On the cover

This artist’s concept shows the Mars Helicopter, a small, autonomous rotorcraft, traveling with NASA’s Perseverance rover, which launched in July 2020. The helicopter will demonstrate the viability and potential of heavier-than-air vehicles on the Red Planet.
Before the latest Mars rover even touches down, several of the technologies developed for it have already been commercialized, including an extremely sensitive spectrometer, improved circuit board manufacturing, and a specialized drill bit for geologists. Custom software automated data collection from the space station, distributing it across NASA. Under exclusive license, that same program is now organizing and disseminating patient data for healthcare systems. The space agency makes its own data freely available and provides additional tailored tools to help humanitarian and environmental efforts. NASA created technology that absorbs toxins from sediment and groundwater. A company licensed it and now sells a system that is both cheaper and more effective than traditional cleanups. Many water-purification technologies have spun off from space missions. NASA co-created the first open source cloud infrastructure, OpenStack, which companies like Red Hat have commercialized and built upon with other open source tools like the OpenShift platform. Open source cloud computing subsequently exploded across industries. As the pandemic gripped the world in early 2020, NASA engineers, technology transfer offices, and commercial partners redirected their attention from space missions to the crisis at hand. They found that rocket engineers can make pretty good medical engineers.
Introduction

Welcome to the new edition of Spinoff! If you’ve picked up any of our other books in recent years, you’ll notice that this one has a whole new look, one of a host of changes designed to improve how we deliver our content to you.

However, the important things remain the same. As ever, we are focused on telling you the wide range of ways your investment in the nation’s space agency is paying off for everyone here on the ground, in the form of technological advances and commercial products that safeguard our environment, grow the economy, and even save lives.

So what’s new? We’ve still documenting dozens of spinoff success stories from across the United States, but we’ve curated 19 of those stories in a quick, easy-to-read section we’re calling Spinoff Capsules. This year, you can learn about aircraft whose aerodynamics were improved thanks to NASA’s most-awarded software, a program to help astronauts visualize repairs that now assists workers on the ground, and NASA expertise that helped improve home tankless water heaters.

We’re also going in-depth on some features, introducing the NASA inventor whose lunchtime brainstorm (it involved her drinking straw) led to a product that could finally clean up decades-old pollution and the engineers who copied the biological mechanism geckos use to climb walls to create a gripper for both zero gravity and the factory floor.

Within this section of the book, you will also notice some stories on larger themes. This is a brand-new way to think about our long track record of spinoff successes. With these features, we step away from individual companies and products to look at the broader trends. For example:

• How a single NASA mission, like the Perseverance rover, can lead to benefits across industries and environments, for manufacturing circuit boards, sampling minerals, and even diagnosing infections. (page 24)

• How NASA’s support for small businesses has paid off not just in improved space technology but in safer hip replacements, more efficient supercomputer coolers, and even better water bottles. (page 46) and

• How protocols first developed to safeguard the food we were sending to the Moon are now mandated across the food industry here and around the world, drastically reducing the incidence of food-borne illness. (page 58)

In addition to these commercial success stories, this issue of Spinoff also delves into NASA’s response to the coronavirus pandemic and the work our Technology Transfer team did to ensure the innovations our inventors were racing to create or help improve, including new ventilators and sterilizers, got into the hands of businesses and the public for the biggest impact. (page 59)

We also feature 20 NASA technologies that the Technology Transfer Program has identified as promising future spinoffs, as well as information on how to license them or partner with us to further develop them for commercialization (page 70).

One last change to highlight: we now publish new Spinoff features year-round on our redesigned site, spinoff.nasa.gov. Once you’ve had a chance to read this year’s book, we hope you’ll visit us there, where you can see our latest stories and browse thousands more in our archives.

Transferring NASA technology beyond the space agency is part of our mandate and our longest-standing mission. Spinoff may look a little different, but the message is not: we’re always working to ensure our innovations find the widest benefit, from space to you.
Over the past six-plus decades, NASA has continually expanded the frontiers of human knowledge, helping us uncover many of the mysteries of the universe. But the work has never stopped there. Here’s a quick glance at a variety of examples of technology we built or funded that have been adapted to benefit all of us.

Support teams arrive at the SpaceX Crew Dragon Endeavour spacecraft shortly after it landed with NASA astronauts Robert Behnken and Douglas Hurley onboard in the Gulf of Mexico off the coast of Pensacola, Florida, Sunday, Aug. 2, 2020. The Demo-2 test flight for NASA’s Commercial Crew Program was the first crewed flight of the SpaceX Falcon 9 rocket and Crew Dragon spacecraft from the Kennedy Space Center Pad 39A. Behnken and Hurley spent 64 days aboard the International Space Station and return them safely to Earth onboard a recently built and Spacecraft Crew SpaceX capsule. Credit: NASA/Bill Ingalls
TetrUSS Stacks Up Building Blocks for Aircraft Design

NASA's most popular and most-awarded software simulates aerodynamics for aircraft development and much more.

Anyone who excelled at the Game Boy's top-selling video game will recall the animated rocket (tetro! ) blocks that celebrated high scores. In addition to simulated remnants and the name, NASA's TetrUSS code has one other commonality with Tetris: unrivaled popularity. The program is NASA's most-downloaded software, simulating aerodynamics for aircraft development and much more. Developed over a couple of Small Business Innovation Research contracts from Langley, it's a software suite comprising a flow solver known as USM3D, along with two other codes, GridTool and VGRID, which enable the creation of grids over a model's surface and a lattice of tetrahedrons to represent the air around it.

Unlike other options available in the 1990s, TetrUSS was fast. The program won NASA's Software of the Year award in 1996. But industry was hesitant at first to trust in CFD. A NASA contract with McDonnell Douglas exploring advanced subsonic airplane designs – and validating them through CFD – helped change that. Rick Hooker, who led the project at McDonnell Douglas, still uses TetrUSS extensively at Helden Aerospace, the company he founded in 2010, based in Acworth, Georgia. Hooker was part of a team that created a toolbox of subsonic airplane designs, and in 1998, the US Air Force recognized this work with a 3D printer aboard the International Space Station in 2014. NASA has been working on 3D printing technology for years. With that interest in mind, NASA's Marshall Space Flight Center in Huntsville, Alabama, awarded Glenn's Huntsville-based company about $1 million in Phase I and II Small Business Technology Transfer contracts to continue developing its printer. Electronic Alchemy also received a Small Business Innovation Research contract.

Electronic Alchemy is continuing to develop new materials for the printer. Glenn says, "The first eForge devices became available for presale in October 2019 through the eForge semiconducting materials can be used in switches, communication equipment, and solar cells, or combined to create diodes and transitions for integrated circuits, computers, amplifiers, and more. Electronic Alchemy is continuing to develop new materials for the printer. Glenn says, "You can design something, print it, test it, make it work, and if it doesn't, you can redesign and reprint it, all within minutes," he said.

Nasa Research Helps Make Electronics on Demand

The agency's interest in printing components in space results in a commercially available 3D printer for electronic devices and parts. Chance Glenn traces the inspiration for his 3D electronics printer to Star Trek, a TV show with a "replicator" that could produce food, ship parts, and anything else on demand. With that as his starting point, he developed what eventually became the Electronic Alchemy eForge, a 3D printer that enables anyone to create custom electronic designs on demand. The machine can print sensors, lights, and other electronic components into shapes or onto fabrics or other materials. NASA has been working on 3D printing technology for years. Being able to print parts or devices in space as needed could help reduce launch mass for long missions by enabling run-down parts to be recycled and replaced. 3D printing could also help crews respond to unexpected situations when there isn't time to return to Earth or wait for a supply ship. Electronic Alchemy has been building 3D printing in space for years because of its potential to make spaceflight safer and reduce mission risk. It's not as easy as it looks. Glenn has made three versions of the eForge printer that includes a filament that lights up with an electric current and a piezoelectric material that generates an electric charge in response to mechanical stress. Users will design components within the eForge software or upload files created in other programs. The first of these devices became available for presale in October 2019 through a Kickstarter campaign. The printers were expected to ship in late 2020. Glenn hopes the machine will appeal to makers at universities and schools, as well as in research and development settings. "You can design something, print it, test it, make it work, and if it doesn't, you can redesign and reprint it, all within minutes," he said.

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As companies and other entities continue making use of NASA know-how, spinoffs from the space agency are bound to bump into each other now and then. That’s what happened as the Blessing Search and Rescue Satellite Aided Tracking (SART) system underwent a major expansion over the last several years.

The U.S. SARSAT system and its global counterpart, COSPAS-SARSAT, detect and locate distress signals from emergency beacons and have enabled the rescue of more than 46,000 people worldwide. In the United States, more than 10,000 people have been saved since the first satellite transponders and ground stations went into effect in 1990.

NASA led the system’s creation and remains the research and development lead, and the National Oceanic and Atmospheric Administration (NOAA) manages the ground stations in the United States (Spinf-2017).

Historically, SARSAT transponders have piggybacked on both low-Earth orbiting satellites and much more distant geostationary satellites. The first can calculate a beacon’s location, while the second can triangulate it. The system had to make difficult decisions about which satellites to track at any given moment. To solve the problem, NOAA turned to Greenbelt, Maryland-based Orbit Logic Inc., which specializes in software for scheduling and mission planning.

The company’s founders built their expertise in the field at NASA: Alex and Ella Herz, Orbit Logic Vice President Doug George, and Alex’s former Johnson Space Center colleague. At NASA, Alex worked with Ella to build the scheduling software for the Vegetation Canopy Lidar satellite at Goddard (a project that was ultimately canceled).

When the three founded Orbit Logic in 2000, they set out to create a planning and scheduling tool flexible enough to be applied to any space, or even non-space, mission.

The first client was NOAA, which had experience with NASA mission planning, but its schedule of research and development projects required precise, real-time guidance to maximize use of the limited number of antennas to generate a planning schedule that ensures the highest accuracy for locating distress signals.

The company’s founders built their expertise in the field at NASA: Alex and Ella Herz, the company’s president and chief operating officer, respectively, worked on payload engineering and operations as contractors at Johnson Space Center in the late 1980s and early ’90s, when scheduling was a major challenge for space shuttle payloads.

The third founder, Orbit Logic Vice President Doug George, later worked with Alex to build the scheduling software for the Vegetation Canopy Lidar satellite at Goddard (a project that was ultimately canceled).

 loan STK Scheduler software, based part on the company founders’ long experiences with NASA mission planning, has a desktop number of SARSAT antennas, which means medium-Earth orbit satellites have to make any given time to maximum accuracy for locating distress signals.

Answering the Call of Distress

NASA-funded sensors test 5G cellular systems

It’s very important that the highly tuned components in sensitive instruments, whether on a spacecraft or used in a lab, don’t see their own reflection. In sensing devices across the electromagnetic spectrum in all spatial scales, structural elements called waveguides are used to direct signals between components, but their design can cause reflections. If the reflection is interesting, they produce standing waves which can severely degrade system performance. Devices called Faraday rotation isolators are used in all kinds of equipment to suppress these standing waves. The Faraday effect, discovered in 1845 by Michael Faraday, states that magnets in a ferrite material can change the polarization of an electromagnetic signal. Isolators use this principle to rotate reflected signals into a resistive layer that absorbs them.

In 2017, researchers at Oregon State University had a research airborne satellite and antennas, such as spectrometers, which measure wavelengths of a few millimeters or meters.

NASA’s Jet Propulsion Laboratory in Southern California needed isolators that worked with these wavelengths to conduct spectrometer experiments. However, existing isolators maxed out slightly above 100 gigahertz — about a three-millimeter wavelength — and caused a high level of signal loss.

Under a Small Business Innovation Research (SBIR) contract with JPL, the team at Micro Harmonics in Fincastle, Virginia, developed a hand-built Faraday rotation isolator that worked at much higher frequencies and at higher power levels. They realized the solution was in the materials. Typically isolators use a long, magnetized ferrite core, which is responsible for most of the signal loss. Micro Harmonics shortened this core to its minimum possible length and tuned the magnetic field significantly reducing the signal loss. The company also replaced the thermally insulating support washers used to suspend the sensor in the waveguide with a diamond disc, which heats away from the resistive layer. They were able to get the low-loss isolator to work at 100 gigahertz, and subsequent developments achieved frequencies in excess of 330 gigahertz.

Micro Harmonics is seeing interest from universities and laboratories around the world. Because new high-speed cell phone bandwidths are in the millimeter range, it is important to test how these frequencies behave in several environments. Corporate telecommunications labs testing 5G networks need analyzer equipment outfitted with isolators to make sure the new systems function properly. Micro Harmonics has already sold their technology to analyzer manufacturers like Keysight.

Micro Harmonics is now on its fourth SBIR contract with NASA, this time working with researchers at Goddard Space Flight Center in Greenbelt, Maryland. While the company’s current research can handle the high, latest research contract is focused on isolators that work in extremely cold temperatures dealing with electronic component cooling in space, and the company is hopeful that these will have a place in the market as well.

Devices for high-speed cellular telecommunication must have spatially isolated sections to work properly. Several manufacturers of this equipment have contracted with Micro Harmonics for their isolators for 5G testing. Credit: Richard Cisneros via Daily Science
Debugging Code Is Rocket Science

Incorrect computer code can blow up rockets, an NASA learned from the first launch in the European Space Agency’s Ariane 5 rocket series. The SOI rocket used computer code written for the Ariane 4 series – but the change to the rocket resulted in an anomaly responsible for an explosion 37 seconds after launch. Finding and fixing coding errors, or bugs, required a new approach.

The airline industry, equally concerned about safety, needed a similar tool.

Software errors are even found during deployment, a major concern, explained Guillaume Braut of NASA’s Ames Research Center in Silicon Valley, California. Industry told NASA to help with software verification, and IKOS is one of the tools the space agency developed.

The Inference Kernel for Open Static (IKOS) Analyzer can evaluate any program written in C or C++ computer language, without running the program it’s analyzing. It looks for mistakes inadvertently introduced by programmers, similarly to how a grammar-check program might find errors in an essay.

The program will occasionally identify some coding as having an anomaly when it doesn’t. Fortunately, IKOS has a low rate of those mistakes. Error-free code is marked green. Problems are noted in red. And yellow indicates a potential problem that requires a programmer’s review. Less than 5% of the code is mistakenly marked as needing correction, compared to 20 to 50% for other automated analyzers.

The automated review ultimately saves thousands of staff hours and related expenses. The cost of catching coding errors for business as well as rockets A simple NASA static program analyzer finds the cost of catching coding errors for business as well as rockets

IKOS was “optimized for the type of software found in civilian aircraft, ranging from small drones to transport systems for industrial machines. In addition to using the software to automatically find bugs before they can be hooked to any number of reactants or reagents, they combine in the stack to produce energy and water. More than half of them, however, may not react in the stack and need to be pulled back into the system. Reactants that passively combined unused hydrogen and oxygen that had already passed through the cell with new hydrogen and oxygen coming in from tanks, using something called the Venturi effect (see diagram at lower left).

Space Fuel Cell Provides Deep-Sea Power

The Subsea Supercharger fuel cell can be biologically used to raise and lower hydrogen and oxygen tanks to run for as long as necessary. The team called it an ejector-driven reactant circulation system.

Removing the mechanical pump eliminated a common point of failure and a drain on the cell’s energy, making it more efficient and reliable. The nozzle also took up less space. The team called it an ejector-driven reactant circulation system.

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Rugged, reliable fuel cells provide power for offshore drilling

“Almost everything you need in space, you also need under the ocean,” said Thomas Valdez, manager of chemical engineering at Teledyne Energy Systems in Hunt Valley, Maryland.

Both environments are cold and corrosive, and more importantly, both are difficult to access when repairs, replacements, or refueling are needed. This means they require systems that are rugged, reliable, long-lasting, and affordable.

So after Teledyne Energy Systems worked on fuel cells with NASA, the company is taking the resulting cells first to the offshore oil-drilling industry.

In the late 2000s, a team at NASA’s Johnson Space Center in Houston was working on a fuel cell for the space shuttle when one engineer came up with an idea to replace the mechanical pump that usually maintains circulation of reactants in a cell with a simple, non-moving part. Where the pump would normally go, Johnson engineer Arturo Vasquez installed an ejector nozzle that passively combined unused hydrogen and oxygen that had already passed through the cell with new hydrogen and oxygen coming in from tanks, using something called the Venturi effect (see diagram at lower left).

Removing the mechanical pump eliminated a common point of failure and a drain on the cell’s energy, making it more efficient and reliable. The nozzle also took up less space. The team called it an ejector-driven reactant circulation system.

They demonstrated their invention using a fuel cell from Teledyne Energy Systems, drawing the company’s attention, and under a 2012 Space Act Agreement, Teledyne paid NASA to help design, build, and test a fuel cell with the new technology.

In 2016, the company released its first commercial fuel cell featuring NASA’s innovation – the Subsea Supercharger.

So far, the technology has received the most interest from well operators, who can use it as a backup to the power lines typically run from the ocean surface. If a well has to shut down due to damaged power lines, the operator can lose weeks or months’ worth of revenue. A Subsea Supercharger, which can use it as a backup to the power lines typically run from the ocean surface. If a well has to shut down due to damaged power lines, the operator can lose weeks or months’ worth of revenue. A Subsea Supercharger, which

In 2018, the company released its first commercial fuel cell featuring NASA’s innovation – the Subsea Supercharger.

Meanwhile, companies that serve well operators often rely on underwater remotely operated vehicles to inspect and service wells. These run on battery packs that need frequent recharging, especially in cold water. A Subsea Supercharger, which works underwater, can serve as a charging station for underwater vehicles, providing months’ worth of power.

The military is also a customer for changing underwater vehicles, and the Federal Aviation Administration has purchased a fuel cell based on the ejector-driven reactant technology for hybrid-electric aircraft research.
A rugged drone designed for NASA supports research and commercial enterprise from the air.

Tornadoes can flip a car when the wind speed reaches 130 mph, making them unpredictable, dangerous. Volcanic eruptions are as toxic as they are destructive. Researchers are working hard to improve forecasting techniques and earlier warning systems for these and other extreme events, but they need more data. Collecting that data, though, is no simple task.

Measurements taken from the air at different altitudes add an important perspective. A remotely piloted vehicle equipped with the relevant sensors can dramatically reduce risks for researchers, costs less than chartering a helicopter or plane, and is more eco-friendly than a large aircraft. But a drone must be rugged to perform effectively under such extreme conditions. Thanks to partnerships between NASA and a company in Boulder, Colorado, called Black Swift Technologies, such a drone exists: a fixed-wing aircraft called the S2. Now that same drone provides researchers and commercial enterprises, including farmers, surveyors, and the oil and gas industry, with a cutting-edge alternative for gathering reliable aerial data.

The most important result of the company’s work with NASA is a fully integrated set of miniaturized instrumentation that delivers usable data under extreme conditions, said Geoff Bland, at NASA’s Wallops Flight Facility in Wallops Island, Virginia, who supported multiple Small Business Innovation Research (SBIR) projects with Black Swift to develop the technology, beginning in 2012.

As part of the SBIR work with Goddard and other agency field centers, the company said Geoff Bland, at NASA’s Wallops Flight Facility in Wallops Island, Virginia, who supported multiple Small Business Innovation Research (SBIR) projects with Black Swift to develop the technology, beginning in 2012.

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The S2 is a remotely piloted vehicle that uses a modular design for easy sensor replacement in the field. Designed to meet NASA atmospheric measurement needs, the drone, made by Black Swift Technologies, is now used by universities for research and by industry for industrial and more. Credit: Black Swift Technologies Inc.

The S2 is a remotely piloted vehicle that uses a modular design for easy sensor replacement in the field. Designed to meet NASA atmospheric measurement needs, the drone, made by Black Swift Technologies, is now used by universities for research and by industry for industrial and more. Credit: Black Swift Technologies Inc.

Research done for NASA is now helping airports and businesses around the world track airplanes.

Think of the national airspace as a complex highway system, but with planes. They’re all moving at different speeds and converging on relatively few airports, intent upon arriving safely and on time. Like the highway patrol, the Federal Aviation Administration (FAA) oversees the busy thoroughfares overhead.

Keeping different zones of air and ground activity safe and efficient requires multiple groups. Each one uses a unique software program to support their specific responsibilities.

Over the course of 10 years and multiple NASA Small Business Innovation Research contracts, most of them through Ames Research Center in Silicon Valley, California, Matron Aviation Inc. has used the software for commercial flight providers as a companion tool to automate the communications they use to share schedule details with the FAA.

The Herndon, Virginia-based company, a subsidiary of Airius, has now adapted the software for commercial flight providers as a companion tool to automate the communications they use to share schedule details with the FAA.

Matron’s Harmony, a commercial software package, also shares flight data with any airport authority. Proprietary algorithms track flights, predict weather impacts, and propose alternative flight paths. Additional tools keep users up to date with air traffic around the world.

The software’s weather translation tool is a “big leap” in air traffic management, according to Bob Hoffman, vice president of research and engineering for Matron. It calculates where and how weather will impact the air traffic system. With that information, Harmony can quickly calculate fuel savings for a new route, the cost of time spent waiting on the ground, and other factors related to rerouting and ground delays.

The scaled-down version of the software, Harmony-Horizon, is used by businesses wishing to keep track of flights and air traffic agencies in other countries. This web-based program provides current air traffic management information that helps the communications relying on air deliveries stay current with the ever-changing conditions in the airspace. Horizon includes the weather-monitoring features and other services, but it’s not capable of sharing information with the FAA.

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Odor-Eliminating Shoe Inserts Rely on NASA-Tested Cloth

Zorpads patches use a material that NASA has considered for spacecraft filters.

This is the story of a space-age shoe insert that got its start when a graduate student with smelly feet took off her shoes and another tapped into his aerospace experience to solve the problem.

The result was Zorpads, shoe inserts that use an extremely porous activated carbon cloth to absorb odor. The inserts also work in gym bags, and other foul-smelling places, the company says.

Activated carbons are used in all crewed spacecraft to condition atmosphere for breathing and for odor control, for example, in filters, according to Jay Perry, who works on filtration technologies at NASA’s Marshall Space Flight Center in Huntsville, Alabama.

“There is a rich and long history of using activated carbons for applications going back to Project Mercury,” Perry said, referring to NASA’s first human spaceflight program in the late 1950s and early ’60s.

In most of its applications, NASA uses granular activated carbons but in 2015 the agency ran some tests to see if multiple layers of carbon cloth, including the one that Zorpads uses, could filter more effectively. For that particular application, the granular activated carbon cloth was found to absorb odor. The inserts also work in gym bags, trash cans, and other foul-smelling places, the company says.

“Later when I started to develop the shoe insert, I realized this was the perfect material,” Wiegele said.

“For that particular application, the granular activated carbon cloth was found to absorb odor. The inserts also work in gym bags, trash cans, and other foul-smelling places, the company says.

“Later when I started to develop the shoe insert, I realized this was the perfect material,” Wiegele said.

“I came across a number of really interesting materials, and this one kept staying in my mind,” Wiegele said.

“Later when I started to develop the shoe insert, I realized this was the perfect material for that application,” he said. “NASA had done a lot of testing on it, and those results helped us identify it as the right material from the outset.”

To the business school study group’s surprise, the project won accolades. Wiegele and one of the classmates, Sienna Smith, incorporated the company in New York in 2016 and went on to win a $100,000 investment on Shark Tank, the business reality TV show where entrepreneurs pitch their ideas to investors.

With the help of a material that NASA has also explored for purifying cabin atmosphere in space, Zorpads aims to improve on the odor-eliminating inserts that are already available on the market.

Zorpads have a small “footprint” thanks to the extreme absorption capacity of the activated carbon cloth they are made from, making them suitable for a variety of shoe types.

Zorpads patches use a material that NASA has considered for spacecraft filters. Credit: Zorpads

When astronauts on the International Space Station use Zorpads, for example, the inserts are added after all the beams are in place. A truck-engine manufacturer uses the same software to ensure all the varied configurations are assembled correctly.

Any procedure that can be written down can be presented with ProG. The system uses sophisticated algorithms to recognize errors, determine how to correct them, and direct the remediation.

This visual display can superimpose text, animation, or both over the equipment for each step. All the while, a visual representation of the equipment and condition of the work. At the end of the task, the imagery can be sent back to the office as part of a service report.

This mixed-reality system can also be used for hands-on training. The construction industry uses ProG in the Trimble XR10 hard hat, which has a HoloLens 2 attached. Workers can view various stages of the building process, such as superimposing ductwork that will be added after all the beams are in place. A tract-engine manufacturer uses the same software to ensure all the varied configurations are assembled correctly.

A program to help astronauts visualize repairs assists workers on the ground.
Their experiments began in 2007, but, unsurprisingly, initial tests showed that they couldn’t grab just any off-the-shelf microphone and expect it to work with infrasound. The long wave frequencies tend to get damped out by higher-frequency sounds, which results in interference. Shams and Zuckeierman began developing a sensor that could listen to these low frequencies in high fidelity. When these new microphones were played into a loudspeaker of triangular pattern, they were able to pick up and locate atmospheric turbulence more than 300 miles away.

By 2017, the technology received several accolades, but it hadn’t flown aboard any aircraft. Interest from Stratodynamics Inc. of Lewes, Delaware, changed that. After the company won first prize in the unmanned aerial vehicle (UAV) competition at the 2016 Space Race Challenge co-presented by NASA, the team was invited to visit Langley, where they met Shams.

Stratodynamics realized that the microphone system had significant potential as an in-flight turbulence detection sensor and looked for opportunities to test the technology. After licensing the patents from NASA, the company began to implement the sensor on an unmanned stratospheric glider known as the HiDRON, designed by its Canadian affiliate, Stratodynamics Aviation Inc.

The HiDRON glider carries acoustic instruments to the upper reaches of the atmosphere and listens to turbulence and piping sounds using microphones. By using a NASA-designed infrasonic sensor to find and avoid turbulence, the glider can stay in the air longer. Credit: StratodynamiCS

With the assistance of the infrasonic microphone, the HiDRON can measure the intensity of turbulence in its path at a distance, and possibly detect thermal columns to keep the plane sailing longer. In 2020, the company’s testing saw the microphone perform as expected. Even with rushing wind whipping past the UAV, the sensor could detect and characterize the low frequencies. Pending additional flight tests, the infrasonic microphone will become a part of the standard atmospheric sensor package flown on the glider, and the team hopes the data provided will become ubiquitous in detecting and forecasting turbulence.

NASA Spinoff 2021

NASA detects unseen air turbulence

Everything in the atmosphere can make a sound, but there’s more to that sound than what our ears perceive. Much like how infrared light consists of frequencies that aren’t visible to the naked eye, there’s an audio analogue called infrasound. Infrasound consists of pitches too low to be heard by the human ear, between 20 Hz and 20 hertz. Turbulence can cause air travel not only uncomfortable, but possibly dangerous. Thought it’s easily detected visually, clear-air turbulence has a definite infrasonic signature. Researchers Qamar Shams and Alan Zuckeierman at NASA’s Langley Research Center in Hampton, Virginia, realized that if air traffic controllers or pilots could listen in on these whirling vortices before airplanes encounter them, an alternate route could be plotted.

Their experiments began in 2007, but, unsurprisingly, initial tests showed that they couldn’t grab just any off-the-shelf microphone and expect it to work with infrasound. The long wave frequencies tend to get damped out by higher-frequency sounds, which results in interference. Shams and Zuckeierman began developing a sensor that could listen to these low frequencies in high fidelity. When these new microphones were played into a loudspeaker of triangular pattern, they were able to pick up and locate atmospheric turbulence more than 300 miles away.

By 2017, the technology received several accolades, but it hadn’t flown aboard any aircraft. Interest from Stratodynamics Inc. of Lewes, Delaware, changed that. After the company won first prize in the unmanned aerial vehicle (UAV) competition at the 2016 Space Race Challenge co-presented by NASA, the team was invited to visit Langley, where they met Shams.

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Typically launched by a weather balloon, the HiDRON has soared from over 100,000 feet in the air. Stratodynamics believes that with the infrasonic technology, it licensed from NASA, it can further improve performance. Credit: StratodynamiciCS

Two NASA technologies converge for more comfortable chairs

A new line of gaming chairs combines two NASA technologies to keep users comfortable during even the longest video game marathons.

Raynor Group, a major manufacturer of office furniture, has long incorporated Tempur-Pedic memory foam and Outlast cooling technology into office chairs, but the company is now extending the technology into other offerings.

Phase-change materials manage temperatures by absorbing, storing, and releasing heat as they change from solid to liquid and back. The technique for weaving microencapsulated phase-change materials into fabrics was developed in the late 1980s under Small Business Innovation Research funding from NASA’s Johnson Space Center in Houston, which was considering the temperature-regulating fabrics for spacesuits gloves. Seeking potential, Outlast Inc. quickly licensed the technique and has since sold its fabrics for a wide range of applications.

Memory foam was developed even earlier, in the late 1960s, part of an effort at Ames Research Center in Silicon Valley, California, to improve commercial plane crash survivability. Engineers developed an open-cell polyurethane foam and incorporated it into passenger plane seats. It was nonflammable and great at absorbing impact. Later NASA released the formula for what it called temper foam to the public. Two Scandinavian companies were among those who snatched it up, and they merged to form Tempur-Pedic, which brought its version of the foam to market after refining it over about a decade.

Raynor was introduced to Tempur-Pedic in 2009, and the two companies spent a year working out the right formulation for seat cushioning. Tempur-Pedic also introduced Raynor to Outlast, which it already used for temperature control in its mattresses. Raynor, located in West Hempstead, New York, now has an exclusive license to use Tempur-Pedic’s foam in chairs, and it incorporates Outlast fabrics into many of its office chairs. Raynor sells the chairs to furniture dealers, as well as the government via the General Services Administration. It also makes several lines exclusively for big box stores like Staples.

In summer of 2017, the teenager-son of a Staples’ merchant asked his father if it would be possible to make a gaming chair with the cooling technology he heard was in some of Staples’ office chairs. Raynor passed the question on to Raynor, which built a prototype within two weeks, said Marc Saban, director of gaming for Raynor Group. After launching a gaming line for Staples, the company started Raynor Gaming in summer of 2018.

Tempur-Pedic foam is used in the seats of several of Raynor’s gaming chairs, and all of them use Outlast cloth wherever the user’s body would stay in contact, sometimes in a double layer. Saban said, adding that he didn’t know of anyone else using Outlast in chairs.

The company is now an official partner of several professional sports gaming organizations, including the NBA 2K League, Digitalis, and the New York Excelsior Overwatch League team.

An electron micrograph shows how Outlast Technologies Incorporated microencapsulated phase-change materials into cloth, a technique that was pioneered for NASA in the 1980s.

For Work or Play, Comfort All Day
Tankless water heaters, which rapidly heat water as it passes through the unit instead of heating it in a tank, have existed since the 1950s. However, they couldn’t be used for an entire home because they drew too much power. David Seitz, CEO of Houston-based Seisco International LLC, wanted to make a better design. Seitz devised an electric tankless heater that could fully replace or work alongside a traditional water heater using digital controls to manage power draw – but he needed help to make it happen.

He turned to two former NASA contractors, who had built their expertise on spacecraft. The first, Thomas Harman, a contractor for Lockheed Corporation, helped install microelectronics in testing facilities at NASA’s Johnson Space Center in Houston that would put spacecraft through their paces. After leaving in the late 1970s, he became part of the National Electrical Code, helping to create standards for everything from laboratory testing to home design.

The second, Louis Everett, was also a microelectronics expert, who had also worked as a consultant for Johnson. Everett helped develop code to improve the space shuttle’s robotic arm. Everett took the knowledge he developed on this and other projects into consulting after he left Johnson. In the 1990s, Seitz brought on Everett as a consultant and approached Harman, asking how whole-home tankless water heaters could work within the bounds of the National Electrical Code. Harman would soon join the team as the company’s head of R&D.

The Seisco team soon patented a new design that used microelectronics to keep the water from heating to dangerous levels, with Harman designing the circuits and Everett handling the code. Everett says working with embedded electronics is much like designing hardware for space. It’s important to ensure that the technology can work in any environment for as long as possible.

The heater is now being used around the world. Harman says the original design for home use has since been expanded to heat water in apartments, offices, factories, and gas stations. Seisco is no longer making new heaters, but its technology helped open up the market. Several Seisco patents are expired and open to use, and multiple manufacturers now make whole-home electric tankless heaters.

The privately funded Bishop Airlock expands commercial access to the space station

Anyone who has gotten a sofa stuck in a doorway on moving day knows how frustrating it is when you can’t move something the other way in or out. In the same way, astronauts on the International Space Station, or ISS, have worked just fine for 20 years. But as more researchers and companies wish to expand the scope and size of the projects they send into low Earth orbit, a larger doorway could help.

Opening a second portal to receive more shipments and deploy more satellites and experiments is the challenge a private company took up – Nanoracks LLC, headquartered in Webster, Texas. With support from NASA, the company built a new and different kind of doorway into space.

The Nanoracks Bishop Airlock Module will serve as another door to space, helping to move larger payloads on and off the station. This alleviates one bottleneck slowing down the deployment of new small satellites and CubeSats from the space station. Bishop has also significantly increased the amount of research that can be done in low Earth orbit – research that helps us better understand the space environment but also has implications for Earth imaging, medical research, and biomanufacturing.

The new airlock is one of the first permanent commercial areas added to the space station and is attached to the port on U.S. Node 3, also called Tranquility. The arrangement is part of NASA’s strategy to offer more opportunities for U.S. industry on the space station with the goal of establishing a sustainable economy in low-Earth orbit, in which NASA will be one of many customers. This is allowing the space agency to prioritize deep-space exploration such as the upcoming Artemis Moon missions.

Bishop provides five times the capacity of the station’s only other operational airlock being used to send things outside the space station, which is provided by the Japanese space agency, JAXA. “That’s more volume than could be either brought inside or taken out,” said Mike Read, manager of the space station business and economic development office at NASA’s Johnson Space Center in Houston. Charged with supporting NASA’s public/private relationships on the station, Read described the agency’s allocation of the port to the new airlock as “a huge dedication of resources” that will serve public and private customers alike.

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Communicating via Long-Distance Lasers

A NASA partnership made lasers viable for satellite communications

Visible light has been used to communicate for centuries, but now there's a new way to use light to communicate even further distances and with more accuracy – lasers. The vision is an environment where lasers would replace radio waves. While there are no atmospheric or buildings to impede the beam's path, but before NASA could use this technology on deep-space missions, it had to be tested closer to home. In 2013, a demonstration on the Lunar Atmosphere and Dust Environment Explorer (LADEE) relayed video between ground stations on Earth and the orbiter. In testing, LADEE was able to transmit enough data to carry 30 HDTV channels. To further explore how this technology could work, NASA's Goddard Space Flight Center in Greenbelt, Maryland, partnered with the private sector. Denver, Colorado-based BridgeComm, formerly known as BridgeSat, was founded in 2015 to dive into the opportunities presented by using lasers to communicate in space. They sent their proposal in response to Goddard's call for partners and ultimately won the competition, signing a Space Act Agreement soon afterward.

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Over the course of this and subsequent agreements, BridgeComm engineers consulted frequently with their counterparts at NASA, facilitating their access to NASA's wide knowledge base. While working with Goddard, the company also made agreements with NASA Headquarters, NASA's Ames Research Center in Silicon Valley, California, and Glenn Research Center in Cleveland. With all these centers on board, the company applied NASA expertise to every part of its system.

Compared to the wide area a radio signal can cover, lasers from space can only be received across an area the size of a football field. To allow ground stations to reliably pick up the signals from space, BridgeComm and NASA teams brainstormed a way to ensure the beam remained trained on a spot on the planet below. By mounting the entire laser system on a gimbal and using fine steering mirrors, the engineers could ensure the beam didn't wander. And while lasers can travel a great distance, they need to be powerful enough to travel potentially interplanetary distances. BridgeComm and NASA's amplifiers are able to keep the beams bright, while still small enough to fit on a satellite.

When the time came to renew the agreement with Goddard in 2019, BridgeComm didn't need the center's assistance anymore, as the company had successfully built out its own systems. BridgeComm's primary customers are those that need the center's assistance anymore, as the company had successfully built out its own systems. BridgeComm's primary customers are those that need high-speed communications, but don't want to compete for bandwidth on the already-crowded radio channels, and the company is already contracted for two new satellite constellations.

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Modeling Airflows to Help Air Filters

NASA expertise improves air filtration technology

Whether trapping microscopic germns or an abundance of pet dander, air filters help homes and offices alike maintain a clean environment. With any technology, research and development can be a huge undertaking. But with a grant from NASA, a small business was able to turn its noisy air purifier into a quiet air-cleaning machine.

Health-Mor of Brooklyn, Ohio, got its start making vacuum cleaners in 1928, but in the early 1990s, it applied its vacuum cleaner know-how to build an air filter. Health-Mor put the Defender Air Purifier on the market in 1995, but there was room for improvement. The Defender was built into a chassis similar to the company’s FilterQueeen vacuum, and it showed one noticeable quality with its cousin: noise. One way to make the filter quieter and more efficient was to improve airflow. To make these improvements, they’d need to redesign the Defender from the ground up.

An Ohio regional industry group, the Manufacturing Advocacy and Growth Network (MAGNET) suggested Health-Mor apply for the Adopt-A-City program they were working on with the local government and NASA’s Glenn Research Center in Cleveland. From 2012 through 2016, MAGNET and local officials selected small businesses from around the Cleveland area in need of consulting, and Glenn would provide technical expertise to the firm for free.

Health-Mor was selected for the 2016 crop of Adopt-A-City finalists. Adam Wroblewski, who specialized in computational fluid dynamics (CFD) jumped at the opportunity to work on the project. NASA researchers use CFD simulations to model airflow around aircraft or spacecraft or fluid flows through engines. Wroblewski had just finished a project where he performed this work for jet nozzles, so he had a good idea where to start.

Wroblewski discovered that some slight modifications could bring Health-Mor’s air filter closer to the company’s design goals. Removing some restrictive bodywork bumped up airflow slightly, and the size of the blower fan improved it even more. Armed with that information, Health-Mor went back to the drawing board and fabricated a new fan system.

With the improvements, the filter moves 138 cubic feet of air per minute on just 65 watts of power. That’s the same as an industrial floor fan, and enough to readily keep a 300-square-foot room. The new fan design also moves air more quietly and efficiently than before, because it’s wider and doesn’t need to spin as fast to achieve a similar result. As of 2019, the Defender had made $2 million in sales after the NASA improvements.

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Recalibrating Fine Motor Skills

A touchscreen control panel similar to an Apple iPad seems like it would be easier to use than a panel of switches and buttons that must be flipped and pushed in the right order. But what if an astronaut’s hand-eye coordination is slightly off? Will she still be able to operate the touchscreen with accuracy?

Research conducted by NASA proved what astronauts learn first-hand—fine motor skills are impaired during the first week in space. The human body undergoes an adjustment to functioning without gravity. However, it adapts quickly, and the motor skills revert back to normal. Returning to Earth also interferes with the motor skills, impacting touchscreen performance for tasks that involve painting and tracing. Those problems can last up to a month, and it’s possible this disruption could also occur after landing on the surface of the Moon or Mars.

The Reston, Virginia company Leidos Holdings Inc. developed the Fine Motor Skills (FMS) test battery app for the Human Research Program at NASA’s Johnson Space Center in Houston, and it was used in research conducted on the International Space Station. Thanks to technical fellow Kritina “Tina” Holden, principal investigator, the agency has quantitative data that may help inform the design of equipment, procedures, training, and more to account for temporary impairment of motor skills. The FMS software is now available for testing fine motor skills on this planet.

Holden and her colleagues are talking with researchers and physicians about numerous ways the app could support ongoing research and patient health. Some likely uses include training and testing the fine motor skills of surgeons, physical therapy for stroke patients, and monitoring recovery after traumatic brain injury. Anyone can download the app from the Apple App Store and test their fine motor skills, but in the near future, it’s likely to be a tool for research studies.

Holden explained that the app can also be used to test skills under different environmental conditions. NASA is currently using it to study subjects’ reach and accuracy when touching targets under G-forces in a centrifuge. The military is interested in using the tool to test the effects of CO2 on performance. While there’s no current plan to make changes to the test battery, it’s possible an Android version will be available sometime in the future.

The Fine Motor Skills app is also available in the NASA Software Catalog.
The Rewards of Perseverance

Even before the Perseverance rover gets to Mars, the work that went into it is paying off on Earth

A laser-light sensor that can identify bacteria in a wound may sound far-fetched, but it’s already becoming a reality, thanks in part to NASA’s Mars Exploration Program. The technology is going to Mars for the first time on Perseverance, which launched in July 2020, but it’s already detecting trace contaminants in pharmaceutical manufacturing, wastewater treatment, and other important operations on Earth.

That’s not the only technology headed to Mars that’s already paying dividends on the ground. Here on Earth, these innovations are already finding applications on Earth. More important operations on Earth.

Giving Geologists a Break

Honeybee Robotics has been working on robotic missions to Mars and other planetary bodies since the 1990s, including a number of projects funded by Small Business Innovation Research (SBIR) contracts from NASA’s Jet Propulsion Laboratory in Southern California. One of the key contributions to come from that work has been a sample collection technology, including a drill bit for extracting rock cores. Half a dozen coring tools that come from research that started more than 20 years ago launched into space for the first time, ready for use in the rover’s turret, or “hand,” at the end of its robotic arm.

On Earth, after drilling a core with a hollow bit, a geologist usually uses a screwdriver or other tool to break the sample off and pull it out. This can result in a fragmented or even contaminated sample. A robot required something different.

With SBIR funding from JPL, Honeybee Robotics developed coring drill bits that can break off and retain rock samples. The bits are flying for the first time on Perseverance and are available to geologists on Earth.

New York-based Honeybee came up with a breakthrough tool nested within a coring bit. After the core has been drilled, the breakoff tube rotates relative to the bit, shifting its central axis and snapping off the core. Unlike other breakoff methods, such as pinching the base of the core, the breakoff tube applies pressure along the length of the sample, reducing the risk of fragmentation.

Honeybee has supplied grinders, scoops, and other sampling systems that flew on previous Mars missions. This is the first time the company’s coring bit technology is going to Mars, because it’s the first time NASA has planned a future mission to bring samples of the Martian surface back to Earth. Perseverance will collect and package those samples.

“It’s the key part of the sample return mission,” said Keith Rosette, who managed the rover’s sampling and caching system for JPL. “You truly can’t collect a sample on Mars if you don’t have a drill bit that can retrieve it.”

While getting a sample return vehicle home from Mars will pose a host of challenges, it will let researchers do virtually unlimited testing with a wide array of instruments. Rosette said, “Rather than trying to bring all those instruments to Mars, it’s less challenging and even more valuable to bring samples back.”

Meanwhile, Honeybee has commercialized its patented breakoff bits in coring toolkits for geologists on Earth. The bits can be used with a standard drill, making the technology easy and affordable, said Kris Zacny, Honeybee vice president and director of exploration technology.

Honeybee has also been in talks with companies interested in using the bits for nuclear disaster remediation where it is too dangerous to send in human investigators, Zacny said, “If there are concrete tanks that are leaking, for example, then robots can go in and take samples to check radiation levels.”

This technology was invented by Honeybee’s late Chief Engineer Tom Myrick. “Tom would have been extremely proud that his invention made a difference to planetary missions,” said Zacny.

A specialized drill bit that will let Perseverance collect samples of the Martian surface for return to Earth has led to a drill bit that makes it easier for geologists to collect rock samples on our planet. Credit: Honeybee Robotics

Honeybee Robotics has now made available to geologists on Earth. Credit: Honeybee Robotics

Honeybee Robotics designed its Rotary Percussive Core drill to collect rock samples on Mars. The reason that flying on the Perseverance rover has key differences, but they share a novel technology for breaking off samples, which Honeybee has now made available to geologists on Earth. Credit: Honeybee Robotics

With an eye toward returning samples from Mars, Honeybee Robotics developed a bit that can break off and retain rock cores. Half a dozen coring bits developed from research that started more than 20 years ago launched into space for the first time, ready for use in the rover’s turret, or “hand,” at the end of its robotic arm.

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Spinoffs from Mars!

NASA has been exploring Mars since the 1960s, pushing the frontier of innovation to get to the red planet and discover its secrets. This new technology was often found on other places here on Earth as well. A few highlights:

**Guiding Cars with Tech for Mars**

Mounted navigators on Mars require “fuzzy” maps made up of detailed neural networks and deep learning algorithms. But the maps can manage another planet, getting the same feel in cars, drones, and toys here on Earth as a re-trainer.

**Decoding Wind Power**

Solar power is great until a Martian dust storm blackens it out. But there’s another option for these blustery days: wind power. Wind turbines with low-maintenance wind turbines that can function in dark or flake-covered conditions – all Mars or on Earth.

**Paving the Way for Hospital Robots**

Mars rovers navigate alien terrain where they gather microbes. But tools to sniff out tiny traces of life’s presence are needed to usher patients to appointments.

**Carving Out Drilling**

Bringing home a Martian sample requires a perfectly sealed container to prevent contamination. A soft, flexible container that can keep Mars samples safe from interfering with the seal and is great for heart surgery sutures and stents.

**Detecting Methane Leaks**

How to fuel a trip home from Mars? A system to break apart gases like carbon dioxide into compounds that could fill the tanks. A similar system made in methane-releasing oil wells turns the greenhouse gas into energy.

**Generating Solar Power**

A human mission to Mars will require extensive use of resources. A fuel cell that uses solar power to break water into oxygen and hydrogen for fuel is ideal. Technology based on that system now creates more energy on Earth.

**Carbontech Bass**

Technology created for a fuel journey from Mars now helps recycle methane from oil drilling sites and another use is in Earth-capturing carbon dioxide emitted by farming, hopes and using it to just the bubbles in beer.

**Suturing with Mars-Grade Materials**

Mars need medical care, too – and one company here on Earth had the skills to handle the challenges. Today that system and other advances for Mars exploration help robots navigate complexities on Mars to help team members.

**Ambulating Rugged Robots**

In the 1990s, NASA came up with a way to combine stereo cameras and a 3D image maker to help a rover/land on to. Today that system is part of the company’s standard procedure. A tool unique to Tempo is what it calls fabrication simulation software that translates a computer-generated design model into a photographic representation of what the final board will look like. What looks like a photo of a printed circuit board is actually a computer-generated design model. The company offers to that end is the process for rapid, automated production of printed circuit boards, even in small batches. One set of tools the company discovered that it was useful in house as well. The manufacturing process can result in discrepancies between the original CAD model and the final product, Samala explained. The simulation—not a source of truth on the factory floor—to communicate the designer’s intent. The first thing we look at is the simulation.

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Mounted navigators on Mars require “fuzzy” maps made up of detailed neural networks and deep learning algorithms. But the maps can manage another planet, getting the same feel in cars, drones, and toys here on Earth as a re-trainer.

**Decoding Wind Power**

Solar power is great until a Martian dust storm blackens it out. But there’s another option for these blustery days: wind power. Wind turbines with low-maintenance wind turbines that can function in dark or flake-covered conditions – all Mars or on Earth.

**Paving the Way for Hospital Robots**

Mars rovers navigate alien terrain where they gather microbes. But tools to sniff out tiny traces of life’s presence are needed to usher patients to appointments.

**Carving Out Drilling**

Bringing home a Martian sample requires a perfectly sealed container to prevent contamination. A soft, flexible container that can keep Mars samples safe from interfering with the seal and is great for heart surgery sutures and stents.

**Detecting Methane Leaks**

How to fuel a trip home from Mars? A system to break apart gases like carbon dioxide into its components that could fill the tanks. A similar system used in methane-releasing oil wells turns the greenhouse gas into energy.

**Generating Solar Power**

A human mission to Mars will require extensive use of resources. A fuel cell that uses solar power to break water into oxygen and hydrogen for fuel is ideal. Technology based on that system now creates more energy on Earth.

**Carbontech Bass**

Technology created for a fuel journey from Mars now helps recycle methane from oil drilling sites and another use is in Earth-capturing carbon dioxide emitted by farming, hopes and using it to just the bubbles in beer.

**Suturing with Mars-Grade Materials**

Mars need medical care, too – and one company here on Earth had the skills to handle the challenges. Today that system and other advances for Mars exploration help robots navigate complexities on Mars to help team members.

**Ambulating Rugged Robots**

In the 1990s, NASA came up with a way to combine stereo cameras and a 3D image maker to help a rover/land on to. Today that system is part of the company’s standard procedure. A tool unique to Tempo is what it calls fabrication simulation software that translates a computer-generated design model into a photographic representation of what the final board will look like. What looks like a photo of a printed circuit board is actually a computer-generated design model. The company offers to that end is the process for rapid, automated production of printed circuit boards, even in small batches. One set of tools the company discovered that it was useful in house as well. The manufacturing process can result in discrepancies between the original CAD model and the final product, Samala explained. The simulation—not a source of truth on the factory floor—to communicate the designer’s intent. The first thing we look at is the simulation.

**Carving Out Drilling**

Bringing home a Martian sample requires a perfectly sealed container to prevent contamination. A soft, flexible container that can keep Mars samples safe from interfering with the seal and is great for heart surgery sutures and stents.
Another technology whose roots reach far back into NASA’s Mars Exploration Program is also flying for the first time on Perseverance and has many potential applications here on Earth.

When two longtime colleagues founded Photon Systems in 1997, research showed incredible promise for spectrometers — devices that use light to determine a sample’s composition — operating at deep-ultraviolet (UV) wavelengths. These had the potential to identify bacteria or detect even the slightest chemical traces. But sources for light in the 220- to 250-nanometer range were too large, heavy, and sensitive to environmental interference, and had many other issues.

William Hug and Ray Reid set out to develop a miniature, lightweight, rugged deep-UV laser source for spectroscopy in the lab. Their first outside investment came in 1998 from a pair of SBIR contracts, mostly with JPL, as well as funding from NASA programs aimed at developing instruments for planetary and astrobiology science.

Now the space agency will get the first big returns on its long investment in the technology. Perseverance is equipped with the Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC) instrument, which uses a Photon Systems’ laser to spot potentially invisible duds in its search for signs of past life on Mars.

Deep-UV photons interact strongly with many materials, especially ones containing organic molecules. This results in higher detection sensitivity and greater accuracy when compared with infrared or even visible-light laser sources.

Deep-UV spectroscopy has been done in research labs, but Hug and Reid had to find a construction that was far smaller, simpler, and cheaper to build than any existing alternatives. “Deep-UV lasers start at $100,000. That’s why they’re not used in industry,” Hug said. “We had to make laboratory instruments using the technology might take up three laboratory tables and take a month to set up.

One major challenge has been the level of perfection the technology requires. The same sensitivities that enable deep-UV wavelengths to detect even a virus make them vulnerable to the slightest defects. A microscopic imperfection in a lens or other surface can disrupt or scatter them, and Hug said it has taken decades to advance across multiple industries to meet the necessary standards.

Photon Systems focuses on two types of spectroscopy where deep-UV laser sources provide major advantages over longstanding spectrometer technology, and SHERLOC will use both. Fluorescence spectroscopy observes the light that most organic and many inorganic materials emit when excited by certain ultraviolet wavelengths, just like detergent glowing under a black light. Each emits a distinct spectral “fingerprint.”

Raman spectroscopy, on the other hand, observes the light that a molecule scatters, some of which will shift to different wavelengths due to interaction with molecular bond vibrations within the sample. These shifts in wavelength can be used to identify the materials in a sample. The higher-energy photons of UV light elicit a much stronger Raman scattering signal from organic molecules than lower-frequency light. And because deep-UV light isn’t present in natural fluorescence or in sunlight, using these very short wavelengths eliminates sources of interference.

In recent years, the company has started developing the technology into products, including handheld sensors and devices that monitor personal exposure to contaminants, as well as lab equipment. Their biggest markets now are the pharmaceutical, food processing, and wastewater treatment industries, said Hug. Deep-UV can identify and measure certain compounds at much lower concentrations than any other method, offering unprecedented precision in quality control, whether examining the active ingredients in pharmaceuticals or ensuring the cleanliness of manufacturing lines.

In waste treatment, the technology can identify and measure contaminants, letting the operator know when treatment process and save on power for ozone infusion and aeration. “For a small wastewater treatment plant, the whole system pays for itself in less than a month,” Hug said.

An application the military has invested in is identifying bacteria and viruses. Figuring out which bacteria are present in a wound, for example, would help prevent the right antibiotics to treat it, rather than using broad-spectrum antibiotics that risk causing drug resistance.

And rapid, affordable deep-UV spectroscopy holds promise for medical research, from diagnostics to identifying proteins, peptides, and other biological material. “NASA has been a constant companion in our journey to date, and the laser is only part of the story,” said Hug. “It is also the deep-UV/Raman and fluorescence instruments we built for NASA and the Department of Defense over the years that are now providing breakthroughs for pharma, wastewater, and water quality in general, and now, clinical testing for viruses.”

On Mars, SHERLOC will look for organic materials and analyze the minerals surrounding any possible signs of life. Researchers can understand their context, said Luther Beegle, principal investigator for SHERLOC at JPL. This will provide more detail about the history of Mars and also help to identify samples for return to Earth. The instrument, which also includes a camera capable of microscopic imaging, will be able to map a rock’s mineral and organic composition in high detail, providing lots of important data.

“We’re going to make a brand-spanking-new measurement on Mars,” Beegle said. “This is something that’s never even been attempted before. We think we’re really going to move the needle on Mars science and find some great samples to bring back.”

UV Spectroscopy

A new application for Photon Systems’ deep-UV lasers is being considered at wastewater treatment plants as a contaminant monitoring tool. Photon Systems’ deep-UV lasers have enabled the identification of even the slightest defects. The company developed the technology with the help of long NASA funding, primarily with the aim of developing the technology into products, including handheld sensors and devices that monitor personal exposure to contaminants, as well as lab equipment.

NASA Spinoff 2021

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UV Spectroscopy
Remote patient monitoring allows care providers and patients to access comprehensive health information from anywhere. Ejenta developed a proprietary system leveraging NASA technology to do just that, allowing medical and technical data to be sent to the cloud in real-time with access to data from any location using a browser or smartphone app. The app is compliant with the Health Insurance Portability and Accountability Act (HIPAA) standards and uses end-to-end encryption for patient data.

Ejenta negotiated exclusive worldwide license for the software, which NASA called Brahms, and for all related applications developed by the agency between 2000 and 2012. The San Francisco-based company is the sole distributor of the program for commercial, government, research, and academic use outside the agency.

Taking Control

The monitoring app handles all that information flowing to and from the patient, with the care team working to develop a voice-based interface to make accessing information easier. “What do I need to do next?” can prompt patients to take medication at a specific time or perform physical therapy exercises. “How’s my nutrition?” can elicit a food diary with customized nutrition assistance.

Compliance with patient privacy laws is of paramount importance, so every aspect of the data-transmission process is encrypted, according to Dhamija. Ejenta has a data protection agreement with the health provider. That means patient information must be kept confidential and authenticated so only authorized individuals can access it.

Voice-activated systems already exist, but they don’t meet the legal privacy requirements for patient data.

“What’s exciting now is that we’re working with Amazon to have a compliant voice-based agent that the patient can speak to,” said Dhamija. The company also continues to improve the remote monitoring platform to provide cutting-edge health care to everyone.

Ejenta negotiated a deal with Amazon to have a compliant voice-based agent that’s very similar to the system at NASA,” said Maarten Sierhuis, Ejenta’s chief technical officer. “We have an artificial intelligence that’s a virtual agent with the ability to ‘learn about the patient through data from wearable and wireless devices, adding to medical records,’ she said.

The cloud-based program employs off-the-shelf health and fitness monitoring devices to collect important health metrics. Through an app, sensors, and wearable technology, medical professionals can now organize and disseminate patient data, including comprehensive reference data in addition to their patients’ medical history.

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The number of illegal gold mines in the Amazon is increasing so fast that activists have turned to satellite imagery to identify them. Still, with thousands of new mines a year, the work was overwhelming scientists at Earthrise Alliance – they needed more hands on deck. That’s how ninth graders in Weston, Massachusetts, began locating illegal mining activity in Brazil’s protected Yanomami territory.

Earthrise is one of numerous organizations getting Earth-observation images, data, and analysis – much of which NASA makes available for free – into the hands of people working on sustainability projects. These efforts by many different aid groups are tracking illegal mining, deforestation, and groundwater resources and informing the decision making of small farmers and governments trying to support them in regions that are feeling the worst effects of climate change.

Earthrise was working with Survival International, a group that has been reporting on illegal mines in the Yanomami territory for years. Mining-related diseases, like malaria and tuberculosis, which can devastate local tribes that have had little contact with people outside their communities, according to Survival International. The highly contagious novel coronavirus now also threatens the region. In addition, the mines themselves pollute the land and waterways with mercury and other toxic substances.

Earthrise Illustrated a striking rise in the number of new mines in the area in a graphic for Survival International. A few months later, shortly before schools across the United States closed in early 2020 amid the global pandemic, Earthrise asked Weston High School freshmen to comb Earth-observation data for environmental stories.

Examining satellite imagery from NASA, the European Space Agency, and the company Maxar Technologies, the students identified illegally unreported illegal mines. The program is part of the Earthrise Education initiative, which provides students with an internship-based tool to use satellite imagery to investigate real problems that are in the news.

Headquartered in Washington, D.C., the Earthrise Alliance was founded in 2019 by former NASA officials, Dan Hammer, previously worked as a presidential innovation fellow with NASA’s chief technology officer, Dan Hammer, previously worked as a presidential innovation fellow with NASA’s chief technology officer for information technology, where he made NASA data more accessible to the public.

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“The original image alone was able to shift perspective for a lot of people,” Hammer said. “With Earth-observation data as a tool, we really wanted to help them identify areas that are the worst effects of climate change.”

Self-Reflection

NASA has been looking back at Earth since the agency was established. In 1960, the agency began sending satellites into orbit to capture Earth images to improve weather predictions and maps. In 1961, Alan Shepard caught a view of Earth as the first American in suborbital space with Project Mercury.

Astronauts in the Apollo program in the 1960s and ‘70s received photography training, not only to learn how to use the equipment, like cameras bracket-mounted to their spacesuits, but also to develop an eye for scientific images. These efforts led to the Earthrise photo and other famous images, including the iconic Blue Marble shot. Images from these early Mercury and Apollo missions were the inspiration for the Landsat program, which in 1972 launched the first satellite specifically designed with observing and collecting Earth’s landscapes. The program has been in continuous operation since then, in partnership with the U.S. Geological Survey, which currently operates Landsat.

Today NASA has a fleet of satellites gathering Earth data, in addition to ambitious airborne and ground-based observation campaigns. Other governments and private companies have billions of dollars’ worth of satellites looking back at Earth. NASA also hosts a data cube marketplace, making free Earth-observation data available to the public.

The agency makes its Earth data available for free to the public. In some cases, organizations are working directly with NASA, benefiting from the agency’s computing power, modeling, and analysis. Organizations can also access the rapidly increasing Earth-observation data from the space agency and other governments and companies around the world.

Working with the Global Partnership and other partners, Brian Killough, explored with the users of the data resources they’ve created.

Satellite data are cubes of satellite data configured to allow the use of powerful cloud computing and rapid analysis, Killough explained. Satellite data from many years in years can be organized into a cube with dimensions of space (latitude and longitude) and time. These cubes are made of small pixels that hold data at a scale of 30 meters – about the size of a baseball diamond – which is Landsat’s resolution. Once a cube is built, it is much easier to analyze and apply the data.

Killough and his team at NASA’s Langley Research Center in Hampton, Virginia, work directly with the users of the data resources they’ve created. “We help them interpret the data and adjust the tools for their needs,” he said. “We also conduct training in each country, where we give people an understanding of the data and tools and let them use it on their own.”

“We’re offering that perspective for emerging news events, the spaceing Earth perspective.”

“We offer additional perspective, which was the idea of Earthrise in the first place,” said Hammer, referring to the Apollo 8 photo for which the organization is named. “Taken during the first crewed mission to lunar orbit, the photo shows Earth rising over the Moon’s horizon, giving humanity a first glimpse of the home planet from another celestial body.

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Adieno said Killough “introduced what is possible — what type of data is available, the duration, what you can actually do with the infrastructure, with the applications that are available — which helped the countries identify who best placed to use it.”

In most cases, the satellite data tools are being used by people who have already been working with satellite imagery, but with less powerful capabilities and extremely cumbersome and often uneventful downloading and processing times. Adieno said officials in Senegal purchased private data for their project but then later moved to the data cube infrastructure for their analysis. “The results were more or less the same, which means they didn’t need the scientific expertise,” he said. “The value here is access to free, open source satellite data that’s analysis-ready.”

Officials in five African countries are using a NASA-developed satellite data tool to identify illegal gold mines and conditions on the ground for small farmers struggling with climate change. Parts of the program are expanding to cover more countries across Africa.

Killough agreed. “People in the developing countries we’ve been working with recognize that satellite data could have a huge impact,” he said. “But they have struggled with the preparation and the understanding of how to directly apply it to their projects. That’s where I think we’ve made great progress.”

The data resources are “certainly very efficient and effective,” said Victor Adiabong, who leads Ghana’s National Disaster Management Organization.

Adiabong worked with Killough to use Landsat data to identify the rate at which small farmers in the country’s north are adopting new growing techniques, like using drought-resistant seeds. This type of information helps the government determine the best ways to support small farmers in remote areas who are making decisions individually while also playing a major role in the country’s food security.

“Through our partnership with NASA, we are building the capacities of smallholder farmers in Africa who have never had access to before,” Levine said. “We envision a future where every smallholder farmer prospers in a digitally interconnected world.”

The effort is part of a growing collaboration between NASA and Mercy Corps, a partnership that began in 2015 with an early project to map groundwater resources in Niger and was formalized in 2019 with a Space Act Agreement. Shanna McClain, global partnerships manager at NASA Headquarters in Washington, said the agency was looking to “engage with partners that it hasn’t worked with in the past in the hope of achieving new ways of understanding complex human and environmental challenges.”

As the collaboration with Mercy Corps matured, McClain and Levine saw increasing possibilities for future work, as they had hoped they would.

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As the collaboration with Mercy Corps matured, McClain and Levine saw increasing possibilities for future work, as they had hoped they would.

"We didn’t just want to work with a new type of partner," McClain said. "We wanted to see the magic that comes only from partnerships." The formal agreement “essentially helps recognize our interest in doing this work as a shared endeavor,” she said, noting no money is changing hands. “We’re putting in an equal amount of resources,” McClain said.

NASA scientists have worked with Mercy Corps from their desks and at the sites of international projects. The agency provides Earth science insights, in addition to data and analysis that Mercy Corps wouldn’t be able to produce on its own.

Together, NASA and Mercy Corps are helping to strengthen the resilience of communities around the world.

Earth Data for Earth

Earthrise estimates that more than half a trillion dollars has been spent on public and private satellites looking to our own planet, primarily for military intelligence and profit-driven fields like commodity trading.

Earthrise, along with Digital Earth Africa and Mercy Corps, is repurposing this technology. “Making the data accessible and usable gives the local users more power to control their future,” McClain said.

"We’re leveraging the hundreds of billions of dollars of existing investment for Earth literacy," McClain said. "With Earth observatory data, people assess how their own lands are changing and what they can do to affect the direction of the change. "Satellite data can be complex," Killough noted. "Making the data accessible and usable gives the local users more power to control their future.”
We have to think about the food, air, and water we’re consuming on a daily basis. Is it clean?" said Ian Doromal, executive vice president and cofounder of ecoSPEARS, learned about the technology, he saw incredible potential—so he formed his company after the NASA technology.

"The SPEARS work like a sponge," Albino explained. "It’s a process called sorption, where it’s taken into a mat structure, and you press it into the sediment. You leave it in the sediment for a certain amount of time, and the SPEARS absorb the PCBs or other chlorinated contamination from water and sediments. It wasn’t clear to us initially that’s what the SPEARS. When they’re removed, the contaminants are taken out of the environment permanently."

Among the most contaminated and difficult areas to address is contaminated drinking water. "People are starting to realize that this is not just a problem in the building after hurricane damage in 2004, the company devised a system that uses a benign reagent, or a reaction-causing substance, to generate contaminants from the environment. In addition to limiting shipping costs and time, it markedly reduces the risk of removing and shipping contaminated material to an expensive landfill site for storage and disposal. It pumps pollutants into the atmosphere.

"There’s sensitive eelgrass in California waters. If you were to dredge all that up just to get rid of the PCB contamination, you’re paying four times the price. Everyone who has to deal with contaminated sediment has to be aware of this leagel,” he said. On top of that, whatever little forms are left behind or move later will be exposed to the PCBs left by the debris plumes created during the process. Microbes and small aquatic species absorb the PCBs, so the fish that eat them also become contaminated. As such, new predator species consume contaminated food sources, the PCBs accumulate, and biomagnify every step of the way.

Innovation at Laser

Sequestration in the form of capping is supposed to hold toxic material in place, preventing it from entering the food chain. But it’s unreliable. An example of this came to public attention when the caps in San Jacinto waste pits in Texas were moved or damaged by Hurricane Harvey and subsequent flooding. The PCBs and other contaminants then flowed into residential property and exposed a wide area to the toxins.

"The PCBs, the contamination is the bad guy in this story," said Albino. "But the lack of innovation is an even worse enemy. The folks in this [Brownsville] industrial area have decades of experience with capping, but they really don’t have a good technology for it. So, they continue to dig, harvest, and dispose." Albino and his team negotiated an exclusive license in 2017 for the NASA-developed SPEARS, branding their product ecoSPEARS, and are making it an integral part of an “environmental sound PCB remediation process. In addition to improving the original design, the company has developed its own proprietary reagent for containing the toxins.

The company is now piloting a new method for destroying PCBs on site. This technology breaks down the chemicals at the molecular level, turning them in minutes into harmless gases. The extraction and elimination processes work in water and soil. The alternative is months or years of removing and shipping contaminated material to an expensive landfill site for storage and disposal. The company hopes to commercialize this technology within two years.

"Society is more in tune with the environment and has finally learned what PCBs have been doing on the environment for the 40 years that they’ve been banned since 1976. But the cleanup problem has been difficult, so PCB contamination of soils, sediments, and waterways is widespread. The United Nations and its PCB Elimination Network, PCBs are rarely heard about, partly because they are non-flammable and can withstand both physical and mental developmental issues. The contaminants she was working against were polychlorinated biphenyls, more commonly referred to as PCBs. When the molecules were first developed and manufactured into multiple formulas, they were added to paint because they are non-flammable and can withstand extreme temperatures. That meant paint wouldn’t crack, peel, or catch fire, all important qualities for buildings located near nuclear reactors. But PCBs can also have negative effects on humans and animals, in particular by changing how they reproduce and function. This can cause problems in growth and development, often resulting in physical and mental developmental issues.

“Nobody set out with the intent of hurting anyone when they developed PCBs,” explained Quinn. “We just didn’t know. But when you do know, you’ve got to fix it. That’s what we’re trying to do.”

"A Better Eco-Trap"

To remove PCBs from paint and other materials in its buildings after hurricane damage in 2004, NASA decided to explore a new cleanup method. Based on Quinn’s experiment, Kennedy devised a system that uses a benign reagent, or a reaction-causing substance, to generate contaminants from the environment.

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"It worked in a matter of hours. We saw a decrease in the amount of PCBs outside the building after a total of 28 days. The takeaway for Kennedy was to develop a system that could remove contaminants from soils and groundwater sources. A 2008 study by the Environmental Protection Agency (EPA) found that PCBs sampled from fish from 500 lakes around the U.S. every single one had detectable levels of PCBs.

"We make decisions based off dollars and cents. Eliminating their environmental liabilities protects the company and its shareholders." Albino said. "It’s a long-term play. It’s a way to protect the company from liabilities and threats to human health and environmental health.

"We have these really cool pictures of footprints on the Moon hanging in my office," she said. "I would like to have a footprint legacy behind us that’s positively impacting Earth."
In one recent development, an unlikely partnership between NASA and a Swedish university—with the help of filter technology the space agency helped develop almost 20 years ago—led to the world’s first water-recycling shower. In 2012, Mehrdad Mahdjoubi, then a master’s student in industrial design at Lund University in Sweden, traveled to NASA’s Johnson Space Center in Houston as part of an annual program to learn about the challenges of designing habitats for astronauts. The focus was on a five-year Mars stay. Current astronauts, short on water and gravity, take sponge baths, but Mahdjoubi thought spacefarers with feet planted on Martian ground would prefer a real shower. But water on Mars’ desert surface is still scarce, so Mahdjoubi came up with an idea for reusing the flow. “I have never thought about doing something like this if I didn’t have that NASA experience,” he said.

To rapidly purify and reuse water, he hit on an especially thorough water filtration technology developed in part with NASA funding, known as NanoCeram (Spinoff 2004, 2008, 2013, 2017).

Shower like a Martian

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The ancients, of course, had no idea how it worked—that when positively charged silver ions dissolve into water or other substances, they bond with and disrupt the negatively charged membrane proteins of bacteria and other microorganisms to prevent their replication, and eventually to kill them. But as understanding has improved, so has technology for delivering the ions.

In the 1990s, Johnson, then known as the Manasad Science Centre, commissioned an electrolytic silver ion purifier to purify water in the Apollo mission. The center sponsored a more advanced prototype. The Puronics Defender whole-house water conditioner uses silver ion technology to kill bacteria, viruses, and other disease-causing microorganisms in the water supply. The company, based outside of Copenhagen, has explored is a membrane embedded with aquaporin proteins. While forward osmosis is an old technique, the aquaporin proteins’ extremely high selectivity for water molecules gives Aquaporin A/S an advantage that allows it to perform better than competing technologies. Aquaporin HFFO14 forward-osmosis modules, he noted, often with applications in dialysis, recycling, and the textile industry. NeoPore® Ceramic Membrane System, a membrane that allows for the production of high-purity water for medical, pharmaceutical, and food applications. 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Cloud computing tools gave rise to other open source and gained a huge user base and OpenStack, co-created by NASA, became a popular platform. OpenStack cloud computing subsequently expanded across industries.

That original work has expanded across most industries, because it solved a general problem and opened that solution up to let people expand on it,” said Brian Gracely, senior director of product strategy at Red Hat Inc., based in Raleigh, North Carolina. Red Hat became the first company to achieve major success marketing its own version of OpenStack and subsequent open source cloud computing products, and it remains the biggest player in that field.

Outsourcing to the Masses

The general problem the Ames team set out to solve was a way for computing power and storage to automatically scale up and down according to the needs of individual projects and users across a large number of virtual servers. This is the essential definition of cloud computing, or infrastructure as a service. They called the project Nebula.

Such systems already existed, with Amazon Web Services’ Elastic Compute Cloud as the prime example, but they were proprietary, used on a space. The team at Ames wanted NASA to be able to solve their problem, you can tweak the code to your need, and now others with your need can use it.”

NASA didn’t have the staff to build the whole thing and maintain it long term,” said Gracely. “It’s a problem if a lot of companies had too.”

NASA decided to take the open source route, developing the code online in the public eye, where any other programmers can contribute and no one owns the code.

After a few years of false starts and on-and-off work, the team decided to create its own infrastructure, which companies had commercialized and built upon with other open source tools like the OpenShift platform. OpenStack cloud computing subsequently expanded across industries.

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The result, a collaboration between NASA and Rackspace Inc., was called OpenStack. Since its release that July, open source cloud computing has steadily gained popularity, with many of the world's largest companies making the switch.

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Back at You, NASA

NASA’s Langley Research Center in Hampton, Virginia, is now an OpenShift customer, as the secondary benefits of Ames’ work a decade ago continue to reverberate through the space agency.

The Atmospheric Science Data Center (ASDC) at Langley is working to restructure its applications and services to run on the OpenShift platform.

“We're trying to think about how we can be more ready to reap the benefits of cloud technology to be more flexible and agile,” said Jeff Walter, systems architecture lead at ASDC.

The center houses five to six petabytes of data on local storage arrays and is preparing to migrate some of its data to the Amazon Web Services cloud. But Walter said it’s not the volume of data that’s driving a proposed switch to a local OpenShift cloud platform, so much as a desire to improve efficiency and prepare for the future.

Currently, one project might have a server running at capacity while another server sits idle, he explained. “It would be nice for the first project to be able to use some of the other project’s hardware.” Virtual servers would be able to operate across physical servers or coexist on a single machine. And OpenShift’s automation would eliminate work and human error. “It’s about having a centralized environment that allows developers to think about an application and how it’s structured from a business point of view and not worry about how and where this thing is going to run,” Walter said.

“By migrating to OpenShift, we are preparing our applications to be highly portable and run in any number of possible environments, including on-premises or in any major commercial cloud with little or no rework,” he added.

The group is also weighing whether it might run OpenShift on an OpenStack infrastructure.

Meanwhile, the Jet Propulsion Laboratory has been using Red Hat’s OpenStack Platform in its on-site cloud since 2016.

The European nuclear research facility CERN uses the free, open source Red Hat Distribution of OpenStack to run calculations for the Large Hadron Collider that made the first observations of the Higgs boson. Credit: xenotar via Getty Images

Today, the World

Red Hat’s free version of OpenShift now has well over 100,000 community members and is supported by about 700 companies in 165 countries. Meanwhile, Red Hat remains the world’s largest distributor of enterprise OpenStack, and more than half of the company’s OpenShift customers use it in conjunction with OpenShift.

“We have OpenShift customers in every sector in the cloud computing industry,” said Nick Barcet, Red Hat’s senior director of technology strategy. “OpenShift provides the largest share of the deployments, but from healthcare to manufacturing, OpenStack is delivering value in a very wide variety of cases.”

By May of 2019, more than 1,000 customers were using Red Hat’s enterprise OpenShift Container Platform, including almost half of Fortune’s Top 100 companies.

In 2012, Red Hat became the first open source software company to take in more than a billion dollars in a year. In February of 2019, a few months before IBM acquired the company, it reported total revenue for the previous fiscal year of $3.4 billion. IBM bought Red Hat for exactly 10 times that amount. By then, the company employed more than 14,000 people in offices across the United States and around the globe.

Red Hat was thriving before OpenShift opened up cloud-building to the masses, but the company is one of many that have benefited from that shift, with most of its products now built around open source cloud computing. “At the time of that NASA work, it was really unique,” said Gracely. “We’re thankful they did it, and we’re thankful they’ve remained a partner and a customer today.”

Among the industries where open source cloud computing has become essential are healthcare, which requires the secure management of vast amounts of data. Credit: SDI Productions via Getty Images

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Today, the World

Red Hat’s free version of OpenShift now has well over 100,000 community members and is supported by about 700 companies in 165 countries. Meanwhile, Red Hat remains the world’s largest distributor of enterprise OpenStack, and more than half of the company’s OpenShift customers use it in conjunction with OpenShift.

“We have OpenShift customers in every sector in the cloud computing industry,” said Nick Barcet, Red Hat’s senior director of technology strategy. “OpenShift provides the largest share of the deployments, but from healthcare to manufacturing, OpenStack is delivering value in a very wide variety of cases.”

By May of 2019, more than 1,000 customers were using Red Hat’s enterprise OpenShift Container Platform, including almost half of Fortune’s Top 100 companies.

In 2012, Red Hat became the first open source software company to take in more than a billion dollars in a year. In February of 2019, a few months before IBM acquired the company, it reported total revenue for the previous fiscal year of $3.4 billion. IBM bought Red Hat for exactly 10 times that amount. By then, the company employed more than 14,000 people in offices across the United States and around the globe.

Red Hat was thriving before OpenShift opened up cloud-building to the masses, but the company is one of many that have benefited from that shift, with most of its products now built around open source cloud computing. “At the time of that NASA work, it was really unique,” said Gracely. “We’re thankful they did it, and we’re thankful they’ve remained a partner and a customer today.”

Among the industries where open source cloud computing has become essential are healthcare, which requires the secure management of vast amounts of data. Credit: SDI Productions via Getty Images

“The best, most flexible software gets built in the open source community.”

Brian Gracely, Red Hat Inc.
It’s as true in tech as it is in ancient fables: the little guys can get things done. A dehydrated supercooling drink system, a polymer for hip replacements, and a cooling system for supercomputers, and a polymer for medical implants – through SBIR contracts, a technology company can develop a product that thrives. It helps both thrive.

Fiber Optics Feel the Heat

NASA’s war against weather now includes sensors that can read temperatures at the locations of the micro-holograms distributed along the fiber. The system is based on glass fibers, rather than metal, it’s also immune to electromagnetic interference. Two 2010 STTR contracts from Ames funded the development of spatial, high-temperature versions of these sensors for heat shield testing and tested them up to more than 3,200 degrees Fahrenheit. The sensors were able to read temperature changes more quickly than thermocouple-based sensors, and they allowed all electrical wires to be replaced with a single optical fiber, said IFOS’s Chief Technology Officer Behzad Moslehi.

Robotic hand

IFOS’s sensors are special micro-holograms embedded in thin shards of glass. These holograms, known as fiber Bragg gratings, reflect light differently based on the temperature of the fiber. These sensors are much more durable and would last longer than the body, which was ideal for use in medical implants. With a supplier guaranteed to provide these sensors, NASA funds can also support commercialization.

Fiber Optics Optics Feel the Heat

NASA’s materials science doesn’t end with airplanes. Thermal protection systems are vital to protect spacecraft and astronauts from the incredible heat that builds up during atmospheric entry. Without heat shields, rockets couldn’t land on Mars, and astronauts could not return safely from the International Space Station. The important job of testing these shields and ensuring they stay strong and functional is the responsibility of scientists at NASA’s Ames Research Center in California’s Silicon Valley.

In durability testing at the Ames Arc Jet Complex, temperature sensors called thermocouples are embedded in the heat shields. While durable, these instruments can only measure temperatures in specific parts of the shield and are susceptible to electromagnetic interference. Researchers wanted to get more information and turned to the SBIR program for solutions.

Intelligent Fiber Optic Systems (IFOS) Corporation of San Jose, California, has been working on high-precision temperature and pressure sensor systems for more than 20 years with the help of SBIR funding from NASA and other agencies (Espanol 2002, 2010). As its name suggests, IFOS deals in fiber optics – thin strands of glass that light to transmit data. Fiber optics present more opportunities for distributed data collection than traditional temperature sensors made from metal, in particular because “you can take measurements at all different locations where thermocouples would fail,” said Etling Verholstak, senior researcher for entry systems at Ames.

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NASA SBIR funding to research materials for supercomputers could be used to develop new kind of polymer. This material caught the eye of a medical technology company, which is now trying it out in more durable medical implants.

SBIR contracts, and later their Small Business Technology Transfer (STTR) contract cousins, SBIR contracts, and later their Small Business Innovation Research Program, NASA-backed technology is seeing new life. The agency selects technologies that have potential commercial and government applications, but many require more time, investment, and development than would allow private investors to realize returns. Sometimes it can take years of research and development, and some projects may never materialize. But as these examples show, technologies that undergo risk-reduction and products that are developed with SBIR funding can also eventually become hugely profitable as well as advance NASA missions and research.

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From Supersonic Jets to Medical Tech

In the 1990s, NASA was researching ways to move people and cargo at extreme speeds. While supersonic airliners like the Concorde were wound back through the decades, tickets were very expensive. NASA’s High-Speed Civil Transport research program looked to bring such high-speed travel to the mainstream.

Robert Bryant, an engineer at NASA’s Langley Research Center in Hampton, Virginia, explored materials for building more durable aircraft composites and adhesives. These polymer composites would be able to withstand the stresses of sustained supersonic air travel for much longer than traditional materials. Imtec, a small materials manufacturing firm in Shenendoah, New York, received SBIR contracts to produce samples of the NASA resins and realized that, with modifications, their durability could be useful in other areas.

“The Langley work was developed for composites and adhesives,” Bryant said. “And there were some aspects of the NASA resin chemistry that would allow the polymer to be used in other technologies.”

When visiting Langley, an Israeli medical company named MMA Tech saw potential in the polymers for hip replacements. If the material could withstand the environmental stresses from aerodynamic forces in jet aircraft, similar formulations could be just as good at resisting wear from joints in the human body. In two phases of SBIR research helped pave the way for a new polymer called MP1. Like the other NASA polymers, MP1 was durable and wouldn’t interact with the body, which made it ideal for use in medical implants.

With a supplier guaranteed to make the polymer, MMA Tech contracted with Imtec to obtain MP1 for its research.

In the 1990s, Langley Research Center was testing the polymers to make building and operating supersonic aircraft more stable. In a deviation from the usual research method called ‘cold testing’ MP1 is being tested in hip replacements. Credit: NASA

IFOS’s sensors are special micro-holograms embedded in thin shards of glass. These holograms, known as fiber Bragg gratings, reflect light differently based on the temperature of the fiber. These sensors are much more durable and would last longer than the body, which was ideal for use in medical implants. With a supplier guaranteed to provide these sensors, NASA funds can also support commercialization.

NASA Spinoff 2021

NASA’s Small Business Innovation Research (SBIR) program is a small business development program through which NASA funds technologies that are of interest to NASA – and the benefit both government agencies and private industry. The program encourages small businesses to develop products with wide-ranging benefits.

NASA investment in small businesses helps both thrive
Engine Helps Computers Chill Out

Ensuring that sensitive equipment is the right temperature is important when working with high heat, but sometimes you have to keep things cool, such as computers in a data center. Now a technology originally invented for spacecraft engines is doing just that.

One of the most important elements of rocket design is ensuring that fuel is constantly flowing to the engines. Most of the pumps that do this use a whirling piece of metal to push fuel from one tank into another, but Steve Harrington, president of Flometrics, designed a pump that didn’t have any moving parts at all. His “pneumatic ejector” uses pressure to push the fuel from one chamber to the next, and then out of the pump.

During the late 2000s, NASA was looking for a fuel pump to use in control systems for both a lunar landing module and small satellite launch rockets, so Flometrics applied for an SBIR contract with NASA’s Glenn Research Center in Cleveland to complete its fuel pump research.

“They had a very interesting approach to developing technology,” said Steve Schneider, the former NASA project lead.

By the end of Flometrics’ Phase I SBIR contract, the company’s pump could cycle two gallons of liquid nitrogen per minute through a test loop. The pump showed promise for the launch vehicle application, as it was far lighter and more reliable than other designs NASA was considering at the time. And while the research ultimately did not produce a rocket, the project would soon take a different turn, into keeping computers cool.

When NASA wanted a lighter, more reliable rocket pump, it assigned SBIR funding to a fluid dynamics specialist to develop one. While the resulting pump didn’t find its way into a space rocket, it soon became the starting point for a liquid cooling system for supercomputers and servers.

This demonstration of the Chilldyne cooling system pumps coolant from three chambers into adjacent servers. Changes in pressure between the chambers cause fluids to flow through the loop. Credit: Flometrics

Cooling Rocket Fuel and Drinks Alike

Maintaining the right temperature is important for applications both on Earth and in space, but not all SBIR research ends up in aerospace or computing. Sometimes it’s just to make a nice drink.

Aerogel was first created in the 1930s. When the liquid component in a gel substance is replaced with air, the material gains incredible insulating properties while becoming nearly weightless. NASA has researched aerogels for various purposes, ranging from sample collectors to protecting Mars rovers from the elements.

Under SBIR contracts from NASA’s Kennedy Space Center in Florida in the 1990s, a company developed the first practical aerogels in the form of durable, flexible blankets to keep rocket fuels cool. Aerogel has been spinning off into myriad commercial applications ever since (Grants 1996, 2001, 2008, 2010, 2016, 2020).

Now outdoor equipment company CamelBak, headquartered in Petaluma, California, is using aerogel from that same company for a different kind of insulation. Instead of keeping rocket fuels in liquid form, the Podium Ice water bottle keeps liquids at a stable temperature for hours.

“Our thinking was, what’s the best passive insulation possible so a bicyclist can get the best bottle possible?” said Derek Campbell, senior director of product development at CamelBak.

Aerogels are the world’s best insulators, but it took SBIR funding from NASA to turn them into something usable. Now they’re appearing in all kinds of applications, from a water bottle that keeps drinks hot or cold.
No sooner had the gecko’s secret been cracked than humans got to work trying to copy it.

‘It was one of those mysteries that had been around for a long time,’ said Aaron Parness, who until recently managed the Robotic Climbers and Grippers group at NASA’s Jet Propulsion Laboratory in Silicon Valley, California. ‘I was the first to go on the record saying how the gecko is able to stay upright on surfaces in open defiance of gravity, but anyone watching a six-inch board cross a ceiling would have to wonder. The Greek philosopher’s question wasn’t answered until about 20 years ago, in part because the secret lay in a force of physics discovered millennia later: Aristotle’s death.

Van der Waals forces are weak electrostatic attractions between polarizable molecules. Geckos’ toe pads take advantage of this slight attraction known as a van der Waals force to allow even the smoothest surfaces. It’s a simple concept, but recreating such a surface is not.

From Spacewalks to Circuit Boards

When Parness arrived at JPL in 2010, a decade after scientists had unlocked the gecko’s mysteries, he had already been working on gecko-like human-climbing technology as a graduate student at Stanford University. [Spider-Man gloves are still in the prototype stage.]

NASA was interested in such gripping technology for space operations. ‘Moving around in microgravity is more of a climbing problem than a walking problem,’ he said, noting that gecko-like pads would be easy to use and radiation-resistant and they wouldn’t rely on suction cups or other vacuum technology that’s useless in a vacuum.

Engineers at the Jet Propulsion Laboratory (JPL) spent years working with a team at Stanford University to develop gripping technology that could enable the free flight that geckos do so easily.

A gecko’s toe pads have millions of microscopic hairs that capitate on a weak electrostatic attraction known as van der Waals force to allow even the smoothest surfaces. It’s a simple concept but difficult to reproduce—Credit David Gentile

By the time Nick Wettels joined Parness’ group as a post-doctoral researcher in 2013, the work had turned to grabbing satellites for repair in orbit. Wettels had done his doctoral research and development at OnRobot, the first company to offer a commercial robotic gripper based on the gecko toe pad. At the time, he was leading the company Perception Robotics, which he had recently cofounded. Following his JPL post-doctoral work, and as the company focused on developing standardized products, he said, ‘The gripper was really a prime candidate. I saw potential in automated manufacturing, wherever such a tool could offer advantages over conventional alternatives for lifting and moving objects on an assembly line, for example.’

He licensed the underlying technology from Stanford and the California Institute of Technology, which manages JPL—the two teams had cooperated on the work. And Perception Robotics won Phase I and II Small Business Innovation Research contracts from JPL to fund further advancements. In 2015, the company merged with Hungarian robotic sensor company OptiForce and Danish company On Robot, which specializes in finger-based robotic grippers. The Gecko Gripper debuted almost immediately thereafter, starting to take precedence in July, with the first units shipping at the end of the year.

‘I had never heard of anything like this prior to speaking with Nick,’ said Enrico Krogh Hansen, CEO of the newly merged company, OnRobot, which is headquartered in Odense, Denmark, but produces the Gecko Gripper near Culver City, California. But he immediately saw its potential. In particular, he saw a market in the manufacturing of printed circuit boards. These start out full of holes, so they can’t be handled with a vacuum gripper. Most circuit board manufacturers use finger grippers, but the Gecko-Gripper could do the job quicker and with less programming.

14 Pounds of Grip

OnRobot is still improving the device and releasing new generations, but it’s already come a long way. The gripper can achieve an adhesive force of 35 to 40 kilopascals on a polished surface, compared with a maximum of just four or five kilopascals at the time NASA started working on it. The device is competitive with vacuum grippers. The company says it can easily lift metal weighing up to about 14 pounds.

Wettels noted that this improvement is partly because the company has figured out how to apply even finer tendrils to the ends of the microstructures, increasing their surface contact. The gripper is equipped with an ultrasonic sensor to locate its target and a load sensor to determine its weight.

‘It’s also able to activate and deactivate adhesion using the same technique as a gecko toe: the tiny hairs stick out at an angle, so they only adhere if they’re pulled in the right direction. Pulled the other way, they’ll release their hold.

‘It’s really cool to demonstrate it at a trade show, and people’s eyes light up, and they’ll say, ‘Whoa, that’s magic.’ Wettels said, but he noted that even people working in robotics or manufacturing often don’t intuitively grasp its usefulness. It replaces a Venturi pump—a common vacuum gripper that relies on compressed air—a Gecko Gripper can pick up in 50 times or less what a vacuum gripper would do with a very small vacuum pressure.

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Companies are creating virtual worlds with NASA’s planetary data and augmenting our own, enabling immersive experiences of space.

The collaboration between NASA and Mountain View, California-based Google is one of numerous virtual and augmented reality projects made possible by the high-resolution imagery and data the space agency has collected with spacecraft and rovers on and around other worlds over the years.

Access Mars was created with photos taken by NASA’s Curiosity rover, which has been studying the Red Planet since 2012. Users can navigate Curiosity’s path, including the rover’s landing site, its current location, and Martian landmarks like the Pahrump Hills, Marias Pass, and Murray Buttes, with wind hissing steadily in the background and explanations spoken by NASA scientist Kathryn Stack Morgan.

In a time of quarantines and online learning, guided strolls along the surface of Mars are especially appealing. These tours are possible with Access Mars, a free virtual reality experience of the Red Planet, with interactive landmarks and narration by a NASA scientist, using the Planetary Data System (PDS).

PDS is a long-term archive of digital data products returned from NASA’s planetary missions and actively managed by planetary scientists for the worldwide planetary science community. While all archived products are free and available online, PDS also provides a variety of tools useful in producing, obtaining, and using archived data.

The OnSight app won NASA’s software of the year award in 2018, and Mars scientists at NASA still use it to visualize and understand the terrain around the rover. However, besides a temporary exhibit at NASA’s Kennedy Space Center Visitor’s Center in Florida, it wasn’t easily accessible to the public. NASA shared the same Martian terrain data with Google to make an experience that’s available to everyone.

Google used terrain data from NASA’s Curiosity rover to create Access Mars, rebuilding the imagery into smaller pieces that are easier to load over the internet. Clickable signposts along the way allow users to learn additional details about the Curiosity mission. These smaller files load faster and use less data, giving a high-definition view of the surface of Mars to almost anyone with internet access.

“Access Mars is very active Monday through Friday, while schools are in session, and then traffic dips a bit on the weekends,” Burke said. Getting NASA data into the hands of more people was always the point of the NASA-Google collaboration, which was formalized in a Space Act Agreement (SAA) with NASA Headquarters and is one of numerous SAA partnerships with the tech giant.

Working with private-sector organizations helps NASA get information about the agency’s work to the public, and it can help keep that information up to date and accessible, according to Sasha Samochina, deputy manager of the Ops Lab at NASA’s Jet Propulsion Laboratory in Southern California, which worked with Google on the Access Mars project.

Samochina and her team at the Ops Lab previously worked with Microsoft on a Mars app for the company’s Hololens, mixed-reality smart glasses that can function as a virtual reality headset. The Hololens app, OnSight, allowed planetary geologists at NASA to study the surface of Mars by walking through the virtual terrain captured by Curiosity.

“Scientists could basically do site visits to places they were studying on Mars,” Samochina said. “It was a first of its kind.”

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"Our data is out there to be used," NASA's Samochina said. "The more accessible and the more understandable we can make it, and the more we can put it into easily digestible experiences, the better it is for us and for people who are trying to learn about what NASA is up to, what we're doing."

The Photojournalists who worked with NASA on the Access Mars project.

Credit: NASA/JPL-Caltech
ASTROREALITY uses publicly available NASA data to create models of the Moon and planets that pair with the company’s apps, which provide additional information about specific lunar and planetary features.

Hold a smartphone, with the app installed, over one of the company’s detailed and heavy Moon globes, for example, and information about individual craters and other topographical features will pop up, in addition to general Moon knowledge.

“Rather than learning everything on a computer, we’re trying to merge digital experiences with the best and most up-to-date data we can find with something you can hold in your hands,” said J.R. Skok, AstroReality’s chief science officer.

In creating its models, the company drew from NASA sources, like the Lunar Orbiter Laser Altimeter, or LOLA, which is onboard the Lunar Reconnaissance Orbiter that has been orbiting the Moon since 2009. LOLA has been gathering detailed topographical information that will inform the agency’s decisions about landing sites for future lunar missions.

The company has also consulted the Mars Orbiter Laser Altimeter, or MOLA, data for Mars’s topographical imagery, and NASA satellite imagery for its Earth model. LOLA, MOLA, and much of the agency’s satellite Earth data are managed by NASA engineers at NASA’s Goddard Space Flight Center in Greenbelt, Maryland.

NASA data also helped shape AstroReality’s Solar System Mini set. When paired with the mobile app, the models give users an immersive learning experience that includes a view of the solar system from the vantage point of each planet. Credit: AstroReality

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AstroReality’s products also draw on NASA experience. Skok has worked as a NASA contractor and intern, and he received funding from the agency as a graduate student. He has used his knowledge of the agency’s resources, including PDS, to help the company recreate celestial bodies with detail and accuracy.

In addition to planet models, the company sells augmented reality-enabled notebooks and mugs that also work with their cellphone apps. While enthusiasts are the company’s main customers, AstroReality also works with the Aldrin Family Foundation to bring space to children through schools and curricula.

“There’s something the human mind gets when you can actually feel the craters on the Moon,” Skok says. “There’s an interplay between feeling it with your fingers, seeing it, and then getting the deeper detail through the technology. It creates a human experience, and that makes a difference.”

Using augmented reality technology, AstroReality’s LUNAR PRO Moon model can pair with the company’s mobile app to reveal facts about individual lunar features and to simulate NASA missions. AstroReality drew from NASA data, including Lunar Orbiter Laser Altimeter data, to create the model and the app. Credit: AstroReality

PDS datasets are also feeding the creations of AstroReality, a Cupertino, California-based company that sells intricate Moon and planet models with augmented reality features that are accessible through a cellphone app.

“Hold a smartphone,” says J.R. Skok, AstroReality’s chief science officer, “Listen to a topic in the company’s mobile app, and you’ll get additional information about specific lunar and terrestrial features.

Through another SAA, NASA partnered with Fusion Media Group Labs to create the Mars 2030 virtual experience. And sometimes NASA’s public information is enough. Ireland-based Immersive VR Education created its Apollo 11 virtual reality experience almost entirely from images and drawings posted on NASA’s historical web pages.

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Airports Go Digital

NASA’s aviation expertise helps usher in digital communications at airports worldwide

Airport communications are getting safer and more efficient thanks to a new international technology standard developed with decades of NASA expertise, as managed in a Space Act Agreement with the FAA and now used by private companies.

Some of the best entertainment at the airport is all the action outside the window. Loaded luggage carriers zip past on their way to planes. Fuel trucks come and go. Catering trucks restless gallop. During winter, de-icing crews and snow plows add to the bustle.

This organized chaos is overseen by the ground-control managers as part of an airport-wide effort to ensure the safety of all ground operations.

Coordinating all this activity is time-consuming and is a continuously challenging job at major airports with thousands of flights scheduled each week. Technology helps, but as air travel has increased, the challenge of keeping track of all the moving parts has only grown.

For decades, airports have relied mainly on voice communications over unsecured radio frequencies, with landing phone calls as the only secure backup option. However, a digital, wireless airport communications system developed in part by NASA is now poised to change the game. The Aeronautical Mobile Aircraft Communication System (AeroMACS) will allow Federal Aviation Administration (FAA) staff in control towers to send safety-critical information digitally and securely – and should lead to shorter wait times on the tarmac.

A New Hardware Toolkit

NASA engineers have been part of this process from the start. The agency’s Glenn Research Center in Cleveland took the lead in AeroMACS testing. The center had worked on these issues previously and had extensive expertise, which it made a natural partner for this FAA. The two organizations signed a Space Act Agreement in 2007 to validate the new system and establish functional standards.

“AeroMACS was one of the leading technology R&D agencies that validated AeroMACS,” said Byrne. “The agency deployed a system and tested it. That work was essential for stakeholders in the international aviation community. It proved that this was a reliable standard they could support.”

To run the first aviation tests, NASA worked with the Broadband Wireless Access division of Alvarion Technologies Ltd. to modify existing WiMAX hardware. Acquired by Telrad Networks, the company was able to leverage its work with the agency to become one of the first to receive FAA certification of a WiMAX mobile aircraft communication system. 

“A group of Alvarion engineers called subscriber stations will collect, transmit, and receive data. Telrad builds the base station which performs the same function as a cellular network, routing communications, with GPS providingfiring for the network. The company also assists with identifying the best antenna hips, and placement depends on the airport configuration and signal coverage needed around the surface.”

As audio traffic control managers have communicated with airline pilots in the cockpit, the new system will make it possible to transmit text instructions for runway navigation, gate assignment details, and surface navigation directions.

When any airline lands next, the pilot gets a voice network and talks to the air traffic-control manager over a radio. “If you’ve got a German pilot trying to speak English to a Chinese air traffic controller, the possibility of miscommunication certainly exists,” said Byrne, adding that a base connection can compound the problem.

Aviation authorities from more than 100 countries chose and agreed to adopt the WiMAX standard. Formally adopted in 2007, WiMAX uses cellular network infrastructure that’s customizable for the new frequency – the spectrum of 5.1 to 5.925 gigahertz – reserved for safety-critical aircraft communications only.

A proxy client server executes banking-level security protocols and validates user authentication to verify the sender and receiver, blocking outside intrusions. The Access Service Network gateway enables connectivity throughout the network. This complete system customized by Telrad is all that’s needed to set up an AeroMACS-based wireless network.

“Airports have a dedicated frequency allocated by government regulators that is free of charge for them to use,” said Thijs Amadian, general manager of Telrad’s Broadband Wireless Access division. “Each one can develop it for themselves.”

The Israeli company, which has an office in Delmar, N.Y., is now working with airports around the world to customize system configurations.

Telrad has also created Star Suite, a software network-management program that can support any application an airport might require.

A 20-Year Job

AeroMACS is cheaper to operate and maintain than existing voice-based infrastructure, but it will take time to transition all airports to the new technology. Each aviation authority may choose to implement it in smaller stages. So far, some U.S. airports are using the system to collect information from surveillance sensors, which will help improve aircraft tracking on runways and taxiways, explained Rafid Araj, principal investigator and senior communications research engineer at Glenn.

And for the first time, in 2016, NASA successfully transmitted aviation data, including route options and weather information, to a taxiing airplane over a wireless communication system. The sophisticated electronics used in airplanes are highly sensitive, so inexact wireless communication could disrupt those systems. Successfully eliminating the risk of signal contamination while maintaining throughputs of megabytes per second is one huge accomplishment so far. Only then was the system truly considered ready for airports.

NASA engineers also proved that mobile assets such as taxis, baggage vehicles and laptop computers could be included in the wireless network. This will make it possible to track specific assets when they’re needed.

To date, more than 50 airports in about 15 different countries are using AeroMACS to replace voice with data transmission. It’s estimated that it will take 20 years to transition over 40,000 airports worldwide.

When fully implemented, it will be able to safely and securely route any ground communications.

A Press conference pilot program at the Beijing Airport deployed the system for mobile assets and found that using AeroMACS instead of walkie talkies shaved 20 minutes off the time planes were spending on the ground – a huge cost savings.

As aviation authorities such as the FAA publish AeroMACS guidelines, Telrad and other hardware providers are able to develop new tools to support the use of wireless communication at airports. “We will take off, according to Amadian.

“This is going to be millions of dollars in innovation. We’re thankful to be a part of the companies, then the business can grow.”
As many Americans prepare for a socially distanced Thanksgiving meal, some may be aware that NASA helped develop the tiny, highly efficient video cameras in the devices that will allow virtual family dinners, and a few may know it was the space agency that first modernized conference calling. But few may know it was the space agency that has contributed to the holiday: no one is likely to worry about the safety of the food on their table.

Today, outbreaks of food poisoning from packaged supermarket food are exceedingly rare, thanks in part to the food industry’s nearly-universal adoption of an approach called the Hazard Analysis and Critical Control Point (HACCP) system. Even less-known is the fact that HACCP was created for astronaut food in the early days of the Apollo program.

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This means all the companies putting food in the cabinets of our homes are checking their food production processes to prevent the same types of hazards that were introduced into foods on the Apollo missions.

The HACCP program is now underlies food safety programs and regulations for virtually all meats, poultry, fish, and processed foods, including many Thanksgiving dinner staples. Credit: AlbeFischi via Getty Images

**Analyze Hazards, Establish Control**

Leading the effort at the Manned Spacecraft Center, now NASA Johnson Space Center in Houston, was Paul Lachance, former coordinator for the U.S. Air Force’s Quartermaster Food and Container Institute. That institute had just moved and become the U.S. Army Natick Laboratories, which NASA brought on board as a partner in developing food for the space program.

Lachance’s background in nutrition was complemented by that of Howard Bauman, the microbiologist who was heading Pillsbury’s part of the work. “So he was an ideal person, in some ways, to develop a laboratory whose microbiology had to be paid attention to,” Lachance said in an interview for Johnson’s Oral History Project. “He had to do that initially for Gemini, and so he really had a feeling for how to do it for Apollo.”

In the early Gemini days, Lachance recalled, his team focused on thoroughly testing end products, a technique that had regularities found. The team had started examining its food production processes for points where contamination could be introduced, but Apollo expanded this approach and made it mandatory.

Beginning in 1963, the Apollo Program Office issued a set of guidelines for the program’s contractors, aimed at ensuring reliability in all critical mission systems. Based in part on a system developed by the military, known as Failure Modes and Effects Analysis, these heavily emphasized identifying and controlling any potential points of take. While the NASA guidelines were written primarily with space system hardware in mind, food was also deemed mission-critical. So Lachance and Bauman found themselves applying space-flight-level reliability assurance to astronaut food.

They came up with three guiding principles: Conduct a hazard analysis, looking for points in the process where any type of hazard could be introduced; identify those points and determine how hazards can be prevented, controlled, or eliminated at each one. And monitor these critical control points with frequent measurements. NASA also required the team to keep meticulous records of all this work, which became another critical aspect of HACCP. No one in the Apollo Program Office could have imagined they had set in motion a system that would improve food safety around the world — and it took decades for that to happen, but Bauman Bead what he saw.

“Quality control within the food industry had been focused primarily on testing the end product,” he wrote in a 1976 article in the trade publication Cereal Foods World. “We found we could only assure safe, quality foods all over the world — and it took almost three decades for that to happen, but Bauman Bead what he saw.

Food for the Apollo astronauts was not always perfectly appealing, but thanks to the hazard prevention system, NASA and Pillsbury came up with it. It was almost snails. Credit: NASA

**System created for Apollo astronaut food has become the global standard for hazard prevention**

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Food for the Apollo astronauts was not always perfectly appealing, but thanks to the hazard prevention system, NASA and Pillsbury came up with it. It was almost snails. Credit: NASA
The Seven Principles of HACCP

Principle 1: Conduct a Hazard Analysis

List all steps in the process and identify those where hazards might be introduced. Identify possible control measures.

Principle 2: Establish Critical Limits

List all steps in the process and identify those where hazards might be introduced. Identify possible control measures.

Principle 3: Establish Critical Limits

List all steps in the process and identify those where hazards might be introduced. Identify possible control measures.

Principle 4: Monitor CCPs

List all steps in the process and identify those where hazards might be introduced. Identify possible control measures.

Principle 5: Establish Corrective Action

List all steps in the process and identify those where hazards might be introduced. Identify possible control measures.

Principle 6: Verification

List all steps in the process and identify those where hazards might be introduced. Identify possible control measures.

Principle 7: Recordkeeping

List all steps in the process and identify those where hazards might be introduced. Identify possible control measures.

Results continue to improve. As top-priority hazards, such as e. coli in the 1990s meat industry, have been brought under control, both producers and regulators have focused on standards and relaxers on smaller problems, Seebhoem said. He added that the shift to HACCP also moved some responsibilities for quality control and aesthetics from regulators to the companies, further freeing up inspectors to verify company control of potential dangers.

Because HACCP requirements give industry a general approach to achieve food safety without telling companies the specific steps they have to take, it has been allowed flexibility to come up with new methods and techniques, which have improved continually.

A technicne that’s caught on in recent years is the use of high-pressure systems to kill off bacteria, said Johnson at Butterball. The equipment was costly up front but further reduces the kind of residual that’s necessary when a hazard is found in an end product.

Scott at the FDA said there’s still room for improvement. Her agency is in the early stages of expanding requirements for proactive controls around food allergies – which account for about a third of FDA recalls. And the Food Safety Precautions Control Alliance, which the FDA created in 2011 to bring together federal and state regulators, academia, and industry, continues to improve training for both producers and inspectors. The FDA also continues to publish more detailed guidance for companies.

Meanwhile, this spinoff from the Apollo food safety program has gone global much of Europe took up HACCP many years ago, and many other suppliers around the world have joined the HACCP-like systems to be allowed to export to the U.S. and Europe.
### NASA Spinoff Technology Across the Nation

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NASA’s portfolio includes over 1,000 patents and hundreds more software codes, with new additions being filed every year. The Technology Transfer Program works tirelessly behind the scenes to market this revolutionary technology to maximize its benefit across the country and around the world. This year that took on special meaning as the world faced a historic pandemic—and the program pivoted immediately to finding and adapting NASA technology to help.
“When the problem is translated to physics, we know what to do.”
Leon Alkalai, Jet Propulsion Laboratory

When the problem is old expertise are poised to pay off
translated to physics, Leon Alkalai, Jet Propulsion Laboratory

Response Campaigns
Inside NASA’s Pandemic

In mid-March, as much of the country shut down in response to the rapidly spreading novel coronavirus, a team of engineers at NASA’s Jet Propulsion Laboratory in Southern California got to work. Doctors nearly needed ventilators, so the team set out to design an inexpensive version that wouldn’t use any of the same parts as traditional ventilators, so as not to compete for supplies.

Unsure where to begin and knowing that whatever they came up with would need rapid approval, they reached out to the Food and Drug Administration (FDA). Leon Alkalai, head of strategic partnerships for JPL, connected with the regulator’s assistant director in charge of respiratory devices. “He said, ‘We have no idea what we’re doing, but we have a great team and we’re enthusiastic and we need help,’” Alkalai recalled, “and he said, ‘We’re in.’”

The FDA official noted that ventilator design is essentially “a physics and fluidic problem.” Alkalai said. That was when he knew the team would succeed. “When the problem is translated to physics, we know what to do.”

Across NASA, other centers also found ways to flex their skills and technologies to address the pandemic. As ratios of infection and hospitalization remain high in many states, several of the solutions NASA field centers came up with in the spring now faster on the verge of widespread application.

At NASA’s Johnson Space Center in Houston, home of the Human Health and Performance Center, the Technology Transfer Office combed through more than 2,500 technologies and software programs created in the last decade, looking for anything that might be useful in confronting the health crisis. The center submitted a portfolio of 34 open source technologies to the United Nations and is also helping a handful of groups update and manufacture a simple, human-powered ventilator originally designed for the space program.

Meanwhile, NASA’s Armstrong Flight Research Center in Edwards, California, joined a local public-private task force with a hospital and college, a neighboring city, and two spaceflight companies and ended up printing an improvement to an oxygen helmet for COVID-19 patients.

And when NASA’s Glenn Research Center in Cleveland heard that a familiar company was working to update a device for sterilizing medical equipment and spaces, the center jumped in to help. In all these cases, NASA and its partners found that, with a little guidance, aerospace engineers also make great medical engineers.

If It Helps Save One Life

For JPL, quick turnarounds of a viable emergency ventilator meant reaching out to many partners, said Alkalai, who initiates and manages all these relationships. “These included two local hospitals, several federal agencies, the University of California Los Angeles, and medical device giant Medtronic.

After just 37 days of working around the clock, they had a prototype, called Ventilator Intervention Technology Accessible Locally, or VITAL for short. “There were issues of exhaustion, but we were on a mission,” Alkalai said.

Almost as quickly, the FDA granted the device a ventilator emergency use authorization. The next trick was to get it into the world. This required a new approach to licensing.

“Normally, we’re happy if just one company comes to us saying they’re interested in a license,” said Daniel Broderick, manager of JPL Technology Transfer Office. “In this case, the response was much bigger. Over 300 companies registered on the NASA website to learn more about the ventilator and more than 100 applied to us. Now the challenge was to determine who was capable of producing the machine. ‘We’ve never seen this much licensing demand for a technology,’” Broderick said.

One of those applicants was Pro-Dee Inc., a design and manufacturing company in Irvine, California. Working with NASA on the ventilator was an opportunity to learn new things, grow the company, and “be part of the solution,” said Pro-Dee CEO Rick Van Kirk.

In late June, the company was working on sourcing parts, determining distribution channels, and laying out the assembly line. And NASA is still supporting the effort, having put together documentation, 3D renderings, and videos to assist licensees, including videos about the assembly process. “They did a great job of teeing it up for everybody,” said Van Kirk.

Pro-Dee was one of 29 companies granted licenses, including seven other U.S. businesses. “If half of them end up delivering the devices, that would be amazing,” said Alkalai. “We would be just thrilled if at least one unit makes it into a hospital and helps save a life.”

Other teams at JPL have designed protective respirator masks and a necklace that vibrates when wearers start to touch their faces. The masks and necklace can be 3D printed, and the design files and instructions are available for open source licensing on GitHub.

Human-Powered Solutions

Engineers at Johnson are offering a simpler ventilator solution, primarily for use in developing countries. As the pandemic unfolded, engineers who had developed a ventilator for use on the Orion spacecraft started updating it. The device is similar to human-powered ventilator bags used in ambulances, but those are squeezed by hands, which becomes tiring quickly. Johnson’s ventilator is powered by larger muscle groups in the arms or even legs. It can be used to keep a patient alive for hours, perhaps while waiting for a bed to open up, said Kris Romey, technology transfer officer at Johnson.

“The technical team came to us and said, ‘We think this could help, and we don’t know how to get it out into the world,’” she said. “The center is now offering the ventilator as an open source technology.”

It didn’t take long for Matthew Fiedler and the other founders of 3D printing company re:3D, all former Johnson employees, to hear about the ventilator, which the company is helping to refine.

The Johnson team had computer-aided design files for the ventilator parts but had never manufactured them. “They sent us the files, and we 3D printed them,” Fiedler said. “We’re helping them bring the product to life and figure out how to make it better.”

Patrick Depressy, engineer at JPL, shows the goggles of the ventilator that a team of NASA engineers designed in just over five weeks. The machine uses one of the parts used in traditional ventilators, so as not to compete for supplies.

About 30 entities have licensed the low-cost Ventilator Intervention Technology Accessible Locally (VITAL) technology, including two local hospitals, NASA’s Glenn Research Center, and a manufacturing company in California. (Credit: NASA)

If It Helps Save One Life

For JPL, quick turnarounds of a viable emergency ventilator meant reaching out to many partners, said Alkalai, who initiates and manages all these relationships. “These included two local hospitals, several federal agencies, the University of California Los Angeles, and medical device giant Medtronic.

After just 37 days of working around the clock, they had a prototype, called Ventilator Intervention Technology Accessible Locally, or VITAL for short. “There were issues of exhaustion, but we were on a mission,” Alkalai said.

Almost as quickly, the FDA granted the device a ventilator emergency use authorization. The next trick was to get it into the world. This required a new approach to licensing.

“Normally, we’re happy if just one company comes to us saying they’re interested in a license,” said Daniel Broderick, manager of JPL Technology Transfer Office. “In this case, the response was much bigger. Over 300 companies registered on the NASA website to learn more about the ventilator and more than 100 applied to us. Now the challenge was to determine who was capable of producing the machine. ‘We’ve never seen this much licensing demand for a technology,’” Broderick said.

One of those applicants was Pro-Dee Inc., a design and manufacturing company in Irvine, California. Working with NASA on the ventilator was an opportunity to learn new things, grow the company, and “be part of the solution,” said Pro-Dee CEO Rick Van Kirk.

In late June, the company was working on sourcing parts, determining distribution channels, and laying out the assembly line. And NASA is still supporting the effort, having put together documentation, 3D renderings, and videos to assist licensees, including videos about the assembly process. “They did a great job of teeing it up for everybody,” said Van Kirk.

Pro-Dee was one of 29 companies granted licenses, including seven other U.S. businesses. “If half of them end up delivering the devices, that would be amazing,” said Alkalai. “We would be just thrilled if at least one unit makes it into a hospital and helps save a life.”

Other teams at JPL have designed protective respirator masks and a necklace that vibrates when wearers start to touch their faces. The masks and necklace can be 3D printed, and the design files and instructions are available for open source licensing on GitHub.

Human-Powered Solutions

Engineers at Johnson are offering a simpler ventilator solution, primarily for use in developing countries. As the pandemic unfolded, engineers who had developed a ventilator for use on the Orion spacecraft started updating it. The device is similar to human-powered ventilator bags used in ambulances, but those are squeezed by hands, which becomes tiring quickly. Johnson’s ventilator is powered by larger muscle groups in the arms or even legs. It can be used to keep a patient alive for hours, perhaps while waiting for a bed to open up, said Kris Romey, technology transfer officer at Johnson.

“The technical team came to us and said, ‘We think this could help, and we don’t know how to get it out into the world,’” she said. “The center is now offering the ventilator as an open source technology.”

It didn’t take long for Matthew Fiedler and the other founders of 3D printing company re:3D, all former Johnson employees, to hear about the ventilator, which the company is helping to refine.

The Johnson team had computer-aided design files for the ventilator parts but had never manufactured them. “They sent us the files, and we 3D printed them,” Fiedler said. “We’re helping them bring the product to life and figure out how to make it better.”

About 30 entities have licensed the low-cost Ventilator Intervention Technology Accessible Locally (VITAL) technology, including two local hospitals, NASA’s Glenn Research Center, and a manufacturing company in California. (Credit: NASA)
Once the design is finalized, N2O, whose manufacturing facility is close by Johnson, in Houston, could start producing ventilators, working with federal and international organizations to get them into the hands of those who need them, he said.

Armstrong Flight Research Center engineer Mike Buttigieg, left, led a team that came up with a low-cost, lightweight oxygen helmet that helped with the effort. Credit: NASA

"This is something you can produce without a lot of expense, and it can save lives," said Tomlinson. "Its elegance and simplicity is the beauty of it.

The Spaceship Company, the city of Lancaster, Antelope Valley Hospital, and Antelope Valley College, bringing together resources, medical professionals, and engineers.
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Spinoffs of Tomorrow

Each year we document dozens of spinoff success stories, but the work of the Technology Transfer Program is ongoing. Our technology portfolio contains many exciting innovations ready for an enterprising company or entrepreneur to license and develop into a commercial product.

This section features 20 examples that we think show great promise.

To learn more about— and get started licensing— these or any of the others in our extensive portfolio, please visit technology.nasa.gov.
NASA's National Airspace System Constraint Evaluation and Notification Tool (NASCENT) automatically analyzes routes of aircraft that need to fly in or near constraint regions and attempts to find more time- and fuel-efficient reroutes around current and predicted constraints. NASCENT provides an evaluation of avoidance routes that save more than a user-specified number of minutes of flying time for all 20 Air Route Traffic Control Centers in the national airspace system simultaneously.

The system continuously analyzes all flights and provides reroute advisories that are updated in real time. It includes a graphical user interface that allows users to visualize, evaluate, modify if necessary, and implement proposed reroutes.

### Benefits
- Facilitates geographic and geofenced area and a continuous basis.
- Uses airframes that provide communications, navigation, and surveillance below 10,000 feet.
- Procedures and airspace design to keep drones separated from each other and prevent accidents.
- Plans routes to avoid conflict, collision, terrain, obstacles, severe weather, and wind based on a flight bag or mobile device application.

### Applications
- Aerial imaging and mapping
- Law enforcement
- Communications and rescuing
- Delivery of goods and services, from freight to medicines

### Finding Peak Performance
Approach to detect environmental changes in real time to adjust and improve performance.

Innovators at Armstrong Flight Research Center have developed and are patenting a peak performance-seeking algorithm that can optimize the performance of complex systems in real time. Originally designed for aircraft flying in formation, the algorithm can automatically find optimal formation configurations to reduce aircraft drag, increasing fuel efficiency.

The method is capable of using real-time measurements and quickly adapting to changing environmental conditions. In addition to aerospace applications, including commercial flight, this technology could also be used in situations where optimization is critical, such as in feedback control systems for manufacturing, business processes, energy management, and the automotive industry.

### Benefits
- Integrates more than 250 billion pieces of terrain information into a single map.
- Images are 1,000 times more detailed with two to three times more fidelity than current aircraft mapping systems.
- Maps any number of digital mapping projects to create the best available global map.
- Applicable to existing aircraft systems, offering industry standard C, C++, code base and map formats.

### Applications
- Military and civil aeronautics
- Global positioning systems
- Geographical prediction and planning
- Earth science data collection

### Low Power, High Fidelity
Software for aeronautics collision avoidance and a range of research areas.

Data-adaptive algorithms are critically enabling technology for automatic collision avoidance systems. Available for licensing, these Armstrong-developed algorithms provide an extensive and highly efficient encoding process for global-scale digital terrain maps, along with a real-time decoding process that locates and integrates high-fidelity terrain data. The algorithms are designed to be easily integrated into an aircraft’s existing onboard computing environment or into an electronic flight bag or mobile device application.

In addition to its use within next-generation collision avoidance systems, the software can be adapted for use in a wide variety of applications, including aerospace satellites, automobiles, scientific research, marine charting systems, and medical devices.

### Benefits
- Supports three primary industry verticals: aerospace, aeronautics, and automotive systems.
- Manufacturing
- Chemical engineering
- Tissue and biochemical engineering

### Applications
- Aerospace, aerodynamics, and automotive systems
- Manufacturing
- Chemical engineering
- Tissue and biochemical engineering

### Directing Drone Traffic
Unmanned Aerial Systems Traffic Management.

NASA has developed a traffic management system for commercial aerial systems (UAS), or drones, to maintain safe and efficient operations. This novel technology enables autonomous operations of UAS operations to grow at lower altitudes by developing a UAS Traffic Management system. This system could be used for delivery of goods and services, agricultural imaging and surveillance, and utility management.

### Benefits
- Supports geographically and geofenced areas on a continuous basis.
- Lots cases widely provide communications, navigation, and surveillance below 10,000 foot.
- Procedures and airspace design to keep drones separated from each other and prevent accidents.
- Plans routes to avoid conflict, collision, terrain, obstacles, severe weather, and wind based on a flight bag or mobile device application.

### Applications
- Aerial imaging and mapping
- Law enforcement
- Communications and rescuing
- Delivery of goods and services, from freight to medicines

### Armstrong

#### Ames

- Preventing Traffic Jams in the Sky
- National Airspace System Constraint Evaluation and Notification Tool (NASCENT)

#### NASA Spinoff 2021

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Composites for Extreme Environments

Lightweight, high-performance silicon carbide fibers are utilized for various applications ranging from high-performance aerospace to space-based systems. These composites are an advanced, strong material created through an innovative process. Composites offer a robust, lightweight, and high-strength option, enabling spacecraft servicing rendezvous and high-accuracy, real-time relative positioning. They are adaptable to any physical object and can be used in space cargo transport and robust propulsion.

Benefits
- Lower density, higher temperature capability, and lower thermal expansion coefficient compared to metal alloys.
- Higher toughness and better damage tolerance than ceramics.
- More predictable life and lower permeability than carbon fiber.
- Greater strength, higher temperature capability, better thermal conductivity than oxide/oxide ceramic composites.

Applications
- High-temperature electronics, reactors, and filters for the chemical industry.
- Precast concrete structures and radiant tubes for heat transfer industry.
- Thermal protective systems, throrer radiant, and filters for the chemical industry.
- Turbopump components for space vehicles.
- Nuclear waste and fission reactors as fuel cladding and radiation blankets.

Sun-Powered Propulsion

Small Solar Electric Propulsion Technologies

Glenn has expertise in small solar electric propulsion (SEP). Low-power, high-throughput SEP dramatically increases the capability of small spacecraft and advanced magnetic circuit design results in game-changing thruster performance. These advances can maximize reliability and minimize cost. Glenn can provide this expertise to U.S. companies through a free, non-exclusive license agreement and companion Space Act Agreement.

Benefits
- Fuel efficiency
- Reduced mass
- Robust propulsion
- Long life

Applications
- Satellite mobility
- Space cargo transport
- Space exploration

Using the Power Grid for Geophysical Imaging

Turns the power grid into an extremely large space science instrument.

Goddard Space Flight Center, with the support of the U.S. electric transmission industry, has developed a system that provides real-time data about geomagnetically induced currents (GICs) that flow in power grids during severe weather events. These currents can be a hazard to reliable transmission of electricity. In addition to monitoring GICs for hazard mitigation, the technology also enables the grid to serve as an antenna to study space weather phenomena.

Benefits
- Provides real-time data about geomagnetically induced currents (GICs).
- Enables the grid to serve as an antenna to study space weather phenomena.
- Provides real-time data about geomagnetically induced currents (GICs) for hazard mitigation.

Applications
- Scientific study of space weather
- Monitoring of the electric grid for potentially damaging GIC events

Staying Aligned at Orbital Speeds

FlashPose relative navigation to enable autonomous rendezvous and capture of spaceborne targets.

Goddard Space Flight Center has developed FlashPose, a relative navigation and space-estimation software to provide a real-time pose estimate for non-cooperative targets. This license includes a comprehensive package of design and process documents such as: issued and pending patents, design drawings, material specifications, vendor lists, software, and test data. This license is intended for small companies that provide autonomous rendezvous and capture of spaceborne targets.

Benefits
- Uses existing grid to perform large-scale measurements
- Low-cost autonomous design of the magnetometer stations

Applications
- Spacecraft servicing rendezvous and docking
- Space junk removal
- High-accuracy, real-time relative navigation
- Remotely operated terrestrial vehicles

Goddard Space Flight Center
Mission Development Software

Mission Analysis, Operations, and Navigation Toolkit Environment

Monte, a state-of-the-art Python library, is JPL’s signature astrodynamics-computing platform, supporting all phases of space mission development from early design and analysis through flight navigation services. With over a decade of use on NASA’s most demanding deep-space robotic missions, Monte provides a platform on which users can build their own custom astrodynamics tools.

It supplies the basic infrastructure – trajectory models, coordinate frames, high-precision time, astrodynamics, event searches, sensitivity analysis, numerical integrators, optimization, and more – allowing the user to focus on the problem at hand. All this capability comes with extensive hyperlinked documentation, from introductory tutorials to applications and flight path control libraries.

Benefits
• Serves as a platform for creating custom applications.
• Has an array of tools for trajectory design and space mission analysis and visualization.
• Has world-class orbit determination and flight path control libraries.

Applications
• Adventure: data management.
• Trajectory and coordinate frame representation.
• Trajectory optimization.
• Flight navigation.

Architecture for Robotic Planning, Cooperation, and Reaction

Software enables autonomous robotic vehicles and robotics groups.

Control Architecture for Robotic Agent Command and Sensing (CARACaS) can enable autonomy in vehicles and groups of vehicles, including aircraft, spacecraft, ground vehicles, and surface water or underwater vessels. The software architecture includes a planning engine, a behavior engine, and a perception engine, with the perception and planning engines coupled to a stored world model. CARACaS can make plans and change them according to changing goals, circumstances, or resources. All behaviors cooperate to resolve complex or even conflicting goals within the constraints of the mission.

The Navy has funded CARACaS to serve as the autonomy backbone of several unmanned maritime systems and recently funded advances to improve the technology’s situational awareness, safe navigation, and mission operation, enabling more complex, more autonomous missions.

Benefits
• Enhances robotic systems; can easily be incorporated to enhance an existing grasping assist glove.
• Improved actuators: grades from entry-level to better efficiency, higher reliability and thermal range.
• Position sensors: improved locational movement for better precision assistance.
• Triple brummel anchor: soft material anchors the glove to a hand firmly but without stress or pain.

Applications
• Healthcare: development of grasp-and-assist devices to assist patients with limited hand strength.
• Manufacturing: operation of tools and performance of manual tasks for extended periods.

Precision Low-Speed Motor Controller

Inexpensive low-speed brushless DC motor controller

Innovators at Johnson Space Center have developed a method for controlling precise motion of a brushless DC motor using relatively inexpensive components. Precision motors are usually quite expensive and inefficient when operating at slow speeds. This technology uses a method to control these motors over a broad range of speeds, ranging from about 0.025 rpm to about 7,000 rpm. Its ability to operate at these ranges with high precision provides an opportunity to integrate this technology into many applications and industries. Commercial motorists may employ this technology to expand their dynamic range. It can also be integrated into surgical robots that require advanced precision motion control systems. Hybrid and electrical vehicles can integrate this technology into their operating systems to improve efficiencies.

Benefits
• Precise in low-speed motion; smooth enough to be applied to surgical robots.
• Efficient: reduces noise associated with slow-motion operations.
• Inexpensive able to perform some functions as more expensive motors.

Applications
• Marine systems: precision low-speed motion.
• Noise reduction; extension of the dynamic range.
• Automotive industry: reduction of sensor noise in the cockpit.

New Capabilities for Grass-Assisting Gloves

Spacecraft robotic glove

Researchers at Johnson Space Center have designed and developed spacecraft gloves with grasping and restorative capabilities to increase both strength and mobility. These new capabilities comprise components that can be integrated into existing grasping gloves to enhance operation and range of motions. In particular, actuators were designed to have a greater force output, better efficiency, and higher reliability and thermal range than commercially available actuators. Also, position sensors were added to improve the accuracy of the grasping motion, as was a built-in restorative force to assist movement back into a relaxed, non-grasping position.

A “triple brummel anchor” was designed to improve the interaction between the actuator and a human finger to prevent crushing and avoid high stress concentrations in the line of the “tendon” used to maneuver the wearer’s hand while performing tasks. The anchor can be inserted outside the glove and requires no special tools. Industries such as manufacturing and healthcare can benefit from these components.

Benefits
• Enhances robotic systems; can easily be incorporated to enhance an existing grasping assist glove.
• Improved actuators: grades from entry-level to better efficiency, higher reliability and thermal range.
• Position sensors: improved locational movement for better precision assistance.
• Triple brummel anchor: soft material anchors the glove to a hand firmly but without stress or pain.

Applications
• Healthcare: development of grasp-and-assist devices to assist patients with limited hand strength.
• Manufacturing: operation of tools and performance of manual tasks for extended periods.
Cryogenic Flux Capacitor
A device for solid-state storage and on-demand distribution of cryogenic fluid commodities

Kennedy Space Center’s cryogenic flux capacitor (CFC) capitalizes on the energy storage capacity of liquefied gases. By exploiting a unique attribute of nano-porous materials—aerogel in this case—fluid commodities such as argon, hydrogen, and methane can be stored in a molecular surface-adsorbed state. This cryogenic fluid can be stored at low to moderate pressures desorbing, on par with liquid, and then quickly converted to gas when the need arises.

This solution reduces both safety-related logistical issues and the limitations of complex storage systems. Currently, high-pressure gases are stored in vessels with heavy, thick walls that require constant pressurization and complex storage systems to limit boil-off. These systems are not well suited to dynamic situations where the tank orientation can change suddenly. NASA’s CFC addresses all these limitations of complex storage systems. Currently, high-pressured gases are stored in vessels with heavy, thick walls that require constant pressurization and complex storage systems to limit boil-off. These systems are not well suited to dynamic situations where the tank orientation can change suddenly. NASA’s CFC addresses all these issues, simplifying current operations and opening the possibilities for new applications and new markets for cryogenic liquid.

Passive Porous Tube Irrigation System
System autonomously supplies water and nutrients to plants

The Passive Porous Tube Nutrient Delivery System is a plant growth technique that delivers a nutrient solution to the roots of plants via capillary action. The system was originally designed for use in microgravity. It uses a ceramic porous tube and water-filled nutrient bags connected in a loop. No electricity or moving parts are required. Instead, the nutrients are pumped in through a combination of capillary force and evapotranspiration from the plant. The porous tube supplies the plants with the water and nutrients needed to germinate and grow. This system provides an autonomous plant growth apparatus that is simple to assemble, plant, and harvest, minimizing the amount of intervention needed.

Benefits
- Minimizes labor involved in plant growth
- Ensures any plant can grow
- Ensures acidified water or aeroponics
- No electricity or moveable parts

Applications
- Vertical farming
- Green walls

Holey Carbon Allotropes
Innovative manufacturing methods for bulk preparation of holey graphene and holey carbon nanotubes

Scientists at Langley Research Center have developed new methods to manufacture carbon materials such as nanotubes and graphene with holes through the graphitic surface of the particles. The methods generate materials with increased accessible surface area, increased functional groups at damage sites, and improved through-surface molecular transport properties. The materials generated using these techniques are anticipated to be applicable to a variety of industries, especially energy storage, such as supercapacitors and batteries, and separation membranes for gas, ions, organics, proteins, and more.

Benefits
- Produces carbon nanomaterials with increased surface areas, improved electrical performance, and through-surface molecular transport properties
- Eliminates need for catalysts, solvents, and harmful gases for processing
- Allows for control of material properties such as surface area, modulus, thermal conductivity, and thermoelectric
- In a variety of uses and can be used to generate bulk quantities, only dependent on the availability and cost of pristine materials

Applications
- Energy storage and generation (supercapacitors, batteries)
- Membranes for gas separation, water desalination, bioremediation
- Gas and drug delivery
- Chemical and biological sensors

More Precise Positioning
Improving Global Positioning System accuracy for internet-enabled mobile devices

One factor limiting the possible uses of GPS-enabled devices, such as establishing drop zones for package delivery, is that these devices typically have limited precision positioning capabilities. This system is designed to work with any internet-enabled mobile device that has access to its GPS pseudorange, code phase, and, potentially, carrier phase measurements. The system uses GPS measurements or corrections from a stationary base station to refine its positioning estimate using established computational techniques such as those associated with differential GPS, Real-Time Kinematic GPS, and/or the Local Area Augmentation System. These removes errors common to the measurements of both existing systems, improving the accuracy of position estimates.
Powder-based additive manufacturing methods typically require post-fabrication component cleaning to remove residual powder from the surface and crevices of the part, a task that becomes increasingly difficult and time-consuming with part complexity. This invention uses a large volume of pressurized air to quickly enter a cleaning chamber. Based on the Bernoulli principle and continuity equation, the high flow results in significant air velocity and a decrease in pressure when air flow passes through smaller component orifices, which in turn removes residual powder from the part. The technology can be implemented as a stand-alone cleaning system for powder bed-fusion additively manufactured parts or could be integrated into a packaged post-processing system offering CT scans of complex NASA parts cleaned using a proof-of-concept system revealed promising results. NASA welcomes offering. CT scans of complex NASA parts cleaned using a proof-of-concept system revealed promising results. NASA welcomes

**Benefits**
- Fast, automated process: parts are cleaned in minutes, instead of hours or days
- Effective cleaning: CT-scan of cleaned parts revealed effective particle removal
- Versatile: can clean any component part: removes residual powder lodged in small channels and passageways found in complex additively manufactured parts
- Powder-based additive manufacturing: a shiny direct metal laser sintering, electron beam melting, selective laser sintering, additive laser melting, and selective laser sintering
- Post-processing of complex additively manufactured parts

**Applications**
- Post-fabrication component cleaning to remove residue powder from the surface and crevices of the part
- Cleaning of complex, additively manufactured parts
- Metal powders made in small channels and passageways found in complex additively manufactured parts
- Cleaning of powders lodged in small channels and passageways found in complex additively manufactured parts

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**Supersonic Spike Diffuser**

Double the pumping efficiency in one quarter the space

Conventional cylindrical and second-throat supersonic diffuser designs allow the plume from a de Laval nozzle to fill its cross-section without centerline obstruction. This allows a vacuum to be created within any void upstream of plume impingement, but it does inefficiently due to shock losses at high Mach numbers. Centerbody diffusers provide an improvement by reducing the maximum Mach number but also increase the number of oblique shocks by turning the flow multiple times. Spike diffusers harness the best attributes of each and provide approximately double the pumping performance through Pareto-efficient reduction of both Mach number and flow deflection. Because spike diffusers can start at half the pressure ratio of conventional diffusers, much lower pumping pressures can be achieved for a given feed pressure by using large expansion-ratio ducts and nozzles. Spike diffusers are also compact, requiring a length of only about 20 to 30% of that of conventional designs.

**Benefits**
- Starting pressure ratio is about 65% of conventional diffuser geometries
- Lower vacuum achievable for the same feed pressure
- Compact
- Reduced structural overheat

**Applications**
- Closed propulsion
- Chemical propulsion
- Oil refinement
- Flavors and fragrances (vacuum distillation)