National Aeronautics and Space Administration

spinoff

2019

Introduction

James L. Reuter
Associate Administrator
Space Technology Mission Directorate

The images of Jupiter are arresting. The updates from Mars riveting. We are daily learning new details about our changing climate, watching hurricanes form, and getting ready to peer deeper into our universe than ever before. All this groundbreaking work requires NASA's scientists and engineers to continually innovate and create advances in technology, techniques, and capabilities.

But all that innovation doesn't stop here at NASA. Thanks to the efforts of the Agency's Technology Transfer Program and the many companies, small and large, that partner with us, the same technology created to understand our planet and explore the universe are applied to challenges right here on Earth.

For more than four decades, NASA's *Spinoff* publication has documented more than 2,000 of these "spinoff" stories, from the NASA missions they originated with to their successful launches as commercial products and the benefits they've brought the public. In this iPad app, you can read about the latest success stories of commercialized NASA technology, along with videos and image galleries that let you explore the benefits of space in your life.

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

Health and Medicine

Keeping astronauts healthy often requires innovative advances medicine on Earth. You—but that's not the only way NASA's work benefits health. Whether claiming property all over the world.

In the 1990s, society found use in Upper-Stage Research Program, Langley Research Center scientist Robert Bryant was screening for polymers for use as advanced composites in aerospace. Bryant found a promising substance with a unique set of qualities. This polymer—a class of highly durable materials that make great electrical insulators, among other properties—remained solvable when it shouldn't have and unlike most polymers, could be melted even after it was insoluble. It resulted in different useful products all of the three steps in the polymerization process. These qualities made it a good candidate for medical use.

Bryant helped Langley patent the formula and process as a licensed to Langley Research Center licensee Amoco.

In 2006, Minneapolis-based Medtronic licensed LaRC-SI, and the company eventually brought Bryant on as a consultant, a role he still fills. They spent years developing a process to use the material as a coating and electric insulator for the thinnest left ventricular leads available.

Traditional pacemakers address a slow heartbeat by producing electric impulses charge to the heart's right atrium and right ventricle. About 40 percent of people with congestive heart failure or cardiomyopathy, however, have a condition called left bundle branch and right ventricle this significantly reduces pumping efficiency and isn't addressed by a regular pacemaker.

Cardiac resynchronization therapy addresses this problem by increasing the heart's output, lead to the left ventricle. It's a challenging procedure, because the most has to be threaded through a vein that's often convoluted in a small space.

Using LaRC-SI as its insulator lets the lead be exceptionally thin and flexible without sacrificing strength or reliability, making Medtronic's left ventricular leads more the safest and easiest to implant on the market.

Unique Polymer Finds Widespread Use in Heart Devices

A material that a NASA scientist developed on a whim in the 1960s has now helped keep hundreds of thousands of patients' hearts beating properly all over the world.

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NASA's High-Speed Research Program of the 1990s, which yielded this model built to specifications, was an unusual starting point for a medical device. But it's now helping hundreds of thousands of the safest cardiac resynchronization therapy devices on the market.

Left ventricular leads, used to coordinate the pumping of the heart's ventricles, are continually shifted to inspect tissues for signs of cancer. Thus, they must be threaded through a convoluted vein in a small space. The LaRC-SI polymer used in Medtronic's left ventricular leads is exceptionally strong, allows the company to make leads that are just as strong and thus highly flexible and reliable, making them easier to implant and improving patient safety. (http://www.nasa.gov/)

Material for Mars Makes Life-Saving Sutures

For NASA, "the mission to return samples from Mars is at the top of the planetary science to-do list for some time," says Andy Dyck, Director of the Jet Propulsion Laboratory (JPL).

Rather than bring samples back, the limitations of how much hardware we can deliver by dates, we can pick up the hardware, all of the knowledge on Earth, to Mars samples from Mars, we'd have to bring Mars sample return canister with Small Business Innovation Research funding from JPL and turned to Dongsheng, South Carolina-based Zeus Inc. for one important component: Zeus developed a new process to extrude and expand PTFE (polytetrafluoroethylene, commonly called Teflon) to create a barrier that would wipe dirt off the canister's exterior as it was sealed and spun around the inside of the lid that would block any cross-contamination.

Since then, the company has found numerous uses for the extruded material, including as sutures used for delicate operations, the heart valve repairs.

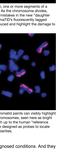
"This material is unique, because it's soft, flexible, and strong—and it's also biocompatible. It's a material that can safely interact in the body," notes Global Business Development Manager Steve Bacon. The material is also used to encapsulate stents also used in heart surgery, as well as for drug optics and to coat catheter for aneurysms.

Medtronic's left ventricular leads, the thinnest on the market thanks to a coating based on a NASA license, have helped to keep hundreds of thousands of people healthy and active.

The photo by NASA's Curiosity rover shows the Windjana rock site, where the rover's tools drilled down for a sample to analyze. NASA learns a lot about Mars and Earth's ancient environments by bringing a rock sample home for deeper analysis in Earth-based labs.

This diagram shows a lid specially designed for a Mars sample canister to wipe dirt off the canister's exterior as it was sealed, the edge of the base that contains the extruded ePTFE barrier to wipe it clean, before it sets in a layer of soft indium metal, which ensures nothing gets in or out.

To make a material tough enough to wipe off all the dust but soft enough that the metal base could cut through, Zeus Inc. had to innovate. The resulting material has been used in a variety of applications, including as sutures for procedures like heart surgery.



In a chromosomal inversion, one or more segments of a chromosome break off, flip, and reattach. Researchers in a physics collaboration using microbeams in the Langley Radiation Laboratory found that the DNA breaks in chromosomal inversions are introduced and highlight the damage to the daughter strands.

Extruded ePTFE is soft, flexible, and strong, and because it is biocompatible, it does not need to be removed, making it ideal for use in the human body. Among other applications, Zeus has used the material to encapsulate arterial stents.

Fluorescent Paints Spot DNA Damage from Radiation, Gene Editing

A new technique for detecting chromosome damage showed enough promise for space exploration that its creators founded a company to market it. And they had to name their technology would put them at the forefront of a decades-old mystery.

That same year, unbeknownst to the founders of KromaTID Inc., a team in France demonstrated that a fraction of bacteria that survived UV exposure could regularly intercepted short palindromic repeats, serves as an adaptive immune system. Researchers have since found that these snippets of DNA can be used to turn genes on and off and to add DNA to a genome in short, to edit genes.

But the potential for gene editing can't be realized until its side effects, such as unintended damage, are understood.

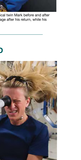
NASA has studied DNA damage because astronauts are exposed to charged particles that can tear DNA in ways inflicting random harm. For years, doctors at Johnson Space Center took blood samples from every astronaut before and after trips into space, checking for genetic damage.

Although they could detect the transversion of DNA—when a bit of one chromosome ends up fused to another—they couldn't see subtle forms of damage. KromaTID's technique promised the ability to spot inversions within a chromosome, where a stretch of DNA gets flipped backwards.

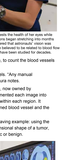
In 2008, Johnson awarded two Small Business Innovation Research contracts to the Fort Collins, Colorado-based company. It was KromaTID's first funding, and it helped prove and refine the technique it calls directional Genome Hybridization.

KromaTID's DNA probes can help doctors select and tailor cancer treatments and help researchers study patients for clinical trials. They've found the DNA variations responsible for undiagnosed conditions. And they can help agencies determine radiation levels and exposures in nuclear disasters.

But the company sees its biggest opportunities in the field of gene editing, which holds enormous possibilities for health and medicine. It requires refinement, studies into unintended consequences, and the establishment of standards and guidelines.



KromaTID's fluorescent chromatid paints can visibly highlight DNA damage, such as chromosomal inversions, which flip DNA sections, that don't match up to the human "reference genome." They can also be designed as probes to locate specific mutations or chromosomes.



NASA used KromaTID's technique to compare DNA from astronaut Scott Kelly, left, and his identical twin Mark before and after Scott Kelly's record-breaking stay in space. As expected, the astronaut's DNA showed some damage after his return, while his twin's was unchanged. The damage, however, was minimal.

Image-Analysis Software Sees Cancer in 3D

Even NASA can be surprised.

The Space Agency works hard to search out surprising discoveries, of course, but it doesn't always find what it's looking for—such as the safety of its astronauts.

But even with decades of study on health risks, notes Craig Kundrot, director director for NASA's Space Life and Physical Sciences Research and Applications, there are still unknowns. For example, "when we went from two-week Shuttle missions to six-month space station missions, all of a sudden we started seeing these vision problems," he recalls. "That caught us by surprise."

Although NASA is still working to fully understand the details of these vision changes and what they pose, researchers believe they are related to blood flow changes in microgravity, which is something that has been studied extensively in one 2011 study on vascular changes in microgravity, funded by Ames Research Center. Researchers found that blood flow slows, and it's hypothesis that these changes impede oxygen and bone loss. Part of his study included analyzing images of tissue samples from the hind legs of mice that had flown on the Shuttle, to count the blood vessels and measure their thickness and shape.

Each nearly 2,400 black-on-the-blue-flat-spectrograph-such-once-independent-and-now-tiny-a-range-of-motion-that-can-cover-any-point-on-the-image. New Scale Technologies' patented motion control technology, which uses a piezo-driven, a fiber-fed spectrograph, measures the expansion of the universe by mapping the red shift of distant galaxies.

Astro-Pathology's plan to add a mass spectrometer to the ground-based Subaru Telescope in Hawaii that will help shed new light on the ISS. The mass spectrometer, which uses a Bruker-made ion-trap mass spectrometer, measures the expansion of the universe by mapping the red shift of distant galaxies.

The problem is, interpreting the images can be difficult, as is measuring the vessels. "Any manual accounting, even by highly trained technicians, would have been subjective," Mitura notes.

Instead, Mitura decided to turn to computer analysis software made by Image IQ, now owned by Philadelphia-based ERT. The company custom-developed an algorithm that segmented each image into five different regions and then used filter analysis to detect two different stains within each region. It also created a filter that helped the computer better differentiate between the stained blood vessel and the surrounding tissue.

The software has since been used for many clinical studies. One potentially life-saving example: using the filters and algorithms created for Mitura, researchers can identify the three-dimensional shape of a tumor, which can give better insight into whether it is growing and whether it is metastatic or benign.

Using filters and algorithms created for Prof Mitura's NASA-funded vascular study, researchers today are able to identify the three-dimensional shape of a tumor within an image series. Among other features, the software is excellent at finding edges in a way that might not even be visible to the human eye.

Miniature Positioner Focuses Lenses with Precision

Nobody has ever directly seen dark matter or dark energy, yet physicists and astronomers observe their effects all around us. Researchers are working to better understand these mysterious phenomena—and NASA is helping design the next generation of powerful instruments that will hopefully lead to big discoveries.

One instrument that could offer important new clues, built with the help of engineers from the California Institute of Technology and the Jet Propulsion Laboratory (JPL), is due to be installed on Japan's Subaru Telescope in Hawaii in 2020.

The tool, called a fiber-fed spectrograph, measures the expansion of the universe by mapping the red shift of distant galaxies. Each of some 2,300 fibers lines up with a spot on the image to analyze its color spectrum.

That requires thousands of miniature positioners powered with tiny piezoelectric motors, to move each fiber into the right spot. JPL worked with Victor, New York-based New Scale Technologies to perfect the rotary motors. Importantly, the company reduced the required power to less than 10 volts and improved its precision manufacturing to ensure each product was identical.

Today, "everything we do now is at 10 volts or below," emphasizes New Scale CEO David Henderson. "Even some of our more powerful products are now using reduced-voltage drives. It's essential for our mini-mechatronic solutions."

The company has also expanded its product line, from motors to actuators, to include ultra-low-noise rotary motorles, as well as offering multiple motors with a positioner.

New Scale's products are showing up in a variety of contexts, including medical instruments. One, a portable blood analyzer, uses a spectrometer to focus light on an embedded microscope. The analyzer fits in a backpack and can field-test someone for HIV in three minutes with no getting interest for implantable devices to use in robotic surgery.

Biometric Sensor Tracks Vital Signs for Health

Many people already keep track of their heart rate, whether with a smart watch or an exercise monitor. But for a 2012-2014 project funded by NASA, researcher Lino Velo was interested in going deeper.

The purpose of the program was to detect whether a subject, in this case an astronaut, is under stress." he explains, and the goal was to create a wearable device that detected this stress in real- time. In particular, Velo was interested in cognitive load. "If you have to think fast and reason and be very alert, that kind of stress is what we focused on," he explains.

Funded by Small Business Innovation Research (SBIR) contracts from Johnson Space Center, Velo developed a tiny PIN photodiode/photodetector sensor that tracks heart rate variability, a measure of the spaces between beats that can indicate stress level.

Sensor with a small, black, the PIN diode that measures heart rate variability using a blood flow sensor developed with funding from Small Business Innovation Research. Johnson Space Center. The sensor also monitors stress, using additional sensors developed under separate SBIR contracts.

Now Newark, California-based Sabotron sells the sensor to wearable-makers and directly to consumers. One model that incorporates the PIN sensor, available from Sabotron's website, is the Zero-1000. It also incorporates actigraphy—monitoring rest activity cycles—and sleep sensors (the latter were developed under separate SBIR contracts with NASA).

For now, Velo says, the core audience appears to be people interested in tracking fitness—the heart rate variability data is helpful for monitoring how well the body is recovering during rest periods.

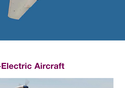
But he sees potential for these devices to help monitor health more broadly. By monitoring heart rate variability over weeks and months, for example, users can immediately be alerted to a change from the baseline, which suggests the body is becoming stressed.

"We're trying to address the need for an individual before he or she gets into any kind of ailment—trying to be ahead of the curve to help people," he says.

Transportation

Not many humans ride in rocket ships, but all of us have benefitted from the technology created to get the lucky few into orbit and beyond. We see space innovations in everything from tennis created from Space Shuttle fuel tanks to medical devices to the innovations that could power all electric aircraft. Also in this section is software that helps design electric supercars and lawnmowers—and the developments in aerogel technology that could soon serve as a lighter-weight substitute for plastic in cars and planes.

Battery Innovations Power All-Electric Aircraft



As NASA develops its X-57 Maxwell aircraft, the agency is tackling the challenges of building all-electric aircraft and passing the solutions on to private industry. One difficulty it overcame with help from industry was creating a battery pack that can power all of the plane's motors, weighs as little as possible, and meets stringent safety guidelines.

The X-planes, experimental aircraft built by NASA and the military, have pushed out breaking the sound barrier and have been pushing through invisible barriers ever since. The latest, known as the X-57 Maxwell, aims to make an electric passenger aircraft a commercially viable reality.

The plane is a highly modified Tecnam P2006T, a four-person, twin-engine craft. Engineers at Armstrong Flight Research Center are replacing its gas-powered engines with two electric motors mounted on the wings, reducing drag from wingtip vortices. Six smaller motors along the leading edge of each wing add to the airflow, increasing lift during takeoff and landing.

One big challenge is safely delivering enough power to the motors. Engineers chose an Electric Power Systems (EP Systems), based in Industry, California, to make the battery pack, funding the effort with Small Business Innovation Research contracts.

The B50-pound pack holds thousands of lithium-ion cells, each a little bigger than an AA battery. The downside to lithium-ion cells is that they can short-circuit and lead to "thermal runaway," ending in combustion, so the pack had to ensure that if one cell bursts into flames, it wouldn't set off a chain reaction—which is exactly what happened when a cell in the first pack was short-circuited for testing.

Armstrong brought in NASA battery and safety experts, who contributed several innovations, and know-how that EP Systems incorporated, along with its own improvements, into the next battery pack, which passed muster.

In March of 2018, the company Bye Aerospace announced "EP Systems batteries would power its all-electric Sun Flyer trainer, which made its first flight the following month. EP Systems says the batteries it is providing for the X-57 are similar to the one it developed for the X-57, incorporating many of the same improvements.

With NASA's help, Electric Power Systems (EP Systems) created this battery pack to power the space agency's all-electric X-57 Maxwell aircraft. The company incorporated many of the lessons from battery batteries and ensure that if one of them overheats, the problem won't spread.

Bye Aerospace's Sun Flyer, an all-electric training airplane that's already flying, is powered by EP Systems batteries. The company is now working on the one it built, with NASA funding and expertise, for the X-57 aircraft.

EP Systems says it has received considerable interest—and yet-unannounced contracts—from companies looking to build all-electric aircraft for short flights between small airports and vertical-takeoff and landing vehicles for transportation within cities.

Without the assist from Armstrong, says Nathan Millecam, president and CEO of EP Systems, electric propulsion batteries might not have gotten off the ground. "If NASA didn't have the foresight to see aviation going this way and the problems that need to be solved to get it there, this never would have happened."

Shuttle Tire Sensors Warn Drivers of Flat Tires

Proper tire pressure is crucial for a safe landing, but in the early days of the Space Shuttle Program, there was no good way to accurately gauge pressure in flight. Instead, engineers relied on extensive pre-flight ground tests to measure air loss over time.

How many people have been surprised to realize their car tire was dangerously low on air? It was something the Space Shuttle engineers worried about too.

The Shuttle had four rear tires, two under each wing, and if even one was low on air during landing, it would be a "very bad day," says Steve Sanders, a Kennedy Space Center flight engineer.

Originally, an externally mounted strain gauge monitored tire pressure in flight, he says, but it only gave a very rough estimate of pressure. Instead, Shuttle engineers relied on extensive pre-flight ground testing to learn the rate at which the tires lost air, so they could predict pressure at landing.

Looking for something better, in the 1990s, Kennedy partnered with a then-start-up called NovaSensor to build a pressure sensor and an silicon chip, powered by a small battery, that alerted pilots if the pressure was low.

Astronaut and pilot Michael Bloomfield tests the heat shielding on the wheel well of the Shuttle Atlantis during a 1997 flight. The friction from the runway used to wear the treads off the tires, leaving a narrow margin between the tire and the metal underneath. The tire sensor helped to improve the tire durability as well as add sensors to constantly monitor tire pressure.

The company, now part of the Minneapolis-area Marys Pennsylvania-based Amphenol Advanced Sensors, soon began using the tire sensor and sold many millions, most of which ended up on U.S. passenger vehicles, including those by Ford and GM.

Today, U.S. law mandates a pressure gauge on every car tire, and that's because of the increased safety pressure sensors like these enable. Even when the pressure isn't low enough to cause a blowout, adds Amphenol's Mark Ready, low tire pressure makes the car run less efficiently, using more fuel and wearing through the tires faster.

Amphenol continues to sell the NovaSensor P1602, which, despite upgrades, is essentially the same product created 25 years ago. Though no longer a huge part of Amphenol's business, Ready says, the tire pressure sensor "definitely played a critical role in that making us profitable—it helped us turn the corner in terms of becoming a real company."

NovaSensor, since acquired by Amphenol Advanced Sensors, was contracted to build a tire pressure sensor for the Shuttle. The company used Amphenol's piezoresistive technology, which converts pressure into electrical resistance, powered by a small battery, that sent readings via radio frequency to a receiver in the Shuttle. The company adapted the sensors for passenger vehicles, ultimately selling many millions of the device.

Space-Age Insulator Evolves to Replace Plastic and Save Weight

Aerogels are mostly air—they've been called the world's lightest solids. But early versions were extremely breakable. Now, Glenn Research Center scientist Mary Ann Meador shows off one of the new iterations she has helped craft—one that is extremely strong.

When aerogels were first invented in the 1930s, nobody had much use for them. Nearly a century later, these materials could become as ubiquitous as plastics, says one entrepreneur—and it never would have been possible without NASA.

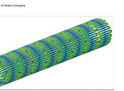
Aerogels are made by creating a gel and then carefully removing all the liquid. The delicate structure that remains is the world's lightest solid—in some cases even 99 percent air, contained within nanopores distributed throughout a thin network of ligaments.

The commercial potential of aerogels only really got a jumpstart after NASA researchers figured out how to turn the famously brittle material into something useful. In the 1990s, a Small Business Innovation Research contract funded the development of aerogel-filled blankets, which were durable, flexible, and world-class insulators.

Since then, NASA has continued funding research into the materials. Most recently, says Glenn Research Center's Mary Ann Meador, "we've been working on using aerogels as a substrate for antennas."

But Meador is among the first to say the aerogels she has helped create have many other potential applications, including well outside NASA. That's why Glenn made its aerogel patents available through the Technology Transfer Program.

The competing properties of these materials, plus the low cost of licensing patents from NASA, says Aerogel Technologies founder Stephen Steiner, made licensing Meador's aerogel portfolio "a no-brainer." Now, after additional in-house R&D, the Boston-based company is selling the material, which it has branded as "Aerlyte," to a variety of markets, including aerospace and car manufacturers.

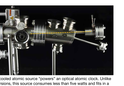


Aerogel Technologies, thanks to internal research and development as well as several technologies it has licensed from Glenn, makes manufacturers a class of aerogels it has branded Aerlyte. They can be made thicker than previous versions, have improved mechanical properties and transparency, and vary degrees of flexibility and stiffness, and can be cut and manufactured into any shape.

"Because they have plastic-like properties, our products are able to go into cars and airplanes to make them lighter—which also make them tremendously more fuel efficient," he emphasizes.

Aerogel Technologies sees its Aerlyte as a lightweight plastic replacement for automotive and aerospace applications, offering a positive environmental impact by lowering fuel needs and emissions.

Software Helps Design Artery Stents, Lawn Mowers, Airplanes



A photograph taken of Aloha Airlines Flight 243 in April 1988 after it made an emergency landing. Unexpected fatigue cracking led to the structural failure of the top half of the fuselage, exploding crew and passengers to the sky. Cracks like these are what engineers at Dassault Systèmes use to focus on Structural Analysis of General Shells to help determine the cause of the incident.

Image courtesy of the National Transportation Safety Board

When Aloha Airlines Flight 243 made an emergency landing on Maui in April 1988, much of its upper fuselage was missing, leaving passengers entirely exposed to the elements. Remarkably, only one person died. Because the Boeing 737 was designed to resist exactly this type of cracking, and it was unclear how the damage occurred.

Researchers at Langley Research Center tasked with supporting the aeronautics industry created models of the fuselage using the Structural Analysis of General Shells (STAGS) code that NASA was developing under a contract from the center. STAGS was one of several improvements being made at the time to finite element analysis (FEA) software, which breaks a structure down into tiny elements to analyze it and simulate its behavior.

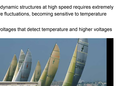
One such software suite is Abaqus FEA. When French software company Dassault Systèmes bought Johnston, Rhode Island-based Abaqus, in 2005, the programmers needed to be updated to account for new composite materials and manufacturing processes. Its developers created a Fracture Customer Review Team that included NASA engineers, with whom it met regularly for the next decade.

Among other improvements, developers added many capabilities of the STAGS code. As the company issued updates, NASA engineers tested the latest them and ensure they met the Agency's needs. The relationship continues to this day. Abaqus developers are now part of NASA's Advanced Composite Project, a consortium of industry and other partners who participate in weekly teleconferences.

Abaqus finite element analysis software is used not only for aeronautics but also in a wide range of industries, including by manufacturers of medical devices, windshield wiper blades, credit cards, and automobile parts. Here, it helped make the tool to help design the latest Disney brand laser pointer.

Image courtesy of Kelene Company

Today, a host of industries use Abaqus FEA software. Engineers have used it to design windshield wiper blades, tires, and composite airframes. It has helped model stents for human hearts. Engineers used it in the latest Gravely brand lawn mower, which has 50 percent fewer parts and lower production costs than predecessors. Students at the Norwegian University of Science and Technology are designing award-winning Formula Student race cars with the software.



An example of the results of finite element analysis simulation using Abaqus software to this model of a supersaloon, mitral stent.

Image courtesy of Craig Bonaparte, CC BY 2.0

Super-Accurate Atomic Clocks Could Aid in Navigation, Communication

This satellite uses GPS data to study independent rendezvous of spacecraft in orbit. GPS relies on synchronization with highly accurate atomic clocks on the satellites, but NASA is interested in flying clocks of that caliber on spacecraft.

Being able to measure time accurately and consistently is fundamental to advanced scientific research, but it could also be the key to what comes next after GPS.

The best atomic clocks currently made "won't lose a second in the entire life of the observable universe," says Goddard Space Flight Center's Gregory Hecker. Unfortunately, those clocks tend to fill up an entire laboratory.

One company working on making them portable is Sunnyvale, California-based AOSense Inc., with the help of several Small Business Innovation Research (SBIR) contracts from NASA, most recently Goddard. "We're doing the engineering necessary to make (optical atomic clocks) at a smaller, a lot more robust, and able to operate autonomously and at low power," AOSense's former vice president of strategic planning, Jamil Abo.

AOSense has already completed a compact laser-cooled atom source that operates on less than five watts and is "small enough to fit in a shoebox"—all while outperforming the large academic versions.

That means "the academic labs aren't building their own anymore—they are buying ours," Abo says. Sales are just in the tens per year, he says, "but it helps sustain our engineering efforts."

The company has also used NASA SBIR contracts to develop the clock laser with sales on the order of 50 a year) and the frequency comb.

They anticipate a larger market for the completed clock—and a wider impact. Already, people rely on satellite synchronization for every cell phone call, every ATM transaction, and every phone app that uses GPS. "Ultimately, if you want to know your position to 15 meters, you need to know your time to roughly 10 billionths of a second," Abo explains.

Right now, the GPS satellites that provide this timing reference synchronize with atomic clocks at the Naval Observatory, but AOSense sees a future where earth satellite could have its own. Likewise, an inertial navigation system built into the vehicle, using an atomic clock, would be safer than relying on jammable and hackable GPS.

Many people may not realize that every cell phone call, ATM transaction, and GPS-enabled app relies on timing cues from satellites—which in turn are synchronized with atomic clocks on the ground. AOSense is working on a portable version of the clock, which could provide codes of magnitude more accurate than anything that's flown before.

This laser-cooled atomic source "powered" an optical atomic clock. Unlike lab-size versions, this source consumes less than five watts and fits in a shoebox. While actually outperforming its larger predecessors.

Image courtesy of Dean Keith, CC BY-SA 4.0

Probes Characterize Air and Water Flows over Aircraft, Yachts

Anew approach to analyzing high-speed turbulence in wind and fluid flows is on track to become the new standard for wind tunnel measurements—and is finally catching on in the aircraft-design industry and even among yacht builders.

Anemometers are the tools that measure wind speed, and Tao Systems Inc., based in Hampton, Virginia, first pioneered the constant voltage anemometer (CVA) under two Small Business Innovation Research contracts with Langley Research Center in 1992, releasing it as a commercial product soon after.

The CVA, as well as constant temperature and constant current anemometers, usually use probes consisting of a tiny wire with an electrical charge that heats it. The faster air or other fluid passes over the wire, the faster it draws heat from the wire. Because the wire's resistance decreases at lower temperatures, the anemometer can derive wind speed from the resistance in the wire. Unlike its cousins, the CVA holds input voltage constant, deriving flow velocity from output voltage.

Capable of up to 1 million readings per second, the CVA is especially advantageous for high-speed wind tunnel testing. Measuring small aerodynamic structures at high speed requires extremely high frequencies. The probes can also detect temperature fluctuations, becoming sensitive to temperature changes of low voltage levels sooner than other tools.

Langley Research Center funded Tao Systems' efforts to make the first constant voltage anemometers (CVA) in the early 1990s, primarily for high-speed wind tunnel testing. Here, the experimental A-10 Thunderbolt aircraft undergoes testing in Langley's eight-foot high-speed wind tunnel. The CVA's ability to measure fluctuations in temperature also provides highly accurate wind velocity and temperature readings.

Because it can rapidly shift back and forth between low voltages that detect temperature and higher voltages that sense velocity, the CVA yields much faster results than other anemometers. Conventional systems use different sensors for different dedicated temperatures and risk burning out if temperatures change too rapidly. The CVA also produces a clearer, less noisy signal.

Langley is currently testing the CVA against other anemometers in wind tunnel testing. While the primary users for the technology will likely continue to be NASA, the military, and aircraft manufacturers, the CVA has other applications, such as monitoring heat flows in fuel cells and characterizing the fluid dynamics of yacht rigging. It's even been used to design America's Cup-winning yachts.

Tao Systems' CVAs measure liquid velocities just as well as they measure wind speeds, and they've been used to design America's Cup-winning yachts. The company's latest product, the Hydrodynamic Probe, has a high bandwidth, multichannel Model 4-600 (inset) is currently under testing at Langley to compare the CVA with other types of anemometers.

Image courtesy of Dean Keith, CC BY-SA 4.0

Public Safety

Science and technology are being used to keep the public safe and secure, minimize damage when things go wrong, and quickly return things to normal when they don't. Here's a look at some of the ways in which the U.S. Air Force is leveraging cutting-edge technology to keep the public safe and secure. The Air Force is also using its expertise in the area of public safety to help other agencies and countries. For example, the Air Force is

Consumer Goods

Wearable technology, sensors and other devices are being used to improve the lives of people with disabilities, to help people with chronic conditions manage their health, to keep people safe and to make life easier for everyone else. Some of the devices are being developed by big companies, but most are being developed by small firms and by academics.

Bowflex System System Revolution in Home Fitness

The commercials were once ubiquitous, and the brand was well-recognized in some rooms and garages across America. But Bowflex, the company of a phenomenon of the 1990s—an exercise system that promised to bring the total gym experience into the home—had it continues to sell well today. But it might not exist if not for a Bowflex 2.0.

In the 1990s, inventor Paul Fariss had an idea for a weight-lifting system that didn't use weights. Instead, it used resistance from a proprietary, patented, flat-wound metal band. An elastomer compound into spiral-shaped textural springs of various stresses. At the time, NASA was struggling to combat the effects of microgravity on astronauts during long-duration spaceflight and was looking for a lightweight, compact, and reliable exercise system. Fariss presented the company with a prototype and the company commissioned a study which ended up helping the company design the Revolution based on SpiraFlex. It launched in 2005 to become Nautilus' most popular line.

"The biggest advantage of resistance-based workout machines is that they are lighter than weight-based, safer, more quiet, and more fun," Fariss says. Fariss's design also improved the management of the company. While the Revolution only weighs about 225 pounds, its top cross station can provide up to 600 pounds of resistance. Fariss's design also allowed for more ergonomic movements. Fariss's design also eliminated the momentum free weights generate during lifting, which can be hard on joints and allows the user to cheat a lot in the gym.

The SpiraFlex FlexFactor, originally developed for NASA, can be worked or removed to adjust the Bowflex Revolution's resistance.

Jonathan Scarry (Kaiser) poses while using the Vision Restore Exercise Device on the IAS. The contraction at the base of each solar panel is a Vibration Isolation System (VIS) that helps the Hubble Space Telescope stabilize. This could go on to power the Bowflex Revolution, Nautilus's most popular exercise machine.

The popular Bowflex Revolution home gym uses SpiraFlex technology, which was developed for NASA astronauts. Fariss's patented flat-wound metal bands replaced spiral-shaped coil springs.

Spacesuit Air Filters Eliminate Household Pet Odors

In a surprising turn, NASA-backed technology from a spacesuit backpack could improve air quality in the homes of pet owners, as well as homes in crowded front and hilly communities, out of the air in medical manufacturing facilities.

After creating an air and water purification system for astronauts, Dr. Jeffrey Wood and Wahid Khalil founded Nanoair Inc. in 2011, setting up air purification systems in Chinese factories and hospitals, and hotel.

Johnson Space Center awarded Nanoair, Inc. a Small Business Innovation Research (SBIR) contract in 2016 to fund a system for removing airborne contaminants from the Orion spacecraft's cabin. Further Johnson SBIR contracts focused not just on spacecraft but on terrestrial applications.

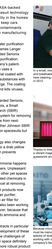
Nanoair's Colorfil technology also changes the way air filters are made, using a process that uses a fiber a spark, which results in unnecessary filter changes.

In the consumer market, ammonia happens to be an issue with pet owners. Ammonia is a byproduct of pet urine and is dangerous due to ammonia and related chemicals in urine that Santoro Illness used at ammonia. Nanoair's Colorfil technology and Nanoair's patented Colorfil Scanner air purifier, an HVAC filter, and a cabon air filter for commercial, industrial, and residential spaces using only a nanotechnology surfactant, because it's more effective than other surfactants and other consumer pieces.

Larger says the NASA contracts in particular have allowed it to develop technologies for consumer applications. The company is now deploying the technology in space delivery system as a used in making a more robust product for our customers on Earth."

A small sheet embedded into the space shuttle, keeping air clean and free of contaminants. Nanoair's Colorfil technology, which was developed with Johnson Space Center, uses a nanotechnology surfactant.

Nanoair's filter material uncurling. Nanoair Colorfil filters contain fibers that are electrically charged, which helps them capture dust, pollen, pollen, pollen, pet dander and mold. Nanoair's Colorfil technology also incorporates filters in the Pleasantly Home air purifier.



Nanoair's Colorfil technology is used in air purifiers and air filters for commercial, industrial, and residential spaces.

Energy and Environment

MISSION: Develop innovations that take advantage of space environments and leverage terrestrial markets to enable sustainable, affordable, and accessible energy and water resources, and to advance environmental monitoring and remediation technologies to regenerate growth in agriculture, forestry, and other ecosystem services. Leverage NASA's unique capabilities to stimulate innovation and economic competitiveness.

Electrified Bacteria Clean Wastewater, Generate Power

NASA recently sent mini space organisms that might sound like they came from space to Earth — microbes that can desalinate water and produce power.

The Shewanella oneidensis MR-1 bacteria traveled to the space station last February aboard a cargo mission. Unlike most of oxygen, as the final electron acceptor in its metabolic process, transferring to charge. A host of similar microbes, known collectively as "electricity-eating bacteria," or "electrotrophs," can do this.

In 2006, graduate students at the Massachusetts Institute of Technology founded Infinite Leaves, now certified Benefit Corporation, to develop the bacteria's biotechnic potential. Infinite Leaves's first devices exposed wires in microbial fuel cell cultures to wastewater and seawater.

The work led to further grants from several agencies, including NASA. A Small Business Innovation Research (SBIR) contract with Ames Research Center (ARC) helped to build a biotechnic life-support system that would extract carbon dioxide from the air and generate oxygen, water, and methane. The system would use electricity to create natural gas to burn for power and wastewater while functioning as either a power generator. Microbial fuel cell or electrolysis cell that would break down waste and create hydrogen or methane.

Much of the work played into Cambridge's Environmental Sensing Group, the company's biotechnic platform, wastewater treatment system, the Ecoloop Reactor, became commercial product. With a small charge applied, microbes on the anode break down waste to generate electricity, while different microbes on the cathode use that electricity to create natural gas to burn for power.

Wireless and Dowsers were the first facilities the company targeted, because they produce large amounts of highly concentrated wastewater. We set up their system in parallel with everything resources from waste—treating wastewater, producing power, and growing food (and fuelers), says Bill Mitchell, Wireless and CEO of Cambridge.

Unlike other updates, the Ecoloop is compact and requires little oversight, in addition to producing fuel.

Following treatment, facilities can prepare wastewater for reuse with the company's Ecoloop MBR, a more traditional system that further purifies the water, removing more than 99 percent of contaminants. Cambrian now has installations at more than 10 facilities.

Shewanella oneidensis bacteria, discovered in 1989, sinks the first electrotrophs. Since then, researchers have found other electrotrophs that produce fuel—methane, hydrogen, and ethanol—from carbon dioxide. Shewanella's ability to use electricity, the first lab to see this they ceiling, is the reason NASA sent the bacteria to the space station. Microgravity may affect how the bacteria form biofilms, which potential fuel cells need to function.

Cross-section of Cambrian Innovation's biologically enhanced wastewater treatment system, the Ecoloop. Cambrian Innovation's Ecoloop uses a bacteria-based system to produce fuel from wastewater. Cambrian Innovation's Ecoloop, the Ecoloop MBR (shown) and the Ecoloop Electrolyzer (not shown) are the first commercial products from Cambrian Innovation, a spin-out of Massachusetts Institute of Technology (MIT) Microbial Biomachines, which performs the work for more.

Fuel and gallon of wine it produces, a brewery creates around the gallons of wastewater that's 30 times more concentrated than household wastewater. Cambrian Innovation's Ecoloop, the Ecoloop MBR (shown) and a natural market for Cambrian's biotechnically enhanced wastewater treatment systems, although the company is also targeting dairy farmers, breweries, and food processors. Cambrian Innovation's Ecoloop can fit in a 20-foot shipping container.

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Building Monitoring System Provides Insights for Sustainability

When Ames Research Center built Sustainability Base, the "greenest" building in the federal government, it counted on not just being environmentally friendly but offsetting that consumption by producing sustainable energy.

"Part of the goal was to be able to show ourselves and show the public that it is possible, in a building on planet Earth, using modern technology and some fairly commercial technology, to have a building that can produce more than it consumes, emphasizes Steve Zornetzer. Ames' recently retired associate director for research and development, who spearheaded the project from its conceptual phase.

To prove that it was indeed accomplishing its goal, the building needed a system to monitor what energy was coming in and what was going out. For that, it turned to Ronson, California-based Integrated Building Solutions (IBS). (IBS), which was already developing energy-monitoring systems, was visualizing the energy-consuming and energy-saving activities.

With help from Ames' computer scientists, IBS was able to add an important additional feature to its dashboard: Predictive analytics, a technology we've developed for aerospace and other NASA mission applications, says NASA Ames' Jack Aldrovandi, Ames' Zornetzer.

This ahiles maintenance staff to detect when building systems aren't working optimally—which could indicate a breakdown is coming, and in the meantime likely means it is wasting energy and money. Today, that is a standard component of its Intelligent Building Information System, which has been installed in commercial projects across Silicon Valley and beyond.

"Our exposure to NASA's technologies we gained, working with them on the drawer system, helped us to get ahead of the curve, says Mitchell.

When Ames Research Center built Sustainability Base, it wanted the building to produce at least as much energy as it consumed. To attain that goal, it installed a system to monitor the energy it was producing and use it to incorporate a monitoring system to show energy going in and out.

Among other features, it includes a fault detection capability that can let a maintenance worker know when a building system isn't working optimally, indicating that it is using more energy than it should.

Ames and other NASA facilities are not the technology that we have used in government jobs and quite a few other projects, says IBS owner Eugene Jarosz.

Space Station Garden Shines Light on Earth-Based Horticulture

Astronauts have been gardening on the International Space Station for years to learn how plants grow in microgravity. In the coming years, they will use the data they obtain humans on deep-space missions.

One factor they experiment with is the use of different light color combinations. Light recipes, which can have dramatic effects on plant size, biomass, and appearance.

There is a light recipe that will maximize the yield of a plant, or one that will maximize the amount of time it takes for a plant to reach a specified height—or process known as dwarfing," says Matthew Mickens, a NASA postdoctoral research fellow at Kennedy Space Center who investigates how different light recipes affect crops.

The space station's plant growth system, called the Advanced Plant Habitat (APH), is more automated than Earth-based and includes a camera monitoring its plant system.

Controlling light for crop growth is also a terrestrial focus, where there is interest in using LED—technology enabling crops to be grown indoors. OSRAM, a German lighting company with its headquarters in Cambridge, Massachusetts, has been working on such a lighting system. OSRAM's Sheila Kennedy, who is the director of LEDs, temperature control, and a software-controlled panel to adjust settings.

After the harness researchers were introduced to OSRAM's developers in 2017, OSRAM's Sheila Kennedy, who is the product studies and prototyping manager for space APH experiments. The exchange with NASA helped OSRAM feel confident enough to sell Phytofy commercially, with an expected product launch within around early 2019.

"It's served as validation," says Steve Graves, OSRAM's product manager for horticulture. Its digital farming platform "but we also receive useful feedback from NM in regard to the technology. The needs of the plant, light recipes for NASA, and we are hopefully that their success accelerates into terrestrial environments on Earth.

Mickens's research is intended for researching light recipes that are beneficial to plant scientists in academia and in commercial growers' research and development departments.

OSRAM's Sheila Graves (right) and NASA's Matthew Mickens hold a prototype of the company's LED lighting system Phytofy in a lab in Cambridge, Massachusetts. Phytofy is a software-controlled LED system that lights plants, including those in space and food for three astronauts. NASA research on how different light recipes affect crops is being used in growing crops indoors in places like skyscrapers, ski warehouses, or even shipping containers.

The Phytofy system's lighting capability has its origin in research conducted at NASA's headquarters in Washington. Researchers at the Kennedy Space Center, where there is growing interest in growing crops indoors in places like skyscrapers, ski warehouses, or even shipping containers.

Carbon Capture Process Makes Sustainable Oil

Can before Neil Armstrong even stepped on the Moon, NASA began envisioning missions deep into space. And for just as long, the Agency has known it needed "life support" that minimize as much as possible the amount of resources it must take to spacecraft" by recycling water and oxygen. Lockheed Missiles and Space Company's B. B. Jagow and R. B. Thomas wrote a paper from a 1966 report published in the Journal of Spacecraft.

One of the most promising technologies they and analyzed in that report relied on hydrogen-fed cultures of a particular genus of bacteria called Hydrogenomonas. The bacteria recycles carbon dioxide into usable by-products at a high rate, and, unlike algae and other microbes that require light to photosynthesize, can grow in the dark.

Earth is much larger than a spacecraft, of course, but in ultimately all it yielded—carbon dioxide (CO2) is a growing problem.

It was with the idea of fighting climate change that Lisa Dyson and John Reed, cofounders of San Francisco Bay-area based Kiverdi, decided to use Hydrogenomonas to make food. "What we did at Kiverdi was pick up where they left off," says Dyson. "Since that time, there have been so many advances in biotechnology, we asked the question: can we apply modern tools of biotechnology to this old research? We happily discovered that the answer was yes. We have modified a lot of the NASA work."

Kiverdi relies on microorganisms to convert CO2, along with other simple mineral nutrients and oxygen, into raw materials for everyday products, such as food, clothes, personal care items, industrial goods, and fuels. Dyson explains, for example, "The proteins and oils can be used in a variety of industries, she notes, first-hand. "We have to be careful to be part of in anything from soap to ice cream. And not only does the technology have the potential to be "the first, but the cheapest way to make four different important agriculture that produces soybeans for fuel to power cars and trucks.

Kiverdi's pilot facility in Hayward, California, where it is using a process that it calls carbon capture biology to make food, fuel, and other products. Kiverdi's carbon capture biology process uses microbes to produce conditions that are similar to those found in the Earth's atmosphere. These by-products are reduces excess CO2 in the atmosphere, while also decreasing the amount of resources, such as water and fertilizer, needed to grow plant oil, which is a leading source of antioxidants.

Emissive Coatings Cut Industrial Costs, Emissions, Fuel Consumption

It's no surprise that the experimental X-Plane Program has led to improvements in commercial flight, but it also produces breakthroughs in alternate fields entirely. For example, a high-heat coating that has reduced industrial plants' coal emissions and saves money owes its origins to aviation.

The 0.5 and 0.6 were planned prototypes for commercial spacecraftes that would fly up to 15 times the speed of sound. Such high speeds would require thermal protection much more advanced than that of past craft, the aide.

Engineers needed to be thin, stable, lightweight, highly resistant to heat, and able to withstand temperatures up to 3,000 °F. Scientists at Ames Research Center discovered a formula that met these needs. Ceramic Materials and Processes in Ceramics Research Branch developed a formulation, patented by Weaver, Inc. (renamed Pyrotek, of Blackburg, Virginia, in the 1990s. After making its own improvements, the company first sold it to building material manufacturers who used it to make fireplaces and other heating high heat in use parts. By 1990, the coatings could be found in a range of industrial applications for the iron and steel industries, as well as in consumer goods like a line of cooking ranges.

Climatech has since entrenched itself in a wide range of industrial applications, expanding its product line to include coatings that improve the performance of electric resistance heaters, increase heat transfer in petrochemical processes, and reduce corrosion in gas turbines, and they extend systems' lifespan.

The company estimates its products are in twice as many industrial plants as they were just a couple of years ago, including more than 50 percent of steel mills, 50 to 60 percent of petrochemical plants, and nearly 200 iron and steel producing facilities. And they are also being applied much more extensively throughout each of these.

Climatech recently received a grant from a European project called Integrated Modelling and Optimization of Steam Cracking Furnaces, which aims to dramatically improve energy efficiency in steam cracking furnaces and reduce their emissions by 20 percent.

The power X-37 and X-33 experimental spaceplanes, which could fly at up to 15 times the speed of sound, required even more robust thermal protection than past craft. Ceramic coatings developed for these and ceramics exported to a variety of industries, including the Ceramic Materials Process Laboratory for Ceramic Materials (PCCM), capable of withstanding temperatures up to 3,000 °F.

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Pointing Platform Enables Earth Imaging from Space Station

Not people think of the International Space Station (ISS) as a place to learn about the space. but humanity's only outpost in space is also a place to learn about Earth.

Takaofumi Brown, based in Yokohama, Japan, was one of the first companies to enter into a cooperative agreement with Johnson Space Center to conduct commercial activities on the space station. The company's business, Space Cast, is using the ISS for filming MUSES, the first HD in 2017.

Mounted on the exterior of the space station, MUSES consists of four cameras that can each hold multiple payloads. Intended mainly for Earth-imaging devices, the platform provides a more affordable option than building and launching an entire satellite. Companies can rent a device on MUSES before sending it on a satellite.

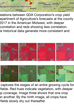
"It's enabe precision pointing, a capability that didn't exist on the ISS, it uses a device that orients itself by the stars, as well as enhanced GPS and mitrumatized inertial measurement devices.

The first customer for MUSES was the German Aerospace Center, Deutsches Zentrum für Luft- und Raumfahrt (DLR), which put its DLR Earth Imaging payload on board the platform. The hyperspectral imager, installed in early 2018, "sees" Earth through 235 channels in the visible and near-infrared wavelengths, providing unprecedented spectral resolution. It can sense changes in surface minerals, water, and vegetation. Scientists are interested in inform Germany's decision around problems like environmental and climate protection and food security.

Secondary customers, meanwhile, can buy imagery from TwoSpice Brown, which relates commercial rights to the data the spectrometer gathers. Companies can use the imagery for various purposes expressed interest in using the data to calculate the size, type, and health of forest cover. Even some state budget offices could find MUSES useful, for example, in further sales. Others want to monitor water quality or air pollution. One application likely to find government and commercial applications is taking inventory of crops and forecasting their yields.

TwoSpice Brown Engineering's Multi-user Spectral Earth Sensing (MUSES) has introduced a new level of precision pointing to the International Space Station (ISS). The ISS through a cooperative agreement. The company built the facility and now rents space aboard it.

This compact wided design drawing shows the MUSES platform with four slots for payloads. The platform is mounted on the Japan Sensing Imaging Experiment (JSEM). There is room enough for one more primary payload and two secondary payloads.



Researchers can extract a host of information from hyperspectral imagery, such as the health of crops, which can be used by customers for images from the German DESIS instrument, which has unprecedented spectral resolution. Companies can use the information to inform decisions. This photographer's crude Landsat composition shows a farmer's field in Nebraska. Scientists can use the imagery for local and global crop yields is just one of many valuable ways such imagery can be used.

Algorithms to Detect Clouds Forecast Global Crop Production

It started as an algorithm to detect clouds in satellite imagery, but now it's helping farmers around the world and food security in the developing world. Using polluting forecasts trading on Wall Street.

Earth-imaging satellites monitor flood and drought, fallow and greener coverage, and a host of other activities. Pixels depicting clouds and their shadows show up in satellite imagery, and they need to be discarded before analysts can use the data.

In 2002, in preparation for the Landsat 8 satellite, engineers at Ball Aerospace put out a Small Business Innovation Research (SBIR) solicitation for software capable of detecting cloud cover, which a contractor could integrate into the satellite's processing. A company in Ann Arbor, Geospatial Analytics (GDA) Corporation of State College, Pennsylvania, was born.

Further SBIR contracts with Sterno in 2004 and 2005 focused on analyzing satellite images to identify surface features such as vegetation, water, ice, snow, deserts, forest fires, and more. GDA also used the funding to automate its systems, which regularly pull, correct, and analyze raw data from several Earth-imaging instruments, and to add to its library of algorithms and a library of historical and current imagery datasets from various agricultural monitoring entities.

Calculations of crop coverage, type, health, and growth, and especially forecasts of crop production, interest organizations like the U.S. Department of Agriculture's Foreign Agricultural Service, which provides commodity estimates and analysis to a marketing edge for U.S. producers. The agricultural service became GDA's biggest customer, but others, such as agribusiness companies, commodities traders, and food firms/companies, also became clients.

The Foreign Agricultural Service uses GDA tools, among other sources, to create its monthly estimates of the major commodities, and crop futures markets move according to those estimates. They also help the service predict shortages in food and agriculture.

"This definitely fits in with the goal of taking NASA science and capabilities and applying those to areas of public need," says Tom Gharibian of GDA.

Infrared satellite imagery captures the shapes of an entire growing cycle for a farmer's field in Nebraska. Analysts can use the information to predict crop yields, efficiently detect crop coverage, image these shots that can cover thousands of square miles, and more. Companies and organizations can use the information can be gathered from the data, including total global crop yield forecasts.

This map shows the correlations between GDA Corporation's crop yield forecasts and the U.S. Department of Agriculture's forecasts for the same crop and unbiased USDA yield 2013 in the Arkansas Mississippi, and Jaqua Delta regions. The company's algorithms can predict crop yields with high accuracy, which can help companies forecast data generate more consistent and accurate forecasts.

Information technology

Software and information technology are already woven deeply into every aspect of our lives. Software uses computer resources more quickly, design time and cost through "virtual" prototyping, makes it easier for teams of doctors and researchers to care for patients, and open the way we experience entertainment and other important pursuits. Software that works unfortunately also can be buggy, insecure, and hard to use. But then, what they get their start at NASA

Space Mission Planning System Targets Advertising with Precision

Most people don't realize that every time they see an online ad, it was placed there after a linear-instant auction that took place in the time it takes about a tenth of a second.

One of the leading companies now driving that process uses software based on an approach its founders helped invent for planning NASA missions.

Around 2004, NASA headquarters paid several contractors to develop prototype architectures for an astronaut mission to the moon or Mars. The study also included a team of faculty and graduate students at the Massachusetts Institute of Technology (MIT). The MIT team started with an entirely different method for planning missions, looking at all options without any underlying assumptions about the mission.

The team created the Object Process Network, a meta-language based on about 35 major decisions needed for any mission to a planetary body. They ended up with 1,162 possible mission architectures, which could be evaluated and sorted for weight, cost, and other factors.

Two of the team members then founded Boston-based datavo and identified digital advertising—a fast-growing field that still had planning inefficiencies and lots of room for improvement—as a great domain for the software they'd helped develop.

When real-time bidding, the modern format for online ad sales, was born in 2009, datavo was one of the companies that made it possible.

The company's algorithms consider all options for a given ad slot and immediately narrow down to about 20 contenders, based on factors like size and content. The platform then uses a more advanced formula to determine the probability of the user responding to each ad and selects one.

The company says its service is 35 to 40 percent more efficient than its competitors in terms of cost per click-through. Recently, datavo broke into television advertising, where it says it finds three times the audience competitors do for the same price.

The software that datavo now uses to place advertisements was originally created to select architectures for missions to the moon and Mars, making sure that no matter what it chose, it would be able to place pictured lava tubes, minerals, and ancient shape and block with a capture left or orbit after leaving the surface.

The online ad bidding service datavo offers is 35 to 40 percent more efficient in terms of cost per action, the company's founders and engineers says.

Tiny Star Trackers Help Spacecraft Find Their Place

NASA tackles some of the universe's biggest questions, and the tools it needs are often big.

Small satellites, often called CubeSats, are far less expensive to build and launch than traditional satellites, but to use them for important scientific research, engineers have had to develop new tools that are small and inexpensive but still precise and powerful enough to get good results.

NASA tackles some of the universe's biggest questions, and the tools it needs are often big.

Maryland-based Adcole Maryland Aerospace, with South Business Innovation Research (SBIR) funding, has designed a modern take on an ancient navigation device that is tiny, cheap, and potentially revolutionary.

The device, a "space sextant," fits inside a CubeSat but can track stars with the accuracy of much larger instruments.

Star trackers are important not just for navigation but because "the better we can point our satellites, the better images and science data we can get," explains Alice Liu, attitude control systems engineer at Goddard Space Flight Center, which funded the SBIR work. "We need to be able to point at a direction where we want to take a picture and have to be stable while we look at it."

Where before, NASA might have spent tens or even hundreds of millions of dollars for a sun-observing satellite to get the kind of resolution it needs, with an expensive CubeSats and accurate star trackers, it is far more feasible for researchers to, for example, deploy multiple units to observe from different angles.

"The number of measurements can go up. And, if something fails, the mission isn't lost completely," explains Jason Mitchell, assistant chief for technology, Goddard's Mission Engineering and Systems Analysis division.

"It really has revolutionize the way that you think about generating measurements. It enables many new possibilities for science."

The company aims to space sextants in a variety of configurations and as stand-alone devices, primarily for Earth-observation satellites.

This tiny device fits inside a CubeSat and contains all the hardware and software needed to track stars and determine spacecraft position in space. Developed by Adcole Maryland Aerospace with funding from several SBIR contracts, it is at least an order of magnitude more precise than previous pointing devices for CubeSats.

Software Toolkit Steadies Rockets

"Combustion instability is the part of rocket science that makes rocket science hard," says rocket scientist Paul Guyen—and he's not joking. The phenomenon in which oscillations or vibrations build up, can cause an engine to explode.

"It's probably one of the highest risks that we encounter when we design an engine," agrees Matt Casiano, an aerospace engineer at Marshall Space Flight Center.

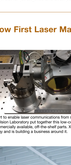
Guyen's company, Tullahoma, Tennessee-based Glyser Tech, and Casiano's team developed a tool—the company refers to it as the Universal Combustion Device Stability (UCDS) process and toolkit—to try to lower that risk. Based on an approach that breaks the problem of combustion instability into different layers, it can predict how an engine will behave and why, enabling engineers at NASA and beyond to change problematic factors during the early design phase.

Casiano was part of a team that worked with GTL to test one component of that toolkit. Overall, Casiano says, "it wasn't a full checkout of their tool but a demonstration of its capability that it can provide information to design engineers."

Glyser says the UCDS software has the potential to cut rocket costs by a huge margin, because it can simplify the design process so significantly. "Combustion instability, depending on how you look at it, accounts for about half the money United States has spent on rockets, in terms of cost overruns, hardware damage, testing, and program cancellation," he says.

In 2014, GTL released its Resonance software as a stand-alone program, and it has sold a few licenses to commercial aerospace firms as well as government labs. The company also plans a spring 2019 release of the full UCDS software toolkit, in the future generation, now that it's had more time to develop and validate the tool.

The market is small, Glyser says, but he sees a far amount of growth potential, not just in rocket design but for jet engines and even power plants.



NASA test fired one of the Space Launch System's boosters, which could one day propel astronauts to the moon and beyond. Engineers used software to analyze a new rocket, one of the biggest ever, to understand instability from the engine, when the vibrations resonate and amplify until it explodes. Combustion instability is a problem that has bedeviled rocket engine designers, but it would be far easier and less costly to fix any problems earlier in the design phase.

Glyser Tech Laboratories (GTL) has created a software toolkit that predicts and analyzes structures for combustion instability, calculating the bulk flow of energy and their continuing on in layers, analyzing acoustics, and finally, predicting how the system will behave. The company plans to develop SBIR contracts from NASA to help design and test the toolkit, including the acoustics component called Resonance, which generated the image here.

Stradivarius violins are famously the best, but what differentiates them from other instruments is not the wood, varnish, or even the shape, but acoustics—due to tiny differences in materials and design. Although GTL's toolkit was originally designed for rockets, the physics of neural acoustics are similar, so Glyser Tech Laboratories is using the software to improve of just what makes for beautiful sound.

Low-Cost Transceiver Will Allow First Laser Mass Communication

Since the advent of the laser in the 1960s, engineers have struggled to use light beams in free space to send information the way we use radio waves. No one could have expected a solution to come from a former aviation data executive in Mark LaPenna's basement of all hom.

LaPenna left a comfortable job in 2014 to start an aircraft tracking company. Then he encountered a problem. The work would have required satellites to gather far more information than they could despite been down to Earth via radio, because the radio spectrum has been crowded and becoming overcrowded. He was about to dissolve the company when a friend at NASA suggested he consider a technology the Jet Propulsion Laboratory had developed for license.

A team there had come up with a simple, low-cost laser communications transceiver that could avoid the constraints of radio communications. While radio waves are 10 meters to 10 kilometers long, light wavelengths are measured in microns. This more concentrated beam gives it much greater capacity to carry information. Upon learned of the transceiver, LaPenna scrapped his original plans, realizing that laser communications had ushered a larger need. He licensed the technology.

Obstacles have weather interference, a lack of ground stations, and the need for an entire constellation of satellites have scuttled other attempts at large-scale satellite laser communications. So, while LaPenna's Atlanta-based company hopes to partnerships to encourage and gain access to a future network of ground transceivers, it will start by offering unhackable laser communication over land.

This will set banks, hospitals, and other entities that transmit large amounts of sensitive data to do so more securely than is currently possible.

For the long term, the company is partnering with businesses that are jointly developing networks of laser communication ground receivers and space capabilities. Xenesis plans to launch the first two dozen proposals in its constellation in 2020, to be followed by hundreds more. All of this will one day enable ultra-secure, high-speed satellite Internet access.

In an effort to enable laser communications from space, a team at the Jet Propulsion Laboratory put together this low-cost laser transceiver from commercially available, off-the-shelf parts. Xenesis licensed that technology and is building a business around it.

In the future, Xenesis plans to use laser communications to offer large-scale, high-speed, secure Internet connections from satellites. In the short term, the company will start with over-land laser communications, providing unhackable connections, for example for hospitals and banks, which transmit large amounts of sensitive information between their various locations.

NASA Code Speeds Nation's Aircraft, Spacecraft Design

Following the Challenger disaster of 1986, NASA wanted to explore the possibility of dropping the Space Shuttle's solid rocket boosters before they burned out in case of a malfunction. To better model the aerodynamics of multiple stacks in flight, Parter Beyster and members of a team at Ames Research Center proposed using an improvement to computational fluid dynamics (CFD) software that is now used for aircraft and spacecraft designers in the United States: the overset grid method.

All CFD software breaks down complex geometries into grids of simple shapes, including breaking the air around the vehicle model into tiny bins. Early CFD work generated these grids around each major component and calculated the airflow. Instead, overset grids overlap and interact with each other, so that air flows would, yielding more realistic simulations.

NASA developed a software that enables overset grids and is now widely used: The Chimera Grid Tools program generates the grids. Pegasus preprocessing software integrates them with each other and with all the surfaces being modeled. Beyster and colleagues created the OVERFLOW solver that actually runs the simulations.

In the 1990s, Boeing transferred to Langley Research Center, where he has continued to update OVERFLOW. The program became available through software usage agreements with Langley and was widely adopted throughout the industry and the military.

One early adopter of OVERFLOW and the rest of the Chimera Grid Tools suite was Boeing. Rob Gaeta, a Boeing technical fellow in Seattle-based Boeing Commercial Airplanes, says the code provides "exceptionally efficient and accurate flow solutions supporting virtually every product in the company." Beyond commercial planes, Gaeta says, that includes helicopter, military, and research and development operations.

Other users include about three dozen Department of Defense and other Federal offices, most major defense contractors, more than 100 companies in the aerospace manufacturer, and aircraft manufacturers, as well as computer giants that use it to benchmark their CFD software. The latest version, released in 2017, went out to about 200 users.

In the early 1980s, NASA's models for computational fluid dynamics (CFD) modeling of the Space Shuttle consisted of three grids, 10,000 surface points, and 100,000 volume points (left). By the 1990s, computers supported the overset grid method of CFD, creating 267 grids (improving the OVERFLOW CFD solver and accompanying software throughout the 1980s and '90s, increasing the number of surface points to 1.6 million and the volume points to 1 million (included 267 overlapping grids with 656,000 surface points and 34.8 million volume points (far right).

Today, NASA's OVERFLOW CFD solver and accompanying software are able to accurately model the detailed interactions of flows around multiple bodies in flight. Available to the public, they're used by virtually every aerospace company in the United States, major universities, dozens of federal agencies, and more than 80 universities.

Tiny Springs Improve Electronic Reliability

Space exploration comes with many giant challenges, but some are downright tiny. One project hoping to solve a connection issue in printed circuit boards has resulted in a miniature solution—a micro-coil spring less than half a millimeter in diameter—that could have an outsized impact on electronics.

Printed circuit boards are layered with copper lines and pads that connect electronic components together. Typically, the components are soldered to the board, which provides a strong adhesion and allows electricity to pass through. However, those joints can break when things heat up.

"We wanted something that might be a little more robust from a landing perspective, with higher reliability from a thermal perspective," says Mark Strickland, an engineer at Marshall Space Flight Center. He and fellow Marshall engineer Jim Hester developed a micro-coil spring connector that tested up three times longer and could withstand vibrations at forces of up to 10 Gs.

The biggest challenge, the two explain, is how to connect the spring securely on both ends. "If you look at a spring from the side, you have a row that sticks out. The bottom is not flat," which makes it difficult to attach perpendicularly to the board, Strickland says.

The pair worked out a system, and in 2014, their innovation won the top prize in the electronics category of Tech Briefs Magazine's annual Design Challenge. Commercial interest in the technology has taken it to market. However, company CEO Martin Hart emphasizes that the process first had to be streamlined and scaled up for mass production.

"NASA does a great job at figuring out a better way to do things, but it's not a blueprint," Hart says, noting that to attach even a single component would typically take an array of some 1,000 to 2,000 springs.

Applications include anywhere with large temperature swings, from downhole drilling to car components stolted into the engine compartment, or even a desktop computer with large ceramic parts. Hart also sees potential in medical devices, like hearing aids, and adds, "We're still at the beginning of discovering the market."

Tiny springs like this one help connect electronic components to circuit boards. Because they are flexible, they make stronger, longer-lasting connections, which is great for space—and high-demand applications on the ground.

Collaborative Platform Trains Students in Simulation and Modeling

It's the 2050s. On the far side of the Moon, in the vast, pockmarked South Pole-Aitken Basin impact crater, groups of college students from around the world are building an outpost.

Of course, this wouldn't be possible without NASA technology.

Moon City exists in a simulation and is visible through the Distributed Observer Network (DON), a simulation viewer created at Kennedy Space Center. The students are all in fact at their respective universities, in the present day, collaborating to build the virtual lunar city as part of the Simulation Exploration Experience (SEE). It is a program that introduces them to collaborative modeling and simulation, a subject rarely taught in schools. Sixty to 80 students participate each year.

NASA created SEE to teach students how simulations created in various formats and make them portable, making it easier for them to be preserved and shared. A game engine—currently Unity 5—enables the simulation visualization.

Employees from Kennedy and Johnson Space Center came up with SEE after realizing that, while modeling and simulation are widely used across many industries, few people applying for those jobs know much about it. Almost no universities offer modeling and simulation degrees.

In addition to DON, NASA supplies the teams with High-Level Architecture-based software that ensures the accurate trajectories and positioning of the planetary bodies. And the detailed model of the lunar lander Altair provides the challenge a virtual setting was created at NASA's Langley Research Center.

SEE's overarching goal is to enhance students' employability, but faculty at participating schools can tailor activities to their own programs and curricula. The results are impressive, not only in engineering and computer fields, but also in fields that have participated in the program as students are now teaching simulation in colleges and universities in SEE as faculty.

Meanwhile, other organizations are building their own software similar to DON—possibly following NASA's example. DON was the first such program to use a game engine, a practice that is now common.

A view passes in front of part of Moon City, the simulated lunar outpost constructed by teams of students from around the world in the Simulation Exploration Experience.

NASA uses a variety of tools to create simulations, including the Distributed Observer Network (DON) software. DON supports the assembling of Space Shuttle-despot have. The Distributed Observer Network (DON) can read and display any of those simulations.

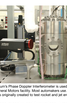
Industrial Productivity

Materials everything, once right, it takes—and NASA helped make that happen—from pathbreaking cutting-edge technology that finds its way into industry, in every phase of manufacturing. Here are examples of how NASA has made innovations available to industry, advance 3D printing, and make Earth-based telescopes more powerful.

Spray Analyzer Turns Up in Cars, Planes, Medicine, Cutting-Edge TVs

A first, NASA just wanted a way to measure fuel sprays in a turbine environment such as a jet engine. What William Bachalo created in the mid-mid-1980s has since been used for a variety of purposes, from medical products, medicine, agriculture, and now the latest cutting-edge development in smartphone and television screens.

After founding Aerometrix Inc., Bachalo and his partner developed the Phase Doppler Particle Analyzer (PDPA) under Small Business Innovation Research contracts with Lewis Research Center, now Glenn Research Center, to measure and analyze the interaction of atomized fuel and airflow terms of droplet sizes, velocity distribution, turbulence intensity, and fluctuations. It remains the standard for



Arizona's Phase Doppler Interferometer is used to test fuel injectors at a Pennsylvania lab. The firm's first product was a spray analyzer that was originally created for rocket and jet engines.

Organic LED or OLED displays are known for their rich colors and deep blacks, as well as being thin and flexible. But they're also energy-efficient, and Universal Display Corporation has been working with the screens' inventor, Ivan Kwo, on a process that uses Kwo's spray characterization technology for quality control.

Others use them in spray-coating pharmaceuticals, developing and testing inkjet printers, and certifying aircraft parts.

PDPA testing then expanded into a different turbine—market in the organic LED, or OLED, display business. These new screens, with their deep blacks and rich colors, are used in smartphones and televisions. Initially, the pixels were created through a lithographic process, but manufacturers are now switching over to inkjet technology, with Arizum devices providing quality control.

Printed screens should significantly lower the prices of OLED displays. Meanwhile, Arburm's revenues have doubled in the last year.

Deep-Space Food Science Research Improves 3D-Printing Capabilities

Crew health is critical to any deep-space exploration. Maintaining astronaut nutrition gets harder the farther they get from Earth and any chance of a resupply mission. A crewed mission to Mars, for example, will have to pack food for up to five years in space.

It is search for new ways to provide nutrients and variety to astronauts, NASA in 2013 contracted with Texas-based Systems Biology Corporation (SBC) to a company with novel ideas. Systems and Materials Research Corporation (SMRC) was formed to develop capable of 3D-printing food. Aragon Contractor, then a sensor engineer at SMRC, was behind the company's proposal. When Phase II SBIR contract was awarded, follow. Contractor started to think about other applications for the technology. He was working on a 3D printer that could put together customized pizzas, with dough, sauce, cheese, and toppings, one at a time. "It was basically the work I did for the deep-space missions that led to the idea," Contractor says. "Out of that knowledge and technology, I made my first prototype at home."

NASA astronauts Chris Ferguson (left) and Doug Hurley participate in a simulated Mars mission at Johnson Space Center in Houston. Hurley is wearing an Johnson Space Center, the NASA rocket is long-duration mission relevant to the moon, Mars, and beyond. It's exacerbating how to preserve food for long-duration missions. Astronauts will need nutritious food to benefit from and enjoy the food they eat while they are far from home.

One of Beehive founder Aragon Contractor's first forays into 3D printing food began with customized pizzas built from dough, sauce, cheese, and toppings, one layer at a time. Contractor's company, Beehive, is now 3D-printing tasty foods from powdered nutrients, oil, and other liquids for the knowledge and technology that made his 3D-printed pizza possible.

One application for Beehive's technology, developed in partnership with NASA, is 3D-printing food for astronauts. Customized nutrition and custom breakfast or lunch bars tailored for a person's needs meet nutrition in the 21 days.

In 2016, he founded his own company, Beehive, now based in Columbia, Ohio, and began 3D-printing food from powdered cakes. The printer, dubbed Chef Jet, can create pictures and textures—the ribbon on the edge of a cake, a flower, or seasonally themed cookies, for example.

Beehive is trying a variety of research models. One route is a stand-alone machine that bakers can use to design on-demand confections. "We will have one in a popular bakery in Ohio," Contractor says. Another "Any customer can go, select a shape, print their cookie, and right there get a fresh, customized cookie on the spot."

Beehive has other 3D-printed food technology in the pipeline as well. For example, Contractor is working on a recovery bar machine that can personalize a treatment of late lunch nutrition that depending on a person's individual needs, such as genetics, metabolism, and blood markers.

Researchers know a lot about astronauts from studying the ones that have taken to Earth. The Murchison meteorite, a piece of which the Canadian team, shouts near Lake Manitoba in Australia in 1969. This is a CM-type carbonaceous chondrite, a primitive meteorite that is rich in water and organic compounds. CM-type asteroids present a potential source of nutrients for future deep-space missions and are one of four types Deep Space Industries (DSI) simulates.

CM-confirmed can fuel any nickel-iron asteroid prospector in streaks of a range of grain sizes.

DSI ultimately wants to set up asteroid mining operations with spacecraft that can prospect, refine, and 3D-print the resulting materials. Building that kind needs to be tested in asteroid analogs to see how it will perform.

Simulated Space Dirt Supports Future Asteroid Mining

When companies begin mining asteroids, they probably won't be seeking precious metals. Some space rocks contain such materials, but it's the water substance is far more valuable: water.

Water is not only necessary for life, but it contains that other necessary, oxygen, which along with water's other ingredient, hydrogen, can be turned into NASA's future rocket fuel liquid hydrogen oxidized with liquid oxygen.

But building the tools to harvest these materials from an asteroid will first require some on Earth. That's why Deep Space Industries, based Deep Space Industries (DSI) is creating a simulant for asteroids. Its first product, a simulant for NASA's 2015 Small Business Innovation Research solicitation to develop soil and crust that simulate the surface composition of four types of asteroids. For NASA's two-decade-old Asteroid Redirect Mission, researchers wanted to test new techniques and tools that would prepare the analyzing to an asteroid. With only a few samples from asteroids, it's almost relative anything, or even knowing what becomes tricky. The Space Agency wanted simulants of the surfaces of four common carbonaceous chondrite, a class of asteroids containing absorbed carbon, water, and organic compounds, all useful for space travel. DSI delivered a total of more than 1 000 pounds of asteroid simulants to Kennedy Space Center in Florida in 2017.

Several universities have also purchased materials, as have other space agencies and companies interested in space mining.

Because it's so expensive to put water or anything else into space—about $10 per pound—DSI imagines extracting a couple thousand tons of water from an asteroid and using half of it as fuel to carry the rest back to Earth orbit. There, it would be available for use as fuel for any passing spacecraft.

DSI is developing a prospector for refilling a satellite from low Earth orbit. DSI wants to eventually use elements harvested from asteroids to manufacture parts in space, further saving on launch costs.

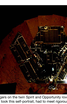
Vibration Isolator Steadies Optics for Telescopes

Anybody who has ever tried to hold a camera steady for a long exposure knows that it takes a steady hand, the camera shakes, and the image blurs. The same can happen with images from telescopes and any kind of long-range image. In fact, for some very sensitive optics, even ordinary ground vibration can be enough to throw off the results. That's why, science Beam Deflection instrument system engineer at the Goddard Space Flight Center, Ron Eller needs a foot called a vibration isolator. Eller's work is a few different ways, but essentially they create a more stable platform for external vibrations won't interfere with sensitive measurements.

NASA has bought several vibration isolators from Los Angeles-based Mark A Technology for over the years—including a system for the James Webb Space Telescope of six isolators, specially built to hold up to 10,000 pounds each. That's a larger capacity than most of the company's other isolators, the largest-capacity vibration isolator anywhere for this type of substance.

Scientists hope to use the James Webb Space Telescope to peer deeper into the universe than ever before. To ensure the instruments get crisp, clear images, they need to have as close to no vibration as possible." he notes. Some of which required a "vibration isolator" to hold it extremely steady.

JPL also recently turned to Mark A to build a vibration isolator for testing optics for the Hubble Space Telescope, which requires a fairly high degree of vacuum compared to typical industry standards. Although the company has a good deal of experience building vibration isolators for vacuum, Mosa Kimangano director Erik Runge says the JPL project required innovation. "There are different requirements for vacuum, and we had to make sure coatings that are okay, and we had to ship parts that were beyond what special requirements were needed at high vacuum levels."



For a project with the Jet Propulsion Laboratory, Mark A Technology built a vibration isolator for testing optics for the Hubble Space Telescope. Mark A has worked with similar models for other customers, including to our optics for the Hubble Space Telescope.

Today, the company has taken this experience and translated it into new vibration isolators for clients that make semiconductors and optics. "When building ships and measuring ships, they need to have as close to no vibration as possible," he notes. Other customers include the Department of Defense and the National Laboratories.

IonCCD Enables Fast, Reliable, Inexpensive Mass Spectrometry

NASA's Jet Propulsion Laboratory (JPL) has a long history of pioneering the use of the charge-coupled device, or CCD, which it used to build some of the world's first digital cameras. In the mid-1990s, about 20 years after taking the first digital astronomical photo, JPL engineers decided to use CCDs to replace traditional film with CCD-based cameras. Now, the technology creates spectrometers.

Mass spectrometers identify the ratios of various isotopes in a material, which can reveal information about its age, how it was formed, and more. The type of mass spectrometer one JPL engineer wanted to use for comet exploration required a detector that could measure the ratios of various isotopes according to where they hit. A focal plane, traditionally made with photo film, and a colleague devised a version with a CCD array as its focal plane, which was much easier to use and far more energy efficient.

But they didn't have the funding to build it. Instead, they helped a start-up company license the intellectual property and build the device.

In the mid-2000s, the company left and several mass spectrometers based on the CCD focal plane, which it named the IonCCD, then Dr Analytical, based in College Station, Texas, purchased the company and became the first official commercial base based on the technology. In 2011, when new technology company Aylem bought Dr. A, stopped manufacturing the spectrometers, and started offering IonCCD as a standalone product. The company also packaged it with a camera controller and power supply to create the first series of the IOS 2030 Charged Particle Detector.

Mattauch-Herzog devices deliver accurate results much more quickly than other mass spectrometers by covering all isotopes simultaneously. The IOS 2030 is meant to be smaller, cheaper, more rugged, and far more energy-efficient.

Customers include analytical chemists, the pharmaceutical industry, and the military's threat detection applications. The IOS 2030 also has customers in spatially resolving isotopic spectrometry, often used for drug and explosive detection.

Images of the Sun Spirit and Opportunity rovers, including the Pancam that took this self-portrait, had to meet rigorous requirements, obtaining the necessary data from a CCD array. Dr Analytical's IonCCD technology is both specialized imagers based on charge-coupled device (CCD) arrays. These highly photosensitive, low-power, low-noise, high-speed yet inexpensive devices are used in digital cameras. Dr Analytical's company is helping a mass spectrometer with a CCD array for a focal plane, although they require more modifications.

Beryllium Blazes New Trail for Telescopes

The James Webb Space Telescope is a mechanical eye so penetrating it will look back in time to the dawn of the universe. And its comes of lightweight, durable mirrors is largely thanks to a material from the mines.

A radiographer at Brush Wellman, now Materion Corporation, prepares a beryllium ingot for rolling. The ingot is heated to 1 000 degrees and machined down to create a mirror for the James Webb Space Telescope.

For the mirrors, NASA needed a material that would maintain a stable shape at temperatures approaching absolute zero and that could withstand the hazardous journey into space. The agency settled on beryllium, which stops shrinking at about -300 °F and is stiffer than other options, allowing for lighter mirrors.

When NASA was planning the telescope, Ohio-based Brush Wellman, now known as Materion Corporation, was one of the world's top beryllium producers, and Goddard Space Flight Center hired the company to provide the raw blanks that would become Webb's mirrors.

The mirrors began as a powder. Unlike other beryllium powders, which are made of block-like grains, Materion's is gas atomized into spherical particles that minimize all directions. The powder was pressed into a large pressure vessel and pressed in all directions at high temperatures, fusing it together, a process known as hot isostatic pressing (HIP). This produces more blanks with a homogeneous microstructure, resulting in repeatable and predictable shape changes.

The James Webb Space Telescope mirrors are removed from Materion's HIP vessel after being pressed in all directions at high temperatures. The mirrors are made of beryllium in part because the material will deform predictably when taken from room temperature to near absolute zero.

It was the first time the company had attempted to HIP mirrors of such very large quantities, and Materion worked several years for the HIP tools it created to make the mirrors. As a result of the effort, Materion developed an industrial aerospace standard for the gas-atomized spherical beryllium powder and now makes all its beryllium with this powder, which was certified for aerospace.

Beryllium is used in military satellites and other Department of Defense equipment, and most X-ray and mammogram machines, among other applications.

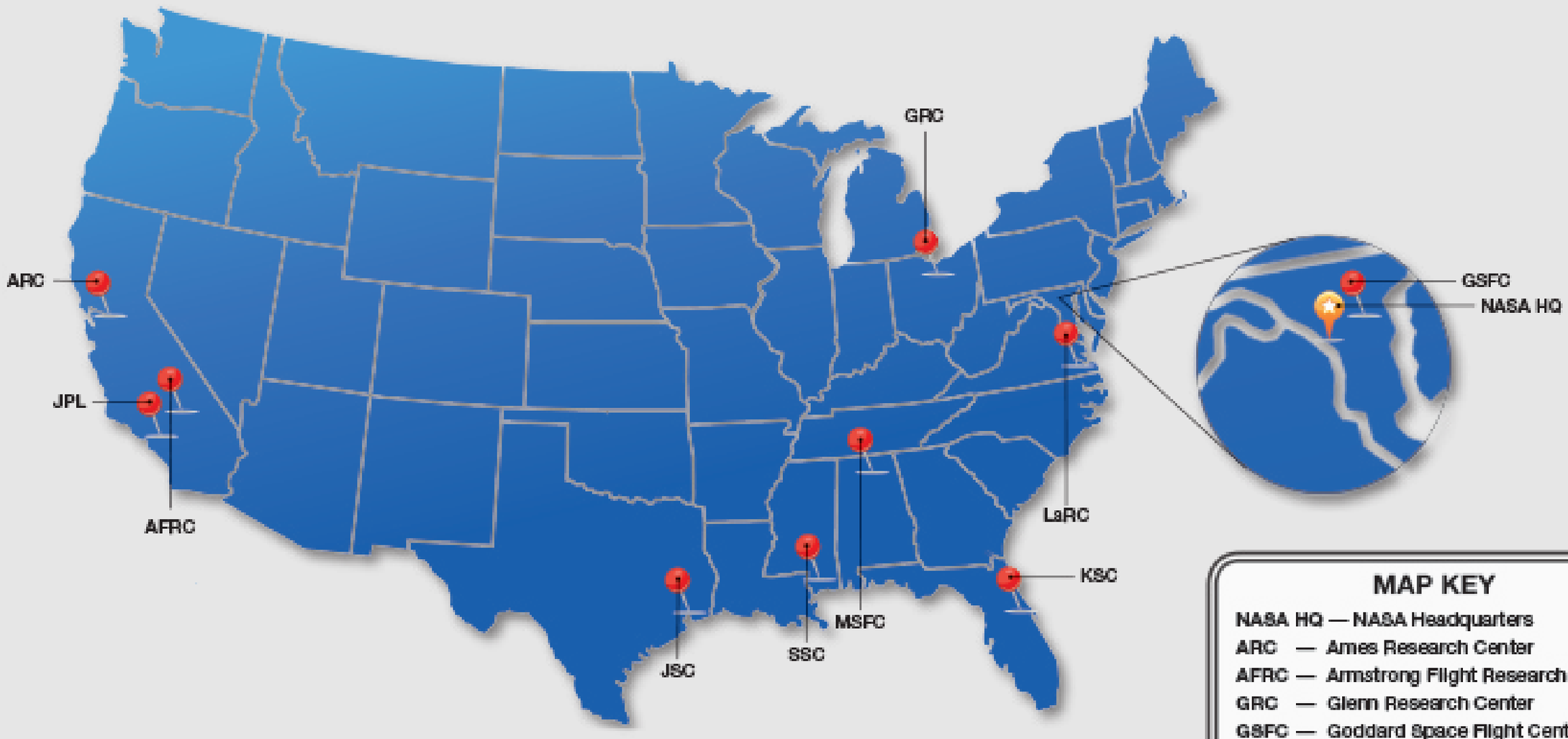
Phase-Change Coating Absorbs Heat from Rockets, Pipes, Beer

Most people enjoy an icy drink without thinking about the physics of the phase-change reaction inside the glass. But phase-change materials can absorb heat and melts—is powerful. It's something NASA has harnessed for two extreme environments, and now a NASA-invented phase-change coating could keep the chill in pipelines—or be the key to an ice-free cooler.

In the early 2000s, Marshall Space Flight Center materials scientist Raj Kapur developed a phase-change coating for a rocket that's prized for its lightness and ability to withstand the Space Shuttle's solid rocket boosters. Previously, NASA had used a material called MCC-1 (for Marshall Convergent Coating), which was "heavy, a mixture of cork and epoxy," Kapur says. "The cork will burn, and that burning process releases the heat. Plus, it ablates—the layer of material that is supposed to burn gets eroded, and then you have to deal with those issues. Because the coating was designed to burn off, however, there remained a danger that the process would cause damage. Kapur's new phase-change coating was meant to prevent heat damage from the jet engines. He has also seen interest from a company that makes heat traps for Veterans Affairs hospitals.

The Shuttle solid rocket boosters were protected from the excessive heat generated at launch by a coating developed in but-off. In the early 2000s, Marshall Space Flight Center materials scientist Raj Kapur began developing a suspending phase-change materials in a paint that plastic that could absorb the heat without burning off, offering more reliable protection.

After licensing the patent for the phase-change coating from Marshall, entrepreneur Chris Bolen founded a company, PhaseMax, and is working on a number of products, including an ice-free cooler.



MAP KEY

NASA HQ — NASA Headquarters
ARC — Ames Research Center
AFRC — Armstrong Flight Research Center
GRC — Glenn Research Center
GSFC — Goddard Space Flight Center
JPL — Jet Propulsion Laboratory
JSC — Johnson Space Center
KSC — Kennedy Space Center
LaRC — Langley Research Center
MSFC — Marshall Space Flight Center
SSC — Stennis Space Center

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NASA Headquarters

National Aeronautics and Space Administration

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

Field Centers

Ames Research Center
Technology Transfer Office Chief:
Tony Strawa
Phone: (650) 604-3437
Email: anthony.w.strawa@nasa.gov
Moffett Field, California 94035

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

Glenn Research Center
Technology Transfer Office Chief:
Harvey Schabes
Phone: (216) 433-8047
Email: harvey.l.schabes@nasa.gov
21000 Brookpark Road
Cleveland, Ohio 44135

Goddard Space Flight Center
Technology Transfer Office Chief:
Nona Cheeks
Phone: (301) 286-5810
Email: nona.k.cheeks@nasa.gov
8800 Greenbelt Road
Greenbelt, Maryland 20771

Jet Propulsion Laboratory
Technology Transfer Office Chief:
Debora Wolfenbarger
Phone: (818) 354-3829
Email: debora.l.wolfenbarger@jpl.nasa.gov
4800 Oak Grove Drive
Pasadena, California 91109

Johnson Space Center
Technology Transfer Office Chief:
Charlene Gilbert
Phone: (281) 483-0474
Email: charlene.e.gilbert@nasa.gov
2101 E. NASA Parkway
Houston, Texas 77058

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

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

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

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

Spinoff Program Office
Email: spinoff@nasa.gov

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

Mike DiCicco, Senior Science Writer
Naomi Seck, Senior Science Writer and Social Media Manager
John Jones, Senior Graphics Designer
Goddard Space Flight Center, Building 35
8800 Greenbelt Road
Greenbelt, Maryland 20771