Dear Readers,

It was a mere 55 years ago that President Dwight Eisenhower established the National Aeronautics and Space Administration. Over the course of the agency's history, technology has enabled amazing science and exploration missions, from sending humans to the moon to landing the Curiosity rover on Mars. In the process, it has expanded our knowledge of the universe and benefitted humankind.

Today is no different. Investments in technology are essential for humanity to extend its reach and realize future NASA missions.

It is for this reason that the agency has elevated its Space Technology Program to its newest mission directorate, re-emphasizing the vital importance of developing the broadly applicable, pioneering technologies and capabilities needed for the next generation of space operations.

I'm proud to introduce you to the new Space Technology Mission Directorate (STMD), which will focus on technology development, demonstrations, infusing technology into future exploration and science missions, proving the capabilities required by the aerospace community, and stimulating the nation's innovation economy.

It's an exciting time to be working on technology at NASA, as you'll see in the pages of our first digital issue of Technology Innovation. We've brought this publication back in electronic form as a quarterly e-zine in order to enhance its interactivity, portability and accessibility. Here we'll highlight the revolutionary work of NASA technologists and innovators across the nation.
I invite you to help us relaunch this publication by competing in our contest to rename it. To participate and win a chance to be featured in the e-zine, email your suggestions for the magazine’s new title to HQ-SpaceTech@mail.nasa.gov. Seize this opportunity to make your mark at NASA!

Since 2012 was such a groundbreaking year for Mars exploration, we’ve devoted this issue to coverage of a few of the innovators and technologies that contributed to this achievement.

I look forward to sharing the successes and challenges of developing bold, transformational technologies that will someday take humans to Mars and beyond.

Cheers,

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

TIME FLIES
MEDLI

TAILOR MADE
Woven Thermal Protection Systems

INNOVATION WITHOUT BORDERS
International Space Apps Challenge

PHOTON EXPRESS
Optical Communications

SPINOFF HIGHLIGHTS

A HOT IDEA
Emisshield

THE EVOLUTION OF FLIGHT
Tao Systems

INSIGHT

with NEIL CHEATWOOD
Principal Investigator for Planetary Entry, Descent and Landing
NASA Langley Research Center
Using cutting-edge technology to gather data that will make future Mars missions a reality.
It was past 1 a.m., and the night had the feel of a blockbuster movie premiere. About 300 people were packed into the IMAX theater at the Virginia Air and Space Center in Hampton, their attention riveted on an event happening millions of miles away. The IMAX screen glowed with a live feed of a pivotal moment in one of the agency’s most ambitious missions to date—the landing of the Mars Science Laboratory (MSL) and its payload, the Curiosity rover.

Michelle Munk, an engineer at NASA’s Langley Research Center and emcee of the gathering, was doing her best to keep her excitement under control; but her heart was pounding and her cell phone buzzed continually with text-message updates from colleagues in California who were monitoring the landing from NASA’s Jet Propulsion Laboratory (JPL). While a global audience had followed the development and launch of Curiosity, comparatively few people were aware of a separate project tied to the mission—one with profound ramifications for the future of robotic and human space exploration.

As the deputy project manager for the Mars Science Laboratory Entry, Descent and Landing Instrument (MEDLI), Munk had spent 6 long years immersed in this project, which is why it seemed so odd that those final minutes of Curiosity’s
journey slipped by so quickly. No time at all seemed to pass between notification of the spacecraft’s cruise stage separation and the two words Munk had been waiting to hear: MEDLI thermal.

To understand the meaning of that cryptic phrase, we must first grapple with a fundamental problem of space exploration: When nearly every mission is a unique endeavor, how can we know with any certainty what to expect? Take Curiosity. Predicting precisely how its landing on the Red Planet would play out presented perhaps the biggest challenge of the entire mission. Naturally, NASA engineers used every possible resource to minimize the risk—data about the Martian atmosphere, aerodynamic testing in wind tunnels, thermal testing in arc-jet facilities, and computer models designed to simulate any condition Curiosity might encounter.

But key information was lacking: actual flight data from entry into Mars’s thin atmosphere. Without real-life mission data for comparison, it was difficult to validate computer or ground tests; nor could planners know the answers to such crucial questions as whether the spacecraft was carrying too much thermal protection or too little. Too much protection would mean excess costs and weight that could have been allocated to useful scientific instruments; too little would mean that the spacecraft could burn up as it entered the Martian atmosphere.

“When we fly a vehicle to Mars, we design in a lot of margin to accommodate for the unpredictability of the circumstances,” explains Munk. “We had little to no feedback from any of the previous Mars entries. It’s like taking a pass/fail test. You’ll know if you passed or failed, but you won’t know if your grade was an A+ or a C–.”

NASA had outfitted a number of previous missions—Apollo, Viking, the space shuttle orbiters, Pathfinder—with sensor systems in order to collect aerodynamic flight data. But, as Curiosity demonstrates, the agency has plans for bigger,
heavier, more complex Mars missions, including those that will carry the first humans to the Martian surface. To ensure the safety and success of these future undertakings, planners will require all the actual mission data they can possibly collect.

“For Mars missions, the better we understand the environment we’re flying through and how well we are predicting things on the ground, the better we can design human missions,” says Munk. “If you look at Curiosity, that was basically 2,000 pounds we sent to the Martian surface. For humans we would need a spacecraft somewhere around 80,000 pounds. Until we understand what our margins are, we can’t really quantify the risk. And it’s that risk quantification that we will need before we can convince ourselves that it really is safe to send humans to Mars.”

Which is why, in 2006, Munk and a team of engineers from Langley, JPL, and NASA's Ames Research Center in Moffett Field, Calif., began work on an effort to fill that void: the Mars Science Laboratory Entry, Descent and Landing Instrumentation suite, or MEDLI. A collaboration not only among NASA centers but among the Human Exploration Operations, Science, and Aeronautics mission directorates, as well as the Space Technology Mission Directorate, MEDLI made
innovative use of MSL's lower aeroshell—the flattened cone base of the spacecraft covered by a thermal protection system (TPS)—to affix an array of sensors designed to provide more and higher-quality Mars entry data than all previous Mars missions combined.

MEDLI thermal. The words Munk was so glad to hear were the first of several “tones” that Curiosity beamed back to Earth as indicators of its progress during its harrowing descent onto Mars. The tones meant not only that Curiosity was alive and well but also that MEDLI’s first set of sensors, seven thermal stacks called MSL Integrated Sensor Plugs (MISPs), embedded in Curiosity’s TPS, had begun collecting data. Made of the same material as the heat shield itself, the sensors acquired data on the aerothermal environment as well as on the heat shield’s performance during Curiosity’s entry.

As the TPS began to char and melt under the intense heat generated by gases flowing around the spacecraft at five times the speed of sound, a recession sensor in each MISP also burned away, providing data points that mapped out how much of the heat shield was lost and how quickly. This information is essential to the design of future spacecraft and the amount of thermal protection they will need.

Also ensconced in the aeroshell was MEDLI’s second sensor set, the Mars Entry Atmospheric Data System (MEADS). These seven pressure transducers, connected by stainless steel tubes to holes drilled in the heat shield, measured pressure
changes over the aeroshell, indicating not only the spacecraft’s path and aerodynamic performance but also the force of Martian winds and the density of its atmosphere. The information gathered by MEADS and MISPs flowed through SSE with some of it transmitted back to Earth during the descent and some stored on board Curiosity for delivery after landing.

Max dynamic pressure. Max heating. Parachute deploy.

That last tone indicated to Munk that MEDLI had reached its end—6 years of hard work culminated as the spacecraft’s parachute snapped open and its heat shield was jettisoned, taking MEDLI with it. There had been a lot of headaches over the course of the MEDLI project, such as failed vibration tests and sets of pressure sensors that stopped working. “There were lunches where we’d ask each other, ‘Is anything going to go right?’,” says Munk.

Just a few days after the world celebrated Curiosity’s successful landing, the MEDLI team had its own reason to celebrate. The team received the entire MEDLI dataset—all 1.3 megabytes of it—which constitutes yet another example of how good things come in small packages.

“Our data is incredibly wonderful, better than we expected,” Munk says. Though the information is still being evaluated, Munk notes, “we are learning that our aerodynamic databases are very good. The capsule flew exactly the way we expected.” Conversely, she says, the data show a lower maximum temperature of the heat shield and less loss of TPS material than had been expected. “We’re
learning more details about the aerothermal environment, how the flow around the aeroshell becomes turbulent and how that affects heating on it,” she says. “These data can help us update our predictions for the next time.”

And that is what MEDLI was all about—the next time. “We’re making measurements for the future,” Munk says. The device was the first of the Technology Demonstration Missions (TDM) to fly in space. An initiative of the Space Technology Mission Directorate, TDM is designed to bring advanced technologies to flight-ready status in support of the agency’s increasingly bold and demanding missions.

“The Space Technology Mission Directorate is giving structure for new ideas to get started in a much more widespread way than we’ve had at NASA in the past,” says Munk.

Following the mission success, Munk is focused not only on what the project’s data can provide for future missions but also on what benefits the next generation of similar systems can offer.

“We’re hoping to fly similar instrument suites on all upcoming missions,” Munk says, which includes vehicles returning to Earth. The MEDLI team is now working on instrumenting the Orion Multi-Purpose Crew Vehicle (MPCV), NASA’s next piloted spacecraft. The data collected by MEDLI and its successors may well help to show the way forward for the next era of NASA’s exploration of the universe.

It was for this reason that, on that special night in Virginia, as 300 spectators cheered Curiosity’s triumphant landing, Munk had a “bittersweet” feeling: bitter because a great deal of hard work now lay as artifacts in the Martian soil, but sweet because she knew it was just the beginning.
TAILOR MADE
WOVEN THERMAL PROTECTION SYSTEMS

The innovative application of an age-old technology may soon enable future space missions.
When Ethiraj Venkatapathy was an aerospace-engineering graduate student working at NASA’s Ames Research Center, his mentor told him—with a note of awe in his voice—about the Galileo mission.

Launched in 1989 to study Jupiter and its moons, the Galileo orbiter sent an atmospheric probe hurtling into the gas giant to gather unprecedented data about its composition. The probe plummeted through the atmosphere at 106,000 miles per hour. As it descended, the only protective barrier between the probe’s delicate scientific instruments and the 30,000 watts per square centimeter of annihilating heat flowing around the probe was a specialized thermal protection system—a heat shield. When it was deep enough in, the probe deployed its parachute and, for 58 precious minutes, collected data on the Jovian weather.

Planets do not provide visitors with easy access.

Galileo and many other NASA missions have been designed with a fundamental problem in mind: Planets do not provide visitors with easy access. As a spacecraft descends at high speed into a planet’s atmosphere, the friction caused by the hypersonic flow of gases around the spacecraft’s hull generates blazing heat that would vaporize an unshielded vehicle in seconds. Without the innovative development of thermal protection systems (TPSs) that reflect most of the heat and absorb the rest, many NASA missions would end in flames and ash.

Venkatapathy describes it this way: Imagine a vehicle such as the space shuttle reentering Earth’s atmosphere at nearly 5 miles per second. The temperature a few inches from the outer surface of the vehicle can be as high as 10,000 °F,
while the temperature of the surface itself reaches nearly 3,000 °F. Inside the vehicle, mere inches from this blistering heat, the astronauts need to remain comfortable and the cargo protected. In this imagined scenario, the shuttle is merely returning from low-Earth orbit; actual spacecraft returning from the moon or from more distant planets reenter Earth’s atmosphere at even higher speeds and endure much higher heating.

Venkatapathy, now chief technologist for the Entry Systems and Technology Division at Ames, investigates ways of preventing the catastrophic thermal effects of entry to a planet’s atmosphere. NASA missions large and small have implemented various solutions. The TPS for the Apollo Crew Module was a fiberglass honeycomb that was hand-filled with resin. The space shuttles employed a reusable, lightweight yet fragile system of tiles composed of several materials and blankets. The Sample Return Capsule (SRC) from the Stardust spacecraft, which reentered Earth’s atmosphere at a record 8 miles per second, used an Ames-invented TPS material called Phenolic Impregnated Carbon Ablator (PICA), as did the Mars Science Laboratory (MSL) for its recent landing on the Red Planet.

According to Venkatapathy, “For every NASA mission up to this point, the TPS [has been] unique to that mission.” A TPS that works for one mission may fail on another. Each kind of TPS material has its limitations, and some require hand-crafting, which introduces an element of human error into a system that cannot afford a single flaw.
Then there is the issue of sustainability. Because NASA missions are infrequent and have unique needs, it is a challenge to maintain the supply of a particular TPS material. (Take, for example, the carbon phenolic TPS that allowed the Galileo probe to survive a veritable inferno: due to a lack of steady demand, Venkatapathy explains, this type of heat shield is no longer made.)

“NASA’s future missions are going to be more demanding,” says Venkatapathy. “Can we develop a TPS material that is sustainable? Can we develop a single material that is scalable to fit any vehicle, to meet any mission need?”

In response to these questions, Venkatapathy; his Ames colleagues Don Ellerby, Mairead Stackpoole and Jay Feldman; and researchers at NASA’s Johnson Space Center in Houston, Langley Research Center in Virginia and Glenn Research Center in Cleveland are working together on a new way to use an age-old technology. This collaboration could result in thermal protection as fitted for each spacecraft as a bespoke suit.

The idea for this innovative solution originated with a space umbrella. Venkatapathy and his colleagues were studying the use of carbon fabric that would unfold in umbrella-like fashion to create a heat shield for spacecraft descending to Mars.
They began to wonder if woven materials could form the basis for a new, highly customizable approach to TPS.

Though weaving has existed since ancient times, the textile industry of today has developed in exciting ways. “The weaving industry does amazing things,” says Venkatapathy. “They can weave all kinds of things, including an entire aircraft fuselage or wing structures.” Partnering with textile manufacturer Bally Ribbon Mills, based in Bally, Pa., the researchers developed three-dimensional woven mats incorporating TPS materials, which were interlaced like different-colored threads in a carpet.

“There are thousands of ways we can weave the materials. It provides us an opportunity to tailor the TPS, just like we weave clothes and tailor them to fit the person,” Venkatapathy says. Using automated weaving machines to produce the TPS eliminates the potential for human error, and partnering with the commercial textile industry solves the sustainability problem.

“A key part of what we are trying to do is leverage capabilities that exist for commercial applications,” said Ellerby, chief of the Entry Systems and Vehicle Development Branch at Ames. “This helps us maintain these capabilities for NASA missions in the future.”

The first samples of woven preforms were manufactured by Bally Ribbon Mills and infused with resin to form the TPS. NASA tested them by subjecting the forms to the withering blast of an arc jet in order to simulate the extreme heating conditions that a spacecraft would encounter during high-speed entry into the atmosphere of
Venus or Saturn. The tests were a stunning success; the samples’ performance compared well with that of the Galileo TPS. One facility researcher at the U.S. Air Force’s Arnold Engineering Design Center in Arnold, Tenn., where the samples were tested, termed the outcome a “remarkable feat” that demonstrated a rate of success he had never before witnessed during his long tenure.

“The feeling was something like, ‘We have an invention here.’ We knew we had something good,” says Venkatapathy. Since launching the woven TPS project just over a year ago, the team has already successfully tested 17 different materials—some dry like the original sample, others impregnated with resin. Like the Apollo honeycomb TPS and the PICA material, these woven TPS solutions are ablative, meaning they disperse the heat of atmospheric entry by charring and melting. While not reusable, the woven TPS is economical to produce and readily available, thanks to the leveraging of the commercial textile industry.

“We are looking at a technology that will sustain itself for the next 50 years, for missions we know of now, and for missions we are not even thinking about today,” says Venkatapathy. As testing and expansion of woven TPS continues, the technology is already being incorporated into parts of the Orion Multi-Purpose Crew Vehicle (MPCV), set for its lunar test flight in 2017. The team is aiming to make woven TPS ready for mission insertion before the end of 2013.

Fostering this kind of mission-enabling, cost-reducing and quick-developing innovation is a primary goal of the Space Technology Mission Directorate’s Game Changing Development (GCD) program, which is funding the woven TPS research. “The Game Changing Development program is going after high-risk, high-payout challenges. When I say risk, I mean educated risk,” Venkatapathy says.

The opportunity to take on these challenges is one of the reasons why Venkatapathy still works in the same office at Ames that he joined as a graduate student more than 30 years ago. He chose to study aerospace engineering because of its cross-disciplinary nature, the way in which it weaves together elements of multiple scientific and engineering fields. At NASA, he sees a similar meshing of talent,
expertise and resources across the agency and, through innovative partnerships, across industries as well.

At the moment, all of that is coming together in small samples of woven TPS, a technology that mere months ago did not exist but now promises to support a future of far-ranging space exploration.
Through the International Space Apps Challenge, NASA’s newest partner in space exploration could be you.
It may be that crewmembers aboard the International Space Station (ISS) will one day—while inhaling the luxurious, comforting scent of freshly baked bread—mark April 22, 2012, as a turning point in the effort to make life in space more like life at home. That Sunday, in Oxford, England, NASA project manager Nick Skytland bumped into a young man named Sam Wilkinson.

“Do I have time to tackle another challenge?” Wilkinson asked.

Skytland checked the time. It was the second and final day of the International Space Apps Challenge—a unique, globe-spanning collaboration bringing together teams of programmers, engineers, students and just about anyone else interested in joining with NASA for 48 hours to tackle some of the important problems in space exploration. At that moment, linked via the Internet and a shared belief in the power of small contributions to create big outcomes, citizen innovators in 25 locations scattered across all seven continents were toiling feverishly to develop solutions to more than 70 challenges related to the exploration of space and the improvement of life on Earth.

Wilkinson wanted to take a crack at a method for making bread in space. Like many other tasks taken for granted in our daily lives, baking bread is far more complicated in space than it is on Earth. Baking requires significant energy that cannot be spared, and bread creates crumbs that could float into and disrupt a spacecraft’s delicate electronics. (This is why ISS crewmembers must make do with tortillas.) Skytland was skeptical about Wilkinson’s chances of revolutionizing space-based baking. The student was only 16 years old and was working on his own.
And he had less than 4 hours to find a way.

The International Space Apps Challenge is the brainchild of Skytland and his colleagues Chris Gerty, astronaut Ron Garan and Kristen Painting of NASA; Ali Llewellyn, Sean Herron and Samantha Snabes of Valador, Inc.; and William Eshagh of Dell, Inc. The idea was inspired by Random Hacks of Kindness (RHoK), an international hackathon that challenges participants to develop open-source solutions to real-world problems. Sponsored by NASA, Microsoft, Yahoo!, the World Bank, HP and Google, RHoK has been a repeat success—but it is not focused on meeting the needs of NASA’s space exploration objectives, according to Skytland. His team saw the potential in creating a similar event with twin goals: to develop technologies that will advance space exploration and to implement NASA technologies that can improve life on Earth.

“We wanted to see if we could apply the concept of a non-monetized collaboration, like an international hackathon, to needs NASA might have,” says Skytland.

A North Dakota native, Skytland was drawn to NASA more than 10 years ago by the allure of state-of-the-art technology and, of course, astronauts. He got his start at the agency training astronauts for extravehicular activities—spacewalks—through underwater exercises in the Neutral Buoyancy Laboratory.

“After I arrived at NASA, I realized many of the things I had heard about the agency were true. There were really smart people, and they were working on truly cutting-edge technologies. I also realized that the only reason more people weren’t involved in what NASA was doing was that we were taking an old approach in that you had to actually work for NASA to make a difference,” Skytland says.
After earning a master’s degree from the International Space University, Skytland developed an interest in open-source software while working on a computational physiology model called the Digital Astronaut. His appreciation for the open-source movement—which encourages programmers to make their code freely available for use and to likewise make any new programs created with that code accessible to all—led to a leadership role in Open.NASA, the agency’s initiative to expand transparency and citizen participation and collaboration. The idea for an international hackathon centered on space exploration dovetailed perfectly with the Open.NASA plan and the ethos of open-source development.

**In only 48 hours, Challenge participants generated more than 100 solutions.**

“There are people all over the world who would do anything to be able to contribute to what NASA is doing, even if it is on a small scale,” Skytland says. “Could we give individuals around the world an opportunity to contribute, no matter their background, expertise level, talent or skill, and then aggregate those contributions to develop relevant solutions for NASA? That is the whole concept for the International Space Apps Challenge.”

Relying on their diversity of talent and experience, social-media networking and a healthy dose of stubborn persistence, Skytland’s small team promptly recruited 125 volunteers to organize collaborative events in 25 cities from San Francisco to Oxford to Nairobi. Challenges were identified in four categories—software, hardware, citizen science and data visualization—and included such problems as delivering NASA data to the public more effectively, enhancing navigation for
robotic spacecraft and, yes, baking bread in space. The inaugural Challenge, launched in April 2012, drew more than 2,000 participants from all seven continents, including researchers at McMurdo Station in Antarctica as well as crewmembers aboard the ISS.

The outcomes, Skytland says, exceeded all expectations.

In only 48 hours, Challenge participants generated more than 100 solutions, many of which Skytland says were “far better than we could have imagined.” Quite a few of the solutions utilized data and content made public by NASA. Among the numerous highlights were an automated algorithm called VICAR2PNG, which translates data gathered by the Cassini spacecraft from the obsolete VICAR format to the widely used PNG format, making them more accessible to the public. “The app was able to render the images successfully and make videos from them, which gave new life to old data,” says Skytland. “There are potentially countless datasets at NASA that this solution can be applied to.”

One of the most successful solutions to emerge from the Challenge is the Pineapple Project. Designed by teams collaborating in seven locations, the software uses data from NASA and other government agencies to power a “recommendation engine” that helps farmers in underdeveloped countries to identify the crops that will grow best in their region, and it even suggests market prices.
The Ufahamu project, based in Nairobi, Kenya, is a data-visualization platform promoting health awareness (ufahamu is a Swahili word meaning “awareness”). The project provides data visualization from NASA and other sources to help improve health conditions in underprivileged communities.

Below: Number of Malaria cases by county

“Many people think what NASA does is separate from what the needs of the planet are,” says Skytland, “but the Pineapple Project is just one example of an outcome from the Space Apps Challenge that can really make a difference [on Earth]—using space data.”

Though six “winners” were chosen, no monetary prizes were awarded—only the satisfaction of contributing to the success of space exploration and to a better quality of life on our home planet. Skytland says the real benefit of the Challenge for NASA is a “community engaged in and excited about space exploration, thinking creatively and technologically and ready to apply that experience to challenges identified by the agency, all at a relatively low cost and on a short timeline.” The 2013 International Space Apps Challenge is already underway, with representatives of NASA and other international space agencies joining scientists and participants in using publicly released data to create solutions for
50 software, hardware and visualization challenges, including robotics, citizen science platforms and applications of remote sensing data. Twelve locations in the United States will host Challenge events, and 38 more events will be held in 30 other countries, at McMurdo Station in Antarctica and aboard the ISS.

“The whole idea of mass collaboration or crowdsourcing innovation makes a lot of sense in the Information Age,” says Skytland. “Through aggregation of a lot of small contributions, a big impact can be made, and no contribution is too small.”

In the waning moments of the 2012 International Space Apps Challenge, Sam Wilkinson ended up making his own contribution. Defying expectations, Wilkinson applied classroom chemistry to develop a low-power, low-resource method for baking bread in space. Skytland and Wilkinson hope to test this method on the ISS.

“It was pretty amazing that a 16-year-old who never had any NASA experience came up with something like this in under 4 hours,” Skytland says. “It shows what can happen when you don’t prejudge people’s ability to contribute real solutions.”
PHOTON EXPRESS

OPTICAL COMMUNICATIONS

THE FUTURE OF SPACE COMMUNICATIONS IS BRIGHT
On cloudy days, John Rush looks up and sees problems. Where some might try to find animal shapes in the fluffy white piles of cumulus or welcome a few overcast hours as a respite from a hot summer sun, Rush is reminded of a significant obstacle he must overcome.

“Clouds are our biggest enemy,” he says.

Rush isn’t suffering from a strange form of paranoia. As a NASA scientist seeking new ways to connect the agency’s Earth operations with its increasingly far-flung fleet of spacecraft, he has a legitimate reason for being troubled by cloud cover. In fact, Rush and his NASA colleagues are exploring a method of communication that could bring the universe home to Earth to a degree never before achieved. And clouds present only part of the challenge.

Space communications are the unsung hero of NASA missions—without it, Rush says, “there really would be no NASA.” Not only do reliable communication links enable NASA to control distant spacecraft, to remotely manipulate scientific
instruments and to receive data and images transmitted from deep space, but they also provide the agency with the means to diagnose and address problems that might otherwise lead to mission failure. NASA can even use communications to make direct scientific observations, for example, by studying variations in radio signals to determine the properties of a planet's atmosphere as the spacecraft passes through, or to detect invisible gravity fields.

Communication is key.

To put it another way, science and science fiction have always recognized the critical role of communication. Phasers and teleporters and warp drive are beyond cool, but what would the crew of the starship Enterprise do without their trusty communicators? How would Captain Kirk get Scotty to beam him up before whatever doomed planet he was currently stranded on imploded? Could the Enterprise rescue the planet’s remaining population if Lieutenant Uhura couldn’t pick up the distress signal? Communication is key to mission success, in the movies and in the real world.

John Rush serves as the Technology and Standards director in NASA's Office of Space Communications and Navigation (SCaN). NASA formed SCaN in 2007 to consolidate its space communications, tracking, telemetry and command services for its entire fleet of spacecraft. SCaN is charged with maintaining NASA’s current communications with missions ranging from the Curiosity rover on Mars to Voyager 1 at the edge of the solar system, and it is also responsible for innovating the next generation of space-communications technology.

In coordination with other NASA programs and international space agencies, SCaN is advancing the evolution of space communications by shifting the mode of information transfer from radio waves to beams of light.
Deep space optical communication, explains Rush, uses lasers to transmit data between a spacecraft and a ground station on Earth. The benefits of this technique over current radio-frequency (RF) transmissions are significant. For starters, optical communication allows for a greatly improved rate of data transfer, transmitting 10 or more times the amount of data that can be sent by RF in a given time period.

Take, for instance, the Mars Reconnaissance Orbiter (MRO), which is currently circling the Red Planet and delivering stunning high-resolution images of the Martian terrain. MRO's maximum data rate—the highest among all Mars missions—is 6 megabits per second. If MRO used optical communications instead of RF, its data rate would be 100 megabits per second. (Due to the distance, it takes approximately 12 minutes for the information to reach Earth no matter what the data rate.)

Optical communication not only provides for faster transfer of more information; it also requires about 65 percent less power—increasing the spacecraft’s scientific measurement capabilities as well as its overall lifespan. The necessary equipment
contributes about 50 percent less mass to the vehicle than an RF antenna would, resulting in lower launch costs and more room on board for scientific instruments. “With optical communication, we can see a significant advantage just in terms of the sheer productivity of our spacecraft,” says Rush.

The Curiosity rover currently transmits its data to the orbiting MRO and the Mars Odyssey spacecraft, which both forward the information to Earth via RF communications. Rush envisions future Mars satellites equipped with laser systems operating as trunk lines between Mars and Earth, rapidly beaming a steady flow of data gathered on the Martian surface to eager scientists here at home. With missions like Curiosity, MRO, and others returning larger and larger amounts of information, the data rates necessary to transmit it will soon surpass what RF communications can reasonably manage—even though RF technology has yet to hit its ceiling.

“With optical communication, we’re talking about a real game-changing technology,” says Rush. “The data rates are significantly higher than what you can do with RF for the same mass, power and volume on a spacecraft. This will be critical for the incredible amount of scientific data—including high-definition images—that we expect to bring in from NASA’s exploration missions.”

The challenges to successful deep space optical communication are complex and daunting, however, starting with those pesky clouds, which can distort or deflect an incoming laser. As a workaround, Rush and the SCaN office are collaborating

Making optical communications a reality for space missions will entail developing advanced technologies capable of accurately directing lasers across millions of miles of space and detecting individual photons from those lasers here on Earth. Seen here are renderings of an optical module for space and an optical ground terminal.
with international space agencies to determine the best locations for ground stations so that, statistically speaking, when one station is clouded over, another station has clear skies to receive the signal. Of course, this solution will work only if there is an accurate means for pointing the laser from, say, Mars to Earth. The laser’s beam will hit only about a third of Earth, unlike the RF signal, which has a much broader span. Then the optical signal must be transmitted while compensating for any vibrations on the spacecraft. And then another problem: By the time the low-power laser beam (no, it won’t be a brilliant energy blast sizzling through space) reaches Earth, it will be quite dim, requiring ultrasensitive detectors to distinguish the signal among the many other electromagnetic signals generated by the sun and other sources.

Fortunately, SCaN has solutions in mind, and Rush says the technology is ready for testing now. Research into passive and active vibration-damping measures is ongoing, and SCaN is collaborating with NASA’s Space Technology Mission Directorate—SCaN’s biggest partner in optical communications development—to build detectors that actually count individual photons, parsing each particle of light to arrive from a spacecraft millions of miles away. (That’s at least as cool as Spock’s phaser, right?)
In 2013, NASA will launch the Lunar Atmosphere and Dust Environment Explorer (LADEE), equipped with a Lunar Laser Communications Demonstration (LLCD) that will, Rush believes, display the viability of optical communications for near-Earth missions. The Space Technology Mission Directorate and NASA's Goddard Space Flight Center in Greenbelt, Md., are also developing the Laser Communications Relay Demonstration (LCRD), NASA's first extended optical communications project, currently scheduled for launch in 2017. LCRD is part of the Space Technology Mission Directorate's Technology Demonstration Missions (TDM), designed to bring cross-cutting innovations to flight readiness and demonstrate them in space.

In the meantime, SCaN is following a clear optical communications roadmap that centers on technology development. Rush says that detection equipment, for example, is already moving ahead in leaps and bounds, improving from 19 percent to 70 percent efficiency. The office will also continue to advance RF communications so that NASA spacecraft can take advantage of the best of both worlds, and the ultimate goal is to integrate all of NASA's space communications networks into an efficient, comprehensive system operating by international standards. SCaN also plans to work with private industry to commercialize resulting technology in order to generate benefits beyond NASA missions.
These are exciting times to be working for NASA.

“NASA is always looking 20 years into the future,” says Rush. “What we are designing now is going to take us places we have never been.”

For someone like Rush, who has been enamored of space ever since the launch of Sputnik and who, as a student, knew the names of every astronaut, these are exciting times to be working for NASA.

“It’s mind-boggling when you think about what we should be able to do with these new technologies,” he says.

It will take a lot more than clouds to get in the way of what’s next.
A HOT IDEA

A SPINOFF OF A CUTTING-EDGE AEROSPACE PROGRAM CUTS COSTS FOR AMERICAN BUSINESSES.

The outcomes of innovation can be entirely unpredictable. This can often be a very good thing.

Take the U.S. X-Plane Program. It conducts first-of-its-kind research in aerodynamics and astronautics with experimental vehicles. The program's milestones include the first aircraft to break the sound barrier; the first aircraft to fly in excess of 300,000 feet; and the first aircraft to fly at three, four, five, and then six times the speed of sound. Since the 1940s, the X-Plane Program has been taking daring chances to advance aerospace technology, with most of its futuristic vehicles operated by NASA and its predecessor, the National Advisory Committee for Aeronautics (NACA), in partnership with the U.S. Air Force.
Breakthroughs in aerodynamic performance? Predictable. Some of the coolest jets you’ll ever lay eyes on? Entirely foreseeable—this is NASA, after all. Benefits for the makers of wine bottles, windshields and more? That one you probably didn’t see coming.

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

During the 1990s, NASA began to develop a new thermal protection material for testing on the X-33 and X-34 experimental reusable launch vehicles. As a result of its research and development efforts, NASA’s Ames Research Center in Moffett Field, Calif., invented the Protective Ceramic Coating Material (PCCM). A thin, lightweight coating of PCCM applied to a surface could protect any material underneath it from extreme temperatures. The remarkable properties of this substance derived from its emissivity, which radiates heat away from the surface it covers, thus decreasing the amount of heat transferred.

PCCM not only allowed surfaces to withstand higher temperatures, it also exhibited impressive thermal shock, vibration, and acoustic performance. In addition, it proved damage resistant and environmentally safe. Even though funding for the X-33 and X-34 ended in 2001, PCCM continued on a path of innovation that has led to business-boosting cost savings for American manufacturers today.
Taking the State of the Art…and Making It Better

Shortly after Ames made PCCM available for licensing, John Olver, president and CEO of Emisshield, Inc. (then Wessex, Inc.), in Blacksburg, Va., heard about PCCM. He talked to the NASA inventors and in 1996 obtained a license to use the technology. With assistance from the Center for Adhesion and Sealant Sciences at Virginia Polytechnic Institute and State University (Virginia Tech), Emisshield performed extensive testing, research, and development of the coating. By 2001, the company had expanded its license agreement to include all applications other than those for space and space vehicles.

During the first few years, Emisshield changed PCCM in ways that made the coating more practical to use. “As we progressed, we took the base license and advanced it into two new patents,” says Olver. “NASA said, ‘That’s what we intended for you to do: License it, make it better and commercialize it.’ ”

Branching Out

Emisshield, Inc., now provides its NASA-derived technology, also called Emisshield, in more than 20 different products. Each formulation is carefully matched to the material it is intended to protect as well as the temperature and environmental conditions. “We are changing the surface properties of existing materials—metals, ceramics—to improve their performance,” says Olver. “It will work just about anywhere there is heat—from electricity to manufacturing glass and plastic bottles.”

Use of Emisshield can result in significant savings; according to customers, Emisshield provides up to a 15-percent energy savings, a 15-percent increase in production, more uniform heating, prolonged substrate life and reduced downtime for maintenance. All of this is done with a coating that is about the thickness of a kitchen garbage bag. And, as Olver notes, “by improving combustion of gases and fuels, products are made with less energy, and that reduces polluting emissions.”
One of Emisshield's most popular applications is in the glass-making industry. “On these big glass furnaces, they are saving about 10 percent of their energy,” says Olver. “The payback for our clients making glass is always under a year.”

As the company moves forward, it is striving to penetrate new market areas. “We started the root system with NASA, then the trunk, and now we’re growing our branches,” says Olver. “We wouldn’t be here if it weren't for technology transfer from NASA.”

*Emisshield® is the registered trademark of Emisshield, Inc.*
A NASA SPINOFF MAY SOON LEAD TO AIRCRAFT THAT CAN SOAR LIKE THEIR FEATHERED COUNTERPARTS.

The inspiration for innovation can come from anywhere. Often, however, engineers seeking solutions to technical challenges need look no further than the work of the ultimate innovator—nature. Siva Mangalam, a former NASA Langley Research Center aerodynamics engineer and the founder of Tao of Systems Integration, Inc. (known also as Tao Systems), demonstrated this principle when he turned to the creatures that inspired humans to fly in the first place as a way to improve aircraft performance. The results of his efforts may one day make turbulence a trivial matter for pilots and their passengers.
For a quick lesson in turbulence, watch how the smoke behaves the next time you blow out a candle. You will see that initially it rises in an even stream. As the smoke disperses, that stream begins to break up into swirls and eddies. Air flowing over a wing behaves in a similar way. The smooth, even movement of air over a wing is what allows aircraft to fly efficiently. Airflow that separates from the wing’s surface breaks up into turbulence, which is responsible not only for those moments of bumpy discomfort during flight but also for increased drag, which reduces aircraft performance. Understanding and controlling the influence of these aerodynamic forces on a wing can lead to aircraft that fly more safely, use less fuel and carry greater payloads.

Currently, the impact of aerodynamic forces on an aircraft is apparent only after the fact; turbulence, for example, is detected only after the aircraft’s structure responds to it.

“Turbulence can be very fast-acting, while the structure is slow-acting,” says Mangalam. This means that neither researchers nor pilots can know the true aerodynamic conditions influencing an aircraft in flight. The ability to detect changes in aerodynamic forces before the aircraft’s structure reacts to them can lead to better control systems and safer, more efficient, more comfortable flight.

**Broad Benefits**

In 1994, Tao Systems began to craft sensors and other components with the ultimate goal of developing a first-of-its-kind system to detect, measure and manage aerodynamic forces in flight. With the support of multiple NASA contracts and flight-testing opportunities at NASA’s Dryden Flight Research Center at Edwards Air Force Base in California, Mangalam’s team designed sensors that enable real-time collection of aerodynamic data.

Corporate customers such as Boeing, Lockheed Martin, Northrop Grumman, BMW and Rolls-Royce are currently using these sensors to measure airflow and temperature characteristics for vehicle design. Sandia National Laboratories...
in New Mexico are using the company’s technologies to explore ways of improving wind turbine operation. Tao Systems technologies are also employed for examining airflow in buildings to determine ways to save energy by optimizing air-conditioning efficiency.

“Wherever there is airflow, the opportunities are plenty,” says Mangalam, and he is quick to note the utility of his company’s technologies for developing and improving underwater turbines that can generate electricity from waves and tidal currents.

**Aviation as Nature Intended**
While Tao Systems customers continue to make use of its innovations, the company has its eye on the potential benefits that a completed flight-control system will offer. Once the system is available, engineers will be able to use it to develop advanced adaptive control systems and flexible wing structures that will allow an aircraft to respond to—and even exploit—aerodynamic conditions as they happen, improving flight safety and comfort and increasing fuel efficiency. Advancements like this would endow human aviation with capabilities closer to those of nature’s perfect aerodynamic creation.

“We could fly by feel,” Mangalam says, “like a bird.”
If you’re interested in visiting another planet or just sending a robot proxy to take in the scenery for you, then Neil Cheatwood is a good person to know. Cheatwood is a key innovator and leader in the field of entry, descent and landing (EDL) technology—the systems that ensure the safe arrival of a spacecraft on a planet’s surface or in orbit. He is the principal investigator for the Mars Entry, Descent and Landing Instrumentation (MEDLI) project, a sensor system integrated into the heat shield of the Mars Science Laboratory (MSL) to provide researchers with unprecedented EDL data. He is also the principal investigator for the Inflatable Reentry Vehicle Experiment (IRVE) and Hypersonic Inflatable Aerodynamic Decelerator (HIAD) projects, which employ inflatable heat-shield systems that could revolutionize EDL for future missions. The MEDLI, HIAD, and IRVE are projects within NASA’s Space Technology Mission Directorate. Previously, in his role as the Aeronautics Research Mission Directorate Hypersonic Project Scientist, Cheatwood defined that directorate’s portfolio of EDL investments. Cheatwood’s résumé also includes work on such NASA missions as Stardust, Genesis, and the Mars Exploration Rovers Spirit and Opportunity, among others. Here, Cheatwood describes the challenges of the critical EDL phase of NASA’s planetary missions and how the agency is innovating new ways to make the next trip to Mars bigger and better than the last.
• When I talk about EDL—entry, descent and landing—I’m talking about places that have atmospheres: destinations like Mars, which has a very thin atmosphere, or Venus, or Titan—even back here at Earth. The investments I’m looking into do not primarily concern landing on the moon or other airless bodies but rather atmospheric flight.

• EDL for previous missions has taken a very tailored approach, coming up with the best solution for a particular destination. Space technologies like HIAD, Woven TPS, aerodynamic control surfaces for lift, airbags for landing systems and other innovations—all of these technologies should be applicable to multiple destinations and a range of scales. They’re not just focused on Mars. They’re not just focused on robotic missions or human missions. These are technologies of interest for both human and robotic missions and a range of destinations and scales.

• I’ve worked on the EDL phase for a number of missions going back to the Mars Pathfinder. It really is make or break. It’s a one-shot deal. Once you start going into the atmosphere, you can’t turn around and say,
“Let’s try that again.” You do all your homework up front in order to set yourself up as best you can for this ultimate event. You try to forecast all possible scenarios.

- They called the EDL phase of the MSL mission “7 Minutes of Terror.” For the Mars Exploration Rovers in 2003, it was “6 Minutes of Terror.” Why the difference? The Mars Exploration Rovers entered the Martian atmosphere in a ballistic vehicle, just plummeting down, something like a rock. The spacecraft had no lift capability. With MSL, we shifted the center of gravity so that the same basic shape that we had for Spirit and Opportunity actually generated lift, kind of like the sail of a windsurfer. In windsurfing, you shift your weight to steer. That is essentially what was done with MSL. One of the ways we used that lift was to increase the accuracy of the landing, but another way we used it was to loft the spacecraft’s trajectory and keep it in the air longer—7 minutes instead of 6—which allowed us to land at a higher altitude than we could have otherwise. The higher altitude is important because there is evidence of past surface water on Mars in what we call the Southern Highlands. Still, we can’t land the MSL rover at those higher altitudes with the current suite of EDL technologies, which were initially developed for Project Viking in the 1960s and 1970s. We need to develop new technologies that meet the needs of today. That’s what we’re trying to do in the Space Technology Mission Directorate by advancing the state of the art.
• **We got a great set of data from MEDLI.** We were looking at it that night during MSL's entry, and we were amazed by how clean the raw data was. It was less noisy than our simulations had predicted. We are now in the midst of a two-year reconstruction of the MEDLI data. A few things are already emerging. One thing that stands out is that we are seeing lower heating on the vehicle’s thermal protection system (TPS). In fact, we designed the system with the expectation that at least a couple of the MEDLI thermocouples would burn off, but we ended up not losing any of them. It looks like our heating environment was about half of what we designed for. If those preliminary findings hold up and we can correct our models to reflect the proper physics, we could possibly reduce the heat-shield mass significantly for future missions. **That could have a huge impact on future missions in terms of how we design spacecraft and how much payload they can carry.**

• One piece of the HIAD project is the IRVE-3, which is the latest flight test of that technology. [IRVE-3 flew a successful demonstration mission in 2012.]
Why are we doing inflatable aeroshells? **For MSL, we built the largest diameter aeroshell ever.** We can’t currently go bigger, because a rigid aeroshell has to fit inside the launch vehicle shroud, and we flew the largest shroud available. But with an inflatable structure, we can store it inside the launch vehicle and then deploy it in space prior to atmospheric entry. **HIAD technology could also be used to return cargo from the International Space Station (ISS) or to recover launch vehicle assets for reuse, reducing the cost of access to space.**

**If you can fall slower, you buy time.**

- **It turns out size does matter.** The bigger the entry vehicle, the larger the drag it creates; and the more drag force you have, the slower you fall. When planning a mission like MSL, you start at the landing point and work backwards along the trajectory and say, “Okay, to get there, the sky crane has to do its job, and before that, we have to jettison the heat shield, and before that we have to have the parachute successfully deploy.” You stack up all these events and all the bumpers you build in to allow enough time between each event. For landings at higher altitudes, you run out of time. If you can fall slower, you buy time. **With that extra time, you can land at a higher altitude and explore places like the Southern Highlands of Mars.**

- **And a HIAD vehicle flies better than most aeroshells,** which are dynamically unstable at supersonic speeds. **You might be able to skip having a supersonic parachute altogether.** We demonstrated that in flight with both IRVE-2 and IRVE-3. The scariest part of those “7 Minutes of Terror” is wondering if the parachute would work. With a HIAD, we could go without that chute.
• Another application we’ve been looking at is aerocapture. **Aerocapture is taking aerobraking to the extreme.** Aerobraking uses dozens to hundreds of passes through the upper atmosphere at a high altitude to take energy, little by little, out of the velocity of the spacecraft and settle it into orbit. With aerocapture, we dive much deeper into the planet’s atmosphere, take out the energy we need to, and then pop back out to the desired orbit. In theory, it’s a great approach, but we have not actually used it yet. Technology we are now developing could be utilized for aerocapture.

• If you look at what we did in the Apollo program, that push for technology advancement, we’re still seeing its impact today—there are many innovations driven by the needs of the space environment at a given point in time. For EDL, we got away from that kind of technology development, at least in a broad sense, during the late 1970s through the mid-1990s. We’ve been focused on particular missions rather than broad technology innovation, and we’re now at the limit of what we can do with the technology we developed for Viking. But materials advancements in the commercial sector have let us revisit some other ideas from the 1960s, like inflatables and flexible TPS. Now we have materials that can handle the environments we would see, and we’re looking at materials that would allow us to protect against even higher temperatures. If the TPS can handle hotter environments, we can go to a smaller diameter. If the structure can handle higher temperatures, we can reduce the amount of insulation and make TPS thinner, lighter and easier to stow. **Each advancement helps to reduce the overall mass and size of the aeroshell. That leaves more mass of a given launch vehicle for payload—making our future space missions less costly and more effective.**