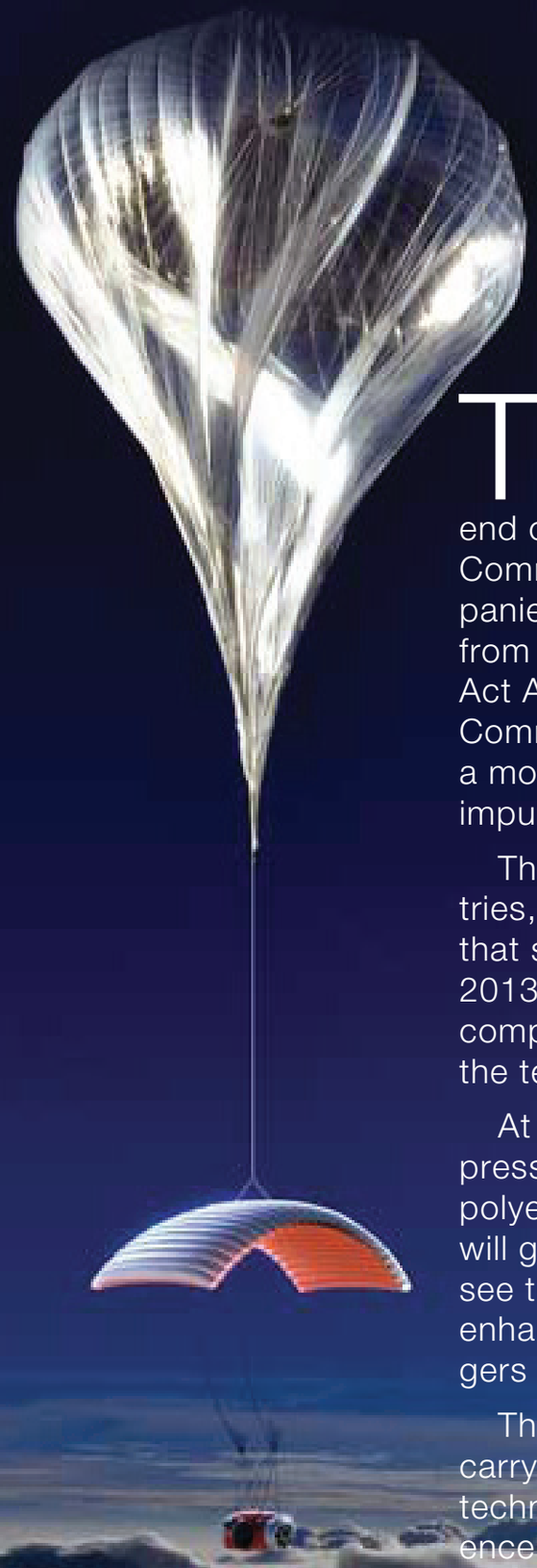
Connect with NASA Spinoff



The Commercial Crew Transport-Air Revitalization System was originally developed for future use on manned missions to the International Space Station (ISS), but World View is using the technology in its capsule to keep crew and passengers safe and comfortable throughout the unique experience.

The cabin is a pressure vessel similar in design to the modules that form the living and working quarters of the ISS. Inspired by the space station's cupola, the expansive windows allow for maximum viewing.

The plan is for the capsule to launch and return to Page, Arizona, where winds are calm. Passengers will also be treated to breathtaking views of the Grand Canyon during descent.



Air Revitalization System Enables Excursions to the Stratosphere

Tucson-based Paragon Space Development Corporation has been involved with many NASA projects, particularly in the realm of life support technologies. For example, following the end of the Space Shuttle Program in 2011, NASA established the Commercial Crew Development (CCDev) program, which paid companies to develop technologies for transporting astronauts to and from the International Space Station. After the signing of a Space Act Agreement under CCDev, Paragon, for its part, developed the Commercial Crew Transport-Air Revitalization System, or CCT-ARS: a modular air revitalization system for keeping spacecraft free of impurities and excess metabolic substances.

The CCT-ARS has been successfully transferred to other industries, for instance, as a life support component for refuge chambers that sustain miners in the event of an underground disaster (*Spinoff* 2013). The leadership at Paragon, through the creation of a separate company, Tucson-based World View Enterprises Inc., is also using the technology to send customers to the stratosphere.

At a launch site, likely in Page, Arizona, customers will board a pressurized capsule fitted with the CCT-ARS and attached to a large polyethylene balloon filled with helium. Two crewmembers onboard will guide the craft to heights of about 100,000 feet, high enough to see the roundness of Earth and its position within a vast universe. To enhance the experience, the journey begins before dawn so passengers can observe the night sky as well has the sunrise.

The craft could also be used for research. "Certainly, we could carry payloads outside," says Taber MacCallum, World View's chief technology officer. "And maybe we'll end up doing dedicated science flights that have a lot of instrumentation inside or outside facing the window or attached to the outside of the capsule."

The maiden launch is targeted for late 2016.

Magnetic Fluids Deliver Better Speaker Sound Quality

In the early 1960s, NASA scientists were trying to work around a major problem for orbiting spacecraft: how to move fuel into an engine without the benefit of gravity. A scientist at Lewis Research Center (now Glenn Research Center) came up with a possible solution: magnetize the liquid with extremely fine particles of iron oxide. That way, fuel could be drawn into the engine by magnetic force.

The quick advancement of solid rocket propulsion technology precluded the need for what would be called ferrofluid technology, but it has since found many commercial uses, including improving speaker sound quality. In 2012 Sony Corporation, through in-house research, also integrated ferrofluid technology, this time into a commercial line of slim speakers, which the company says produces a louder, cleaner sound than others of comparable size.

A key component is the micron-deep pool of ferrofluid that serves as a damper. “The ferrofluid provides a free-flowing movement for the speaker to deliver sound without the vibration of a traditional damper, which minimizes some of the accuracy of the sound reproduction,” says Rob Manfredo, a communications specialist with Sony. “The lack of dampening also means you get three decibels more in volume.”

In 2013, Sony, with US headquarters in New York City, was rated one of the top home audio retailers by sales in the country, says Manfredo. While he notes that not all of the company’s successes can be attributed solely to ferrofluid, he does think that investment in the technology has made a difference in what the company can offer “If people value an attractive, aesthetic design, good performance and a small footprint, which it seems is the case,” he says, “then clearly it’s doing its job.”

Sony’s slim speakers (left) and SRS-BTV5 Bluetooth wireless mobile speakers (right) use ferrofluid dampers, which increase sound amplitude while reducing distortion. The company uses ferrofluid technology in many of its products, from television sets to home sound systems.

Bioreactor Yields Extracts for Skin Cream

Situated in a microgravity environment, the International Space Station is a science laboratory unlike any other. Among other discoveries, scientists have found that microorganisms thrive in those conditions—something now utilized in a NASA-patented bioreactor. Called the rotating wall vessel, the reactor simulates microgravity conditions, leading to faster-growing, healthier cultures that are spurring innovations in drug development and medical research.

During tests with the bioreactor, Johnson Space Center scientists grew adult human kidney, lung, and epithelial stem cells, which produced a range of biomolecules that had regenerative qualities, including fibroblasts—adhesive molecules that help to hold cells together.

The technology was licensed by Renuèll Int'l Inc., based in North Miami Beach, Florida, which now sells skincare products infused with the NASA bioreactor-produced fibroblast extract. In a Food and Drug Administration test, the product (called RE`JUVEL) increased skin moisture content by 76 percent, reduced darkness by 61 percent, reduced wrinkles by 54 percent, reduced dark circles by 57 percent, and increased biological elasticity by 43 percent.

European Space Agency astronaut Hans Schlegel works on the Columbus module of the International Space Station (ISS) during STS-122. Columbus is a science laboratory that has housed many experiments on the ISS, including research into how micro-organisms react to and grow in the microgravity environment.

Image courtesy of ESA

"Negating external **forces** such as **gravity** can lead to **significant new discoveries** in **human biology** for the benefit of humankind."

—Thomas Goodwin, Johnson Space Center

When used as directed, RE`JUVEL has been shown to significantly increase skin moisture and reduce darkness and wrinkles.

Private Astronaut Training Prepares Commercial Crews of Tomorrow

A Waypoint 2 Space payload specialist trains a researcher on how to package and prepare a payload. The company offers payload services, from instruction on how to meet Federal Aviation Administration requirements to accompanying payloads and carrying out experimentation in orbit.

In addition to teaching crewmembers to perform crucial tasks like using their spacecraft's technical devices, piloting a vehicle back into Earth's atmosphere, and landing a shuttle or capsule, major portions of NASA's astronaut training simply teach how to survive and carry out basic tasks in an environment where the dangers and basic physics are completely altered from those of terrestrial life.

A number of sophisticated systems are used to simulate the experience of space travel, including the virtual reality software that is now a common tool in NASA's training regimen, and NASA software developers have developed and built on a variety of simulation programs. Two of those were recently acquired from NASA through a General Public Release Software Usage Agreement by a new company that plans to open up astronaut training to the general public.

Waypoint 2 Space, which finished setting up its training facility near Johnson in fall of 2014, plans to offer its seven-day, level-one training to 300 people in groups of 4 to 12 in its first year. The company is the first to receive a safety approval from the Federal Aviation Administration's (FAA) Office of Commercial Space Transportation to offer commercial astronaut training for all aspects of spaceflight, from pre-flight preparation to extra-vehicular spacewalks. The company plans to offer level-two and –three courses as well.

The training was developed from firsthand knowledge of spaceflight operations and training, as the staff includes a handful of former NASA personnel and contractors.

The company sees its future in the budding commercial space industry, where a number of companies are developing plans to open space travel to consumers. While level one is open to anyone, the upper levels will be reserved for those who already have a ticket.

Underwater "neutral buoyancy training has been integral to the astronaut training developed at Johnson Space Center since the mid-1960s. Now the company Waypoint 2 Space plans to capitalize on the knowledge of former NASA trainers to bring astronaut instruction to anyone willing to pay for it, and especially those who will actually travel into space.

Activity Monitors Help Users Get Optimum Sun Exposure

To further understand the sun's impacts on Earth, in the early 2000s NASA began developing the Solar Dynamics Observatory (SDO), a satellite outfitted with a suite of instruments for providing real-time, high-definition images of the sun's atmosphere as well as measurements of its magnetic field and its varying output of radiation.

One of its instruments would be the Extreme Ultraviolet Variability Experiment (EVE), tasked with measuring extreme ultraviolet (UV) radiation, which plays a key role in atmospheric heating and satellite drag. In 2005 Goddard Space Flight Center scientist Shahid Aslam began experimenting with wideband gap semiconductors for measuring such radiation.

Among the compounds Aslam tested were ones that specifically detected UVA and UVB wavelengths, which affect human health. Our bodies need UVB light to produce vitamin D, critical to building bone density and supporting brain and immune system function, but too much exposure to those bands can cause sunburn, premature aging, and skin cancer.

Seeing the need for a device that would allow people to manage their daily sun intake, Aslam and business partner Karin Edgett founded College Park, Maryland-based Sensor Sensor LLC and brought to market UVA+B SunFriend in 2014. Equipped with wideband gap semiconductors, the device is worn face-up on the wrist and left uncovered. When the maximum recommended daily dose of UV light is reached, LEDs on its face will flash. Aslam says, "At that point you apply sunscreen, go indoors, or put on protective clothing."

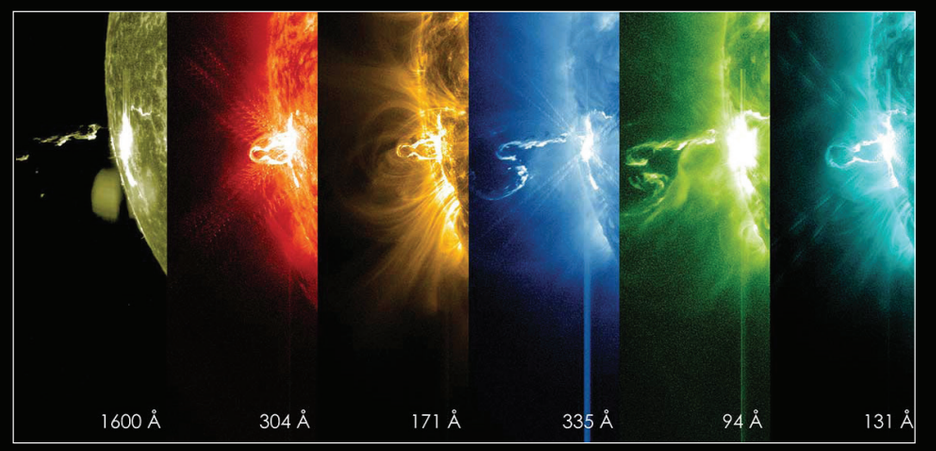
The company is already working on increasing its functionality, such as incorporating Bluetooth technology so information can be communicated to users' smartphones for record-keeping and statistics. "Everyone wants to track how many calories they've burned, their heart rate, blood pressure, blood sugar levels," says Aslam. "The same should be true about the amount of sunlight they're getting. It's just as important."

Since then, so-called radiant barrier technology has been a part of many NASA missions, but it has also been employed with equal effectiveness on Earth. Because it can reflect heat as effectively as it reflects communication signals, radiant barrier technology has been incorporated into a number of insulation products.

In 2010, entrepreneur Ryan Garrett learned about a particular version of the radiant barrier that is manufactured by means of vapor phase encapsulation, a patented process from Sigma Labs in Tucson, Arizona. Garrett founded RadiaSource in Ogden, Utah, to share the benefits of the innovation with others through his unique product offerings. In addition to insulation, the company produces radiant barrier garage doors, shipping materials, and wraps for water heaters, which can save up to 20 percent on residential water heating costs.

"We have to expand into space to continue to satisfy that craving to discover new things," says Garrett. "In the process of trying to see what's in space, we discover technologies that benefit us here on Earth."

Inspired by his work on EVE, Goddard scientist Shahid Aslam conjured up the idea for what is now UVA+B SunFriend, a UV light-detecting activity monitor that informs people when they've reached their maximum recommended daily dose of sunlight.



On February 24, 2014, NASA's Solar Dynamics Observatory (SDO) captured an X-class solar flare in different wavelengths of light, including ultraviolet (UV). One of the SDO's instruments is the Extreme Ultraviolet Variability Experiment (EVE), tasked with measuring extreme UV radiation, which plays a key role in atmospheric heating and satellite drag.

LEDs Illuminate Bulbs for Better Sleep, Wake Cycles

Because NASA is planning for future visits to distant locations like Mars, the agency is researching how to grow plants in space, and one critical component is lighting. NASA is interested in using light-emitting diodes, or LEDs, not only for plants but also for general lighting needs because they require little power, last a long time, can function in extreme temperatures, are lightweight and shatterproof, don't give off heat at the light source, and are able to produce specific colors of light.

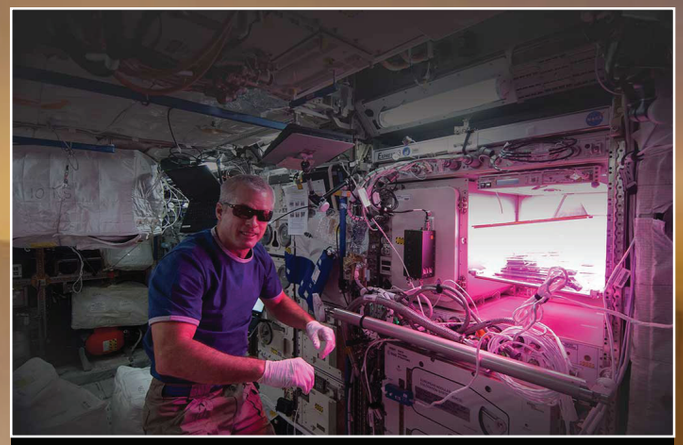
It also turns out that varying colors of light can affect human sleep cycles. Research funded by the National Space Biomedical Research Program found that blue light at a particular spectrum could reduce melatonin production. Melatonin is a hormone that helps to maintain the body's circadian rhythm, or natural body clock. More melatonin helps people sleep; less disturbs the circadian rhythm. As a result, Kennedy Space Center engineers developed prototype color-varying LEDs to help astronauts, who often suffer from sleep deprivation, get adequate sleep. By 2008, the lights were installed on the International Space Station.

With assistance from the agency and NASA contractor Bionetics, Satellite Beach, Florida-based Lighting Science brought the technology back down to Earth as DefinityDigital, a family of products that include four LED lights: Awake & Alert, Goodnight, MyNature Grow, and MyNature Coastal.

According to the company, the Awake & Alert light promotes natural energy, alertness, focus, and overall performance. In contrast, the Goodnight LED bulb emits significantly less blue light than regular bulbs, with the intention of supporting natural melatonin production. MyNature Grow can be used for any plant species, and because it does not radiate heat, the plant can be situated closer to the lighting source. Finally, MyNature Coastal is designed to deliver outdoor lighting that does not attract sea turtle hatchlings, which are often attracted to regular white lights, drawing them inland and away from their natural home in the ocean.

"A lot of **NASA's** learning, **science**, and **research** has **led to** these **new products."**

— Robert Soler, Lighting Science



The newest plant-growing experiment on the International Space Station (ISS), Veggie, went live in May of 2014. Veggie uses LED lighting to stimulate plant growth and will provide fresh lettuce and produce to astronauts on the ISS.

NASA's solid state lighting module, which was flown to and used on the ISS in place of traditional fluorescent lighting. The LED module could be controlled from the ground and uses different colors of light in an attempt to induce focus and alertness or rest and relaxation as needed.

Charged Particles Kill Pathogens and Round Up Dust

A conceptual rendering of what a Martian garden could look like. Plants naturally produce ethylene gas, which hastens decay, especially if left to build up in enclosed spaces such as this. The Wisconsin Center for Space Automation and Robotics used NASA funding to develop a titanium dioxide based scrubber that converts the gas into water and carbon dioxide, both of which are beneficial to plants.

Aerus Holdings' Air Scrubber Plus incorporates NASA ethylene-scrubbing technology. The device is installed into home ventilation systems, which disseminate the product's "friendly cleaners" that kill pathogens in the air and on surfaces.

To keep plants in space fresher longer, in the 1990s the Wisconsin Center for Space Automation and Robotics, a NASA Research Partnership Center located at the University of Wisconsin–Madison, developed a device that uses a titanium dioxide-based catalyst to reduce the amount of decay-inducing ethylene gas that they emit into the air.

In addition to converting ethylene into harmless byproducts, the scrubber was also found to kill pathogens. As a result, air purification systems utilizing the technology are now on the market that keep food fresh in warehouses and markets and also decontaminate the air in homes (*Spinoff* 2002, 2009, 2013).

Electrolux (now Dallas-based Aerus Holdings), of vacuum cleaner fame, also furthered the technology but took it in a slightly different direction. Rather than clean passing air, the company's Air Scrubber Plus product takes the circulating air generated by a building's heating and cooling (HVAC) ventilation system and produces molecules that disseminate into the environment, killing potentially dangerous pathogens such as E. coli in the air and on surfaces.

The key to its function is a proprietary blend of reactive metals added to the original titanium dioxide coating. When exposed to ultraviolet light, these metals mix with the surrounding air and humidity to produce charged clusters of hydrogen and oxygen, such as hydrogen peroxide, hydroxyls, and superoxide ions, which are antimicrobial agents found in nature. "We call them friendly cleaners," says Air Scrubber Plus Executive Director Tom Lozano. "They go out and reduce contaminants throughout an entire home."

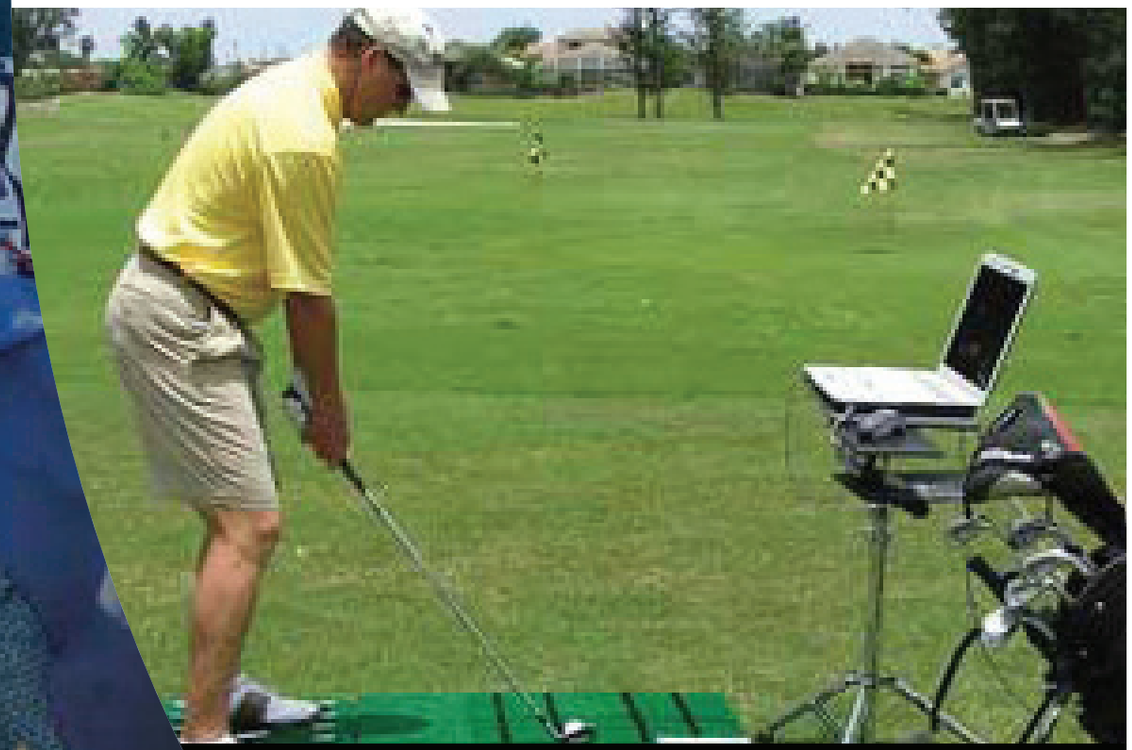
These "friendly cleaners" are also mostly negatively charged ions. The majority of particles around the house are positive, so these ions pull these particles from the air, greatly reducing loose dust and pollen. The Air Scrubber Plus is also available in models equipped with ozone, greatly enhancing the device's ability to combat strong odors from pets and cigarette smoke.

Balance Devices Train Golfers for a Consistent Swing

As part of the effort to understand the effects of spaceflight on astronauts, NASA funded research that resulted in a commercial product to treat balance disorders. West Palm Beach, Florida-based Sports Therapy Inc. worked with the inventor to modify the technology, creating the Dynamic Balance System (DBS) for sports applications. DBS is now used by Professional Golfers' Association-owned facilities and golf academies to help players achieve an effective, balanced swing.

Currently, there are 128 units being used around the world for physical therapy and sports training in hospitals, medical clinics, country clubs, and golf schools. Some of the organizations that the company has partnered with include the Professional Golfers' Association's (PGA) Center for Golf Performance and Learning, the PGA Tour Academies, the Leadbetter Golf Academy, and Keiser School of Golf.

Sports performance specialists, physical therapists, athletic trainers, exercise physiologists, strength and conditioning coaches, and personal trainers are using the DBS not only for golf but to help people practice and train for tennis, karate, bowling, and dance.



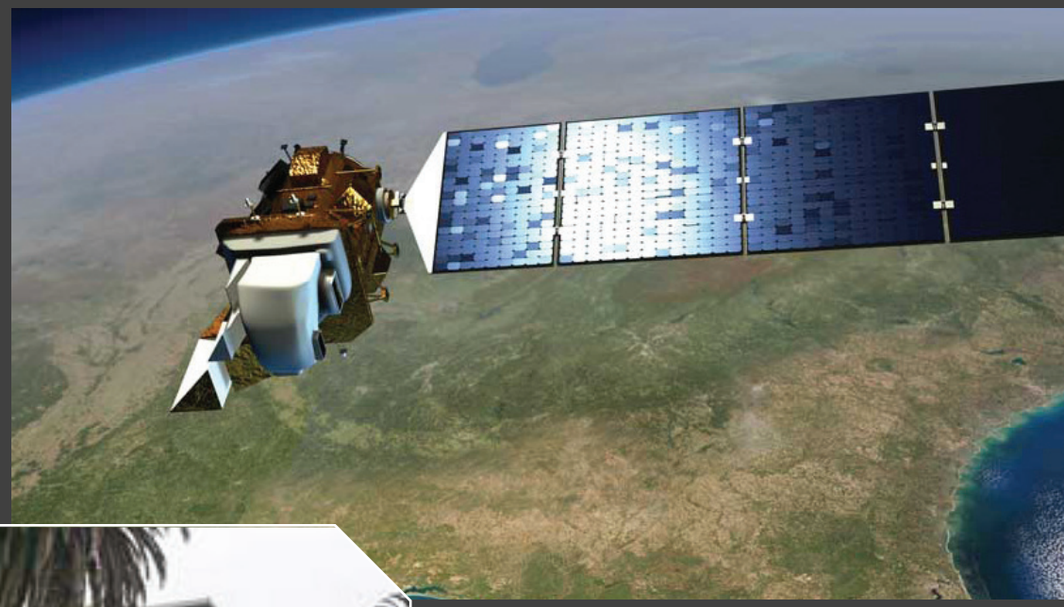
The Dynamic Balance System from Sports Therapy helps golfers learn what proper balance feels like, not only improving their golf swing but helping them prevent injuries, too.

Following five months onboard the International Space Station, Expedition 35 astronauts Chris Hadfield, Roman Romanenko, and Tom Marshburn sit in chairs outside the Soyuz Capsule they used to return. Having landed just minutes before, their bodies require extra support as they begin to adjust once again to the full effects of Earth's gravity.

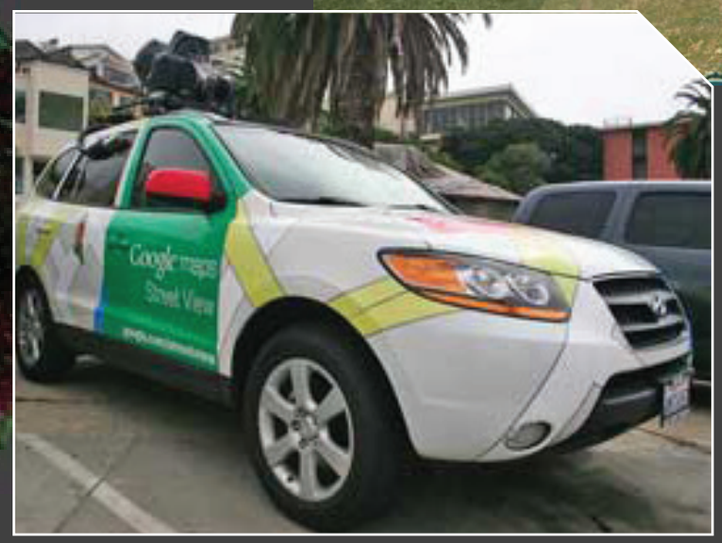
Energy and Environment

NASA has an obvious interest in energy efficiency, and its work in this area has been repeatedly commercialized, such as technology that reclaims oil and gas at drilling sites. But tools the agency builds to observe Earth, Mars, and the far reaches of the universe also help organizations monitor the environment and find a multitude of secondary environmental applications on our planet.

A collaboration between Google and the University of Maryland used data from NASA-built Landsat satellites to create the first global study of Earth's forest cover over time. This 2012 map depicting the Amazon rainforest shows existing forest cover in green, forest loss in red, forest gain in blue, and replaced forest in purple. The Amazon is the world's richest and most diverse biological reservoir, has 20 percent of Earth's fresh water, and has been losing thousands of square miles to logging, farming, and illegal road construction every year.



Landsat Imagery Enables Global Studies of Surface Trends



Google used data from the NASA-built Landsat 7 satellite, above, to regenerate its image of the entire planet and also to cover the last dozen years or so of its time-lapse animation of the planet's recent history. Meanwhile, the company's fleet of cars and other vehicles outfitted with elaborate camera and laser mounts, right, continue to capture the street view of Earth.

Landsat 8 is the latest in the NASA-developed series of satellites that have provided a continuous picture of Earth for more than 40 years. Mountain View, California-based Google has incorporated Landsat data into several products, most recently generating a cloud-free view of the globe in Google Earth. At the end of 2010, Google unveiled its Google Earth Engine, a cloud computing platform for accessing and processing Landsat images of the planet going back about 40 years. With the digitization of a warehouse of information, scientific study of worldwide trends using Landsat data suddenly became possible.

"Now you can ask questions on a global scale, over time, that have never been possible before," says Rebecca Moore, engineering manager for the Google Earth Outreach program, a humanitarian arm of the Google Earth and Maps team.

The company has also teamed up with researchers at the University of Maryland to create the first ever global study of forest cover: a map of the world accurate down to 30 meters, depicting current forests and gains and losses between 2000 and 2012, with layers of data for each year available for download.

"The uses of Landsat data are really broad," says James Irons, a Landsat data scientist at Goddard Space Flight Center. "Urban expansion, glacial retreat, agricultural production, coral degradation, ecosystem change—wherever you can think of land cover and land use changing, Landsat data has been applied there. Disaster recovery, water resources management—the list just keeps going on."

Ruggedized Spectrometers Are Built for Tough Jobs

Ocean Optics collaborated with NASA to redesign its miniaturized spectrometers for use in space and has since transferred those technologies to some of its commercial product lines, which are now more resistant to the effects of shock and vibration and are more protected from extreme temperature swings. Pictured here is the company's EMBED spectrometer, which offers those enhancements.

One of the Curiosity rover's instruments is the Chemistry and Camera system, otherwise known as ChemCam. It uses laser-induced breakdown spectroscopy (LIBS) to analyze the elemental composition of materials on the Martian surface. What make the instrument especially remarkable are its ability to take measurements from as far away as 23 feet and its capacity to remove dust from the sample before testing.

Three spectrometers in the belly of Curiosity are responsible for determining a sample's makeup, and they do this by measuring incoming wavelengths and intensities, which are unique to each element. Roger Wiens, a planetary scientist out of Los Alamos National Laboratory, serves as principal investigator for the ChemCam. Among his tasks was to modify a spectrometer so it could withstand the rigors of both space travel and the Martian surface.

In the early 2000s, Wiens came to an agreement with Dunedin, Florida-based Ocean Optics. Founded in 1989, the company had developed the world's first miniaturized spectrometer, revolutionizing the field. Together, they worked to protect the device against the ravages of heat and cold by replacing its aluminum casing with titanium and using less temperature-sensitive materials for the optics, redesigning the mounting systems for the optics to prevent data corruption, and hardening various electronics against radiation. As the world witnessed, the LIBS spectrometer launched with the rover in November 2011, and since landing the following August, the instrument has identified more than 140,000 samples.

Some of those improvements have been incorporated into Ocean Optics' newer spectrometer models, which now have greater protection from extreme temperature swings and can endure rougher handling. "We have spectrometers that are used in research applications from Antarctica to volcanic peaks and the Amazon," Creasey says. "Our units need to be robust enough to make it there, and thermally stable enough to take high-quality measurements once in place."

One of Ocean Optics' NASA-improved spectrometers is attached to an all-terrain vehicle, which is utilizing the instrument for analyzing upwelling and downwelling types of radiation in the desert. The temperature- and shock-resistant properties of the spectrometer prove vital in such a rugged environment.

Gas Conversion SystemsReclaim Fuel for Industry

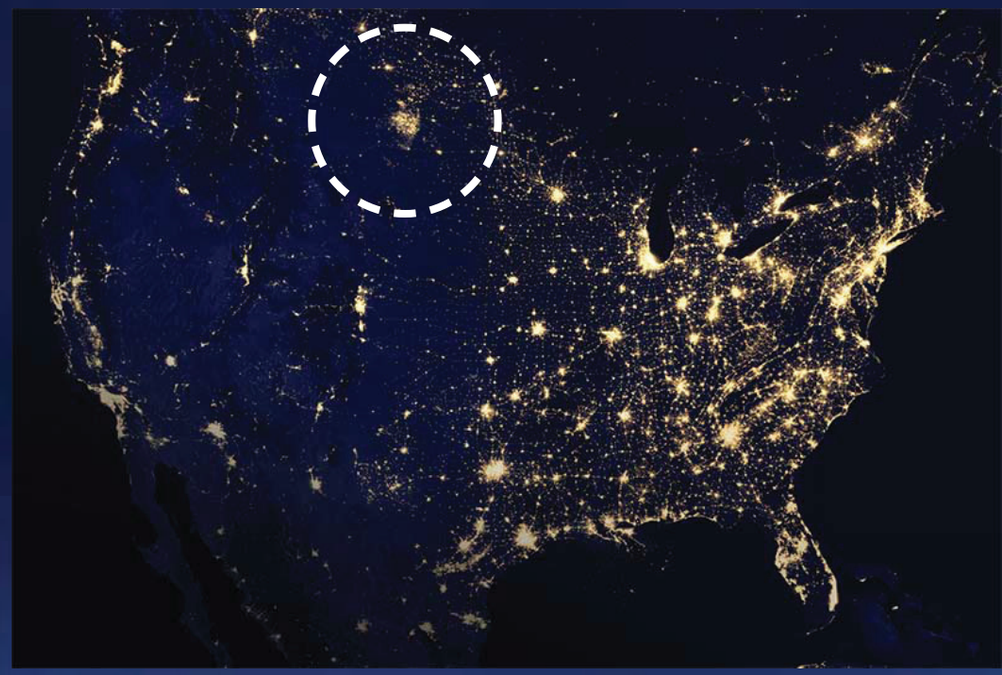
A human trip to Mars will require astronauts to utilize resources on the Red Planet to generate oxygen and fuel for the ride home, among other things. This can be accomplished through any number of chemical conversions, and Robert Zubrin—president of the Mars Society and founder/president of multiple companies—has spent much of his career devising methods for turning Martian soil and air into useable products.

While working on technologies for proposed Mars missions, Zubrin realized that the same principles could be applied on Earth to take advantage of natural resources. In particular, oil wells and drilling sites waste natural gas onsite and leave a substantial amount of oil in the ground when they leave. Pioneer Energy, based in Lakewood, Colorado, now sells systems that can address both problems.

The Pioneer Energy Mobile CO_2 EOR Technology (PERT) offers drillers the ability to produce carbon dioxide onsite from ongoing operations, reversing a process originally developed for Mars. The CO_2 is then pumped into the wells, where it pressurizes the oil and also decreases its viscosity. Using the system, Zubrin estimates, many wells might yield an additional 20 percent of their total oil supply.

While working on PERT, Zubrin got another idea—a sort of spinoff of a spinoff—to resolve the problem of wasted natural gases at drilling sites. In the industry, these are known as “flare gas” because, being byproducts released in isolated locations that lack plants and pipelines for processing them, they’re often simply burned onsite. This has become a contentious practice, particularly in North Dakota, where there is so much flaring that it appears almost as bright as a city when seen from space at night.

Pioneer Energy’s Mobile Alkane Gas Separator (MAGS) system separates these gases into three streams. One consists of liquid propane, butane, and pentane, which can be captured in tanks and shipped off for sale. Another stream, methane, can be used to run a generator that would replace the diesel generators powering the oil drilling rig. And finally, ethane is captured and can be used to power the MAGS system itself.



So much gas is being flared off at oil drilling sites over the subterranean Bakken formation in North Dakota that at night the oil fields can be seen from space, shining nearly as brightly as any metropolis.

Currently, natural gases released during oil drilling operations are often simply burned off in gas flares. Pioneer Energy’s Mobile Alkane Gas Separator (MAGS) system would separate these gases into three streams, one to be captured in tanks and shipped off for sale, another to run a generator that would power the oil drilling rig, and one to power the MAGS system itself.

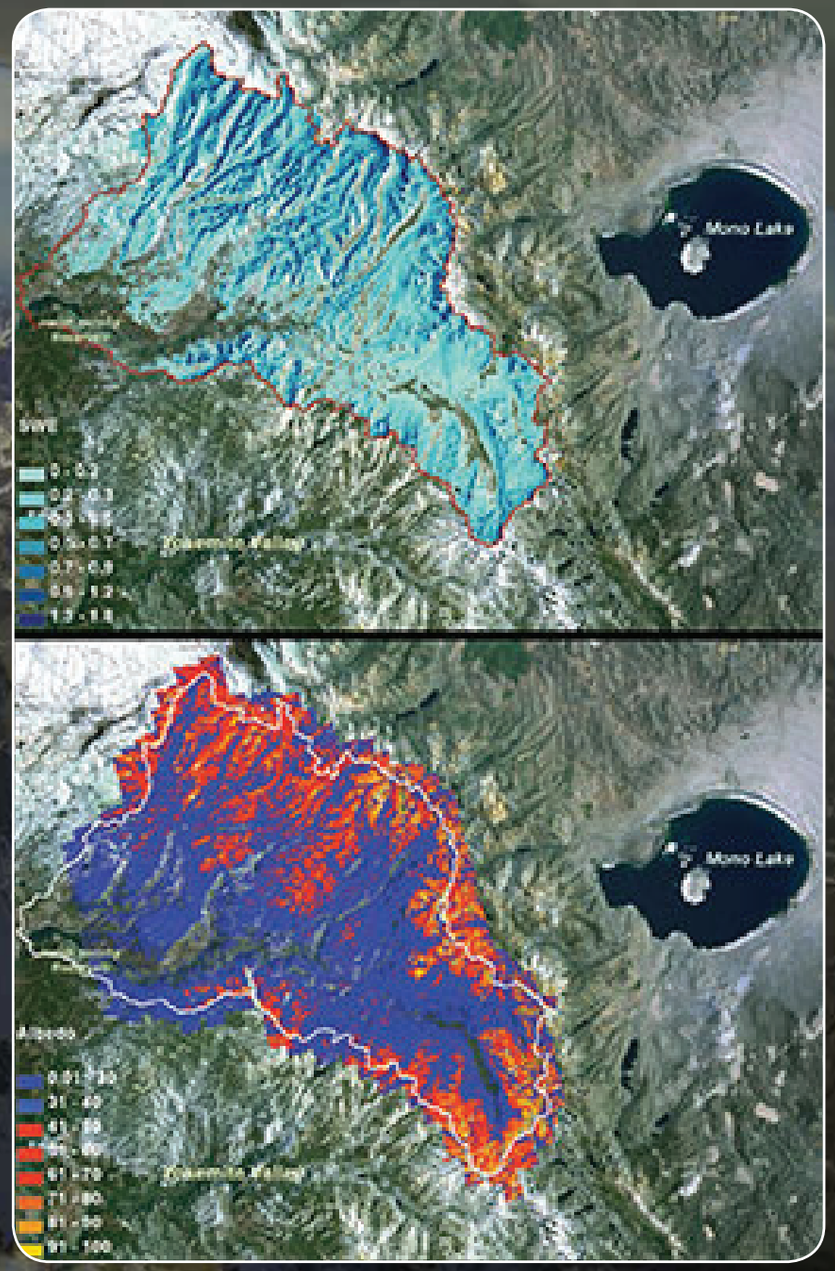
Remote Sensing Technologies Mitigate Drought

California is an agricultural powerhouse. In 2012, its 81,500 farms and ranches produced $42.6 billion in cash receipts, the most by any state. But that abundance is threatened by what's been called one of the worst droughts in the state's history. However, by using satellite data, NASA has been working with the California Department of Water Resources (CDWR) to provide water managers with more tools to mitigate the drought.

Forrest Melton, a senior scientist at Ames Research Center, was among a group of scientists that discovered they were able to use frequent, incoming Landsat and Moderate Resolution Imaging Spectroradiometer satellite data to derive what are called crop coefficients. Those numbers, when multiplied by CDWR's own fluid reference evapotranspiration data, result in useful information for preventing the over- or under-watering of crops. Through the Satellite Irrigation Management Support (SIMS) project, Melton says, the two agencies are working together "to deliver a consistent reference that can help growers adjust their irrigation to match each crop's biological demand for water."

The space agency is also using Landsat data to develop tools for spotting areas where water shortages have led to reductions in farmed acreage. That information will be used by the state to help allocate resources to nearby farmworker communities that, because of the water shortages, are facing loss of income, resulting in economic hardship.

The Jet Propulsion Laboratory, for its part, is heading up the Airborne Snow Observatory, whereby an airplane is using an imaging spectrometer and scanning lidar to collect snowpack depth and water measurements in the Sierra Nevada mountain range. Snowmelt supplies water to more than 25 million people and sustains nearly a million acres of farmland, which means the more accurate its estimation, the better the state's predictive capability for both drought conditions and flood risk.



NASA's Airborne Observatory mission, flying over Mt. Dana and Dana Plateau in the Tuolumne River Basin within Yosemite National Park in California on April 3, 2013, utilizes a Twin Otter aircraft equipped with a scanning lidar system and an imaging spectrometer to measure snow depth and snowmelt speed, respectively. The resulting data will be used to estimate how much water will flow out of the basins when the mountain snow melts. A color-coded map (inset) visualizes the results of the flight. The top image displays the amounts of water contained in the snow in the millions of cubic meters, and the bottom image projects snowmelt speed, with the blue sections indicating a faster snowmelt rate and runoff.

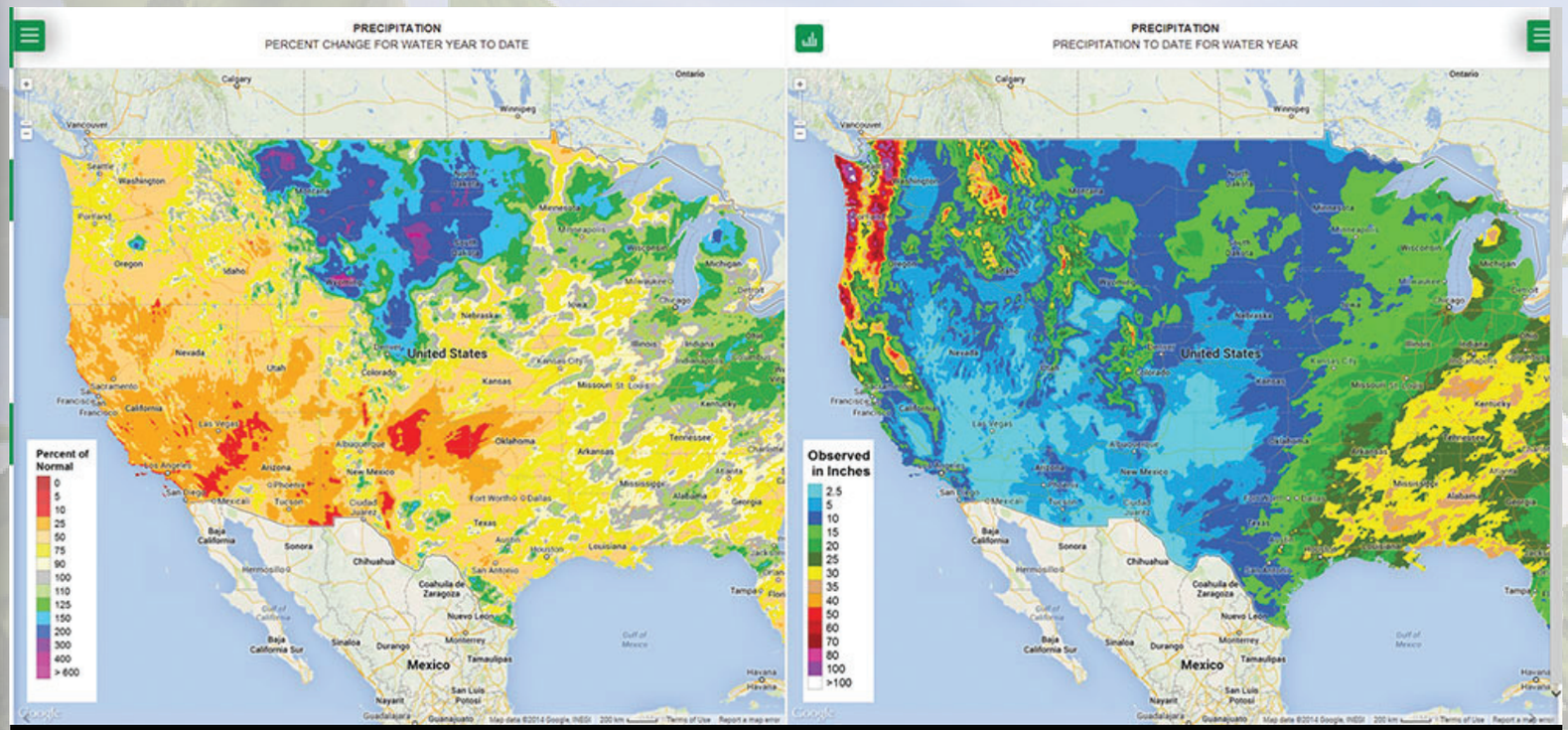
Satellite Data Inform Forecasts of Crop Growth

Farming has never been more productive, but increasing demands from a growing economy and world population mean age-old risks such as insects and plant disease remain significant challenges for agriculture. To advance technologies that would make farming more efficient and productive, NASA teamed up with the United States Department of Agriculture in 2000 to form the Ag 20/20 program. Managed on NASA's end by scientists at Stennis Space Center, Ag 20/20 developed fertilizers and new systems that could use NASA imagery to monitor plant health and better target applications of pesticide.

During the program, an engineering contractor developed models for using NASA satellite data to predict crop yield. The model was eventually sold to Genscape Inc., based in Louisville, Kentucky, which has commercialized it as LandViewer. Now commercially available as subscription-based software, LandViewer uses a variety of data to provide daily updates on the state of corn vegetation, incorporating nearly 30 variables that include NASA satellite data. The result is a prediction of future corn production on national, state, and county scales—a level of detail that is rare among competing products.

It is used by ethanol plants, grain elevators, and grain traders to judge likely crop production and manage some of the risks associated with buying large quantities of corn. Genscape's NASA connection is an ongoing one, as the company grabs the latest satellite data every day to inform its prediction models. But Ken Copenhaver, the creator of LandViewer and current Genscape engineer, says the real core of the technology is a product of his time at Stennis.

"The model powering LandViewer came directly from those days: I worked with different groups that were using MODIS data, calibrating it, and developing new products for MODIS. It was while I was at NASA that I learned a lot about how to do this."



LandViewer is an online, subscription-based product that predicts crop production. The software dashboard (above) provides real-time views of the latest data and includes tools such as comparison map views and data commentary.

Probes Measure Gases for Environmental Research

Aeroprobe's new sensors can be employed on a variety of craft to measure atmospheric gases. The company sells fast-response sensor systems all over the world, including a recent commission by Turkish Aerospace Industries, a major manufacturer of aerospace equipment (such as the unmanned aerial vehicle pictured in background) for research and military purposes.

To understand climate change, we need to understand the movement of carbon, one of the planet's most abundant resources and a building block of life that is endlessly being exchanged throughout the planet. Launched in 2014, NASA's Orbiting Carbon Observatory-2 (OCO-2) satellite is making the first space-based measurements of CO_2 in Earth's atmosphere. Such measurements will contribute to a better understanding of how increasing CO_2 concentrations are affecting climate around the world.

An important part of learning from OCO-2's measurements will be validating them from inside the atmosphere. To construct an instrument that could be mounted on an aircraft to take measurements of CO_2 moving through the air, Goddard Space Flight Center started working with Christiansburg, Virginia-based Aeroprobe Corporation. Working together, the partners developed and tested an instrument called the Fast Response Atmospheric Turbulence (FRAT) probe that could provide the acceleration and rate of speed of the plane that would carry it.

Aeroprobe now sells the FRAT probe, which has been purchased by universities and government research organizations. The probe is currently being tested on meteorological towers that are part of a multi-government agency effort to measure CO_2: existing television, radio and cell phone towers are instrumented to sample gases and determine how the gases are moving high above the ground.

The Orbiting Carbon Observatory-2, launched in 2014, watches Earth "breathe" from space by mapping carbon dioxide emissions.

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Information Technology

The tremendous complexity of NASA missions has led the agency to develop information technology tools for countless functions, and many of these have since been licensed for commercial use, such as software that assists in home building, project planning, and vehicle-noise management. Commercial entities are also increasingly finding unique ways to employ NASA data in a variety of solutions, such as in cloud computing platforms that enable environmental research.

Connect with NASA Spinoff

Cloud Computing Technologies Facilitate Earth Research

By using the agency's Earth-observing satellite data, NASA scientists have investigated an array of environmental issues, such as deforestation, aerosol accumulation, carbon cycles, and glacier recession. In the late 1990s NASA made all of its satellite data freely available, but over the years, as datasets have grown larger in volume and are covering longer periods of time, uploading and downloading them has become more time-consuming.

To help NASA-funded researchers more quickly access and analyze satellite data, in 2010 Rama Nemani, senior Earth scientist at the Advanced Supercomputing Division at Ames Research Center, led the development of NASA Earth Exchange, or NEX. Through NEX, which is hosted on the agency's network, researchers not only have access to datasets; they are also able to tap into Ames' Pleiades supercomputer. The platform also facilitates collaboration and information sharing between participating scientists.

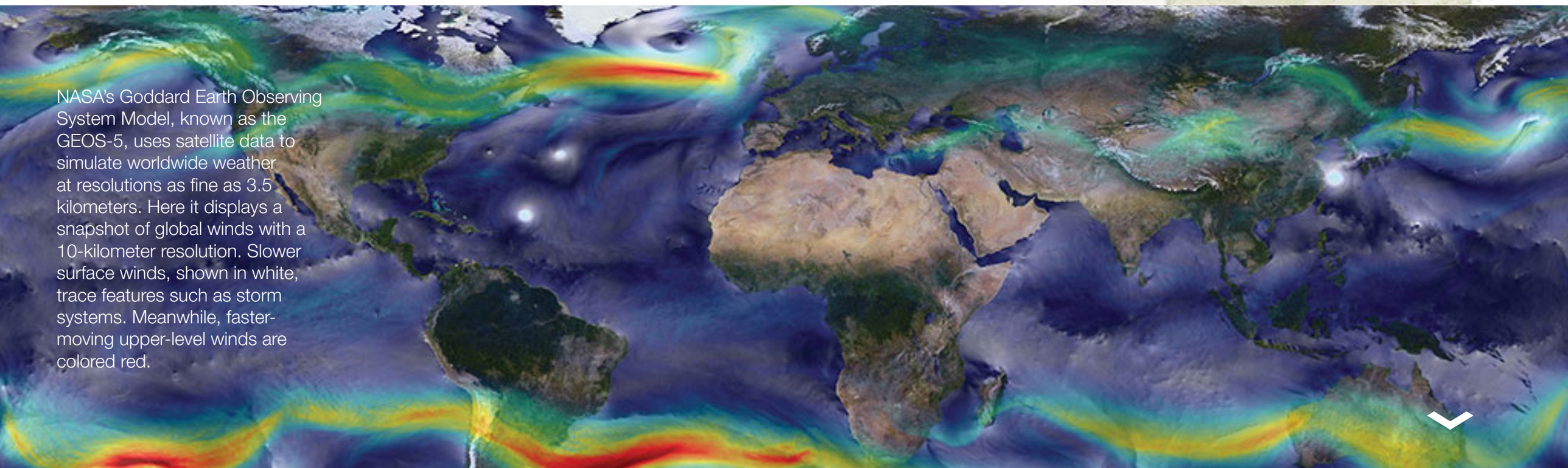
To facilitate access to satellite data even further, in November 2013 NASA and Amazon Web Services (AWS) announced that, through a nonreimbursable Space Act Agreement, for a year the computing division of the online retail giant would be hosting OpenNEX, which contains the agency's Landsat Global Land Survey information from the 1970s to 2005, Moderate Resolution Imaging Spectroradiometer vegetation indices, and the NEX Downscaled Climate Projections.

With OpenNEX, NASA-funded researchers access the data directly, bypassing the time-consuming security clearance procedures for sharing in the agency's network. The greater scientific community also has the same simple access to both NASA datasets and AWS's supercomputing services. And, like NEX, OpenNEX has a platform for sharing and collaboration.

If well-received, OpenNEX will continue beyond the first year and more datasets will be added.

"In a few years we hope to have a large section of the scientific community from around the planet using OpenNEX on a daily basis for climate change research," says Nemani. "That's our big goal."

NASA's Goddard Earth Observing System Model, known as the GEOS-5, uses satellite data to simulate worldwide weather at resolutions as fine as 3.5 kilometers. Here it displays a snapshot of global winds with a 10-kilometer resolution. Slower surface winds, shown in white, trace features such as storm systems. Meanwhile, faster-moving upper-level winds are colored red.the tree canopy. Through NASA's partnership with Amazon Web Services, researchers will also have access to MODIS data.



NASA's Goddard Earth Observing System Model, known as the GEOS-5, uses satellite data to simulate worldwide weather at resolutions as fine as 3.5 kilometers. Here it displays a snapshot of global winds with a 10-kilometer resolution. Slower surface winds, shown in white, trace features such as storm systems. Meanwhile, faster-moving upper-level winds are colored red.

Software Cuts Homebuilding Costs, Increases Energy Efficiency

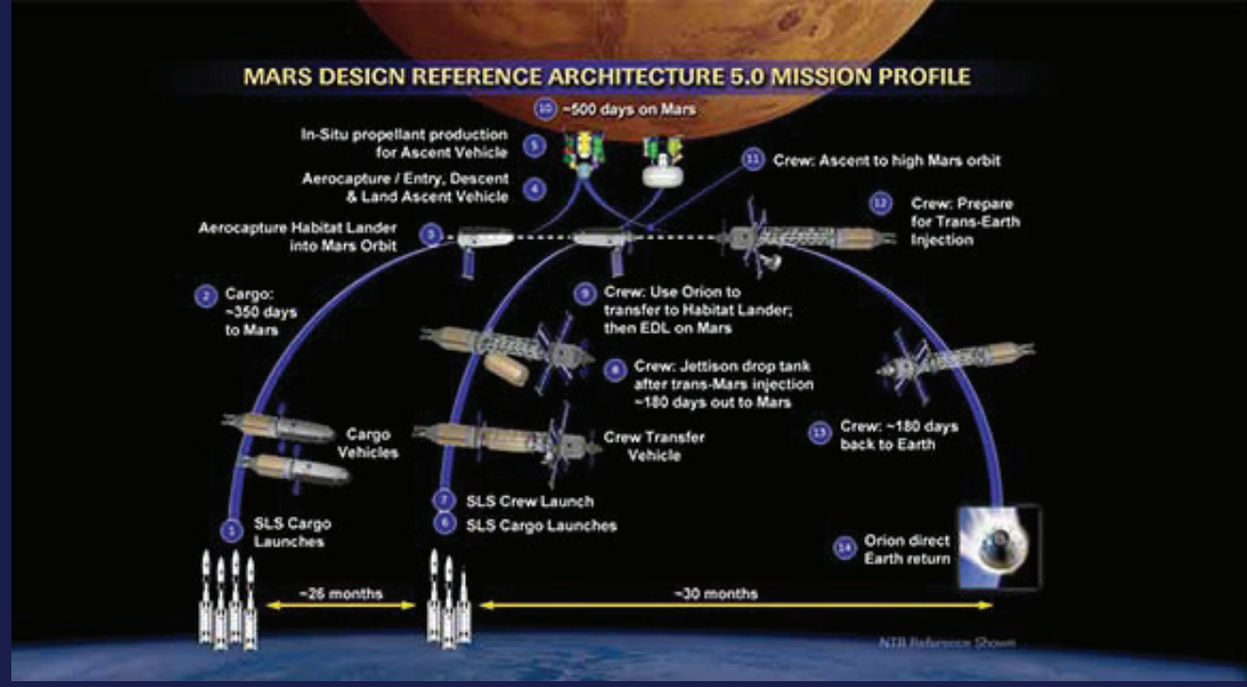
The agency's goal of sending humans to Mars requires developing new astronaut life support, propulsion, and power technologies. Adding to the complexity, each technology decision has to be made in relation to how it would impact other potential technologies. Having to evaluate a multitude of components in relation to each other makes for an overwhelming number of possible systems, or architectures.

To incorporate a logistical framework for such an undertaking, throughout the 2000s NASA Headquarters awarded research grants to Massachusetts Institute of Technology aeronautics professor Ed Crawley. He and his team of graduate students developed an algorithm-based tool that evaluates the various design combinations and comes up with the best options: those that are the most promising in terms of cost and mass while also offering the highest chances for success.

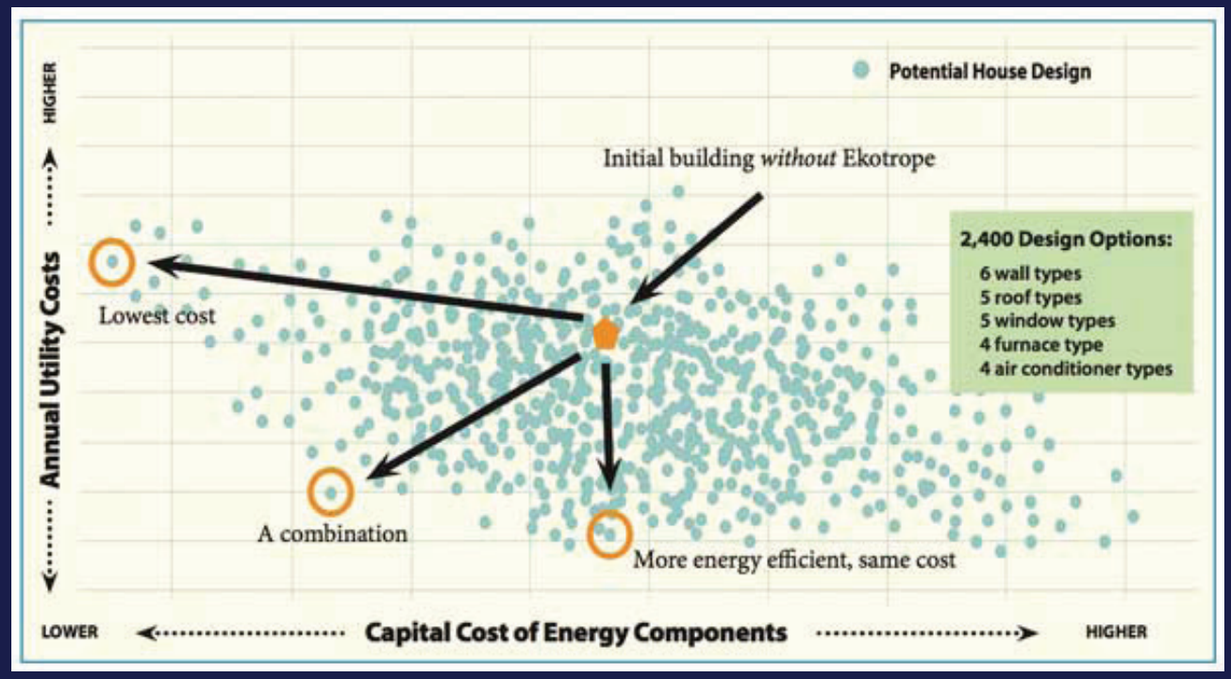
Using these tools for figuring out the most sensible plan of attack for a complex project would work well for not only space missions but also home construction. In 2010 Crawley and his team at MIT developed a software program called Ekotrope, which takes the virtually endless number of construction methods to arrive at the most promising energy- and cost-efficient plans.

All a builder needs to do is input into the cloud-based program known parameters for the future house, such as its interior and exterior dimensions, the potential materials, and its orientation. The software takes that information and runs it against a year's worth of local weather data for the area, then comes up with plans where either energy or construction costs, or both, are low. A builder can then choose from those options based on specific cost, energy efficiency, and design considerations.

According to the company, a typical client will end up choosing a house that's up to 40 percent more energy efficient and will save $1,000–$3,000 in construction costs.



An example of a Design Reference Architecture summary for a human mission to Mars. Ed Crawley and his team at Massachusetts Institute of Technology developed an algorithmbased software tool to help NASA choose the most costeffective and efficient architectures, or systems of technologies, for what will be one of humankind's greatest achievements.



By utilizing his work with NASA, Crawley developed Ekotrope, a software tool that helps homebuilders narrow down the thousands of design options to the ones that are the most cost- and energy-efficient.

Portable Planetariums Teach Science

With funding from NASA's Earth System Information Partners program, Rice University and the Houston Museum of Natural Science developed the country's first digital planetarium. Here, a fisheye lens photo shows students at the Houston museum watching Lucy's Cradle, a digital show about human origins in the East African Rift Valley.

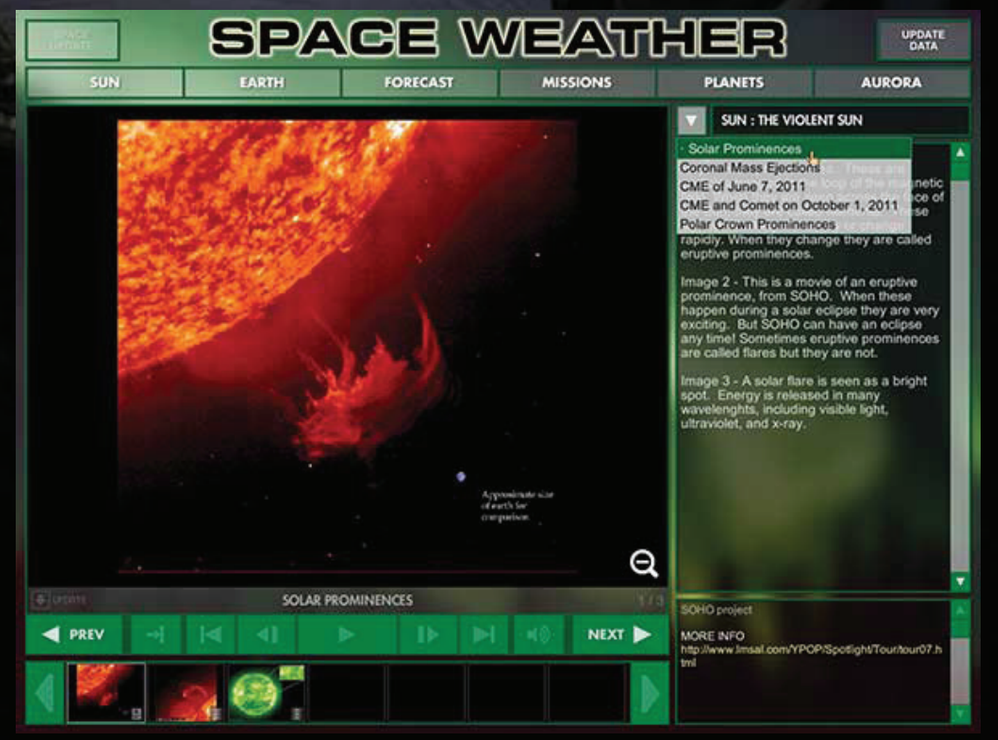
By the mid-1990s NASA was collecting an enormous amount of information about Earth and the universe from its satellites, including the deep-space-imaging Hubble Telescope and the Earth Observing System, comprising a fleet of satellites, which was gathering long-term data on the world's atmosphere, land surface, and oceans.

As the Internet was becoming mainstream, the agency provided funding to Rice University and the Houston Museum of Natural Science to work together on projects that used the new medium. They went on to create the world's first Internet-accessible museum kiosk and home and school science education software programs, and the country's first fully digital planetarium, along with Earth sciences educational shows. Afterward, Patricia Reiff, a space physicist at Rice University who was a co-principal investigator in the NASA-funded projects, founded Houston-based Museums Teaching Planet Earth Inc., or MTPE, in 1999, to distribute the shows and software.

In 2002, through funding from the agency's Research, Education, and Applications Solutions Network, or REASoN program, the two institutions also developed the world's first portable digital planetarium, along with new educational shows. MTPE was granted a license to promote and sell the technology to schools and institutions.

Among the portable planetarium's features is a unique double-door entrance, allowing for wheelchair access. It also acts like an airlock, which not only prevents the dome from deflating but also stops light pollution from seeping in. Additionally, its dull gray microsurface interior absorbs sound and minimizes reflections caused by wrinkles in the fabric.

MTPE is now available for either purchase or rental. Among the shows to choose from are *Earth's Wild Ride*, which imagines life in a lunar colony; *Dinosaur Prophecy*, which offers a glimpse at how dinosaurs throughout time lived and died; and *Impact Earth*, which explains the birth of the solar system, the origin of asteroids, and the surface features of Mars. Also available is a software package called *Media Show*, which plays not only the movies created through the NASA agreements but also traditional movies.



Rice University and the Houston Museum of Natural Science received NASA funding to develop the world's first Internet-accessible museum kiosk. One of its software programs is Space Weather, which describes how Earth's magnetic field and atmosphere protect it from the hazards of space.

Schedule Analysis Software Saves Time for Project Planners

Schedules for major projects get long and complicated, involving a slew of interdependent tasks and timelines, and few organizations handle projects more complicated than NASA's.

When Jimmy Black joined a technical resource management team at Marshall Space Flight Center in 2003, finding a discrepancy in a schedule could mean hours or even days of tedious searching.

He and others on the team had a rudimentary set of filters to pull up and organize information in Microsoft Project, the primary software application NASA uses to develop and manage spacecraft build schedules. They came up with a list of common scheduling mistakes and programmed the filters to identify them, and they automated the filters to run simultaneously and pull up reports.

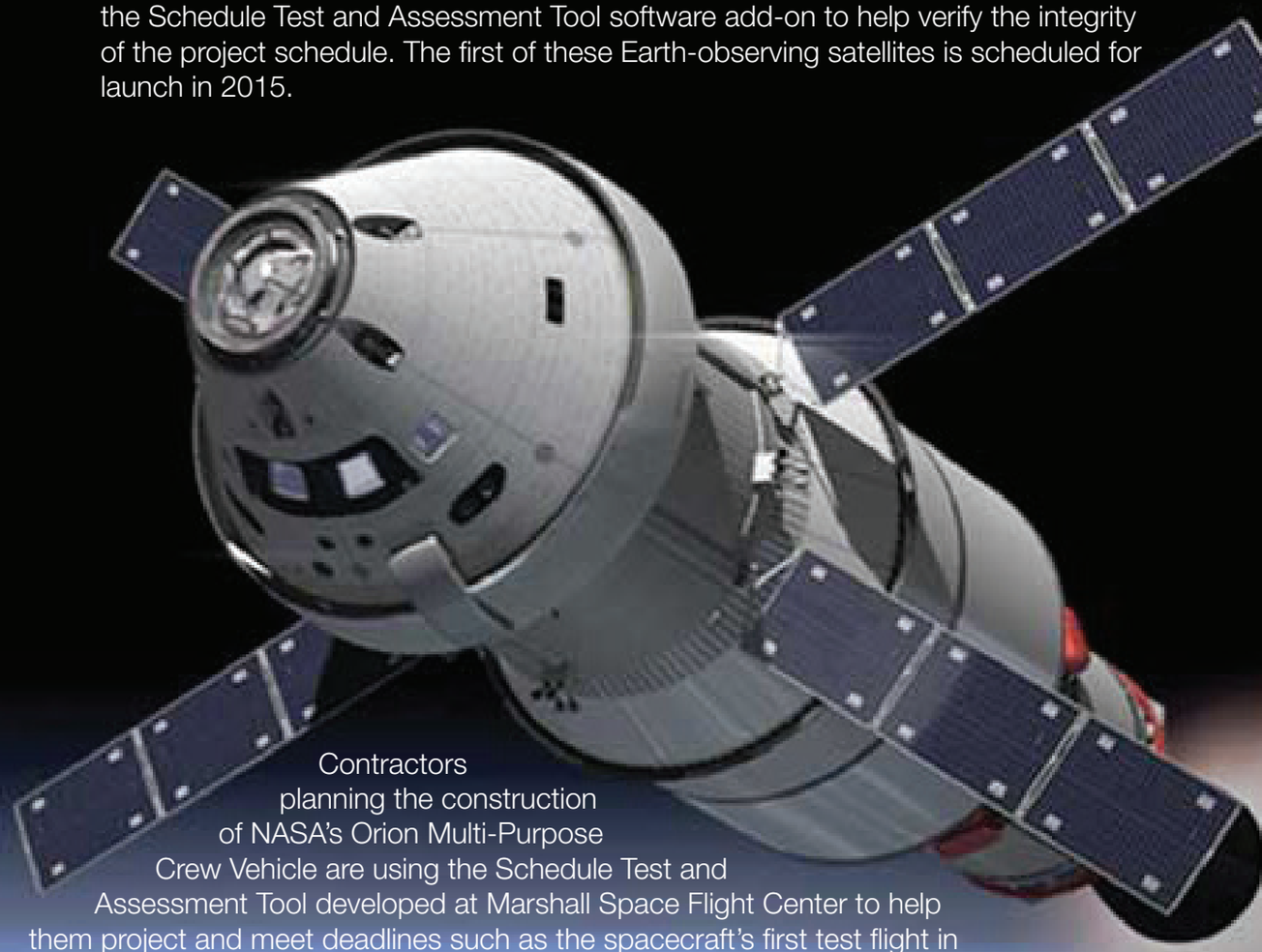
This was the beginning of what is now the Schedule Test and Assessment Tool (STAT) suite, a Microsoft Project add-on capable of running health checks on schedules, producing different summary reports, tracing the "logic" behind steps, listing possible errors, and other functions.

What once may have taken days now takes just a few minutes, Black says.

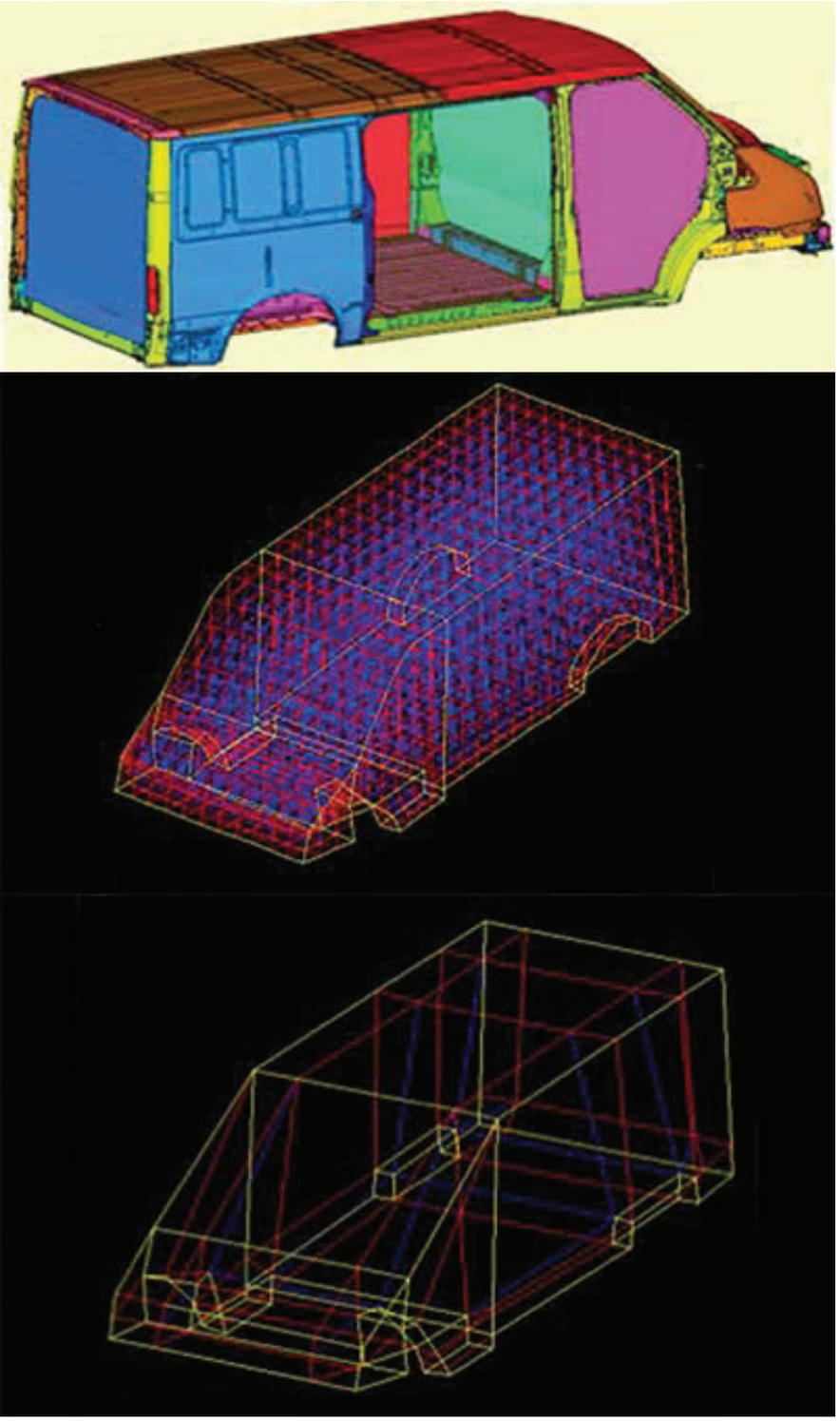
Like more than a 1,000 software codes developed by NASA, STAT is offered for public release at no cost, and since it became available in 2009 it has become one of the top-requested codes, released to more than 200 companies, government agencies, universities, and other entities.

Among those is Lanham, Maryland-based Vantage Systems Inc., whose James Perry is the lead program planner and scheduler for the Geostationary Operational Environmental Satellite-R program, one of NASA's largest current programs. "It's mainly helpful to schedulers, but it also gives verification to your boss that you know what you're doing and the things you're doing are correct," he says, adding that the add-on is also useful in reviewing schedules built by outside organizations.

The contractor planning the construction of the Geostationary Operational Environmental Satellites-R Series, better known as GOES-R—shown here under construction at NASA's Goddard Space Flight Center—is among those who use the Schedule Test and Assessment Tool software add-on to help verify the integrity of the project schedule. The first of these Earth-observing satellites is scheduled for launch in 2015.



Contractors planning the construction of NASA's Orion Multi-Purpose Crew Vehicle are using the Schedule Test and Assessment Tool developed at Marshall Space Flight Center to help them project and meet deadlines such as the spacecraft's first test flight in 2014 and its first mission in 2017.



Software for sound modeling using traditional finite element analysis (FEA) relies on a highly detailed computer model of the structure being analyzed, like the one at top. To predict the behavior of higher-frequency sound using statistical energy analysis, engineers have had to create another, coarser computer model. Comet EnFlow software eliminates that step by building less refined models, such as the lower two, based on the FEA model.

Sound Modeling Simplifies Vehicle Noise Management

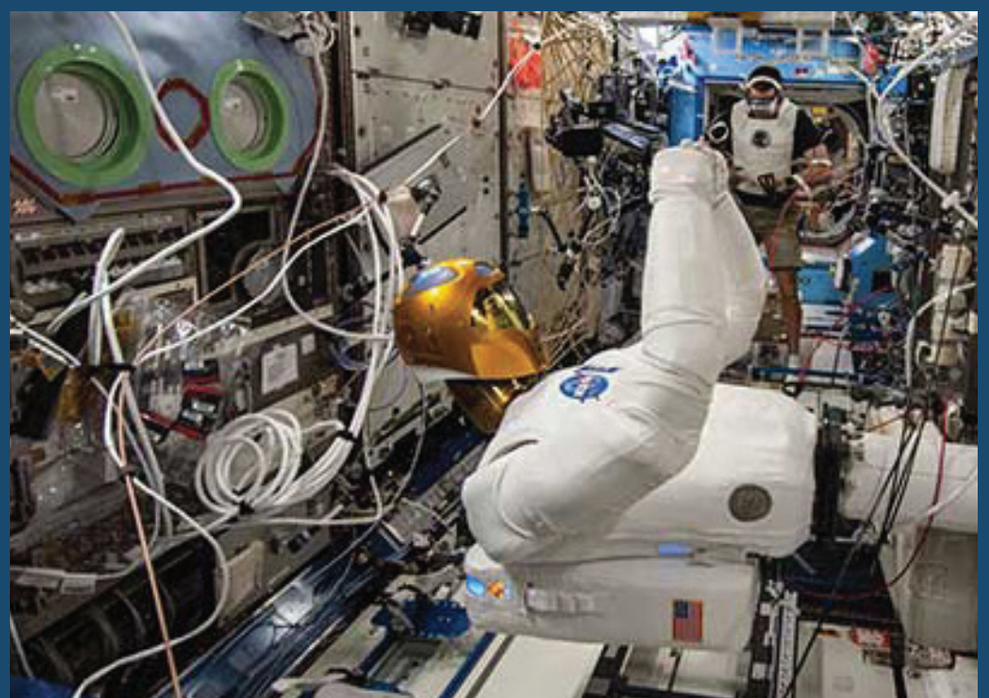
During liftoff, rocket components are exposed to sound levels up to about 170 decibels, a sound blast so intense it could destroy the rocket or damage payloads if not properly managed. Virtually no one but rocket scientists works to manage sustained acoustic levels of this magnitude.

Vibration management begins with using software to predict and understand noise and vibrations. To do this with lower-frequency noise, engineers use finite element analysis (FEA), which relies on a computer model of the structure in question, represented as a set of elements interconnected at nodes and assigned various properties.

An FEA model, however, requires a certain number of elements per wavelength, and as wavelengths get smaller at higher frequencies, the elements become so tiny and numerous that conventional FEA becomes cumbersome. So, to predict high-frequency noise, engineers use statistical energy analysis (SEA), which uses a simpler model with, for example, an airplane's structure divided into a few large regions. Having to build another model, however, increases workloads and introduces possibilities for error in the acoustical analysis.

In 2004 and 2005, Langley Research Center awarded Phase I and II Small Business Innovation Research contracts to Ann Arbor, Michigan-based Comet Technology Corporation, which had proposed software that would use the original model for FEA to create an accurate but coarser model for predicting high-frequency vibration.

The company now markets Comet EnFlow to automobile and aircraft manufacturers, the consumer product industry, and ship builders. Using this technology, companies are able to achieve the cost savings and quality improvement that comes with early-stage noise modeling while saving the time and money it takes to create new computer models for use in the SEA method.



NASA's Robonaut works in the US Destiny Laboratory module of the International Space Station (ISS). Finding a pressure-wall leak with a handheld leak detector is a challenge in the ISS, where the interior walls are covered in storage and equipment. The agency found an unexpected use for Comet EnFlow software in detecting leaks with a series of sound sensors on the walls of the Destiny module.with the help of GPS is about 90 percent less.

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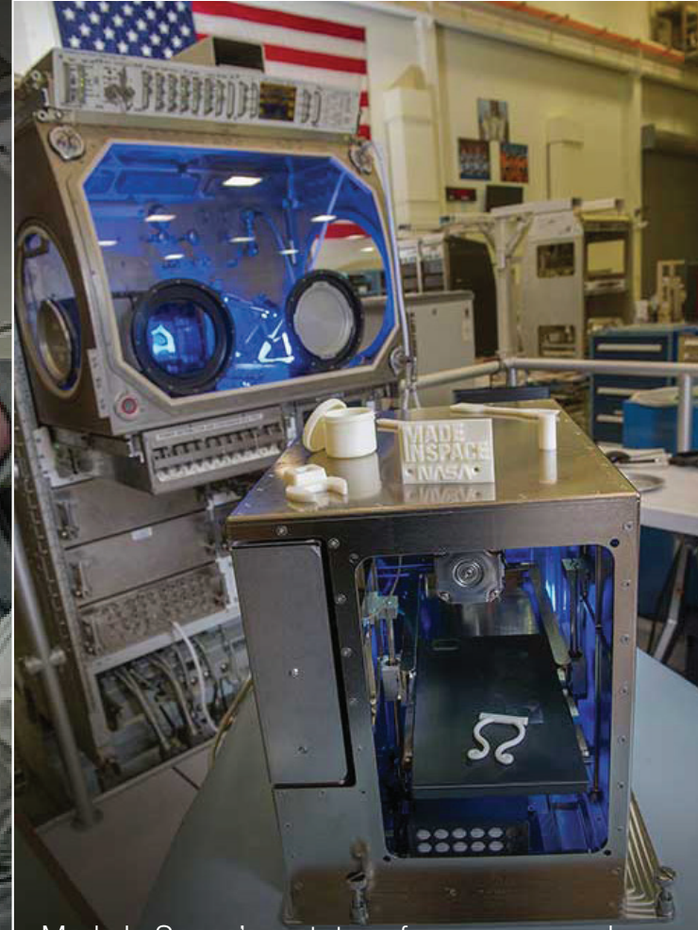
Industrial Productivity

Because NASA often pushes the limits of technology in attempting to do what no one has done before, the agency has pioneered a wide variety of industrial innovations, many of which are just as useful to commercial manufacturers as they are in building rockets or developing space-rated electronics. These can be new alloys and lubricants, technology for mass-producing unbelievably tiny parts, large-scale camera calibrators, and more.

Connect with NASA Spinoff

Custom 3D Printers Revolutionize Space Supply Chain



Made In Space's prototype for a space-ready 3D printer is shown with some of the products the final model might produce aboard the International Space Station.

Like a desert caravan, a space flight crew has to bring with it everything it will need over the course of its journey into an utterly barren environment. This has always meant allotting room for every gyroscope or astrolabe, every LED housing or oil lamp. In space travel, not only is payload capacity at a premium, but these objects also must be made to withstand the g-force and jarring vibrations of liftoff.

All that is about to change.

Under a series of Small Business Innovation Research contracts with Marshall Space Flight Center, Made In Space Inc., based in Moffett Field, California, built a prototype of a high-precision 3D printer capable of operating in microgravity and is creating a final printer to be installed on the International Space Station (ISS). The prototype was tested aboard the ISS in summer of 2014.

Once the printer is installed, NASA will become a paying customer, using the machine to create parts, tools, and other supplies that currently have to be brought via infrequent resupply missions. However, she says NASA will be far from the only customer. Made In Space has already spoken with a number of companies, universities, government agencies, and even artists who are interested in the ability to easily create objects in space and even launch them into low orbit from the ISS.

The ability to manufacture goods in space will be essential to missions beyond Earth orbit, says Niki Werkheiser, NASA's project manager for the 3D Printing in Zero G Technology Demonstration. "We're using the space station as a test bed to test the technology we know we'll need on exploration missions."

Made In Space Chief Strategy Officer Mike Chen, left, and Chief Technology Officer Jason Dunn test the company's prototype for a space-ready 3D printer in simulated microgravity aboard Zero G Corporation's modified Boeing 727 in 2013.

Improved Calibration Shows Images' True Colors

> "What's only been possible in a comprehensive radiometric calibration facility, now anyone can do."
>
> — Tom Stanley, Stennis Space Center

One of NASA's applications for radiometrically calibrated cameras is "plume diagnostics"—using imaging to monitor propulsion tests, such as this test firing of Aerojet's AJ26 engine No. 8 at Stennis Space Center.

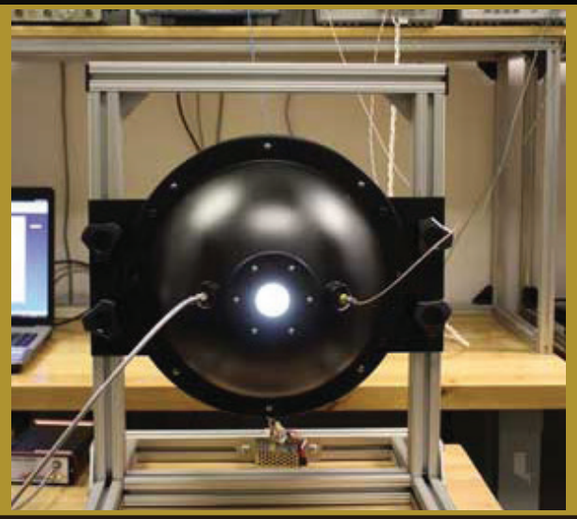
In satellite images, the waters of the Pearl River, which winds around Stennis Space Center, are about the same brownish green typical of waterways the world over. Odds are, though, that these images do not capture the precise, true color of the river, or anything else they depict.

This is because radiometric calibration, which ensures the color accuracy of an image and enables it to be used to solve remote sensing problems, has always been expensive. A dual-use agreement between Stennis and Innovative Imaging and Research Corporation (I2R), which is based at the center in southwestern Mississippi, is changing that.

Under the agreement, I2R and NASA shared the cost for the company to develop a cheaper, more energy-efficient, and more accurate large-scale integrating sphere. The device creates a uniform field of light that a camera can use to calibrate each pixel in its focal plane. To calibrate an array of cameras—the sort that is normally used for satellite imagery, for example—requires a large sphere, something that has historically cost $100,000 or more and required an inordinate amount of energy to power.

By using LEDs to light the sphere, I2R managed to dramatically reduce the amount of energy it consumes and also reproduce the spectral signature of solar light, ensuring color accuracy. Then, by building the sphere from cheaper materials than have been used in the past, the company was able to assemble it for a fraction of the usual cost.

"I think it's going to start putting a whole lot more fidelity in some of these commercial camera systems being developed from off-the-shelf products," says Tom Stanley, who manages the Small Business Innovation Research and Small Business Technology Transfer programs at Stennis. "It's an industry-enabling technology."



I2R built this small integrating sphere, used to calibrate cameras, for sale to a commercial company. Using LEDs, the company was able to accurately and affordably reproduce the wavelengths of solar light for proper calibration.

Micromachined Parts Advance Medicine, Astrophysics, and More

Not limited to lasers, Potomac Photonics also fabricates tiny, plastic parts with a high-precision 3D printer. These molds the company made for Johns Hopkins University were used to make high-aspect ratio wells in a polymer material.

Anyone who remembers the Micro Machines line of toys might be surprised to learn that the tiny model vehicles are positively gargantuan compared with actual micromachine manufacturing. While specimens of the miniature toy collection may indeed have been "smaller than a silver dollar," some industrial micromachined parts compare similarly to the breadth of a human hair, which is around 75 microns.

For example, Baltimore-based Potomac Photonics might use a high-speed laser to drill a grid of 25,000 holes, each less than two microns across, through a steel surface with an accuracy of plus or minus 0.3 microns—and do it cheaply enough that the part can be considered disposable.

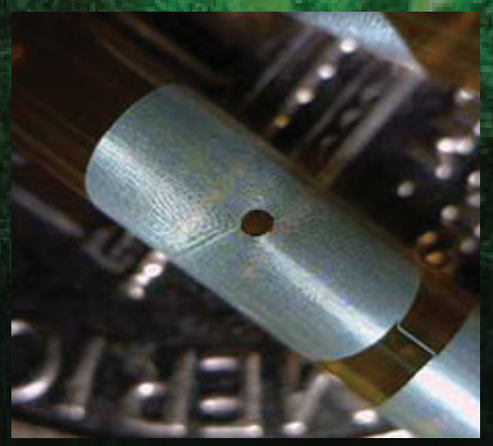
Mike Adelstein, the company's president and CEO, says it was a set of Small Business Innovation Research contracts with Marshall Space Flight Center in the mid-1990s that was especially influential in putting the company on the cutting edge of micromachining, leading to the work it does today. Potomac Photonics used the funding to develop an integrated, computerized workstation capable of mass-producing tiny, highly detailed optical components, using AutoCAD software to digitally control the process and make it faster, more flexible, and cheaper.

Around 2008, the workstations were discontinued, and the company now focuses on "rapid contract micromanufacturing," as Adelstein puts it, as well as continuing to develop new technologies to that end. The work ranges from microhole drilling and precise laser marking to hot embossing and 3D printing, working with metal, plastics, glass, ceramics, and silicon. Popular applications include medical devices, biotechnology manufacturing, and electronics, among others.

NASA is still a frequent customer, as is Johns Hopkins University, which has used Potomac Photonics-made parts for cutting-edge cancer treatments, among other applications.

> "The work with NASA showed a different way of making these components and pushed the limits of the technology. It really set the tone for our direction in leading this field."
>
> — Mike Adelstein, Potomac Photonics

This 532-nanometer laser system is used for micromachining metal and silicon wafers (background image).



Here, silver nanoparticle conductive lines are embedded in Kapton tubing for use in a medical device.

This example demonstrates the company's ability to laser micromachine polyethylene terephthalate, a thermoplastic polymer, at micron scale.

The equipment designed to recycle urine and other wastewater aboard the International Space Station (ISS) must reliably withstand a corrosive environment. A new wastewater processor scheduled to be installed on the ISS will incorporate Nitinol 60 ball bearings manufactured by Abbott Ball.

Titanium, which is a highly reactive metal, does not normally work in bearing applications that require lubrication. When combined in the right proportions with nickel, however, NASA discovered that it performs as well as the best bearing steels.

Metalworking Techniques Unlock a Unique Alloy

In 2000, an engineer at Abbott Ball Company named Glenn Glennon came across Nitinol 60, an obscure alloy that had sat dormant for a half century. In this unique substance Glennon saw a potential solution to a problem that has long hampered the ball bearing industry.

Typically, he says, bearings are made from stainless steel because of its hardness. But that comes at a cost, as stainless bearings typically can't handle much exposure to the elements before corroding. "We knew this industry standard could be replaced with something better if it was available," says Glennon. However, Abbott Ball is a small company and didn't have many resources to devote to research and development. So Glennon turned to the NASA Engineering and Safety Center at Glenn Research Center for help.

Engineers at NASA agreed to investigate, and by using special metalworking techniques, the partners developed a method for manufacturing and working with the material, which Abbott Ball has now commercialized. Nitinol 60 provides a unique combination of qualities that make it an excellent material for ball bearings, but it also has potential applications in a number of areas. The company is also working with Glenn Research Center to incorporate the material in a wastewater processor scheduled to fly to the International Space Station in the near future.

Low-Cost Sensors Deliver Nanometer-Accurate Measurements

As part of a unique partnership program, Kennedy Space Center collaborated with a nearby business school to allow MBA students to examine and analyze the market potential for a selection of NASA-patented technologies. Following the semester, a group of students decided to form Winter Park, Florida-based Juntura Group Inc. to license and sell a technology they had worked with: a sensor capable of detecting position changes as small as 10 nanometers—approximately the thickness of a cell wall.

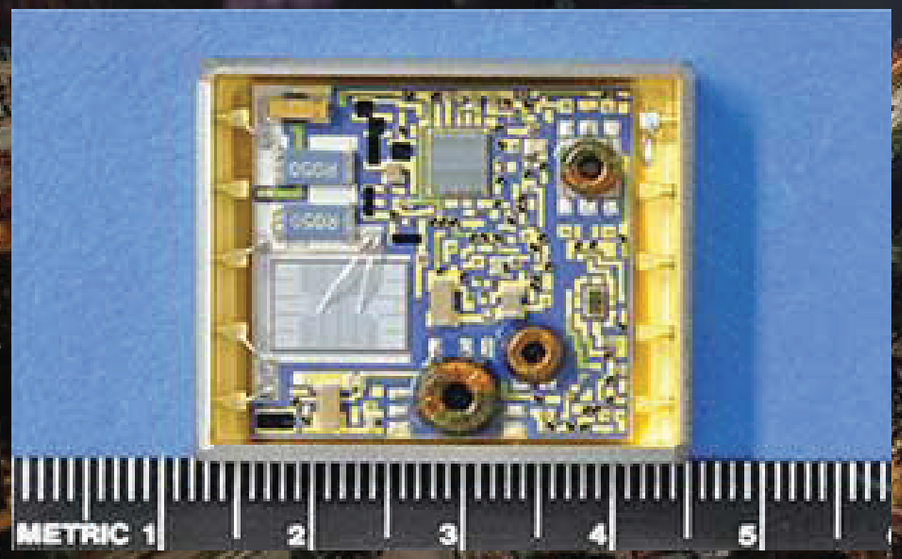
Since acquiring the license, Juntura has set its sights on 3D printers, laser holders and beam-steering mirrors, military technology, and robotics. The company's sensors have recently been purchased by a researcher at the Florida Institute of Technology who is using 3D printers to produce human tissue. Bioprinters currently cost upwards of $2 million, and the client hopes to reduce that price to something closer to $50,000— something Juntura's competitive prices help enable.

"Imagine being able to take one of these printers to Haiti or a country in Africa and printing out skin grafts for burn victims," says Carlos Capiro, one of the co-founders of the company. "I think we're going to be part of changing the world, and we have NASA to thank for support in that."

Juntura's sensors have become part of 3D printers that may soon be found in remote areas, providing on-site medical care—such as printed skin grafts—that was not possible before.

Juntura engineer Pankaj Patil holds a prototype of the company's first position sensor.

Electrical Monitoring Devices Save on Time and Cost



The cavity of one of Micropac's solid-state power controllers (SSPC) (inset), 96 of which are currently being used on the SDO to monitor instruments for power overloads. The technology replaces traditional fuses, which, once they're blown during a power surge, cut off power to space-based instruments permanently. Back on Earth, SSPCs are applicable for any system that uses electricity, from commercial buildings and sports complexes to industrial plants and hospitals. The device makes it possible to control the power supply to electrical devices remotely, saving time and money in the process.

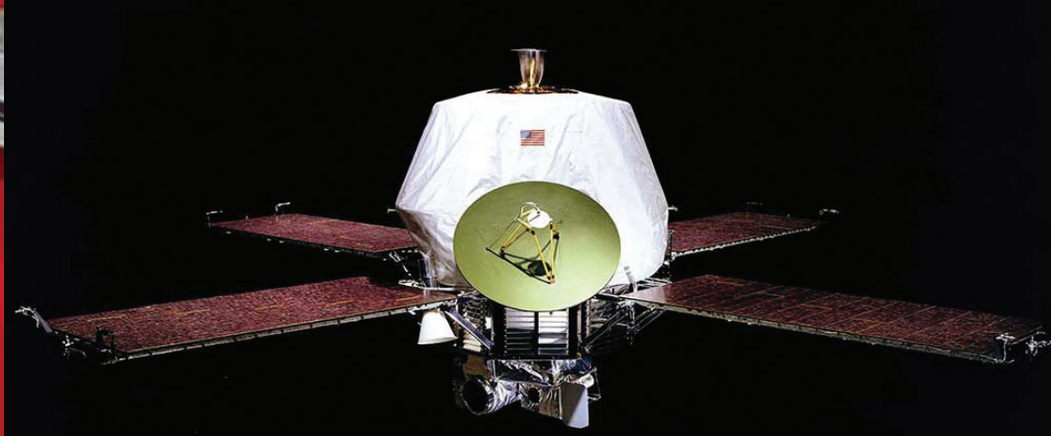
In space, satellites run the risk of what's called a single-event upset (SEU), where a radioactive particle transfers energy by ionizing a satellite's circuits, igniting a fleeting surge of electricity, not quite powerful enough to fry a component such as a camera, for instance, but strong enough to blow its corresponding fuse, rendering the camera useless just the same.

On a spacecraft, fuses prevent overheating or even fire by cutting off the flow of electricity to a device when the passing current exceeds an allowable number of amps. But the downside, as is the case with an SEU, is they can knock an otherwise operational instrument permanently out of commission. For high-cost projects, NASA had installed backup instruments, but during construction of the Solar Dynamics Observatory (SDO), the agency also wanted a technology that could protect the spacecraft and other big-ticket satellites from dangerous excess currents without deactivating functioning hardware.

NASA turned to solid-state power controllers (SSPC). As with fuses, SSPCs control for current overloads by shutting off power to circuits when the number of amps goes above the allowable threshold. But unlike fuses, they can switch the power back on as well. The technology allows for remote monitoring and diagnosis, and, if the issue is resolved, electricity can be restored through the push of a button. Goddard Space Flight Center worked hand in hand with Garland, Texas-based Micropac Technologies Inc. to make their SSPCs space-ready, which included hardening them against radiation. They have since been used on several space missions.

Other improvements made to the company's SSPCs—more adept handling of instant short circuits, steady state overloads, and inrush currents—figure into its current commercial units. The military has since purchased a number of them for various ground-based applications, and the industrial sector is in the process of incorporating the technology for use in a variety of settings, from hospitals to gas stations and homes.

Bearings, including the slim-section bearings used on shuttles, are among the machine components that Applied Tungstenite coats with tungsten disulfide for use in a wide variety of applications.



The Mariner 9 planetary space probe was among the later Mariner craft that tungsten disulfide was developed to support. The first spacecraft to orbit another planet, Mariner 9 gathered information on the composition and properties of Mars' atmosphere and surface, as well as images covering the entire planet.

Dry Lubricant Smooths the Way for Space Travel, Industry

Most of the technology on the Mariner planetary space probes—cutting-edge at the time—is now the NASA equivalent of stone tools. However, one technology, a dry lubricant developed for the later Mariner missions in the late 1960s and early '70s, is still essential to modern spacecraft, especially in the growing commercial space industry.

Robert Nelson of Stanford University came up with the idea and methodology to use tungsten disulfide in support of the missions, managed by the Jet Propulsion Laboratory (JPL). The substance is slicker than Teflon, and it's unaffected by temperatures ranging from -450 to 1,200 °F. Because it forms a molecular bond with the surface it's applied to, it can withstand loads of more than 300,000 pounds per square inch. Its coating is only half a micron thick—about 20-millionths of an inch—and because it doesn't bond to itself, that thickness is uniform.

By the mid-1980s Nelson's technique had exploded into a variety of industries (*Spinoff* 1989). Impinging the material onto surfaces using high-pressure air, in accordance with aerospace manufacturing code, is costly and labor-intensive, though, and companies eventually found cheaper ways to apply tungsten disulfide. NASA, however, still requires it to be impinged in accordance with specifications.

Less than three years ago, Applied Tungstenite started up in Temecula, California, and became the only company still impinging the lubricant the old way in a certified facility. The company counts a number of commercial space companies among its end users.

"The material was designed to be impinged, and that was the whole original science," says Eric Woods, the company president. "Holding right to that specification, the business grows because the quality is there."

Thermacore worked with NASA to develop the Thin Titanium-Vapor Chamber, a thermal management device for PEM fuel cells, which are being considered for future NASA missions. It is now commercially available as Therma-Base.

In 2012 Glenn Research Center partnered with the Greater Cleveland Regional Transit Authority (RTA) and other organizations to add a hydrogen-fueled demonstration bus to the RTA fleet. Here the bus is refueling at a station that uses an electrolyzer to convert water into hydrogen and oxygen. The vehicle's Proton Exchange Membrane (PEM) fuel cells use the hydrogen to generate electrical energy. NASA is looking to use PEM fuel cell technology to power future spacecraft.

Compact Vapor Chamber Cools Critical Components

Advances in Proton Exchange Membrane (PEM) fuel cell technology has NASA considering its use for powering future spacecraft. As a result, in the early 2000s Kenneth Burke, an electrical engineer at Glenn Research Center, began looking into new ways of cooling these devices in space. Traditionally, NASA has used liquid coolant, which is cumbersome. "The fuel cell has to seal and pump another fluid within it and manage all its plumbing and electronics," Burke says.

As a workaround, Burke turned to heat pipes: hermetically sealed metal plates that use an internal phase-changing fluid to transfer heat. But the particulars of PEM fuel cell design and the special demands placed on devices destined for space made existing tubular-shaped heat pipes unworkable. Burke needed planar-shaped heat pipes that were strong enough to handle the considerable pressure exerted by stacked fuel cells, yet light enough to avoid adding too much to the overall mass.

To build such a device, in 2008 NASA granted Small Business Innovation Research funding to Thermacore Inc., a Lancaster, Pennsylvania-based company that specializes in passive thermal management technology. The resulting product, made of titanium, is two times lighter than its conventional copper counterpart and considerably stronger. Its properties allow the overall thickness of the vapor chamber to measure a mere 1.3 millimeters while still being able to withstand 2,000 pounds per square inch of force, which means it has more than enough strength to handle the force imposed by several fuel cells clamping together.

In March 2013 Thermacore commercially released its Thin Titanium-Vapor Chamber Therma-Base. The device provides dependable, passive, thermal management to heat-generating electronics such as processors, video cards, and radio frequency amplifiers, power amplifiers, and others that require lightweight but strong thermal management systems.

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