Dear Colleagues,

NASA is redefining what is possible in space technology in order to develop the new knowledge and capabilities that will enable future exploration. NASA’s investment in technology development spurs economic growth here on Earth while maintaining American pre-eminence in space exploration.

Through NASA’s Space Technology Mission Directorate, the agency is making breakthroughs in such technologies as solar electric propulsion and cryogenic propellant storage, which are essential for deep space missions.

Through our NASA Innovative and Advanced Concepts program and our Space Technology Research Grants program, we’ve funded studies for early-stage transformative technology concepts—groundbreaking ideas that may one day change how we explore space. We’ve also demonstrated more than 35 “firsts” in our Game Changing Development program, revolutionizing a broad scope of technical challenges.

The Space Technology Mission Directorate continues to offer researchers a way to flight-test technology development payloads on suborbital flights before exposing the hardware to the harsh environment of space.

NASA is advancing the state of the art in technologies ranging from green propellants and the largest-ever solar sail to the next generation of robotics and additive manufacturing, or “3D printing.” Through prize competitions, we’re promoting the expansion of autonomous robotic capabilities. As part of our Small Business Innovation Research program, we’ve partnered with Silicon Valley’s Made in Space organization to demonstrate 3D printing aboard the International Space Station next year.
These are just a few of the many exciting activities NASA is engaged in to ensure that America's aerospace technology remains at the cutting edge. I hope you'll find the following articles about the agency's investments in space technology informative and thought-provoking. I encourage you to join us in our efforts to keep our programs at the forefront of scientific discovery, which will guarantee our nation’s leadership in today’s new innovation economy. Stay tuned for information on our upcoming Space Technology Industry Day in 2014 to learn more about the progress made to date in space technology and to see where we are headed next.

Cheers,

Dr. Michael J. Gazarik
Associate Administrator
Space Technology Mission Directorate
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INSIGHT

with MICHAEL GAZARIK
Associate Administrator
Space Technology Mission Directorate
A NASA team is working on something big in space propulsion: advanced technologies that may help bring a part of the universe back home.
On September 5, 2012, a NASA spacecraft named *Dawn* left its orbit around the massive asteroid Vesta and began the second leg of its interstellar road trip, trailing a blue glow in its wake. Its next stop: an even larger body, the dwarf planet Ceres, about 930 million miles away. When it arrives at this destination in February 2015, Dawn will become the first spacecraft to orbit two different celestial bodies beyond Earth. But even now, well before Dawn reaches that remarkable milestone, NASA is already propelling forward to the next big idea, the next conceptual leap along the path that Dawn is blazing.

Visiting an asteroid is one thing. How about bringing one back for a closer look?

NASA’s *Asteroid Redirect Mission* (ARM) has ambitions worthy of a double take: identify a suitable near-Earth asteroid (nothing on the scale of a Vesta or Ceres, just a mere 500–1,000-ton specimen), launch a robotic spacecraft to capture it and redirect it into a high orbit near the moon, and then land a crew on it to gather samples and return them to Earth. The initiative joins the agency’s best science, technology and human exploration efforts into a single mission. In the process, it will demonstrate ion propulsion technologies on a scale never before attempted.
"In space, there are multiple ways to transfer momentum to a spacecraft," says Kurt Hack, Lead Engineer at NASA’s Glenn Research Center in Cleveland, Ohio. Hack has recently been working on finding the right fit between a special type of propulsion technology and the missions it can enable. Called solar electric propulsion (SEP), this mode of moving a spacecraft eliminates the massive amounts of fuel required by traditional chemical propulsion—think of the space shuttle's external fuel tank and solid rocket boosters; instead it draws on the sun's energy to power thrusters that accelerate xenon ions to incredible velocities. The blue glow emitted by electric propulsion (EP) thrusters is the result of these ions being expelled at the rate of nearly 19 miles per second.

With SEP, a host of new missions can become realities.

SEP offers fuel efficiency 10 times greater than that of conventional chemical propulsion. “Unlike chemical propulsion, in which more than 75 percent of your vehicle can be taken up by propellant, the same missions performed using SEP need much less propellant,” which opens up valuable room aboard the spacecraft for additional payloads, Hack explains. And while the resulting thrust is hardly impressive—Dawn’s SEP engine takes a leisurely five days to accelerate from 0 to 60 miles per hour—in the vacuum of space, the consistent application of that thrust can gradually generate staggering speeds. Over nearly four years of powered
spaceflight, Dawn has accelerated to a speed of 18,500 miles per hour. While SEP has successfully driven Dawn’s deep space science mission, the challenge facing Hack and his NASA colleagues is how to make ion propulsion technologies bigger and better, so that a host of new missions, including moving a multi-ton asteroid, can become realities.

“About 2 kilowatts of electrical power generated by the Dawn spacecraft is used by the EP system,” explains Meg Nazario, the SEP project manager. The EP system required for the Asteroid Redirect Mission concept, she says, would require roughly 30–40 kilowatts to propel a spacecraft that will be more than 10 times heavier than Dawn.

“SEP has been around for a long time,” Nazario says, “but it hasn’t flown at higher power levels for various reasons, one of which is that we haven’t been able to practically generate the power in space to drive these larger thrusters.”

One of the innovations required will be a much larger xenon fuel tank and feed system. Dawn’s xenon tank—the largest ever flown—stored 400 kilograms of propellant; the SEP team is exploring designs for tanks that will hold upwards of 10,000 kilograms of xenon.
Then there is the problem of generating the electricity needed to ionize and accelerate the xenon out of the thrusters. To this end, Nazario says, “we are looking at technologies that allow us to deploy, in space, large solar arrays that generate a lot of power but don’t require humans to deploy.”

As Hack notes, “The International Space Station’s solar cells have roughly half of the efficiency of those that we would use for the ARM mission, but their size is huge. It took many missions and people to install those. We could get the same power as the space station with half of the area.”

The key innovation, explains Hack, is a shift from rigid solar panels to deployable systems of flexible blankets. “The problem is not so much solar-cell efficiency as the amount of solar-energy-collecting area that can be packaged inside a launch vehicle,” he says. With the new approach, “we’re able to increase the size of the deployed solar arrays, and even sticking with the current state-of-the-art solar cells, we can generate greater power while still fitting inside an existing launch vehicle.”

According to Nazario, this kind of advancement has implications not only for NASA missions but for commercial satellite designs as well. Commercial satellites in geostationary orbit use SEP systems to maintain their orbital positions. “There
is a lot of interest in these arrays, and industry is very excited that NASA has made this investment,” she says. “This is one of the long poles in the tent with regards to advancing SEP. This is a big deal.”

"The potential is phenomenal."

The Asteroid Redirect Mission concept would be a flagship application for SEP. The plan now, says Hack, is to mature the needed SEP technologies in time for a 2017 or 2018 launch, though the timing of the actual mission would depend on when a suitable asteroid candidate comes within range. In the meantime, there are numerous other applications for the advanced SEP systems being developed by the Glenn Research Center team and its partners. These include transporting heavy payloads already delivered into low-Earth orbit via chemically propelled rockets into higher orbits—possibly even to points between Earth and the moon—where in-space assembly could take place. Further deep space exploration, commercial and military applications and orbital debris removal are all on the table, says Hack. “This technology will open up a whole new approach to space transportation,” he says. “The potential is phenomenal.”

“It’s huge,” Nazario agrees.

Asteroid huge.
A space propulsion technology once imagined by famous astronomers and science fiction writers is on the verge of becoming a cost-saving, mission-enabling reality.
Ron Unger never loses sight of the uniqueness of his job. Arriving at his office at Marshall Space Flight Center offers him a daily reminder that working for NASA is an experience like no other.

These days, that experience involves guiding a mission that has been theorized for centuries but is now being executed on an unprecedented scale.

Exploration has long evoked images of ancient mariners braving the high seas, ocean winds driving them toward the unknown. Around the turn of the 17th century, astronomer Johannes Kepler observed comet tails the sun, as if caught in a solar wind, and imagined intrepid racers by “vessels and sails adapted to the heavenly breezes.”

Centuries later, a short story by science-fiction writer Arthur C. Clarke envisioned a space-based yacht race—a sort of interstellar America’s Cup—between ships equipped with parachute-like sails and propelled by nothing more than the light of the sun. While solar sailing seems like a flight of fancy, NASA and its partner

This solar sail prototype being evaluated in the world’s largest vacuum chamber, located at NASA’s Plum Brook Station facility, is roughly one-quarter the size of the planned Sunjammer spacecraft.
L’Garde Inc. of Tustin, Calif., are constructing a spacecraft, dubbed *Sunjammer* after a space yacht in Clarke’s sci-fi story, to demonstrate the very real benefits this mode of propulsion can provide.

*Solar sail propulsion* is a concept that is simultaneously simple and mind-boggling. Light has both particle and wave characteristics, explains Unger, mission manager for the Solar Sail Demonstration (also known as the Sunjammer Project). Light particles striking and bouncing off of a reflective surface exert a miniscule amount of force on that surface. “The propulsive power of these particles is very small, so in order to extract that tiny amount of particle energy coming from the sun, we need a large surface area, like a sail,” says Unger. A big enough sail will reflect enough solar energy to push a spacecraft forward. That steady, ever-so-gentle pressure is continuously applied, Unger says, “so you can build up a reasonable amount of acceleration.” Requiring no chemical propellants of any kind—the spacecraft steers using control vanes, much like a sailboat adjusting its sails to navigate—*solar sail propulsion* represents the pinnacle of fuel efficiency.
“We’ve been trying to push the envelope beyond what our experience has been with chemical propulsion rocket engines to see if we can develop propulsion techniques that result in much higher efficiencies,” says Unger. “It’s kind of like a measure of gas mileage. If you have higher-octane fuel, you’d expect to get more energy out of it, and your miles-per-gallon rating goes up. With a solar sail, where your propulsive energy is being provided by the sun and you don’t use any propellant, your efficiency is essentially infinite.”

NASA has successfully applied solar sail principles in the past; both Mariner 10 in the 1970s and more recently the MESSENGER spacecraft employed their solar panels as secondary means of attitude control, though neither mission was intended as a solar sail demonstration. While Sunjammer will not be the first to demonstrate solar sailing as an exclusive means of propulsion (that title goes to the Japanese IKAROS spacecraft flown in 2010), it will be by far the largest, with a sail almost 13,000 square feet in size—seven times larger than any flown before. To get a sense of the amount of propulsive force Sunjammer’s sail will gather, the next time you’re in your favorite coffee shop, hold a packet of artificial sweetener in the palm of your hand. It feels like next to nothing, but that slight pressure—the equivalent of 0.01 newtons of force—is all Sunjammer will need to sail through space.

For a closed caption version of this video, click here.
To do that, however, Sunjammer must be exceedingly light (weighing roughly 70 pounds, just one tenth as much as the largest solar sail spacecraft to date) and must carefully deploy a sail so thin it is referred to as a “gossamer structure.”

“With a solar sail, ... [fuel] efficiency is essentially infinite.”

“Trying to handle these sails is like handling smoke,” says Unger. They are made from a polyimide film called Kapton, he explains, that is thinner than a sheet of paper. “You can’t even tell when the material is in your hand, it’s so light.”

Sunjammer’s mission will focus on sail deployment, attitude control and navigation. A successful demonstration will open up a host of possible applications for solar sail spacecraft, such as solar weather monitoring. Right now, NASA has a pair of satellites stationed at Lagrangian point L1, a position of gravitational balance between Earth and the sun, about 900,000 miles from our planet. “It’s like climbing in a roller coaster and coming to a stop right at the top of the hill. You’re in this precarious balance between falling toward the sun and falling toward Earth,” Unger explains. These satellites monitor solar weather directed toward Earth, providing advance warning of potentially dangerous events such as solar flares and coronal mass ejections.

“Being dependent on satellites and the power grid, we are very interested in when the sun ejects a stream of particles in our direction that could knock satellites offline, affect the International Space Station crew with high doses of radiation, or knock out power grids. We’d like to know when those events are coming, just as we do with weather on Earth, so we can take preventive measures,” Unger says.
Using the pressure on its sail from the sun's gravitational pull, a spacecraft similar to Sunjammer can position itself about 2.3 million miles from Earth to provide more effective advance warning of approaching solar storms. Unger also notes that future satellites could carry a lightweight sail for deployment when they reach the end of their lifespans. The sail could be used to maneuver the satellite out of low-Earth orbit to avoid collisions, or to deorbit the spacecraft and have it burn up in the atmosphere—a safe, cost-effective means of mitigating the problem of orbital debris.

Sunjammer is the most recent fruit of efforts stretching back to 2005, beginning with two sail-deployment experiments conducted by L’Garde in the simulated space environment of the massive vacuum chamber at NASA’s Plum Brook Station. The mission also builds on the 2011 flight of NanoSail-D, which sported a sail slightly more than 9 square meters in size. As part of NASA’s Technology Demonstration Missions (TDM) program within the Space Technology Mission Directorate, the Sunjammer Project is one of a number of missions
designed to prove the viability of new technologies during actual spaceflight, rapidly maturing the technological innovations needed to overcome the scientific and engineering challenges of space exploration.

Unger says the design being completed by NASA and L’Garde can be scaled up to create solar sails significantly larger than Sunjammer’s record size. While solar sails are impractical for a mission to Mars, the excitement in Unger’s voice is evident as he describes bigger, faster solar sail spacecraft capable of missions that would, for instance, enable a rendezvous with and close study of an asteroid. It’s these kinds of possibilities that make Unger marvel at his luck to be working at an agency where a goal of every mission is to broaden the realm of the possible.

“There is nobody else doing this work,” Unger says. “This is one-of-a-kind stuff.”

Though work on Sunjammer began only in 2011, it won’t be long before this spacecraft demonstrates the remarkable capabilities of solar sail technology. As if plucked from the giddy imaginations of ancient astronomers and modern-day science-fiction writers, Sunjammer is set to unfurl its silvery sail—adapted to the heavenly breezes—in late 2014.
BIG IDEAS
SMALL PACKAGES
THE SMALL SPACECRAFT TECHNOLOGY PROGRAM
Within the Space Technology Mission Directorate is a program that is shrinking spacecraft and diminishing costs without minimizing the resulting benefits as it opens up space research opportunities to new communities across the nation.

On April 21, 2013, an Antares rocket launched from Wallops Island, Va., carrying three groundbreaking spacecraft that together could easily fit inside a grocery bag. Though each satellite weighed only about three pounds, they carried a greater weight—the burden of proving an affordable, effective technology concept that could enable direct participation in space research and exploration by groups ranging from small businesses to university classes.

Over the course of a week, the tiny spacecraft transmitted data about their status as their orbits around Earth slowly decayed. Two of the satellites recorded images that were beamed to the ground, collected by amateur radio operators around the globe, and then assembled by a team at Ames Research Center. The resulting composite image was a bit choppy, but it represented a resounding success—considering that the visual data The PhoneSats snapped photos using their cell phone cameras and beamed the images to Earth, where amateur radio operators collected them. An Ames Research Center team then assembled the transmissions into composite images of Earth like the one seen here.
came from the same camera technology people carry around in their pockets. Serving as the brain of each 4-inch cube satellite was that most ubiquitous of modern consumer technologies: the smartphone.

“We’re really just getting started,” Andy Petro says.

Petro is the program executive for the Small Spacecraft Technology Program, one of nine programs within the Space Technology Mission Directorate designed to innovate, develop, test and fly hardware solutions that support NASA’s science and space exploration missions. Petro thinks small, but at NASA these days, that’s a big deal.

The Small Spacecraft Technology Program represents a trend within NASA that isn’t necessarily new but, as Petro explains, is gathering enthusiastic support both within the agency and beyond. “There has been a small spacecraft community outside of NASA for some time,” he says, noting that, at the dawn of the Space Age, spacecraft in general tended to be small in size out of necessity, because launch vehicles at the time were unable to accommodate large weights or volumes. As a consequence, NASA set out to miniaturize electronics and other components in order to reduce weight and cost. Many of these innovations have found their way into modern commercial products, such as cell phone cameras, that are now becoming essential components of new generations of small spacecraft.
As the space program has progressed toward larger and more capable spacecraft, there has been a movement among people who could not afford to pay for the launch of a large spacecraft to find ways to innovatively use small, commercially available components to create very small spacecraft,” Petro says. “This is a distinct new field where we felt NASA could make a big contribution.”

The Small Spacecraft Technology Program launched in 2011 and within a year had its first major project underway: the PhoneSat, a demonstration of how off-the-shelf consumer electronics could serve as the basis for a new space mission. Two first-generation PhoneSats, named Graham and Bell, flew on that April 2013 mission, carrying radios, extra batteries, minimal instruments and Android smartphones that functioned as onboard computers. In keeping with the Silicon Valley maxim of “release early, release often,” a second-generation PhoneSat, called Alexander, was also launched on the same mission, sporting solar panels for longer operation and a later-model smartphone. The PhoneSat project proved that, rather than always engaging in the costly, time-consuming process of custom-designing solutions for missions, engineers can turn to commercially available technologies as potential, cost-effective alternatives. The mission won the Popular Science 2012 Best of What’s New Award for innovation in aerospace.
“There is always going to be a place for larger spacecraft, but the smaller ones are finding new niches where they can contribute to collecting information about specific kinds of scientific phenomena and perhaps [provide the impetus for] new kinds of missions we haven’t considered before,” Petro says.

“The space program belongs to everyone.”

In addition to PhoneSat, the Small Spacecraft Technology Program has added three missions to further demonstrate the capabilities of small spacecraft. The Integrated Solar Array and Reflectarray Antenna (ISARA) satellite will use the back of its solar array as a reflector for its radio antenna, significantly increasing the amount of data the CubeSat can send back to Earth. “One limitation of very small spacecraft is the amount of data their communication systems can actually transmit,” says Petro. “This mission will boost that capability by several orders of magnitude.” The Optical Communication and Sensor Demonstration (OCSD) mission will demonstrate optical communication technology that uses lasers to transmit information, as well as navigation sensors that use the same technology as a computer mouse and ranging radar that uses the same technology found in cars that warn drivers when they are about to back into something. The mission will “not only help the small spacecraft world but space operations in general,” Petro says. The final project, the Cubesat Proximity Operations Demonstration (CPOD), will fly two small spacecraft that will maneuver around each other and demonstrate docking in orbit.

And as if that isn’t enough, the program has issued two public solicitations for small spacecraft technology development and small spacecraft propulsion and Earth return vehicles. Motivating these efforts in part is an agency-wide desire to involve the public as partners in space research and exploration.
“The space program belongs to everyone,” says Petro. “What we are doing is for the benefit of the public as a whole, and it makes sense for people to be able to participate and for NASA to take advantage of what they can offer.”

Petro notes that the small spacecraft movement has made access to space easier and more affordable; a PhoneSat, for example, costs about $3,700 for parts and assembly.

“For a few thousand dollars, anyone with know-how can build a satellite,” says Petro. “This has opened space up to universities, small businesses, and others that would never have considered that building and flying a spacecraft is something they can do.” Those opportunities return benefits to NASA as well, he explains: “It is a tremendous value to NASA, in terms of developing our workforce, and to industry across the country that there are people graduating from college now who have built and flown a spacecraft. This is something that never would have been the case a few years ago.”

According to Petro, the Small Spacecraft Technology Program is representative of how NASA and the federal government have responded to the need to develop new technology not only for the space program but for the nation, because “every field benefits from these advancements.”

“There is a new emphasis on developing technology at NASA, and that is going to enable us to do things that have never been done before.”
TAPPING THE SOURCE

SMALL BUSINESS INNOVATION RESEARCH

A pair of NASA partnership programs adds fuel to the national, innovation economy while generating technological solutions for the Agency’s mission needs.
What do we know about small businesses?” Rich Leshner asks.

We know they are the starting point for great entrepreneurs and innovators. We know they can be flexible and that even with limited resources they have the agility to pursue big, risky ideas.

We know they’ve produced radiation filters for satellites staring at the sun—along with advanced vortex hybrid-fuel rocket engines, nanofiber filtration media for recycling water in space, and inflatable concentrators for gathering solar energy.

These disparate technologies span a wide range of NASA mission needs, from space and Earth sciences to propulsion to human spaceflight. But they are all products of NASA collaboration with small businesses through a pair of programs that, while not new, are taking on new significance as NASA pushes the boundaries of space exploration.

“Small businesses are the drivers of job creation and economic growth and innovation.”

Leshner knows a few things about the value that small business represents for both NASA and the nation. He’s the program executive for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. Established by Congress in 1982 and recently reauthorized, the programs are now managed under NASA’s Space Technology Mission Directorate (STMD) and constitute what Leshner calls “an invaluable source of early stage technology development.”
“Where a need for ideas combines with an opportunity to invest money to explore those ideas and build out early-stage prototypes—that’s where the SBIR and STTR programs come into play,” Leshner says. “We invest in companies that, in many cases, are proving out technologies and concepts for the first time to determine their feasibility and benefit to NASA’s missions in the future.”

The SBIR program creates partnerships between NASA and small businesses with 500 or fewer employees. These collaborations invigorate technology development and target technology gaps in NASA missions. The smaller STTR program facilitates the commercialization of technology developed by research institutions such as universities by pairing them with entrepreneurial small businesses. Each year, NASA solicits proposals from the small business community across a broad range of innovative research topics. In both of these highly competitive programs, businesses that are awarded contracts enter into a three-phase system designed to shepherd new technologies from the early stages of development through commercialization of products with applications beyond NASA’s mission needs. This year, despite a tight fiscal environment, the programs selected 295 proposals from 216 small businesses, with potential resulting contract awards amounting to $38.7 million. On tap for development
are advanced spacesuit life-support systems, new unmanned aerial vehicles for environmental monitoring and Earth science, a small-satellite launch system, supersonic flight innovations for reducing aircraft drag and increasing fuel efficiency, and much more.

“Small businesses are the drivers of job creation and economic growth and innovation,” says Leshner. Through the SBIR/STTR programs, NASA infuses small businesses with early investment capital, leading to the addition of new jobs and the expansion of operations. The programs also help companies to maintain ownership of the intellectual property they develop during their contracts, providing opportunities to cultivate technology portfolios ripe for commercialization and licensing.

“Our scientific and engineering contributions to NASA programs ... all began with SBIR awards.”

Such has been the case for Intelligent Automation Inc. (IAI), based in Rockville, Md. The company has developed a diverse offering of products and services through multiple SBIR contracts with NASA centers.

“NASA’s SBIR program has provided irreplaceable support for our company’s growth and development,” says IAI Chief Executive Officer Joseph Schwartz. “Our licenses and products in agent-based software, communications and rehabilitation medicine and our scientific and engineering contributions to NASA programs in air-traffic management, environmental data collection and UAS [Unmanned Aircraft Systems], among many others, all began with SBIR awards.” Through the SBIR program’s support, Schwartz says, “IAI has provided key
technology contributions to programs and products throughout government and industry while confidently growing its staff and business base.”

“By being responsive to NASA’s needs, small businesses have the chance to explore their own capacities for developing cutting-edge research,” Leshner observes. Meanwhile, he notes, NASA gains the benefits of “tapping into an innovative and entrepreneurial culture.”

These benefits extend beyond the generation of new ideas and approaches to aerospace challenges. As SBIR/STTR-developed technologies mature, says Leshner, “we are able to do more than just get an idea off the ground; we are able to invest in capability demonstrations that help move the technology closer to flight. What we see is a pool of technologies that over time become embedded in our mission architecture thanks to the early-stage, long-term investment of the SBIR and STTR programs.”

What do we know about small businesses? We know the positive outcomes of their partnerships with NASA contribute to industries nationwide, supporting diverse regions, promoting medical advances, aiding first responders, powering manufacturing and protecting the environment.

Those radiation filters for sun-observing satellites? We know that the same manufacturing technique used to create those filters is now being used by the Virginia company that developed them to create specialized parts for medical imaging devices. We know that the technology for the advanced vortex hybrid-fuel rocket engine was later adapted by its Wisconsin developer to create a revolutionary ultra-high-pressure system that firefighters can use to extinguish
a blaze in mere seconds. We know that the nanofiber filter a Florida company invented through its SBIR contract is now in use everywhere from industrial plants to water bottles. And we know that an Alabama company licensed the technology developed for inflatable solar collectors and applied it to a new design for inflatable antennas, which are ideal for providing emergency communications after disasters. In fact, new spinoff technologies emerge every year from the SBIR and STTR programs, benefitting both businesses and consumers and improving the quality of life here on Earth.

According to Leshner, the role of small businesses in helping NASA to redefine the limits of technology can only grow. “Putting technology, human spaceflight and science together to accomplish really interesting things is the future of what we are going to see from NASA’s big missions,” he says. “STMD is getting off the ground at the same time NASA is pioneering this new kind of mission approach. I think we are going to see a lot more of this in the future, and it will be to the advantage of the agency and the nation. And we are going to get more and more out of the SBIR and STTR programs every year.”
A MATERIAL DIFFERENCE

WITH THE HELP OF NASA’S SMALL BUSINESS INNOVATION RESEARCH PROGRAM, A COMPANY HAS PIONEERED THE MANUFACTURE OF A MATERIAL POISED TO DRAMATICALLY IMPROVE BOTH AIRCRAFT PROPULSION AND MEDICAL IMAGING.

As a result of NASA research and an innovative partnership, the future of aeronautics looks bright, light and green, while the future of medical imaging looks more efficient and affordable—all thanks to one groundbreaking technology.

The division of NASA’s Fundamental Aeronautics program called the Subsonic Fixed Wing Project expects to reach new heights during the decade of 2025–2035, reducing the environmental impact of air travel by developing new capabilities for cleaner, quieter and more fuel-efficient aircraft. One way NASA plans to reach
its aviation goals is by combining new aircraft designs with an advanced
turboelectric distributed propulsion (TeDP) system.

A NASA innovation has led to business-boosting cost savings for American manufacturers.

“The TeDP system consists of gas turbines generating electricity to power a large number of distributed motor-driven fans embedded into the airframe,” says Jeff Trudell, an engineer at the Glenn Research Center.

TeDP promises many advantages but requires advanced technology to support it. “While room-temperature components may help to reduce emissions and noise in a TeDP system, cryogenic superconducting electric motors and generators are essential to reduce fuel burn,” says Trudell.

NASA APPLICATIONS, COMMERCIAL OUTCOMES

In 2001 a material called magnesium diboride (MgB2) was discovered to be superconducting. Since then, the challenge has been learning how to manufacture MgB2 wire inexpensively and in lengths long enough to wind into large coils while still meeting the application requirements.
For more than a decade, Hyper Tech Research, which is based in Columbus, Ohio, has been working on the development of MgB2 superconducting wire. Early in the process, the company received funding from Glenn Research Center's *Small Business Innovation Research (SBIR) program* to investigate the potential for using MgB2 in motors and generators for turboelectric aircraft propulsion systems.

“At the time we made the coils for NASA, they were probably the longest length MgB2 wires and highest-performing MgB2 coils anyone had made in the world,” says Hyper Tech president Mike Tomsic. According to Tomsic, the NASA projects helped his company to advance MgB2 to the point where it could be used for commercial products.

**FROM AIRCRAFT ENGINES TO MRIS**

Hyper Tech has received funding from the National Institutes of Health, the Department of Energy, and others to apply MgB2 superconducting wire in the design of magnetic resonance imaging (MRI) devices. Most MRIs generate a strong magnetic field by means of superconductors, which allow for the highest-quality imaging. By using MgB2 wire for MRI background coils, the company hopes to help MRI manufacturers drive down the cost of MRI machines. “That’s the number one application for MgB2 wire,” says Tomsic. “We have programs with Siemens and General Electric working on developing replacement magnets for their existing MRI background magnets.”
Since 2003, the company has grown from 8 to 27 employees, with 16 employees involved in MgB2 superconductor-wire research and fabrication. The company has also increased its revenue from approximately $1 million to $5.4 million, with $3 million attributable to MgB2 superconductor wires and coils.

Applications for Hyper Tech’s spinoff technology continue to multiply. Among the latest is a lightweight generator to be used in offshore wind turbines.
A CUTTING-EDGE PROPULSION SYSTEM SUPPORTED BY NASA’S SMALL BUSINESS INNOVATION RESEARCH (SBIR) PROGRAM LEADS TO A REVOLUTIONARY ADVANCE IN THE PRACTICE OF FIREFIGHTING.

Much deserved attention is given to the feats of innovation that allow humans to live in space and robotic explorers to beam never-before-seen images back to Earth. A single technology makes all of these accomplishments possible: rockets.

Since its founding in 1960, the Marshall Space Flight Center has been at the heart of the agency’s rocketry and spacecraft propulsion efforts. Today, Marshall hosts innovation in rocket and spacecraft propulsion at state-of-the-art facilities such as its Propulsion Research Laboratory in Huntsville, Ala. Like many of its
past successes, some of the Center’s current progress is being made with the help of private-industry partners. These collaborations have led not only to new propulsion technologies but also to terrestrial benefits in seemingly unrelated fields—in this case, the realm of firefighting.

SMALL BUSINESS, BIG SOLUTIONS

Orbital Technologies Corporation (ORBITEC) of Madison, Wis., has been a longtime NASA partner, working with the agency on numerous projects—many through the Small Business Innovation Research program—from growing crops in space to advancing rocket engines.

Rory Groonwald, chief engineer for HMA Fire, an ORBITEC subsidiary, saw an unimagined potential in ORBITEC’s propulsion technologies. “We were trying to make something more effective and safer for firefighters to use,” says Groonwald. After seeing how ORBITEC managed high-pressure flows in its rocket-engine design, he began to think about managing high-pressure water flows in the same way. Working with ORBITEC, HMA adapted elements from its SBIR propulsion technologies and incorporated them into a new fire-suppression system that utilizes ultra-high pressure (UHP) for firefighting.

HMA’s propulsion-inspired design introduces an approach to fire suppression that is complementary and, in a number of cases, superior to traditional firefighting methods.

A series of tests using empty houses at Vandenberg Air Force Base compared an HMA system with a 20-gallon-per-minute, 1400-pound-per-square-inch (psi) discharge capability (at the pump) versus a standard 100-gallon-per-minute, 125-psi standard hand line—the kind that typically takes a few firemen to control. The standard line extinguished a fire set in a living room in 1 minute, 45 seconds using 220 gallons of water. The HMA system extinguished an identical fire in 17.3 seconds using 13.6 gallons—with a hose that required only one person to manage.
In addition to rapidly extinguishing a fire, HMA’s UHP system also quickly reduces the temperature around a blaze, in the case of the Vandenberg test from 1400°F to below 250°F within 60 seconds, about 2.5 minutes faster than the standard equipment. The system also results in less smoke.

“What this does is create a safer environment for the firefighters to conduct an offensive suppression attack on the fire,” says Groonwald. Using less water also reduces one of the major sources of damage from a fire event: the water itself.

**INSTANT CREDIBILITY**

While HMA’s systems are not intended to replace standard firefighting technology in all cases, they can be installed on fire trucks as a first-response tool that complements traditional low-pressure, high-volume systems.
“Our systems become a force multiplier,” says Groonwald. “You can do more safely with the same amount of people.”

Government partnerships like those between HMA and ORBITEC, NASA, and the Air Force have supported research and development leading to the creation of these game-changing firefighting tools, says Marty Gustafson, ORBITEC engineer and applications research manager.

“This is where the government-industry partnerships make a difference,” she says. “They allow you to prove out a technology in a way that gives you instant credibility.”
“All throughout my career, I’ve worked on hardware and software to solve problems,” says Michael Gazarik. “I worked on Navy submarines, in the telecommunications industry, on weather satellites, always trying to make a system work or work better.” Now, 10 years into a NASA career that has earned him NASA’s Outstanding Leadership Medal and the Silver Snoopy Award—one of NASA’s highest honors—Gazarik has taken the lead at the agency’s new Space Technology Mission Directorate (STMD), where he is charged with developing a culture of innovation within NASA and nationwide that will foster the next generation of NASA space missions while also providing solutions to major challenges here on Earth.

Gazarik discusses the bold vision for technology development that NASA is executing through STMD; the essential role of risk and failure in shepherding truly innovative concepts from research labs and clean rooms into actual, unprecedented space missions; and how the mission directorate is partnering with the nation’s universities to cultivate the innovators of the future.
• **NASA has been making incredible advances in technology for decades.** But if we look at humans’ desire to explore deep space, we recognize that we’ll need a few things to be able to do that. We’ll need a *heavy-lift rocket,* and we’re working on that. We’ll need a *human-rated capsule,* and we’re building that. We’ll need a place in space to live and operate; we already have that in the *International Space Station.* **We know we’ll need a host of new technologies in order to explore and really thrive in deep space.** And what we’re seeing in the creation of STMD is a renewed focus on technologies that are applicable as solutions not only for the agency but also for the nation.

• We also see a **renewed focus on connecting with academic institutions and with the brightest minds that we have in the nation.** We have graduate students from over 70 universities working side by side with researchers in NASA labs. We have over 400 activities throughout the mission directorate designed to engage faculty and students. Getting young innovators to identify and attack the challenges we face is a key part of STMD.

• All of our programs have a competitive element. **That’s how we get the best ideas, inside and outside of NASA.**

We are reinvigorating that culture of risk and reward.

• We’ve had a growing budget these past couple of years, which I think reflects the recognition that the work we do at NASA benefits the nation as a whole. **When times are tough, it’s time to invest.** As in the stock market—the time to buy is when the market is down. Investing in technology development increases overall productivity while creating more capable and more cost-effective space missions. **You just have to be bold.**
• A dollar invested by the agency in high-tech innovation generates multiple dollars within the economy, and that, in turn, generates jobs. There are cascading positive effects.

• Sorting science fiction from real, transformative breakthroughs is a tricky process. To do it effectively, we use a very project-focused approach, carving up what we need to accomplish into manageable segments. So at the early stage, we make a small investment that may or may not pay off. When we reach the point where a demonstration in space is necessary, then the project becomes larger and requires more funds. By that point, however, we have developed a high degree of confidence that the idea will work.

• Failure is not an option in human spaceflight. But if you want to have breakthrough technology, you must be willing to incur some technical risks. The history of invention and technology development has demonstrated this principle again and again. Within NASA we are reinvigorating that culture of risk and reward. We are transitioning our workforce, both inside and outside the agency, from space-shuttle operations to laboratory research
In this business, if you want to develop truly innovative technologies, you must be able to tolerate and embrace setbacks. They are going to happen, and if they don’t, are you really pushing the envelope?

What are the shared characteristics of high-performance teams? They typically include a small number of innovators who work quickly, efficiently, and don’t require a lot of resources. Success has to do with communication and creating an environment where everyone can participate and knows what to do. You may not be able to build a space shuttle or a space station this way, but there are many technology demonstrations that can be executed using this kind of approach.

Over the years, NASA has developed a tremendous amount of technology that has made life better for everyone on planet Earth. Right now we’re doing exoskeleton work down at Johnson Space Center, producing wearable hardware to assist crewmembers with movement in low-gravity environments. It’s kind of like Iron Man. We’re also working with the Veterans Administration to see if this technology could be used by some of our wounded soldiers. Making that technology real and helping some of our nation’s heroes to walk on their own again is incredible to me.
• **What am I looking forward to?** We have a humanoid robot on board the ISS called *R2*. Working with the station crew, R2 has begun to perform some mundane tasks using his arms and his eyes. We’re sending up his legs later this year, so R2 will soon be mobile. Out at China Lake in California, we’re testing inflatable aeroshells that spacecraft will someday use to land on other planets, like Mars. We will also be flying demonstrations of *small spacecraft* called CubeSats. The world’s largest supersonic parachute, optical laser communications, high-power *solar electric propulsion* capable of redirecting and relocating an asteroid—these are just a few of the technologies we’ll need to explore deep space, and I look forward to seeing all of them as part of future NASA missions.