National Aeronautics and Space Administration

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# ask

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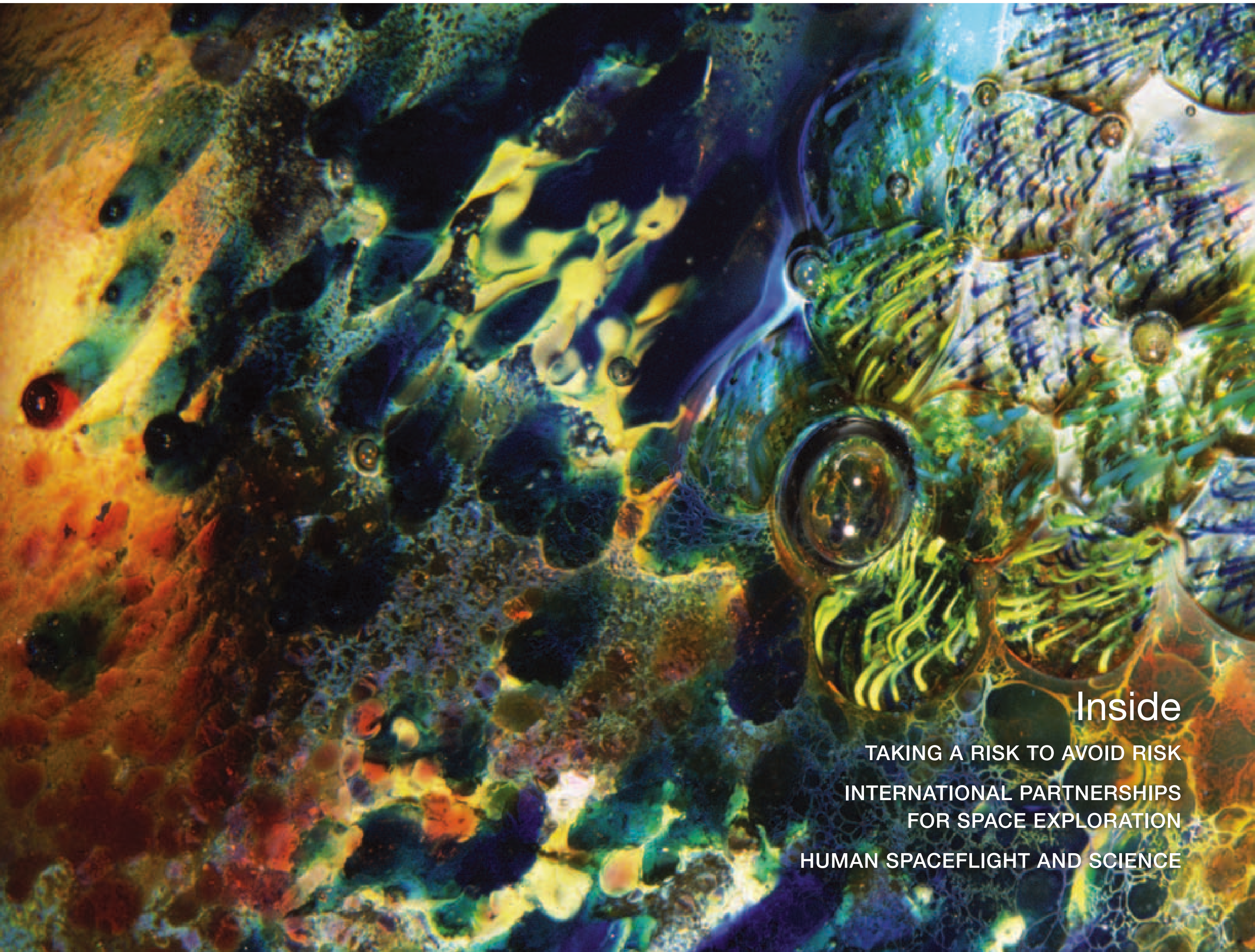

## Inside

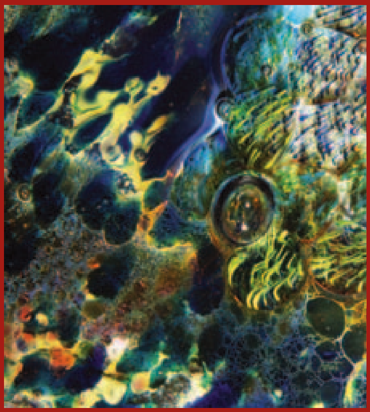

Photo Credit: Tommy Olof Elder

**ON THE COVER**

Close-up detail of the surface of one of Josh Simpson's glass "Planet" sculptures. Inspired in part by photographs taken by Astronaut Cady Coleman, his wife, he creates his fantasy planets in his studio in Shelburne Falls, Massachusetts.

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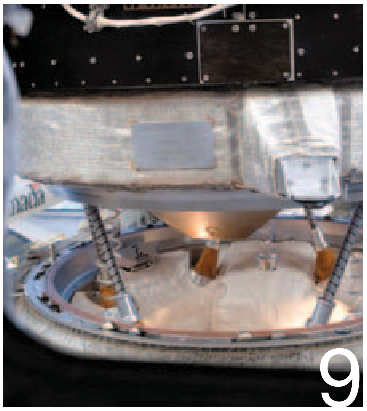


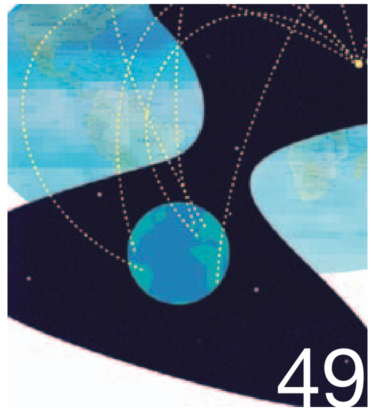


ask

Issue No. 43




The Academy of Program/Project and Engineering Leadership (APPEL) and *ASK Magazine* help NASA managers and project teams accomplish today's missions and meet tomorrow's challenges by sponsoring knowledge-sharing events and publications, providing performance enhancement services and tools, supporting career development programs, and creating opportunities for project management and engineering collaboration with universities, professional associations, industry partners, and other government agencies.

*ASK Magazine* grew out of the Academy and its Knowledge Sharing Initiative, designed for program/project managers and engineers to share expertise and lessons learned with fellow practitioners across the Agency. Reflecting the Academy's responsibility for project management and engineering development and the challenges of NASA's new mission, *ASK* includes articles about meeting the technical and managerial demands of complex projects, as well as insights into organizational knowledge, learning, collaboration, performance measurement and evaluation, and scheduling. We at APPEL Knowledge Sharing believe that stories recounting the real-life experiences of practitioners communicate important practical wisdom and best practices that readers can apply to their own projects and environments. By telling their stories, NASA managers, scientists, and engineers share valuable experience-based knowledge and foster a community of reflective practitioners. The stories that appear in *ASK* are written by the "best of the best" project managers and engineers, primarily from NASA, but also from other government agencies, academia, and industry. Who better than a project manager or engineer to help a colleague address a critical issue on a project? Big projects, small projects—they're all here in *ASK*.

You can help *ASK* provide the stories you need and want by letting our editors know what you think about what you read here and by sharing your own stories. To submit stories or ask questions about editorial policy, contact Don Cohen, Managing Editor, doncohen@rcn.com, 781-860-5270.

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# In This Issue

Every NASA project is a collaboration. A few, like the microsatellite development at Marshall Space Flight Center (see "FAST Learning"), are carried out by a small group at one location, but still depend on the cooperative efforts of engineers, scientists, and managers with different skills and responsibilities. Most involve teams at space agencies, corporations, and universities around the world. International participation in space science and exploration is becoming the norm.

That trend partly has to do with money. Space programs are expensive; many only happen when costs are shared. More important, though, is shared expertise. As Laurence Prusak says in "The Burden of Knowledge" ("The Knowledge Notebook"), no single individual or institution can know everything important about any subject. Increasingly, accomplishments in science and technology bring together the knowledge of many and diverse people. Connecting and coordinating that diversity are key to the future of aerospace.

Both the demands and benefits of international cooperation spring from differences among partners—the differences in ways of working and thinking that must be understood and negotiated also generate a robust variety of ideas. Several articles in this issue of *ASK* consider those demands and benefits. In the interview, Steve Smith talks about his eight years as NASA's space station liaison to the European Space Agency. His earlier experience as an astronaut contributes important practical knowledge to discussions of plans and procedures, but the heart of his job is understanding and respecting how NASA's international partners work (and earning their understanding and respect). Kathy Laurini ("International Partnerships for Space Exploration") emphasizes the importance to these collaborations of building relationships and understanding cultural differences over time.

Laurini makes clear that the only way to learn to work together is to work together. She describes how a series of Russian–American missions built a foundation of trust and understanding that made their International Space Station partnership possible. The International Project Management Committee, discussed in "Weaving a Knowledge Web," was formed to bring together members of space agencies and related institutions because its founders recognized the importance of sharing knowledge and the fact that it could only be shared through relationships developed by joint work.

Which suggests a familiar *ASK* theme: learning by doing. Another aspect of the burden of knowledge, especially at the frontiers of science and technology, is that you can't understand things just by thinking about them. You learn the most from unanticipated results and problems that arise in the course of doing real work. So Adam Harding explains the role of mistakes in his professional development ("Learning to Be an Engineer"), and Howard Ross, in "Human Spaceflight and Science," describes how a simple experiment led to improved spaceflight safety and unexpected benefits on Earth. In "Delivering Clean, Affordable Power," Bo Schwerin offers another example of an unforeseen return on research, in this case a technology for producing oxygen and hydrogen on Mars that can generate clean energy on Earth. One of the great things about working at the leading edge of science and exploration is that you don't know what you'll find until you get there.

Don Cohen
*ASK* Managing Editor

From the Academy Director

# On the Importance of Values

BY ED HOFFMAN

*"If you don't live it, it won't come out of your horn." —Charlie Parker*

In the early 1980s, I was involved in conducting a study to determine the effectiveness of a new initiative promoting a more participative organization, interviewing employees and managers.

One young woman assured me that leadership had no interest in a more participative environment. I gently disagreed, pointing to efforts under way to promote participation—quality circles, training, and employee–manager dialogues. She countered by telling me about her recent experience. She had returned from a quality circle and was offering ideas for the office. Her manager told her, "Look, you've had your four hours of quality-circle participation; for the rest of the week, just do what I tell you." Over the next month of interviews, I discovered that her experience was typical. There was a complete disconnect between what managers believed and their superficial support of this change initiative.

The more management pushed formal participation programs, the more employees considered the change to be insincere. In my briefing to leadership, I recommended placing much less emphasis on formal tools such as quality-circle groups, a recommendation that came as a jolt to senior leaders.

This experience motivated my dissertation research on "the impact of the managerial belief system on participative behavior." I concluded that, when managers do not really believe in an organizational change, their informal behaviors communicating that lack of support are more powerful than formal approval.

Leader values and beliefs communicate to a team what really matters, but few project managers and teams take time to address the importance of values to their mission. This lost opportunity contributes to dangerous disconnects between desired and actual performance.

NASA has four core values—safety, integrity, teamwork, and excellence—and projects have unique requirements that make additional values essential to success. For example, the Lunar Crater Observation and Sensing Satellite (LCROSS) project depended on low-risk integration, intense partnering, and trust-building communication. NASA project manager Dan Andrews and industry project manager Steve Carman, Northrop Grumman, clearly communicated these core values to the team. (Read about LCROSS at www.nasa.gov/offices/oce/appel/knowledge/publications/lcross.html.)

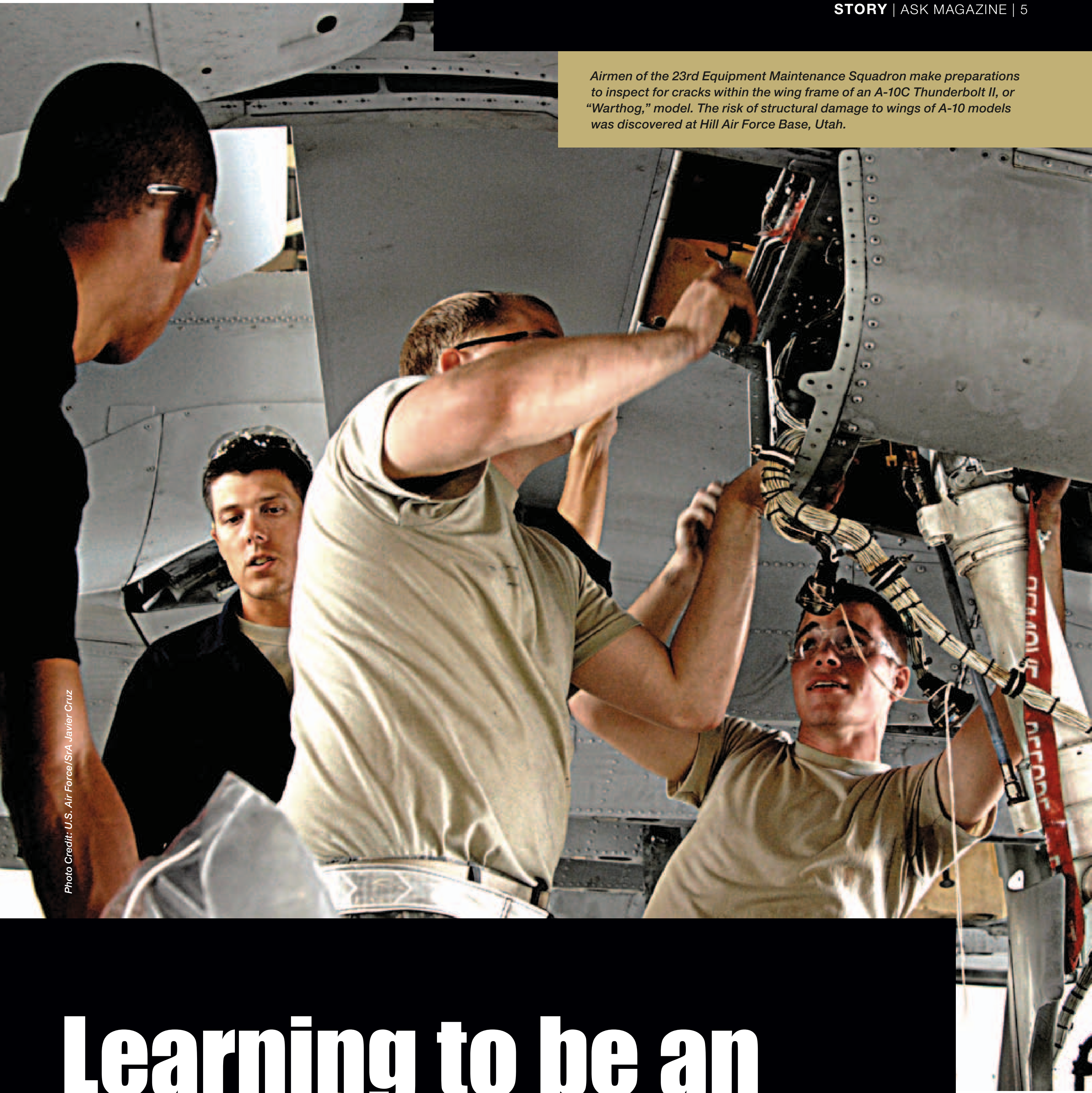
And look at how safety, excellence, teamwork, and integrity play out in the STS-119 Flight Readiness Review: www.nasa.gov/offices/oce/appel/knowledge/publications/STS-119.html.

Successful leaders embody desired project values and tell stories that amplify them. Practice and talk about open communication and that's what you get; show and talk about lack of trust and you get that. It is no accident that the stories of successful and unsuccessful projects sound so different.

Every project team should take the time to clarify their critical values and beliefs, asking the following:

1. What values will drive us to success?
2. Are our behaviors consistent with those values?
3. Are the stories we tell about our project (and each other) helping or hindering our performance?
4. Do we have a governance framework consistent with our values?

Charlie Parker said you need to live it for it to come out of your horn. Leaders and teams need to live—and talk about—the value that drives their projects. ●



*Airmen of the 23rd Equipment Maintenance Squadron make preparations to inspect for cracks within the wing frame of an A-10C Thunderbolt II, or "Warthog," model. The risk of structural damage to wings of A-10 models was discovered at Hill Air Force Base, Utah.*

*Photo Credit: U.S. Air Force/SrA Javier Cruz*

# Learning to be an ENGINEER

BY ADAM HARDING

A new engineer's career with NASA usually begins by being tossed into the deep end. You are immediately handed real-world engineering challenges and face the overwhelming data, procedures, and calculations needed to solve them. There are mentors and training opportunities along the way to help adjust to the relentless pace of learning to be an engineer at NASA, but there isn't much time during these formative years to pause and reflect on the evolution of your career or formulate potential advice for those about to follow in your footsteps. This is exactly the opportunity afforded me as a member of the "Developing New Engineers at NASA" panel at the 2011 PM Challenge in Long Beach, California. As a panelist, I was to appraise experiences that either promoted or detracted from my development and then share these perspectives.

Unlike the four other members of the panel, I didn't begin my career with NASA. That allowed me to provide some comparisons with another government agency that hires and trains many aerospace engineers: the U.S. Air Force.

After graduating with a BS in mechanical engineering from the University of Utah, I accepted a position at Hill Air Force Base to support the A-10 "Warthog." I spent my first year learning about military aircraft, designing repairs to jets damaged by enemy fire, and learning how to maintain an aging aircraft. Fortunately, I was placed on a team with a good mix of greybeards and newer engineers.

I had many experiences working for the air force that helped me develop as an engineer, including some notable mistakes. Part of becoming successful in a profession is being given the chance to fail. Making mistakes is part of becoming a good engineer. As Niels Bohr said, "An expert is a man who has made all the mistakes which can be made, in a very narrow field." One memorable mistake that helped me better value my own contributions and appreciate the insight of experts occurred when I had been working for only a few months. Being the new guy, I was assigned easier projects like repairs on damaged bolt-holes. While not the epitome of engineering glamour that is dreamed of in college, it was nonetheless critical to airworthiness. I began to notice a pattern of damage in the wing-attach fitting area and decided to compile a summary of all documented repairs for this fitting over the past fifteen years. The end product was a reference table allowing quick turnaround on repair requests for any hole in this critical fitting that held the wing on the aircraft.

Several of the experienced engineers took note of my increased efficiency and started to talk with me about it. I proudly showed them my summary of all the previously approved repairs. Instead of praise for the new guy's accomplishment, they showed concern as they recognized a major flaw with my approach. While any single hole could be enlarged to the respective "clean up" diameter, only one hole in that particular fitting could be enlarged to that degree. If another hole on the same fitting required repair, it could not safely have that maximum diameter due to serious fatigue issues, something I was unaware of.

Finding the flaw in my summary led to a fleet-wide evaluation of these basic repairs. My branch supported about thirty aircraft located at three different air bases at any one time, and there was no cross-check on this repair among the fifteen engineers who carried it out to ensure that multiple hole repairs weren't being done on the same fittings. Soon this issue was resolved with an updated technical order that included a new summary table of the limits for each hole as they related to other damaged holes on the same fitting. I was not the one who engineered the solution; I was just the engineer who made the biggest mistake and highlighted the problem in the first place.

This experience taught me two principles that have helped me in my career. The first is how important the big picture is, and that I needed to rely on those with enough experience to see the big picture. Sometimes the solution to one problem creates new problems that you won't see if you don't have that broad vision. The second principle is, if an answer comes too easily, ask experienced engineers to evaluate the solution. It's true that the right answer is sometimes the simplest one, but not always, and the simple right answer is not necessarily the easiest to find.

The air force allowed me to return to graduate school to earn a master's degree in engineering after my first year. This additional schooling was very valuable to my development as an engineer. I had spent a year learning from mistakes and interacting with experienced engineers. That gave me a different perspective

*Testing the Orion crew module using air bearings.*
*Photo Credit: NASA*

when I returned to the classroom. I appreciated the fact that most great engineering solutions are not pounded out individually, but through collaboration among team members. I had seen firsthand how things are built, broken, and rebuilt.

Following graduate school, I returned to the maintenance hangar and tried to apply what I had studied in class. Although my job was inherently technical, the greatest challenges for me would be better classified as learning how to apply research skills to understanding the engineering already in place. Essentially, I was fixing problems that required an engineering degree to understand the proper contextual background for established technology but not for direct application for research or new design. The real engineering had already been done. Despite this, I still experienced a high degree of job satisfaction.

In 2007, I accepted an offer to work at NASA's Dryden Flight Research Center. NASA's mission is oriented toward research-based engineering. I was coming from an "end-user" focus on established engineering and, to a degree, felt like I was starting over with a greater technical emphasis. Instead of focusing on A-10 fleet maintenance, I was now working on research and development of the Orion crew module.

My initial assignment was to the structures team. I had responsibility for the mass property testing of the crew module. This involved developing test equipment capable of manipulating the crew module in a variety of positions and attitudes while inducing oscillations and recording precise measurements to determine the center of gravity and moments of inertia (a measure of an object's resistance to changes to its rotation).

EVEN THOUGH NASA'S CULTURE AND MISSION WERE DIFFERENT FROM THE AIR FORCE, THE PRINCIPLE OF LEARNING BY TRIAL AND ERROR STILL HELD TRUE. THE SIMPLEST OF OVERSIGHTS ON ONE OF OUR CENTER-OF-GRAVITY TESTS EMPHASIZED A GREAT LESSON: ALWAYS READ THE OWNER'S MANUAL.

These measurements would directly influence the success of the launch. I had not worked on anything like this in my five years with the air force. Fortunately, I had access to seasoned engineers who had information dating back to similar testing done during the Apollo era.

However, the greatest contributor to the success of these tests was a young engineer named Claudia Herrera, who had only been out of school for a couple of years. She had experience with the mass property testing of airplanes at Dryden, but not space capsules. Claudia tackled the technical and programmatic challenges head-on. As I worked with Claudia, I saw that the few years of hands-on experience at NASA had really given her an edge in continuing her development as an engineer. While I had already experienced some mental atrophy on principles taught in school, Claudia had been able to catapult ahead in her development thanks to the challenges of working at NASA.

Even though NASA's culture and mission were different from the air force, the principle of learning by trial and error still held true. The simplest of oversights on one of our center-of-gravity tests emphasized a great lesson: always read the owner's manual. We were using air bearings to provide a near-frictionless interface for our test fixtures. These allowed us to tilt the crew module to various angles for measurements. We had received on-site training by the manufacturer, who stated that our concrete floors were adequately smooth to interface with the air bearings. However, during our initial testing, the crew module caused the air bearings to drag despite weighing only a fraction of the system's capacity. Due to schedule constraints, we didn't have time to solve the problem and decided to retest when the next window opened in the schedule.

Six months later, as we prepared to retest, we moved to another hangar with smoother concrete. As we began testing we noticed the same dragging problem. Our team was stumped. A mechanic recommended reviewing the owner's manual, which we had previously only skimmed. A careful reading revealed a suggestion to use sheets of aluminum to improve performance. We did this and finally had the results we needed. This time, the answer was easy to find—it was right there in black and white—but our team took a long time to find it.

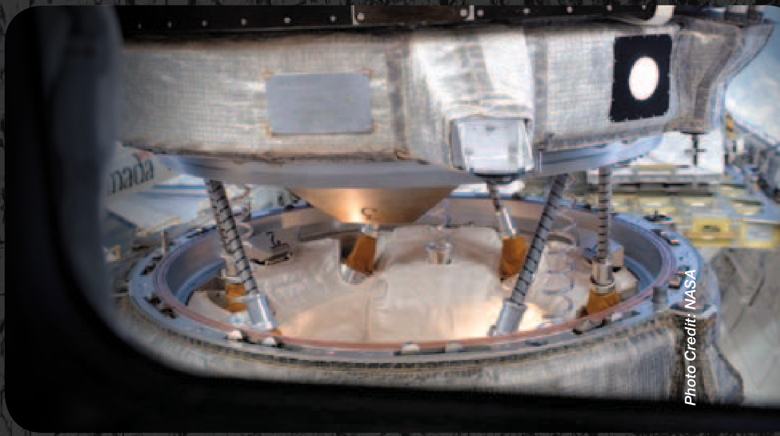
If asked by a recent engineering graduate whether to accept an offer to work at NASA or the air force, I would recommend NASA. Here's why: NASA engineers are directly responsible for cutting-edge research, testing, and publication of flight data. This makes NASA a premier training ground for new engineers. A new engineer develops best by building, testing, and breaking, and learning from the process. My development as a new engineer has accelerated since joining NASA. The maintenance environment at the air force was purposefully designed to reduce opportunities to make mistakes. That inherently reduced opportunities for growth. Despite this, I still found ways to mess things up there, too.

My evaluation of what benefited me most as an engineer is that trial and error taught me more than reading and research. Exposure to the technical accomplishments of others is no substitute for experiencing failure yourself. My advice to new engineers is to volunteer for the challenging assignments and don't be afraid of the mistakes that will happen along the way. Keep in mind that these mistakes are necessary steps to success. ●

**ADAM HARDING** is an aerospace engineer in the Aerostructures Branch at Dryden Flight Research Center. He is currently supporting the Environmentally Responsible Aviation project.

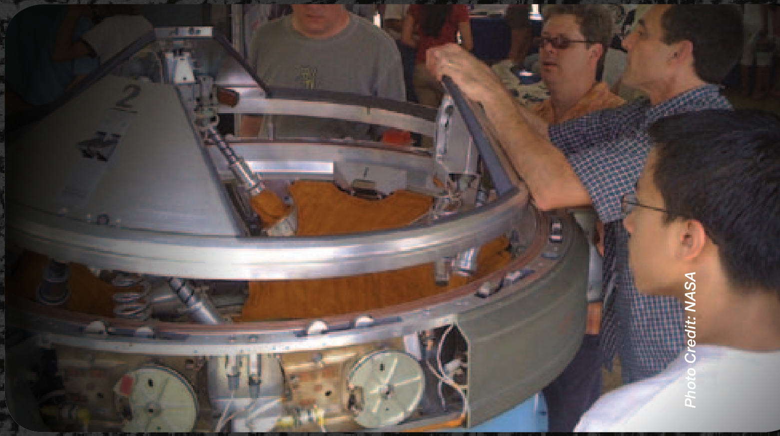
# TAKING A Risk TO AVOID Risk

BY JOHN McMANAMEN




*The shuttle and station docking mechanisms after soft capture and before retraction during STS-121.*


*The shuttle capture ring ready to dock with station during STS-131.*




*Visitors learn about the docking mechanism that allows the Space Shuttle to dock with the International Space Station.*

One of the many lessons I've learned during my career is we aren't always as smart as we think we are. When we discovered large oscillations occurring during docking between the Space Shuttle and International Space Station (ISS), I had a chance to learn that lesson again. It's amazing the kinds of problems you can find even in a mature program like the shuttle, which has been operating for thirty years. It teaches us to be vigilant and always stay curious, questioning things that don't look right.

Photo Credit: NASA

*Partial view of the nose and crew cabin of* Discovery *taken from the International Space Station during the shuttle's docking approach.*

In this instance, what didn't look right was a recurring misalignment during docking retraction: a process that occurs after the shuttle and station have successfully joined (known as "soft capture") but have not yet achieved what we call a "hard mate," when the docking is complete and everything has successfully sealed. Retraction is the process of the ISS docking mechanism slowly pulling in the docking mechanism on the shuttle side. Considering how close these two massive objects get to each other—anywhere between six and fourteen inches—a little wobble can mean a lot of risk: in this case, contact between things not intended to touch.

Docking is one of those highly integrated operations that involves massive spacecraft and many systems, including relative rate and alignment sensors, digital autopilot for attitude-control systems, crew piloting to maintain lateral alignment and translational velocities, and a complex docking mechanism that can deal with residual misalignments and rates. Then consider that, once capture is achieved, both vehicles begin free drift—turning off their thrusters and thus giving up attitude control—and you can begin to imagine the entire process as a very complex dance happening at more than 17,000 mph, and up to 280 miles above Earth.

During the STS-133 docking operation, significant oscillations were experienced between the shuttle and ISS as the retraction was occurring. Reviews and a more detailed post-flight assessment raised numerous concerns about the current docking procedure and posed fundamental questions about whether we were operating within certification limits.

## Trajectories and Timelines

When the docking procedure was originally created during the Space Shuttle–Mir missions and early ISS flights, the orbiting stations were much smaller, and the shuttle could approach and dock fairly quickly—usually in less than 20 minutes—along a trajectory much less susceptible to gravity-gradient torques during free drift. The gravity gradient (a greater gravitational pull on the parts of objects closest to Earth) can affect the orientation of satellites in space, inexorably pulling them out of alignment. In the case of shuttle and station, this force can pull hard enough to change their orientation to each other. This usually isn't a problem when the station and shuttle can use thrusters to realign themselves individually. But when they shut off those thrusters and enter free drift, the gravity-gradient torques begin disturbing the operation. The longer the free drift lasts, the worse the wobble becomes. This wasn't a problem when the shuttle–station docking process was completed within the nominal less-than-20-minute timeline, but that timeline had been getting progressively longer over the years—a result of making operational changes to deal with docking-system idiosyncrasies discovered over time.

One such idiosyncrasy occurred when an electromagnetic "brake," the high-energy damper, inadvertently stuck beyond its normal time to disengage. We dealt with this by adding steps to the docking process: extending the docking ring and then retracting it briefly to reverse torques in the system, which allowed the clutch plates holding on to the high-energy damper to release. Adding steps also added time.

As the station grew in size and mass, the gravity-gradient effect became more dominant during shuttle–ISS docking. As this rotation built up over tens of minutes of time, the centrifugal force would create a misalignment during docking, which would slow down the docking procedure. If a sensor indicated a misalignment, the crew would follow procedure by stopping the automatic docking sequence, which would then disengage "fixers," a design feature meant to limit misalignment during retraction. This would cause more wobble, and the crew would have to wait for alignment to reoccur before starting up the process again—more time.


*This partial view of the starboard wing of Space Shuttle* Discovery *was provided by an Expedition 26 crewmember during a survey of the approaching STS-133 vehicle prior to docking with the International Space Station.*

Everything culminated during the STS-133 mission; the docking took nearly 50 minutes—more than double the nominal time. I had a moment to speak with the commander during a debrief about the mission, and he described what he saw looking out the overhead window: the ISS pressurized mating adapter coming fairly close to the orbiter, and the ISS guide pins looking as though they were going to hit the orbiter docking interface as misalignment grew. When I heard what he was talking about, my jaw dropped. We realized that with the evolution to our current procedure, we had no way of controlling the growing misalignment and no integrated tools to analyze the gravity-gradient implications for the hardware, vehicles, or mission timeline. We needed a solution quickly, and we had just under four weeks to find it: STS-134 was getting ready to launch.

## One Line, One Light

Convincing anyone to make a procedural change in under four weeks is no easy task, so we made sure we had our facts straight and our data validated to prove that the resolution was less risky than letting the system proceed as it had been.

Though we showed that the shuttle and ISS could never actually collide if oscillations happened during the soft-capture phase—though they could get worryingly close, closer than six inches—there were other risks to station that were very severe. Because the timeline had grown from less than 20 minutes to nearly 50 minutes, the station was at risk of losing its power-generation and thermal-heat-protection capabilities due to longeron shadowing; the station's solar arrays could not generate enough power for vital onboard systems. Something had to change to avoid this risk.

We knew there was no time to make any hardware changes, so we looked at what we else could do. Some of our concern was with the earlier procedure changes, which had the fixers operating in a different way than what had been certified. A fixer is just what it sounds like: a small switch that deploys to fix something in place, in this case the gears controlling the orbiter docking-ring rotation. We needed to understand what the fixers were doing in the new procedure. Were they engaging or not? Were they working properly or not? Were they failing or working?

The operations community was very concerned about ensuring the fixers were working; if they weren't, and we had a large gravity-gradient-induced oscillation, we could impact parts of the docking mechanism not intended for contact. We had to come up with a new technique to determine what was happening with the fixers in real time.

The previous procedure included shutting off the automatic sequence if misalignment occurred in order to protect against a fixer failure. Our perception at the time was that the fixers could not structurally handle the stress of gravity-gradient torques. But stopping the sequence stopped the ring retraction and disengaged the fixers, so the fixers never got to do their job: preventing the orbiter capture ring from rotating. What we discovered during testing was the misalignment sensor would actually trip before ever making contact with the fixers. So we had to look creatively at what else was available in the system in terms of more accurate sensors, and we needed to better understand the fixers' structural capacity.

The initial-contact sensor in the docking system is odd because that is all we use it for—it turns on a display-panel light for the crew—but it's actually an unreliable indicator of initial contact. It turns out to be a very good indicator of how much the capture ring has rotated, though. We found that the initial-contact-sensor indication always occurred after the fixers engaged. Once we understood that, and were able to demonstrate it on the brassboard docking-mechanism unit we have—a test model which is essentially a flight unit—we knew the sensor was a very good indicator of whether a fixer had failed

*Backdropped by Earth,* Discovery *approaches the International Space Station during STS-133 rendezvous and docking operations. Already docked to the station is a Russian Progress spacecraft.*

CONVINCING ANYONE TO MAKE A PROCEDURAL CHANGE IN UNDER FOUR WEEKS IS NO EASY TASK, SO WE MADE SURE WE HAD OUR FACTS STRAIGHT AND OUR DATA VALIDATED TO PROVE THAT THE RESOLUTION WAS LESS RISKY THAN LETTING THE SYSTEM PROCEED AS IT HAD BEEN.

*Photo Credit: NASA*

*The International Space Station and the docked Space Shuttle* Endeavour *photographed by Expedition 27 crew member Paolo Nespoli from the Soyuz TMA-20 following its undocking on May 23, 2011.*

*Photo Credit: NASA*

or not. The only time we should see that sensor light during retraction is if a fixer has failed.

The fixer load capacity was refined based on discussions with our Russian colleagues, who had originally designed, built, and tested the system. We were able to demonstrate through test data that loads applied to the test-unit fixers far exceeded our predicted worst-case gravity-gradient loads. With this information and our new knowledge of a sensor that could accurately indicate a failed fixer, we were confident we could modify the docking procedure to make it safer and more robust.

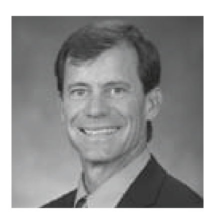
The procedure change ended up being very small. We altered only one line of code in the auto-sequence programming, and trainers advised the flight crew to ignore the misalignment sensor and instead use the initial-contact sensor to judge misalignment. But that small change had profound consequences for the overall operation. We mitigated huge risks to the docking mechanisms on both the shuttle and ISS, as well as risks to the vehicles themselves. The team worked hard and through long hours to find the simplest, safest solution before the next shuttle mission launched, and we found it in one light and one line of code.

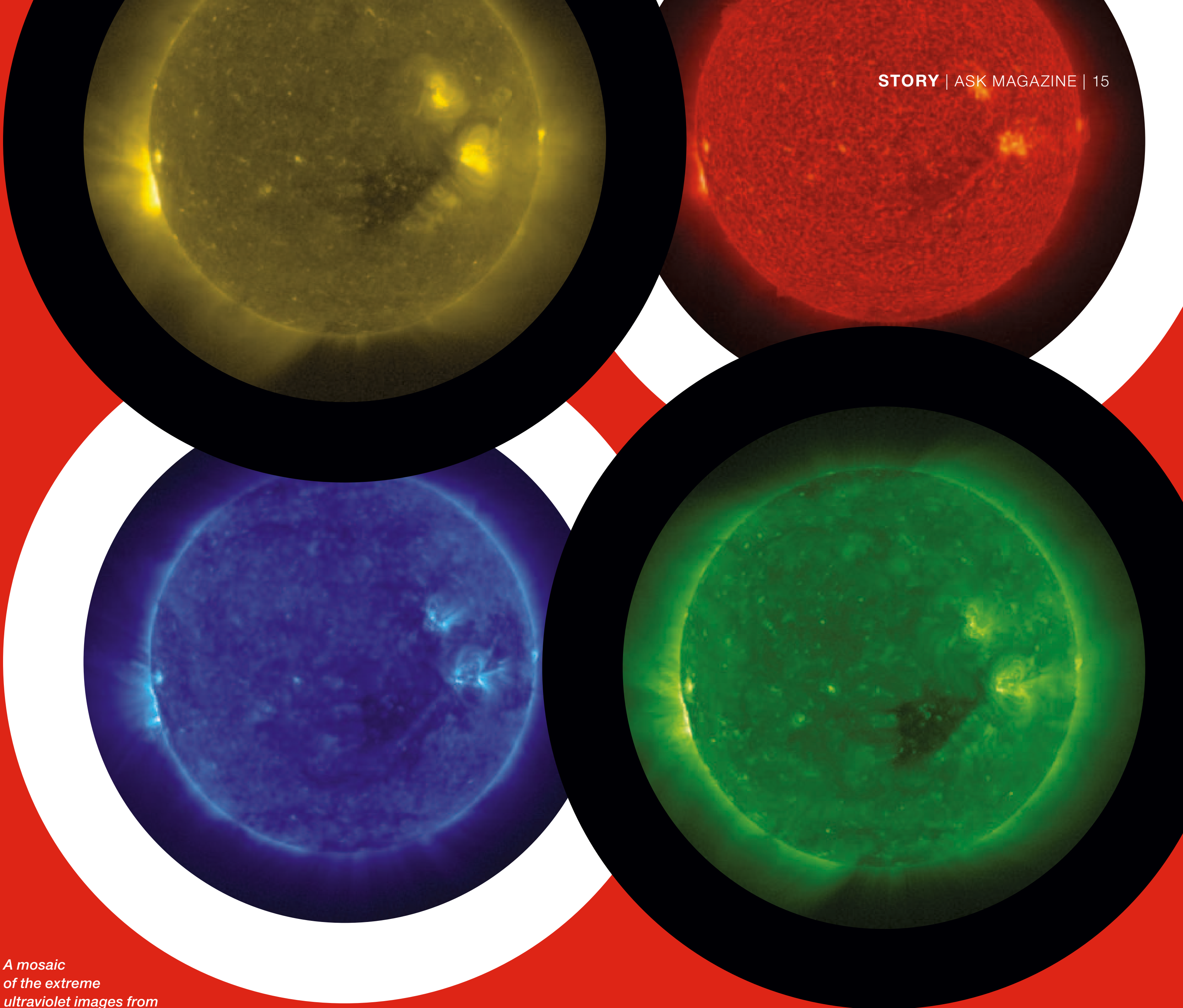
By making those changes, we were able to decrease the delays caused by the automatic stop programmed into the docking procedure, which occurred whenever the first misalignment-sensor indicator lit up. Our hard work and innumerable data were validated once more when STS-134 docked without any of the delays experienced on STS-133. In fact, it achieved the transition from soft capture to hard mate in just 13 minutes and 4 seconds.

## Mitigating Potential Problems

Very few anomalies are caused by just one thing. It's usually a number of factors, events, or changes that line up to result in a real problem. In our situation we had a number of things lining up for a potentially bad outcome. Thankfully, our team was able to recognize the signals and mitigate the risk before the potential could become reality. And we learned some very valuable lessons in the process: a thorough assessment is required even for the smallest, simplest procedure change; environments and systems can change, even after thirty years of proven performance, so re-evaluate integrated system certification/verification regularly to ensure operations are still valid and safe; and, most importantly, stay hungry, be curious, and question things if they don't look right. If those questions lead to hardware modifications or procedural changes, have a rigorous certification process in place to assess unintended consequences. This will help ensure one risk doesn't unintentionally lead to more. ●

**JOHN McMANAMEN** began his NASA career at Johnson Space Center in 1987 as an aerospace engineer in the Mechanical Design and Analysis Branch of the Structures and Mechanics Division. In 2000 he became chief engineer of the International Space Station, seeing it through final development and early on-orbit assembly operations. In 2003, he was selected as an inaugural member and Technical Fellow in the newly formed NASA Engineering and Safety Center. He is currently chief engineer for the Space Shuttle program.





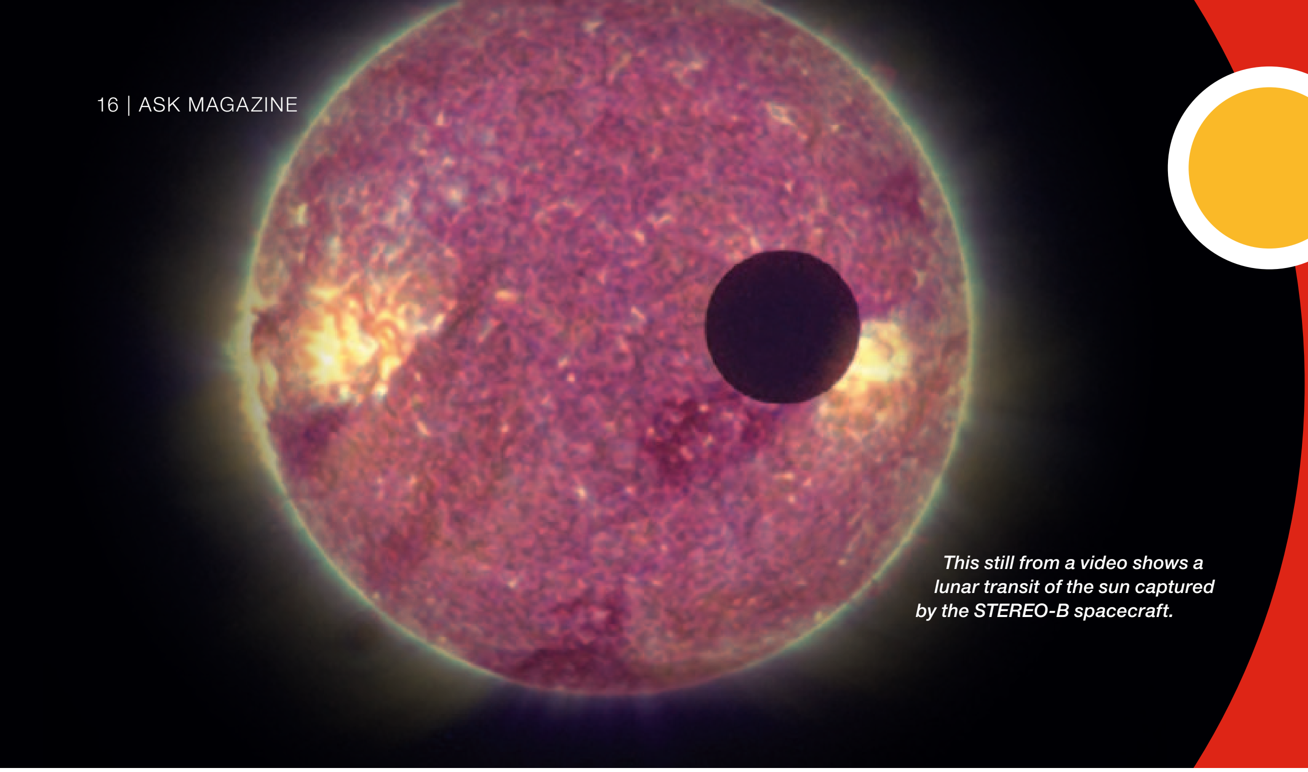
*A mosaic of the extreme ultraviolet images from STEREO's SECCHI/Extreme Ultraviolet Imaging Telescope taken on December 4, 2006.*

# FIXING A TROUBLED PROJECT

BY NICK CHRISSOTIMOS

The three main areas that can lead a project down a slippery slope are team dynamics, technical development issues, or those things outside the project's control—external support, problems, or direction.

*Photo Credit: NASA*



This still from a video shows a lunar transit of the sun captured by the STEREO-B spacecraft.

Photo Credit: NASA

Dealing with technical development is a challenge that we engineers and scientists embrace, though we often underestimate the difficulties and do not allow adequate cost and schedule to develop the technology. Dealing with issues outside our control is always difficult, as we constantly face the challenges of budget cuts and delays pushed on us by the powers that be. I think we need to learn to say, "No, we cannot give you the same program requirements with less funding, inadequate cost reserves, or less time." If they want the original requirements, they must provide the resources needed.

But I will concentrate here on the team dynamics of projects, which have a powerful effect on project performance and can mean the difference between success and failure. I want to acknowledge 4-D leadership with providing the resources and background for bringing to light this important aspect of project management and leadership. The 4-D assessment process, developed by Dr. Charles Pellerin and offered by the Academy of Program/Project and Engineering Leadership, analyzes the relative effectiveness of teams in terms of four behavioral norms:

- **Valuing:** Expressing authentic appreciation; addressing shared interests
- **Relating:** Appropriately including others; keeping all agreements
- **Visioning:** Hope and vision; commitment to outcomes
- **Directing:** Resisting blaming or complaining; roles, accountability, and authority

## Taking Over a Troubled Project

There are a few things you need to understand as a project manager when you come into a troubled project. First, you really do have a "get-out-of-jail-free card" at the beginning. You need to assess the project's status and then work with the stakeholder to renegotiate the requirements, cost, and schedule in order for you to succeed. But this is a one-time deal. So this is the time to ask for adequate resources. It is also the time to assess the team emotionally as well as logically, and then forge a team that will make the project a success.

In 2003, I was asked to take over the Solar Terrestrial Relations Observatory (STEREO) project. STEREO, one of NASA's Solar Terrestrial Probes program missions, was designed to simultaneously launch two spacecraft, each with sixteen instruments, into orbits around the sun, one moving ahead and one moving behind the earth's orbit around the sun, thus providing a stereoscopic view of the sun. STEREO was a NASA-led mission with multiple international partners (United Kingdom, France, Germany, and Switzerland), other U.S. government agencies, Federally Funded Research and Development Centers, University-Affiliated Research Centers, industry, and universities providing the instruments. The spacecraft bus, observatory integration, and test and launch occurred in the United States. When I joined it, the project was behind schedule. From a technical standpoint, it was not in worse shape than any other project I had seen following critical design review, but parts of the project that were performing at lower efficiencies than expected were threatening the schedule and would eventually drive the mission cost higher than predicted.

Prior to my first full STEREO project team meeting, I was provided information on the team's social dynamic by personnel from 4-D leadership. A 4-D survey showed that it was performing in the bottom 20 percent compared with typical NASA projects. Project members surveyed made some strongly negative comments, to say the least. There was mistrust, blaming, non-cooperation, and indifference. There was the "not invented here," we-know-what-we're-doing-but-they-sure-as-hell-don't syndrome. There were no clear or established roles, accountability, or authority.

The STEREO spacecraft in the Goddard Space Flight Center cleanroom.


Photo Credit: NASA/JHU APL

At the first meeting I had with the STEREO team, which included the principal investigators, observatory/spacecraft provider, and NASA project personnel, I felt I had to put the fear of God into the team. Right off the bat, I made it clear that if we could not improve efficiency and team dynamics and develop clear roles and responsibilities, this project would either be descoped to a mission called "Mono" (a single spacecraft that never would have met the Level 1 requirements) or be canceled. They got the message, and I got their attention and commitment. The rules were No Whining and No Blaming; they could complain once, but then we would move on to fix this project and make it a success. We had one shot to get it right and everyone had to contribute.

I then met with the project business manager, the deputy project manager, the lead systems engineer, and the lead scheduler—the most important folks on any NASA flight-project team. We scrubbed the schedule and looked at what resources would be required to get us to a launch-readiness date that made sense. We assumed that current inefficiencies would continue for a while, added the appropriate contingency to compensate for this performance, and laid out our known risks and the associated mitigations. This later turned out to be an excellent approach as we had enough contingency to cover delays due to industrywide parts problems and late delivery of some instruments, and to partially cover a launch delay due to launch-services issues. In addition, we looked at all the instrument teams and assessed which ones would need additional personnel, schedule, and cost resources to have them deliver on time and meet performance requirements.

How did we improve the work and team environment? My deputy suggested a retreat. I am not a big retreat fan, as most of them end up with proposed actions that are not addressed at all or are forgotten within a week or two. So we decided to have a retreat where we would get all key partners together and concentrate on defining common mission goals and clear RAAs (roles, accountability, and authority), as well as socializing as a team. The only actions that would come out of the meeting would be the RAAs needed for the hardware development and integration phase of the mission. Clear RAAs show who is responsible for decisions.

MAKING NO DECISION IS WORSE THAN MAKING THE WRONG ONE. IF YOU MAKE THE WRONG DECISION, YOU AT LEAST HAVE LEARNED A LESSON.

Making timely decisions is critical, even when you may not have all the data. That is where experience and gut instinct come into play. Making no decision is worse than making the wrong one. If you make the wrong decision, you at least have learned a lesson. And we always had a Plan B, the "what if" in case we went down the wrong path.

One example of making a timely decision with incomplete data is a situation that arose with respect to the thruster valves on STEREO. The valves had already been welded into the propulsion system when the manufacturer notified all its customers that there was a potential defect in some of them. We sent both NASA and the spacecraft developer folks from STEREO to the thruster-

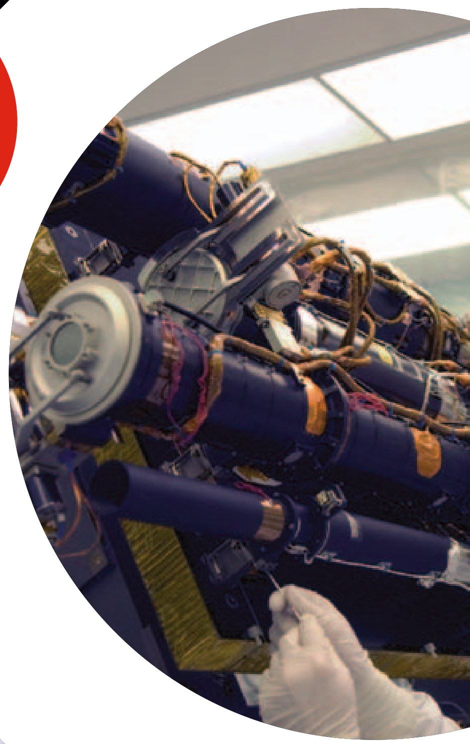
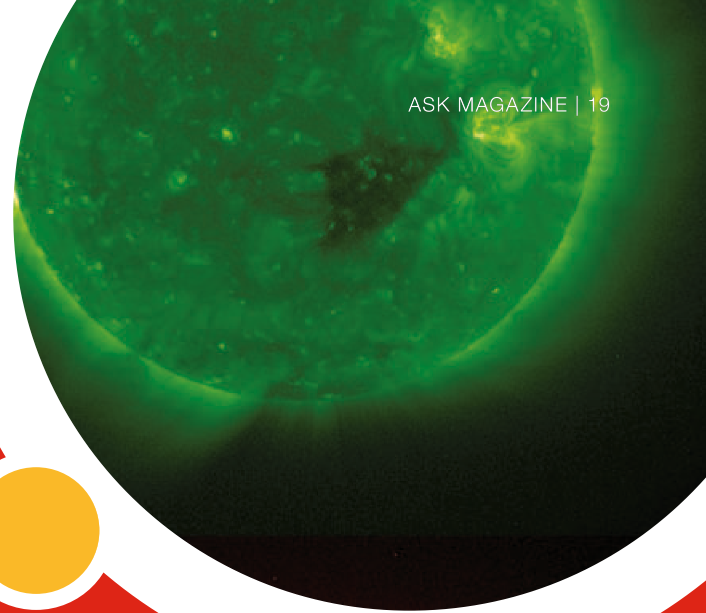


Image Credit: NASA/JHU APL

*Artist's concept showing the two STEREO observatories opening their solar panels.*

The STEREO spacecraft in the cleanroom at the Naval Research Laboratory.

Photo Credit: NASA/NRL/Chris Gunn



valve vendor to discuss the problem. The vendor at that time was not sure which serial numbers were affected, but indicated that we probably had at least seven plus possibly eight more that could be faulty. They were still working on a fix and developing criteria for determining if some were flight worthy. So we were facing the possibility of fifteen out of twenty-four thrusters affected, and not yet knowing the criteria for acceptance nor the fix.

When we looked at our schedule, it was obvious that the propulsion system was on the critical path. In addition, we knew we were not the only project affected by this potential recall. Mars Reconnaissance Orbiter, New Horizons, and at least two defense department missions were in the mix—all with launches either ahead of or close to ours. Our choices were to wait for more information, which meant we would be in line with all the other projects for rework/inspection, or to cut the suspected valves out immediately and send them back to the manufacturer, where they would be first in line for inspection/rework. The latter choice meant breaking flight configuration and having to re-weld and retest the entire system. But with the schedule critical and not knowing our priority status, we decided it was essential to be first at the valve vendor's facility. We removed the suspect valves and sent them back to the vendor. As it turned out, the vendor recalled hundreds of valves, but with ours already there we were the first set out of the gate when they determined the fix. Our decision minimized the effect on our launch-readiness date.

## Building a Real Team

The retreat worked great. The socializing evening was the winner. There was no business done, just discussion of common interests and family in a relaxed atmosphere with, of course, some alcohol. Folks from the different organizations stayed up to the wee hours. It was a great bonding experience. In addition, we documented our common goals for mission success while discussing differences and coming to understand that no one organization was necessarily smarter or better than the others. We were not NASA and not individual organizations. We were STEREO.

One example of our teamwork had to do with STEREO's contamination requirements, which were extremely stringent because of the mission's multiple remote-sensing instruments with optical telescopes. The spacecraft and instruments required at least a Class 10K integration and testing facility and the use of tents, at times, with a Class 1K (no more than one thousand particles per cubic foot of air) rating. In addition, strict cleanliness protocols needed to be followed by all personnel at each facility to keep the total accumulated contamination as low as possible.

ANOTHER IMPORTANT ASPECT OF THE SOCIAL SIDE OF LEADERSHIP AND TEAMING IS APPRECIATION. WE CREATED A QUARTERLY PEER-AWARD PROGRAM THAT INCLUDED BOTH INDIVIDUAL AND GROUP AWARDS.

An engineer looks on as the stacked STEREO spacecraft undergo a spin balance test.

Photo Credit: NASA

This meant that all hardware providers needed to adhere to the contamination requirements and protocols. So we established a contamination working group with leads from both NASA and the spacecraft developer. These leads ended up working extremely well together as well as with the instrument providers and the launch-processing and launch-vehicle providers to develop and prepare the facilities for handling the STEREO observatories and to adhere to a common protocol. As it turned out, STEREO was the cleanest spacecraft ever launched. If the team dynamics had not changed to be “one for all and all for one,” this would not have been possible.

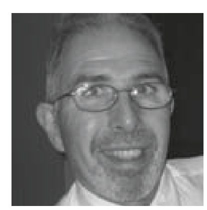
The first retreat was so successful that we held two more prior to observatory integration and test, and then for the launch-processing campaign, when we felt we needed to redefine the RAAs for those phases. Each time, we came out of the retreats stronger as a team. By the time we reached the launch campaign, two additional 4-D surveys showed our team dynamics improving from the bottom 20 percent to average to the top 20 percent.

Another important aspect of the social side of leadership and teaming is appreciation. We created a quarterly peer-award program that included both individual and group awards. Although there was no money involved, recognition by one’s peers and management did wonders. We were very careful not to abuse the process by handing out too many awards. The project management team would personally hand out these awards at team meetings and social events, at times traveling to the recipients’ facility and presenting the awards in front of their management.

## Success

STEREO launched in October 2006. It completed its baseline two-year mission and is currently in its fifth year of orbiting and providing stereo views of the sun. The STEREO science coverage of coronal mass ejections has provided the heliophysics community with groundbreaking science. In addition, the STEREO spacecraft, currently 180 degrees apart—in combination with the recently launched Solar Dynamics Observatory—are providing full coverage, images, and observations of the sun’s near and far sides for the first time.

STEREO showed that the social dynamic of a team can make or break a project. When I think about my experience on the project, I think of one of my favorite quotes, from C.S. Lewis: “Experience: that most brutal of teachers. But you learn, my God do you learn.” ●



**NICK CHRISSOTIMOS** has twenty-nine years of project/program management experience at Goddard Space Flight Center. He is currently the associate director of Flight Projects for Heliophysics, where he is the program manager for Explorers, Living with a Star, and Solar Terrestrial Probes.

INTERVIEW WITH

# Steven Smith

BY DON COHEN

As a NASA astronaut, Steven Smith has flown on four shuttle missions and taken seven spacewalks to carry out Hubble telescope repairs and install the S-Zero Truss in the International Space Station (ISS). He is currently the NASA International Space Station program liaison to ESA, the European Space Agency. Don Cohen talked with him in May.

**COHEN: At the International Astronautical Federation anniversary celebration in March, you showed a drawing of a spaceship you drew as a child. What made you want to be an astronaut then and hold on to that ambition for so many years?**

**SMITH:** There were multiple reasons. The first was that I loved airplanes and flying. My dad was an IBM engineer and we were stationed in Japan for a couple of years, so we flew a lot on Boeing 707s back and forth across the Pacific Ocean. We got dressed up for each flight. We would go watch the airplanes take off and land. Spaceflight in particular grabbed my fancy. I was one of those kids that loved to go out in the wilderness. Going into outer space was the ultimate adventure in terms of going out and exploring. It involved aviation; it involved adventure; it involved math and science, which I was thrilled with, coming from an IBM engineer's family. And my parents said, "You always want to do something that contributes back to society." With all great adventures comes knowledge that makes our lives better, so it was really a perfect fit. If you talk to friends from my youth, they'll tell you, this guy always wanted to be a pilot and an astronaut.

**COHEN: When you eventually flew into space …**

**SMITH:** I was turned down by the astronaut office four times.

**COHEN: When you finally flew, did it live up to your expectations?**

**"WE HAVE WORKED WITH THE RUSSIANS for a long time, BUT THEY HAVE fifty years of experience AND WE HAVE fifty years of experience, AND WE DO THINGS DIFFERENTLY."**

**SMITH:** It was thrilling as I expected … and more. Seeing the earth from space and traveling at Mach 25 were incredible. Living in microgravity was like a magic show—you could even sleep on the wall or ceiling. Seeing the sun rise and the sun set sixteen times per twenty-four-hour day is amazing. And then when you are lucky enough to go outside for a spacewalk, it is even more intense. I went inside the Hubble Space Telescope and held items that were 1,000 or 1,500 lbs. with my fingertips. The challenge ever since has been to accurately convey to people who haven't had a chance to experience it—yet—what it is like.

**COHEN: Do you ever feel weighed down back on Earth?**

**SMITH:** It's interesting when you come back. Right after I landed at the end of my first flight, my wife handed me my two-year-old daughter. She weighed a ton. I handed her back because I was a little unsteady and I said, "I can't hold on to her." Tom Jones handed me a very expensive camera just after we came to wheels-stop on my first flight and he said, "Would you mind taking a picture of me?" This multi-thousand-dollar camera had been weightless for a couple of weeks. When he let go of it, I almost dropped it. My mind was still thinking it was weightless. It is tough to come back in that respect.

**COHEN: Tell me about your current work.**

**SMITH:** I'm what's called the liaison between the NASA and ESA space station programs. That one word—liaison—is a good description. I help the two agencies work together on all things related to the space station, a wide range of things from technical discussions to financial discussions, export control, legal and political issues. We work together extremely well, but there are huge differences in experience and cultures. We've now got nineteen cultures at the European Space Agency. So my job is to try to bring the two together so they work well.

**COHEN: Can you give me an example of a specific issue you've been involved in?**

**SMITH:** One of the most common issues is technical disagreement: for instance, about how we operate the Automated Transfer Vehicle [ATV] at a certain part of its rendezvous. ESA might be seeking to improve their operations or save money or both. They'll come to our flight controllers and say, "On the second flight of ATV-2, can we do something different than we did on ATV-1?" Often engineers meet these proposals with a bit of reluctance. But we dug in and understood what ESA wanted and decided to go ahead and support their request. We also have times when rumors go around about a reorganization or the position of senior managers on either side, and often I'm just trying to correct the record, making clear what's actually going on and what the actual conversations have been about.

**COHEN: So you're a knowledge-transfer agent. How do you get accurate information about ESA to communicate to NASA, and about NASA to communicate to ESA?**

**SMITH:** On the NASA side, I've got several bosses and have all kinds of meetings with managers from different offices and different disciplines, so it's pretty easy to get the NASA story to bring to our European colleagues in a concise, well-ordered way. In terms of transferring information from here back to NASA, a lot of it is available both in literature and on the Internet, but, as usual, by far the best way is by networking and walking the halls. I've been here for eight years now, so I've gotten to know many of the people very well. They understand me and understand the trust they can have. The best way to understand things is face to face.

**COHEN: Was it hard to develop that trust and understanding?**

**SMITH:** I started off on the Automated Transfer Vehicle project, ESA's first attempt to build a human spaceflight vehicle. NASA was responsible for making sure it was safely integrated into the program. I'm sure when the first NASA reps arrived, there was some skepticism on the Europeans' part that we would be overwhelming and try to impose all of our rules on them. I'm sure there still is some of that to this day. But my predecessors gave me one really good piece of advice. They said, "Your job is to keep NASA out of ESA's way." There are a lot of people in NASA who will ask for things; I need to be a filter before I pass them on to the Europeans. So I had to gain credibility. I think also they were a little bit concerned that an astronaut was coming over, someone who had operational experience but maybe not other kinds of experience. They didn't know my background. I did have seven years of industry experience at IBM and have a Stanford MBA, so I have some business experience, too.

**COHEN: I assume your astronaut experience has been helpful to you in this job.**

**SMITH:** Definitely. Astronauts have a unique opportunity to see so many things when we're in the flight crew office. We get different experiences all over the agency and all over the space program. I was also a flight controller before I was an astronaut. I was in mission control for some shuttle flights, so I had some ground operations experience and had human spaceflight experience as well as the specific ISS experience. Of course, having been in the space station is a huge benefit because I can understand the situation we're talking about when we're debating technical topics.

**COHEN: For instance?**

**SMITH:** When we were designing the way the crew would watch the ATV approach to make sure it was safe, it was really easy for me to judge whether or not we were asking too much of the crew. If there were times when we were giving too much information to the crew or not enough or not the right type, it was really easy to speak up and say, "You know, I think this is what my colleagues really would like." We were also blessed with having a second astronaut working the program from the ESA side, Jean-François Clervoy, who I flew with to the Hubble Space Telescope. Together our operational experience was valuable. And we had experience with the Russian cosmonauts and Russian ground controllers and knew that their philosophies were a little bit different from ours. So we tried to decide what would be a happy medium on, for example, what we would ask a crew to watch and do during an ATV rendezvous.

**COHEN: If the people trying to make decisions haven't been up there …**

**SMITH:** Yes, we forget that in zero gravity cables will bend in this direction or that the crew really should stand on the wall rather than the ceiling when they do a particular task—things that people who hadn't actually been there might not think about.

**COHEN: Has it been a challenge to understand the different cultures you work with?**

**SMITH:** We have nineteen countries here, and it's hugely important to understand

> "NOW THAT WE'RE TALKING ABOUT **getting out of low-Earth orbit**, ISS IS GOING TO BE AN **international platform** FOR US ALL ADVANCING TOGETHER TO **wherever we decide to go**: NEAR-EARTH OBJECTS, THE MOON, MARS, **whatever we do**."

how each culture works. It's also important to guess what stereotypes they have of Americans, so I can dispel them. In any international negotiation, you need to understand the culture of the other party. My parents lived in Europe for six years, so I had some exposure to European cultures, but the first year that I was here I was trying to be very open-minded, very respectful, very quiet in my responses, just to gather in how all the cultures worked together. When I got to Les Mureaux, which is where the ATV ESA team was working, there were seventeen people but seven different cultures and seven different languages. It took some tiptoeing at the beginning. We have worked with the Russians for a long time, but they have fifty years of experience and we have fifty years of experience, and we do things differently. It's really important to go in with a mind-set that we're in the extreme on this particular topic on the left, they're in the extreme on the right; probably the answer is not on the left or the right, it's somewhere in between. I've tried to have that philosophy on everything I've done: that we're not completely wrong and they're not completely wrong. Somewhere in the middle is probably the happy medium.

**COHEN: Do you find that working in English—the official ESA working language—is a handicap for people who are not native speakers?**

**SMITH:** Almost not at all. The people are incredible. I'm jealous of their language skills every day. In eight years I don't remember us ever miscommunicating. Maybe we stumble for thirty seconds just to make sure we understood what the other person is saying. I think they're so skilled that it doesn't even cross their minds.

**COHEN: How do you see the future of the ISS?**

**SMITH:** I think it's going to be a fantastic platform to continue to do our basic research. We're just getting our legs under us in terms of good research. Now that we're talking about getting out of low-Earth orbit, ISS is going to be an international platform for us all advancing together to wherever we decide to go: near-Earth objects, the moon, Mars, whatever we do. This incredible infrastructure is in place. I think ISS is the perfect place to try different operational techniques and technologies before you venture away.

**COHEN: I'd say the space station has been a huge technical achievement and a great example of international cooperation.**

**SMITH:** I have a couple of pictures of the space station on the wall in front of me. It's really amazing what was achieved, building something that's the size of a football field that generates the power to support six humans in space. In terms of contributions to world peace, it's been a huge asset. I think the best way to understand that is to talk to people who are in their middle to late sixties. They figured out how to do the space station and decided that, "You know what, we'd better work with the Russians on this or we're not going to have a space station." Those are the people that experienced the big turnaround. Those of us in the program now travel freely to see our friends in Moscow. It wasn't too long ago that that would have been unheard of. It's interesting to talk to some of the NASA personnel who traveled there in the Apollo–Soyuz time. Everyone was watching each other very carefully and was a little bit skeptical. Now there is none of that. We hold thousands of teleconferences a year, freely working together to make life better on Earth. That's been a huge benefit to all of us.

**COHEN: What would you say are the biggest challenges coming up for the space station program?**

**SMITH:** There are a certain number of partners in the ISS program. I'm sure some non-partners are interested in flying with us to the moon and to Mars. So it will be really exciting and challenging to bring in even more cultures. There are some major countries in the world that are not part of ISS that I'm sure would be interested in being part of the next great adventure.

**COHEN: Like the Chinese?**

**SMITH:** Well, the two big countries that are not part of the ISS are China and India. The United Kingdom is not a major player; Australia isn't; South America does not have countries involved. But participation in the next great adventure is going to come from all over the world. ●

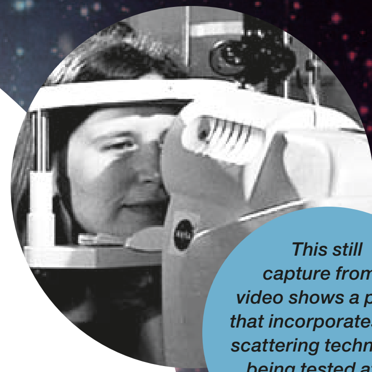


Photo Credit: NASA

*This still capture from a video shows a probe that incorporates light-scattering technology being tested at the National Institutes of Health.*

# human Spaceflight and Science

BY HOWARD ROSS

Photo Credit: NASA

*A candle burning on Earth (left) versus in microgravity.*

Intentionally igniting a fire inside the Space Shuttle might seem like a bad idea, but done safely and correctly, it could answer all sorts of seemingly simple questions, such as, "Would a candle burn in zero gravity?" Several university doctoral programs had asked this very question for years, and nobody—not even microgravity-science experts—could agree on an answer. What we never expected was that the answer would lead to even more answers, and some remarkable scientific discoveries and advancements.

## Small Flame, Big Discoveries

What started as a trivial hallway conversation between me and a couple of grad students eventually grew into something more concrete. My colleagues, Dr. Daniel Dietrich of Glenn Research Center and Professor James T'ien of Case Western Reserve University, presented the idea as a simple high-school education experiment when, in fact, we didn't know the answer ourselves. The idea sold.

Since the shuttle had flown so few combustion experiments, we had to put the candle inside a nonflammable Lexan box, which was then placed inside a glovebox already installed on the orbiter. We drilled some holes in the candle box (the candle needs oxygen to burn), included a hot-wire igniter for the crew to operate, and away we went.

What we discovered was a candle would indeed burn in 0 *g*: unlike lit candles on Earth, it had a round flame, except near the bottom where the candle wax quenched it. It burned for about 45 seconds (we had a bet going about how long it would burn; I lost—I had 20 seconds, Dan had 40 seconds). But later we realized the time it burned may have been limited by the number of holes in the box, preventing oxygen from the glovebox from easily getting to the flame. Would the candle burn longer if we used a different design?

We had also wanted to study two candles facing each other (unlike a birthday cake where the candles stand next to each other in parallel lines, here the candles were on a single line with the wicks facing each other). To our surprise, we learned that once we lit one candle, we couldn't light the other, because the oxygen concentration near the second one was too low—the first candle effectively used up the necessary amount of oxygen.

We were lucky to get a chance to try the experiment again on Mir, and the Russians allowed us to switch from a Lexan box to a wire-mesh one, which was much more open. But they required us to fly oxygen sensors with the experiment if we wanted to get it on board. We used commercial off-the-shelf sensors. They didn't work well in flight, but their mere presence did allow us to get approved and onto Mir.

This time we learned that a candle that burned for about 10 minutes on Earth burned for 45 minutes (not seconds!) in space once we got rid of the Lexan box. The flame was incredibly weak (about 5 watts in space compared with 50 watts here on Earth), but it could survive a very long time.

During the experiment with the wire-mesh box, we asked crewmembers to turn the lights on and off. What we found when we did that is all the candle wax had melted, but it didn't drip off the candle because there was no gravity to pull it down. With the lights off, it was possible to see these incredibly fast, thermal, capillary-driven flows—essentially aerosol spray—inside that wax melt.

At the end of one of these Mir experiments, Astronaut Shannon Lucid turned on the lights and said, "I see something that looks like a dandelion there, sitting there. I will take a picture of it, as well as make a drawing of what I see, in case the camera fails." This happened right after the flame went out. Now, on Mir, you had 10 minutes of communication ("comm") time followed by 70 minutes of no communication. So right at the end of her comm she said, "Can you tell me what that is?" Suddenly all the lights lit up from Moscow with people (especially those in safety) wanting to know, What is that thing? In the 70 minutes we had, we came to the conclusion it was a fog of condensed water vapor, which we told to Shannon and those in safety, and everyone seemed satisfied. Months later, when we saw the pictures and video, we came to a different conclusion: it was probably a cloud of condensed candle wax. Once the flame went away, the aerosols inside the wax melt condensed into a little round ball of flammable material.

Fortunately at the time, when her comm time came around again, we told Shannon to turn on the fan inside the glovebox to blow the cloud of material into a filter in the glovebox. The whole event served as a realistic reminder of the need for careful post-fire cleanup operations. From this we learned that if there ever were a fire on a spacecraft, the crew would need to worry about the safety of their operations even after the fire was out.

Later, there was a chance the agency would let us fly the experiment again. Since the oxygen sensors had not worked, we really wanted to know what the oxygen concentration was while the candle burned. We couldn't find sensors that were minuscule enough to avoid hurting the delicate flame in 0 *g* that were also reliable over a wide temperature range, so we ended up building our own oxygen sensor. The same was true for the carbon-dioxide concentration: we designed, built, and tested our own non-intrusive sensor to measure the $CO_2$. We were all set to fly, but the flight opportunity got canceled.

Dan began to wonder what else we could do with what we had created. Somebody said, "Well, you need to know oxygen and carbon dioxide concentrations for metabolic analysis during exercise, and our sensors are really small—could we integrate them into a mask?" So he led a team that did just that. He began talking and working with a doctor at University Hospitals in Cleveland, Ohio. The resulting Portable Unit for Metabolic Analysis, or PUMA, ended up weighing less than two pounds and could collect and transmit data wirelessly in real time.

Fast-forward a number of years and a number of tests—we showed it to flight surgeons, demonstrated it could work at 2 ½ atmospheres underwater during NASA Extreme Environment Mission Operations—and eventually a private company and the U.S. Navy became interested. Today, PUMA has been successfully used for testing oxygen and carbon dioxide concentrations, monitoring metabolic analysis, and testing for hypoxia in pilots flying at high altitudes.

So you start by wondering, "Will a candle burn in 0 *g*?"

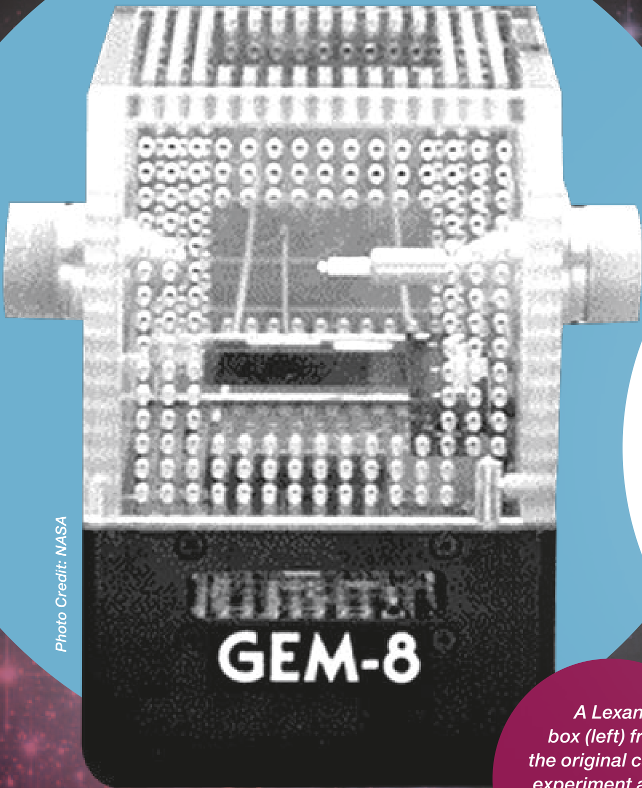



Photo Credit: NASA

SO YOU START BY WONDERING, "WILL A CANDLE BURN IN 0 *g*?" AND YOU END UP EIGHTEEN YEARS LATER HELPING PILOTS UNDERSTAND THEIR PHYSIOLOGICAL STATUS WHEN FLYING AT HIGH ALTITUDE.

*A Lexan box (left) from the original candle experiment and a wire-mesh box later used on Mir.*

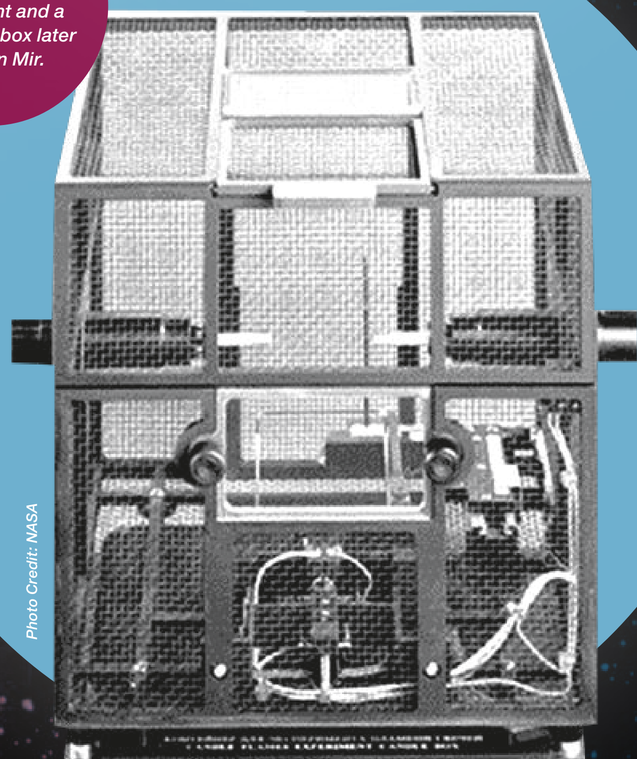


Photo Credit: NASA

*The Portable Unit for Metabolic Analysis.*

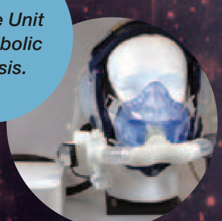


Photo Credit: NASA

and you end up eighteen years later helping pilots understand their physiological status when flying at high altitude. Along the way, our descriptions of this silly little experiment packed the house at combustion-science symposiums where, honestly, much more important research was being discussed. *Scientific American* carried a photo of the Mir flame, and references were made to it in the *Encyclopedia Britannica*'s annual updates. Professor T'ien tasked graduate students with modeling what was happening with the 0 *g* candle flame, and this effort proved far more challenging than anyone imagined.

## From Fire to Fluids

Another experiment made possible by the Space Shuttle started by wondering how colloids—the small particles that float around in paints, shampoo, soaps, detergent, milk, etc.—actually aggregate, or condense. On Earth, they tend to sediment over time, so producers of these products need to acquire stabilizers to help keep the colloids in place. But would they exhibit the same behavior in space?

When we flew them on board the shuttle, the colloids created weird, treelike dendritic structures not normally seen on Earth. Some things that had never previously crystallized actually crystallized in space. And when the colloids did separate from each other, they did so under conditions completely contrary to the theory being used at the time. They would segregate under conditions far different from what anybody predicted.

During one of those experiments, Rafat Ansari, a project scientist who looked at the light scatterings where we measured particle concentrations, discovered that what he was seeing acted the same way as his father's cataracts. Rafat realized that a cataract is simply a collection of particles that have come together just like the colloids he was seeing in space. He used the measuring technology that we flew in space, miniaturized it, and started applying it to see if he could detect the formation of cataracts very early on. Turns out, he could detect it—ten times sooner than any other device that existed on the market at the time. In 2003, the National Eye Institute featured this device to Congress. And in 2009, it wasn't just the National Eye Institute but the entire National Institutes of Health citing it as one of their top six technology advances in the past year.

Afterward, I asked Rafat why he became a scientist. He told me that when he was a seven-year-old in Pakistan, he saw people walking on the moon, and he said, "That's absolutely amazing. I want to go into science because of that." Human spaceflight touches people in ways we don't expect.

## Unexpected Outcomes

These are just a few examples of how scientific curiosity, no matter how trivial it may seem at the beginning, can manifest itself in unexpected ways. This is an important aspect of science in general: what you learn along the way can end up being applied very differently than you ever anticipated. And space also teaches us to think differently, which makes those who work on these experiments a needed commodity even in environments outside space.

If there is any lesson in all of this, it's to not be afraid to ask what seems to be a really simple question; you never know where it will lead. And always look at your own life for motivation to create solutions to common problems.

The Space Shuttle played a big role for thirty years in helping foster scientific discoveries and technological innovations such as these. The International Space Station and countless other missions will help us continue to do so in the future. As long as scientists continue to ask questions, and the space program flies the resulting experiments, big discoveries can come from very small beginnings—and the impact of human spaceflight can continue to surprise us.

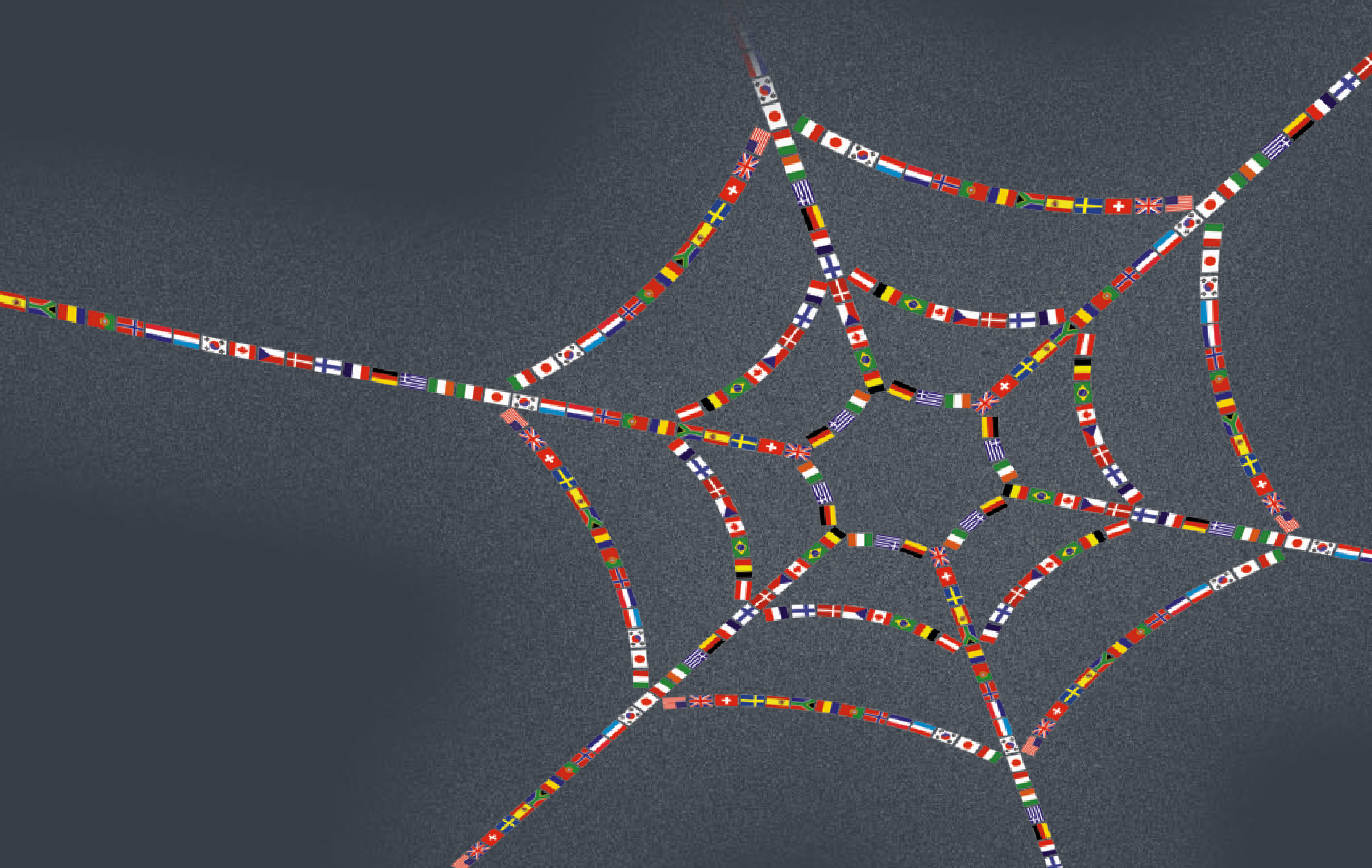
Each time we flew it felt like a personal Olympics: years of preparation for a few moments or days when proof would be forthcoming on whether our efforts—and yours—were worthwhile. I can say unequivocally and in every case, yes, they were. I want to thank everyone who played a part in making the shuttle fly so successfully for so long. I will always be grateful to all of you. ●

**HOWARD ROSS** is currently the chief technologist at Glenn Research Center, as well as the director of the Office of Technology Partnerships and Planning. Among his previous roles, he once served at NASA Headquarters as deputy associate administrator in the Office of Biological and Physical Research and helped select many spaceflight experiments that flew on the Space Shuttle and International Space Station. This assignment was based on his service as a principal investigator and project scientist on many microgravity experiments.

# Weaving a Knowledge Web

BY *ASK* EDITORIAL STAFF

In March 2011, some two dozen representatives from space agencies and related organizations around the world meet in the top-floor conference room of the European Space Agency's (ESA) Paris headquarters. Outside the windows lining one wall, flags representing ESA's nineteen member nations stir in the breeze. A painting of two human figures floating on a background of stars and galactic dust—an image of space exploration—hangs at one end of the room. Space exploration is why the members of the International Project Management Committee (IPMC) have gathered here. The group meets twice a year to develop ways to share the project management expertise that successful space programs depend on.



The space agencies of Germany, France, Italy, Czech Republic, Canada, South Korea, South Africa, and the United States are represented. Committee members from JAXA, the Japanese space agency, have sent their regrets; the aftereffects of the recent devastating tsunami have kept them home. Ed Hoffman, director of NASA's Academy for Program/Project and Engineering Leadership, chairs the meeting.

The committee is just over a year old. Prior to NASA's 2010 Project Management (PM) Challenge in Galveston, Texas, Hoffman asked Lewis Peach to help bring the international space community together. The result was two days of panels at the PM Challenge featuring senior leaders from space agencies around the world and focusing on multinational aerospace projects. Participants in that international track stayed an extra half day to explore the possibility of forming the committee that became the IPMC.

The value of such a committee was clear to Hoffman and the others at that meeting. International collaboration on aerospace projects is increasingly the norm. Most efforts today are multinational, bringing together space agencies, universities, and industries from around the world. And carrying out ambitious and expensive future science and exploration missions will undoubtedly require the resources of many nations. Those missions will demand that all the partners involved possess high-level project management and collaborative skills. An international committee focused on sharing the collective project management knowledge of many space agencies could help make that expertise widely available and build some of the relationships that collaboration depends on.

Bettina Böhm, head of human resources for ESA and now vice-chair of the IPMC, explains ESA's interest in the committee, noting that the need to collaborate with others is becoming more and more important and that, at the time of that first, exploratory meeting, ESA had just carried out a study on new and better ways to prepare people for program and project management. Bringing experienced people together to share practical learning was clearly one valuable approach.

At that initial meeting, the group established some foundational norms, namely, inclusiveness, mutual respect, and the need to show practical benefits.

The IPMC had its first official meeting a month after the 2010 PM Challenge in conjunction with the International Astronautical Federation's (IAF) spring meeting in Paris. It became an IAF Administrative Committee. That official link with IAF's more than two hundred organizations that are active in space in nearly sixty countries gives the committee visibility and the potential for widespread influence. IPMC meetings since have been coordinated with IAF events: the International Astronautical Conference in Prague in the fall of 2010 and now in Paris again, where the IAF was holding its sixtieth-anniversary celebration and planning for the next conference.

THE VALUE OF SUCH A COMMITTEE WAS CLEAR TO HOFFMAN AND THE OTHERS AT THAT MEETING. INTERNATIONAL COLLABORATION ON AEROSPACE PROJECTS IS INCREASINGLY THE NORM. MOST EFFORTS TODAY ARE MULTINATIONAL, BRINGING TOGETHER SPACE AGENCIES, UNIVERSITIES, AND INDUSTRIES FROM AROUND THE WORLD.

Böhm says these early meetings have been mainly—and appropriately—devoted to developing relationships, and creating and maintaining trust and openness. There have been some concrete actions taken, though. The most ambitious so far is the International Project Management course held at Kennedy Space Center in early 2011. Participants in the five-day course included fifteen people from ten IPMC agencies and organizations. At this Paris committee meeting, Andrea Cotellessa, an ESA staff member who attended the course, describes his experience. His review is positive (as were the assessments of other attendees), but he does suggest that some of the sessions were too much from a NASA point of view, with little attention to the different experiences of other agencies. The committee discussed ways of bringing more cases and lessons from other agencies into the curriculum. The second International Project Management course at Kennedy was held in July.

The committee has also recognized the importance of reaching out to young professionals—the engineers, managers, and scientists starting their careers—who will have the privilege of shaping international space-exploration missions over the next several decades and will face the challenges of those ambitious space programs. Young professionals have been invited to the meetings as observers, and the committee is considering a proposal for a young-professionals workshop and young-professional membership.

Emphasizing the need for continuing action, Böhm suggests that at least a couple of hours of every future meeting should focus on an issue in a way that results in specific, useful activity. Her emphasis on concrete action resonates with other members of the committee, who know that the benefits they can bring to their organizations justify their investments of time and travel.

The committee's key challenge, says Hoffman, is to learn how to share the right expertise in the right ways among agencies that differ in size, experience, and how they approach aspects of the work. Continuing activities and conversation among members, like Cotellessa's International Project Management course critique, are helping to develop a fuller understanding of member agencies' practices, which will make effective learning possible at future International Project Management courses and in other settings.

Another challenge is how to keep committee members who are scattered around the globe productively connected, given that they meet formally only twice a year.

That seems to be happening. Relationships formed here are proving to be the foundation for gatherings of small groups to work on issues of specific concern to their agencies. For instance, DLR, the Germany Aerospace Center, brought practitioners of several space agencies together at a small PM Challenge–like event, something unlikely to have happened without DLR's participation in NASA's PM Challenge and connections developed through the IPMC.

The committee will meet next at the International Astronautical Conference in Capetown in October. It is still very much at the beginning of its efforts. Its contribution to building the knowledge and networks to support twenty-first-century space exploration will no doubt take a variety of forms, likely including joint conferences and courses and a range of collaborative initiatives that arise from members' discussions of their shared concerns and challenges. It is not possible to say exactly where its commitment to inclusiveness, respect, and the pursuit of practical benefits will take the IPMC, but it hopes to have a significant role in improving international aerospace learning and cooperation. ●

# From Masters with Masters: Rob Manning and Rudi Schmidt

In February 2011, Academy of Program/Project and Engineering Leadership Director Ed Hoffman sat down with Rudi Schmidt, from the European Space Agency (ESA), and NASA's Rob Manning at the Jet Propulsion Laboratory (JPL) as part of the Academy's Masters with Masters series. Dr. Schmidt, the head of ESA's Telecommunications Satellite Programs Department, was the project manager for several of ESA's Directorate of Science and Robotic Exploration Programs, including Mars Express, Venus Express, and Gaia. Manning was formerly the Mars Exploration Program chief engineer at JPL and is currently the chief engineer for the Mars Science Laboratory (MSL).

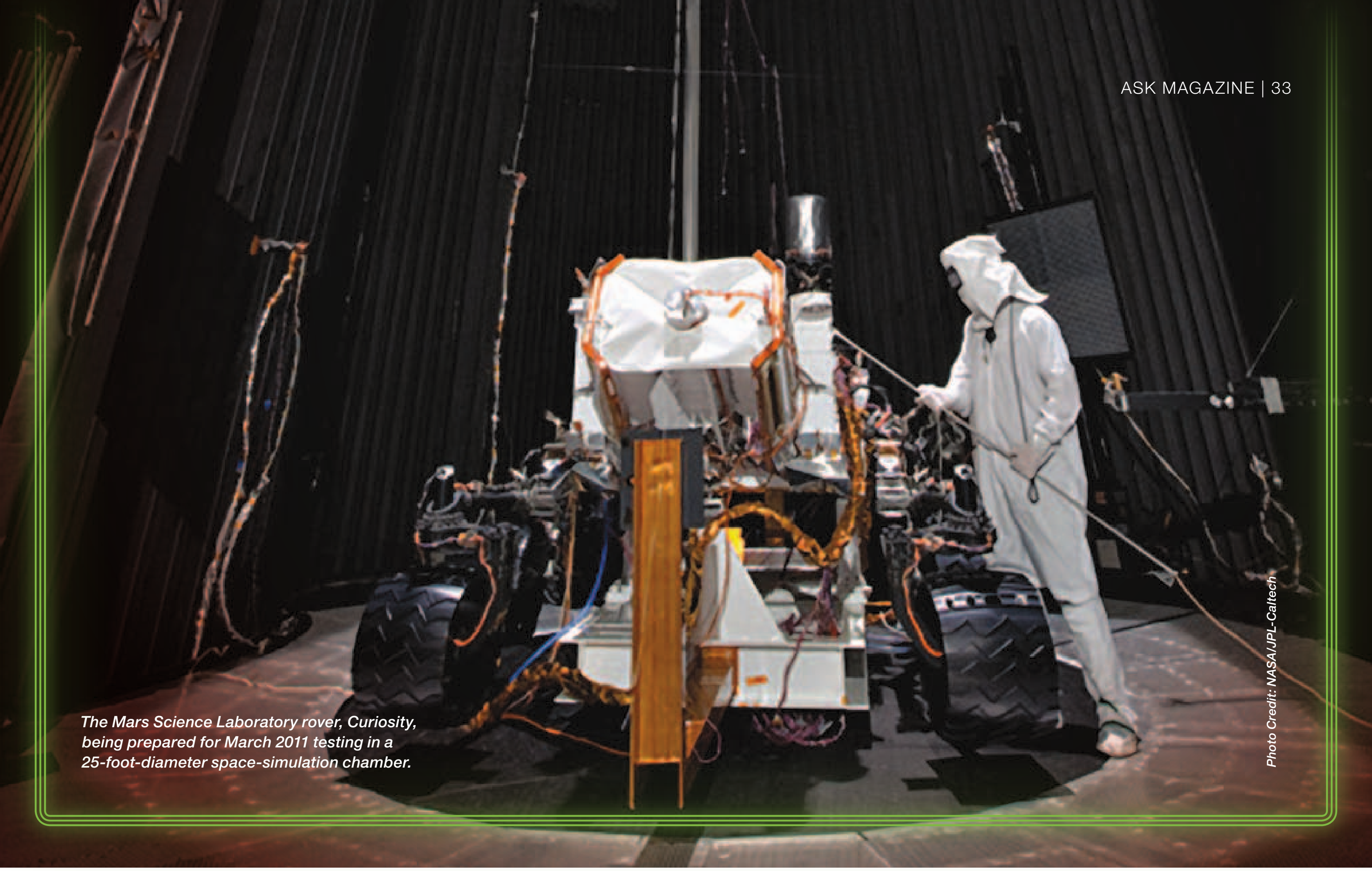
**Hoffman:** What makes Mars so fascinating?

**Manning:** The Viking landers that arrived on Mars in the 1970s did sampling of the soil that was believed to tell us that the surface of Mars appeared to be a dead, sterile, boring place. But the Viking orbiters showed tantalizing hints that water may have coursed over the surface in huge deluges. Starting in the mid-90s, the Mars Global Surveyor mission showed signs that water may play an active role on Mars even in geologically recent time. We see what we think is water ice along with the $CO_2$, and we see a dynamic atmosphere with huge dust storms. In the early nineties, I had this fantastic opportunity to become chief engineer for Mars Pathfinder. It allowed me to take all of my childhood desires, and all of the things I admired from the ten or twelve years of engineering, and put them together with a small team to build a vehicle to move around on the surface of Mars.

**Schmidt:** I never expected that I would end up leading a mission to Mars. I started in the European Space Agency in the early eighties as a scientist. I sat in my office doing data analysis, trying to conceive new ideas for new measurements of electric fields, magnetic fields, particles in space. Eventually, I became the project scientist for a mission called Cluster. I spent fourteen years working on that mission. We lost it within twenty seconds after launch in '96. When the Russian Mars '96 mission failed, some of the big European member states of the agency said, "We have lost so much money, so much knowledge, so many instruments on Mars '96, we Europeans have to do our own mission." I was asked whether I would take over the preparation of Mars Express. At that point, nobody knew whether we could launch in 2003, whether the 150 million that we finally found would be sufficient to build an orbiter, launch, fly, and operate it. That preparation period lasted until maybe early 2000, when we said, "Yes, we could launch in 2003. Yes, we can do it with 150 million." At that point, I became Mars Express manager.

It was the first deep-space mission which we did alone. Mars Express was a fully European spacecraft operated by us and implemented by us, with some NASA instruments on board. We did not know whether we had enough experience to carry it through, so we took quite a careful approach. I said to my people at that time, "When I wake you up at two o'clock in the morning, without any hesitation you have to give me your ten biggest risks." We built up lots of margin. Then politicians told us that we could not fly to Mars without a lander. All the reserves we had built up went to build Beagle 2, the lander.

**Manning:** That's a lot of pressure, having the first Mars mission with a lander and the first mission that you had to do from scratch.



The Mars Science Laboratory rover, Curiosity, being prepared for March 2011 testing in a 25-foot-diameter space-simulation chamber.

Photo Credit: NASA/JPL-Caltech

**Schmidt:** We had little budget and a small team. At that time there was a big mission called Rosetta, which was supposed to be launched about the same time. They would have all of the development technology and the Mars Express team would buy the current units. In the end, our small team was much more efficient than the bigger Rosetta team. We overtook Rosetta in terms of development, and the small Mars Express team started to drive the technology. It was quite challenging. In several instances you don't have enough background to make a decision, but you know that the launch is coming and the decision has to be made.

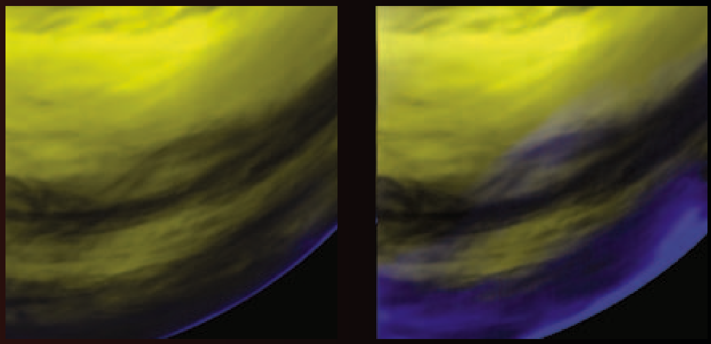
**Manning:** My first Mars mission was Mars Pathfinder. We had a tiny budget, compared to the Viking missions. The best thing is having a small team. We were allowed to work in the shadow of a very large project, the Cassini mission. We were told to work in the faster-better-cheaper mode. We had to do a lander with very few, not-very-complicated requirements. It made for a very exciting environment because a small team could work very efficiently. Like Rosetta and Mars Express, we had Cassini technology that we could borrow from, but we beat them to the launchpad mostly because the planetary orbit demanded it but also because we were small and much more agile. Unlike your project, we didn't have a lot of eyes looking at us.

**Hoffman:** How does a program change when you're managing a small team?

**Manning:** You constrain the mission objectives, keep the system as simple as you dare, but no simpler, and give yourself healthy reserves. We initially had 50 percent cost reserves. Obviously, from NASA's perspective you don't know what you're doing if you're asking for 50 percent reserves. That's correct, we didn't. We had never done a low-cost lander and rover before. We spent every penny of that 50 percent, by the way. On the other hand, the risk model we were working with was not the same one we would use today. We had very little redundancy, with just a few key places where we felt there were high-risk components: pyrotechnic devices, the radio transmitter, and a few other places.

**Schmidt:** After Mars Express, I am a fan of small project teams because they are efficient. A small team driven by launch date and constrained by cost has to be innovative. Our starting point was different from Rob's because Mars Express is the child of a failure. We could not fail again. The inspector general reviewed us over and over again to make sure our margins, reserves, design assumptions, and requirements were all tight. In the end, it worked out well.

**Manning:** Larger projects have more instruments, they have a more complex mission definition, there's just more you have to manage. It's not just a scale-up. There are more interfaces that you have to deal with. As a consequence, you have to



This false-color view was obtained by the Visible and Infrared Thermal Imaging Spectrometer onboard ESA's Venus Express.

Photo Credit: ESA/VIRTIS/INAF-IASF/Obs. de Paris-LESIA

use more rigorous systems engineering techniques so that the various things that are going on in parallel succeed and come back and meet you at the end. For a smaller mission, you have fewer things to manage. As a consequence, you can apply different management disciplines to improve efficiency without necessarily changing the risk posture. In some cases—for example, MSL—we were asked to put a lot of redundancy in, approaching the redundancy of some traditional, large, flagship missions. That means you have twice as much equipment to build, more to integrate, more different permutations of testing to do. There's a lot more complexity you have to manage.

**Schmidt:** I'm not sure I fully agree with you. My budget following Mars Express was about five times Mars Express. The project team size was far from five times bigger than the Mars Express project. Instead of twelve people, it was seventeen. I like small, horizontal teams. That means people close to the project manager, a straight information path from the lowest member in the project team up to the project manager. Each person in the team feels responsible and knows that they have immediate access to the project manager in case of a problem.

**Hoffman:** Do you learn most when things don't go right?

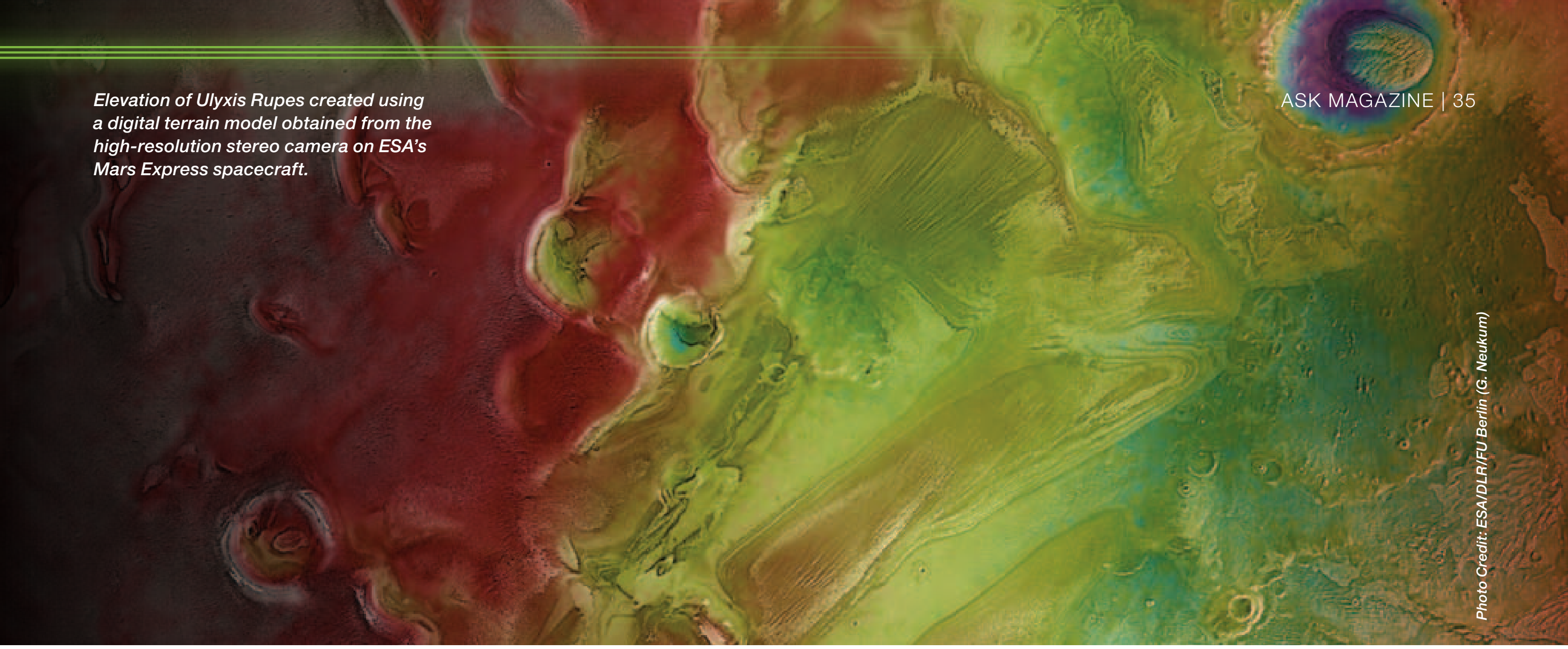
**Manning:** The great thing about failure is that people start believing you when you say there are issues you need to solve and you need the resources to solve them. In a project that is so cost-constrained that they can't afford to even assess the risk, you're getting on thin ice. You need to have not just done the work, but to have it reviewed with independent people who make sure that you didn't forget anything. MER [Mars Exploration Rover] was much more complex than Pathfinder, and we were paying not just for hardware, but for additional work and double checking.

**Hoffman:** Rob, when you were going through the Mars Exploration Rover lessons learned, you said that one of the things that stuck out to you was sometimes you just need to stop and reflect.

**Manning:** Yes, having a little extra help so that there are key people who really understand the design and you can stop and ask, "Did we really think this through?" On Phoenix, even though the design was directly based on the Mars Polar Lander, we bought ourselves some time and people to think through the entry, descent, and landing problem. We said, "Let's take the design and analyze and test it as if it were brand new." In the process, we learned new things about Phoenix *and* about Mars Polar Lander.

**Hoffman:** How do you balance managing risk and being able to innovate?

**Manning:** If we can get to our objective with something that's tried and true, we will do it. But if there's a new technology that we need to succeed, we will put our heart and soul into making it happen. A lot of people say, "Why didn't you throw this technology in as well?" Well, because I can do this mission with a technology where I've already retired the risks. In the case of MER, we said we are going to use all that technology from Mars Pathfinder and adapt it with minimal or no changes. In fact, all the hardware had to be redesigned in order to meet the mission objectives. Less than 1 percent of the total mass of what we launched was heritage hardware from prior missions. We had to change everything a little bit to deal with larger landed masses. Even so, the knowledge of what was learned on Mars Pathfinder directly reduced the risk on MER, but it did add to cost. You just have to be quick on your feet and willing to learn. When you find information that tells you your assumptions were wrong, don't hold on to them. Throw them away, learn the new ones, and go forward.




*Elevation of Ulyxis Rupes created using a digital terrain model obtained from the high-resolution stereo camera on ESA's Mars Express spacecraft.*



**Schmidt:** The plan was that we procure recurring units developed by Rosetta and that we re-fly the instruments of Mars '96. The reality was the scientists said, "We need new instruments because we learned so much in building the first set of instruments that now we'll do it differently." We couldn't stop the scientists developing new things because the payload was under member-state control. One day, relatively late in the project, the scientists came with the idea to change the orbit. This is the last thing you want because all your computations, all of your modeling, all your operational documents are written for a certain orbit. I must admit, quite often we found what I originally thought was a pretty stupid idea turned out to be implementable one way or another. But it doesn't make your life easy if you keep changing what you thought is a solid goal post. That's the result of working with people. People change their mind and you have to adapt.

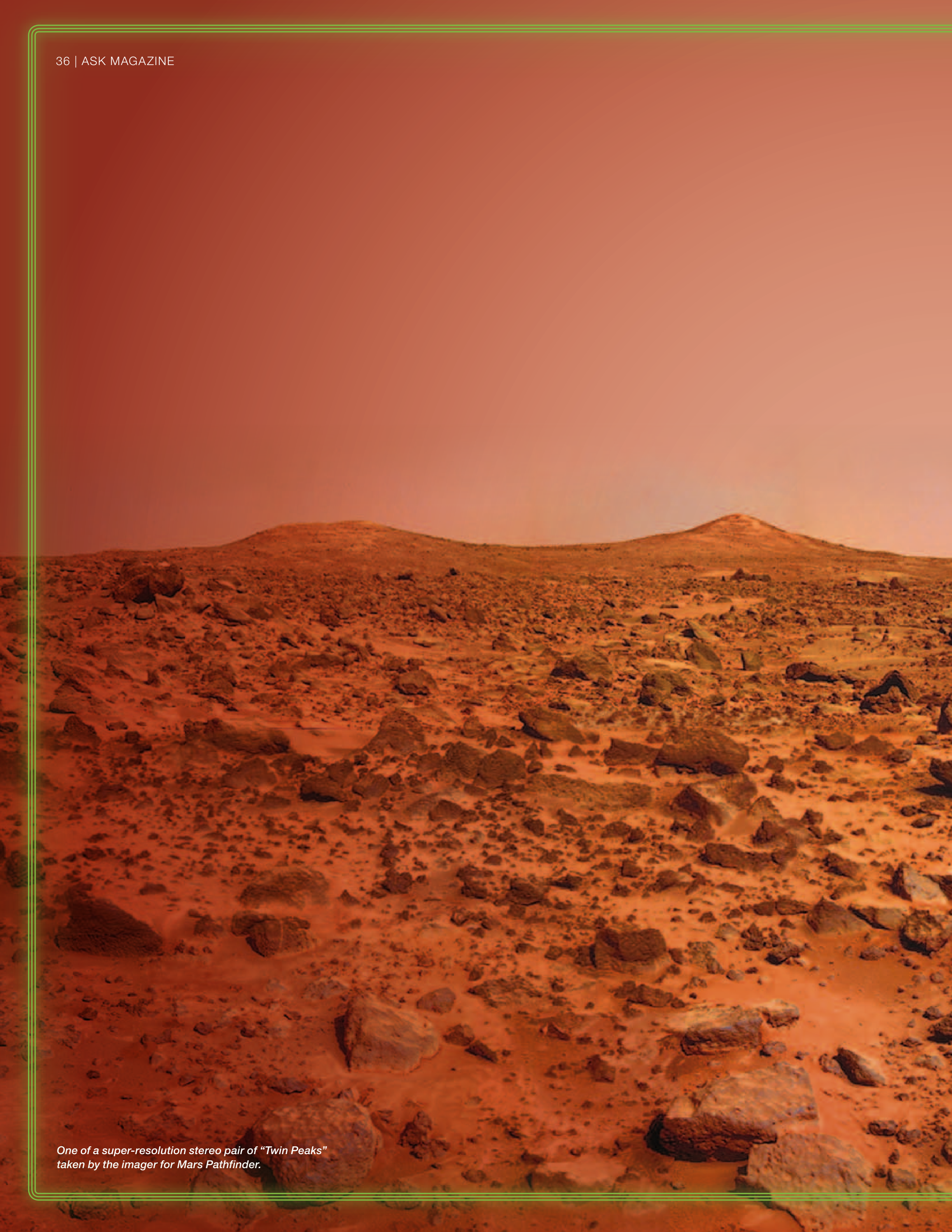
**Hoffman:** Aerobraking is obviously one of the breakthrough technologies in your area of expertise.

**Manning:** The great thing about entry, descent, and landing is that there is a heritage to build upon—a technological heritage, not a hardware heritage. The Viking missions developed something called SLA 561V, which is similar to the spray-on ablative heat-shield material used on the shuttle external tanks. This material was validated and tested thoroughly in the years leading up to the Viking launch. We were able to adapt that technology to very different conditions. We had to make it thicker, we had to redefine the formula after the twenty-year hiatus, but we used that same technology, the parachute technology, the whole structure of how to get rid of your heat shield and get out of your vehicle, undress yourself in a few seconds in a very dynamic environment. On MSL, technology that we had relied upon for many years for many missions suddenly didn't work. Mars Science Laboratory has a four-and-a-half-meter-diameter heat shield, the largest circular heat shield anyone's ever built. When MSL flies through the Mars atmosphere, its radiative heating environment and the shear dynamics are so great that the old technology just doesn't work. So we had to come up with a whole new technology and adapt the PICA heat-shield material that we used on Stardust. That was a huge left turn, but it was done with our eyes wide open. For a project manager, it's very scary going from the devil you knew to a devil you don't, but this devil has worked out very well so far.

**Schmidt:** Because Mars Express moved forward nicely, the project team had the idea to build a second Mars mission for launch in 2005 with all the leftovers. We naïvely assumed it was going to be a second Mars mission. But the director said we have to do a competition, we have to open it to all communities. So the ideas came back, and what did we get? A Venus mission. We needed a new solar array. We needed a completely new thermal system. So we bought ourselves a lot of problems, but in the end we also made this mission successful.

**Hoffman:** How do you work effectively when you have so many different stakeholders involved in something that's naturally complex?

**Schmidt:** The needs of all the member states involved in the mission are a priority. It means you're not always getting a certain piece of hardware from the best company; you have to make compromises, you have to be sure that enough money went to various countries according to certain computations. It's a big fraction of my daily business; it's the price of being a European. And because the cultures are different, the experience of the companies is different. And you have to build up an industry in new member states. We recently had a case where one of the project engineers was assigned to a company as a kind of resident. He trained them, he showed them, he explained to them, and in the end the hardware came—a week late, but working perfectly.



*One of a super-resolution stereo pair of "Twin Peaks" taken by the imager for Mars Pathfinder.*

AFTER MARS EXPRESS, I AM A FAN OF SMALL PROJECT TEAMS BECAUSE THEY ARE EFFICIENT. A SMALL TEAM DRIVEN BY LAUNCH DATE AND CONSTRAINED BY COST HAS TO BE INNOVATIVE. OUR STARTING POINT WAS DIFFERENT FROM ROB'S BECAUSE MARS EXPRESS IS THE CHILD OF A FAILURE. WE COULD NOT FAIL AGAIN. THE INSPECTOR GENERAL REVIEWED US OVER AND OVER AGAIN TO MAKE SURE OUR MARGINS, RESERVES, DESIGN ASSUMPTIONS, AND REQUIREMENTS WERE ALL TIGHT. IN THE END, IT WORKED OUT WELL.

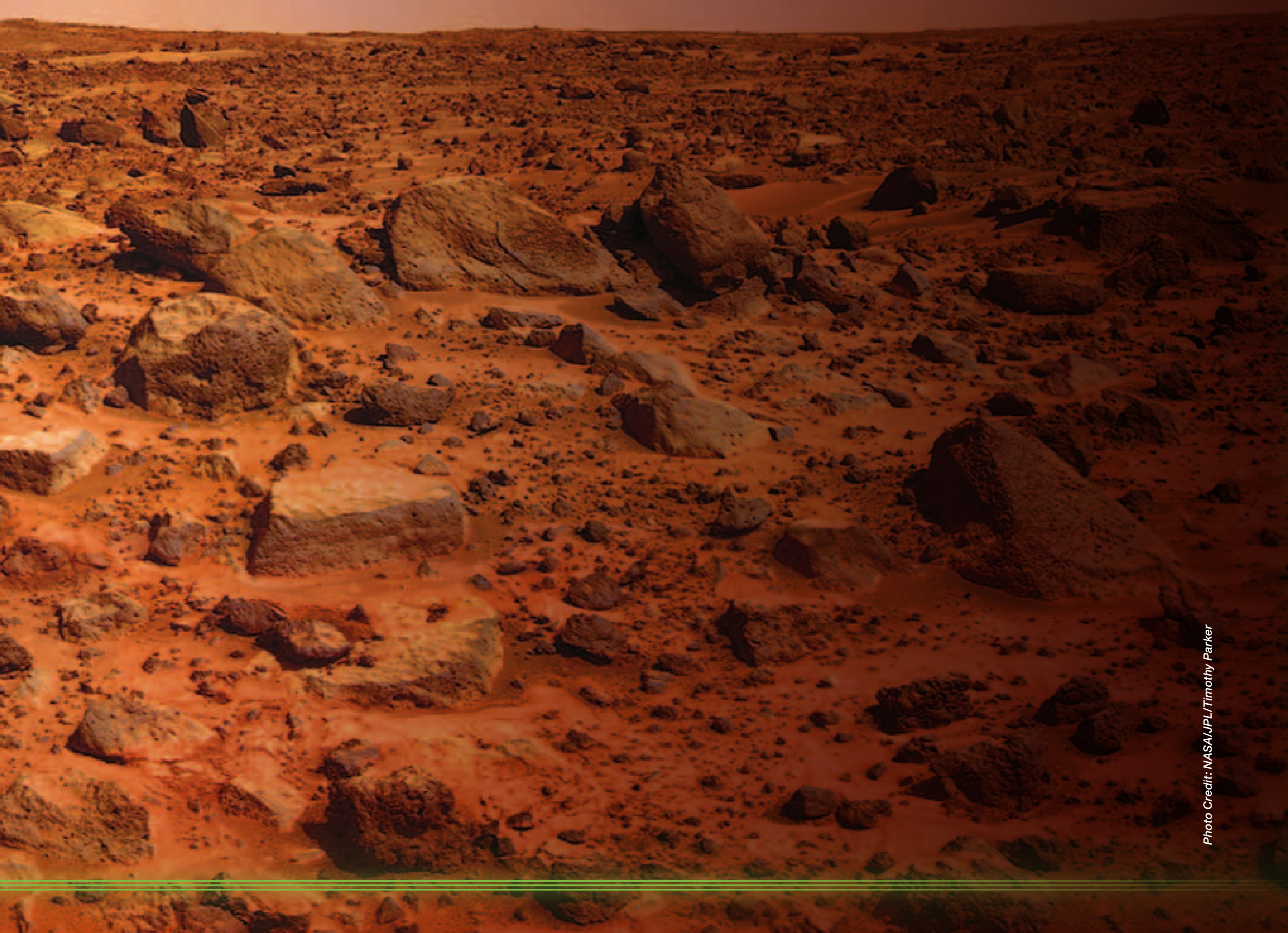


*Photo Credit: NASA/JPL/Timothy Parker*

THE THINGS WE WANT TO DO NOW ARE HARDER AND HARDER: BRINGING THINGS BACK FROM ANOTHER PLANET, GOING TO ASTEROIDS, GOING AND STAYING AT JUPITER, LANDING ON EUROPA. COST SHARING MAKES A LOT OF SENSE.

The next time around this company will have a good chance to win the competition.

**Hoffman:** Rob, obviously NASA has been increasingly involved in international missions. What are the benefits?

**Manning:** From a parochial perspective, sharing the cost of a project. We have been looking at collaborating on a Mars sample return for years. We have European science instruments on board Mars Science Laboratory. We aren't as good as Europeans are at managing these complicated relationships. We are used to being able to solve the problems directly, finding the best, cheapest company, and having the control on our side. But the flip side is that having a partner can produce significant contributions. Our biggest challenge is how to do technically challenging and exciting, high-return missions across international boundaries, especially given ITAR [International Traffic in Arms Regulations]. It can be done. The Huygens-Cassini mission is a perfect example. It was a fantastic relationship.

**Schmidt:** I think it is relatively easy for European scientists to build international teams because they have to bring in their own money. I have seen PIs [principal investigators] coming in with a team proposal which included scientists from all continents. I am impressed by the capabilities of the scientists to put together these extremely complicated instrument proposals with complicated team structures behind them.

**Manning:** The things we want to do now are harder and harder: bringing things back from another planet, going to asteroids, going and staying at Jupiter, landing on Europa. Cost sharing makes a lot of sense.

**Hoffman:** Both of you have work that you love. What is it you love the most about what you do?

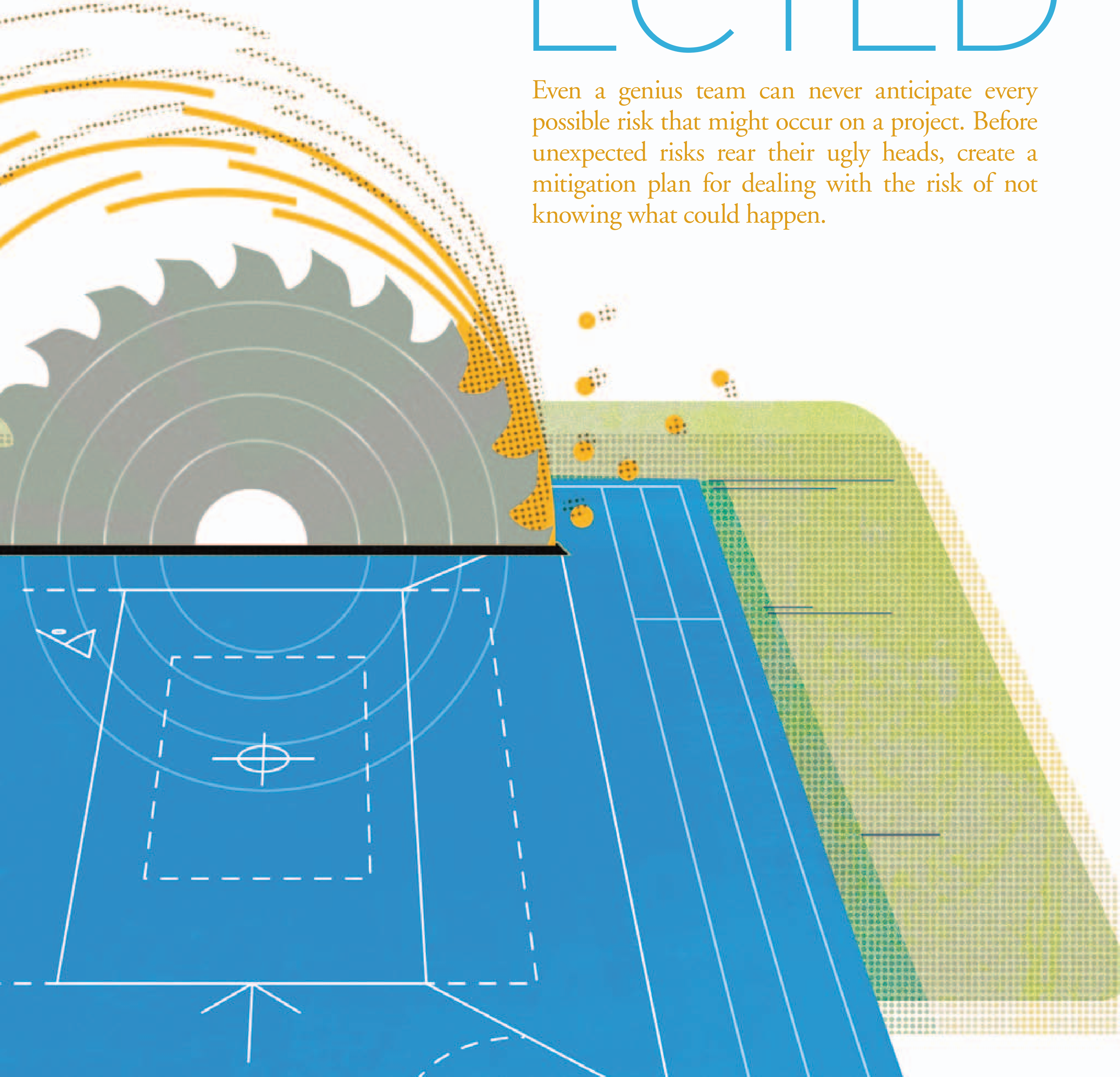
**Schmidt:** I am really grateful the European Space Agency gave me the opportunity to work on the most fascinating missions. We had the first interplanetary mission under our own control, and we went to Venus with Venus Express. We had a Mars orbiter, we had a Venus orbiter, and then, of course, we have the Earth-observation program. So we monitored three planets totally different in terms of atmosphere evolution and environment evolution.

**Manning:** The best part was being there for the revolution of rediscovering Mars. The whole unfolding from one mission to another, including Mars Express, Mars Reconnaissance Orbiter, the Odyssey mission, on and on, every mission has turned over a whole page of understanding about this planet. And we have gone from an almost cartoonish view of what Mars was to an encyclopedic understanding of Mars. Of course, each new page brings up new questions. Being part of that revolution has been very exciting for me. ●

# EXPECTING THE UNEXPECTED

BY TARALYN FRASQUERI-MOLINA

Even a genius team can never anticipate every possible risk that might occur on a project. Before unexpected risks rear their ugly heads, create a mitigation plan for dealing with the risk of not knowing what could happen.



In December of 2009, I had the opportunity to manage a great project. It was a huge renovation and technological upgrade to the main theater at the Walt Disney Animation Studios in Burbank, California. It would be the biggest project in terms of budget, schedule, and crew that I had managed in my Disney career. This project would also be an opportunity to show what serious project management could do and how necessary it was.

Since 2007, I and my media-engineering team had been going through all the phases and processes of a new project management life cycle. Before then, we hadn't had any standardized methodologies. That lack of structure was contributing to project failures. When I was handed the project management reins and tasked with making some big changes, the first thing I did, after wigging out, was create a structure and a methodology that would work for my team and the kinds of projects we delivered.

This large-scale shift didn't occur overnight. I worked diligently to discover what project management meant for us, and to uncover what processes worked and didn't work. Sometimes I'd ask my team for direct feedback about our process. They didn't mince words about the things they didn't like. Sometimes we learned by making mistakes together and realizing a change was necessary. Truthfulness and pinpoint criticism helped me make an honest assessment of my skill level as a project manager, how mature our project management system was, and where it (and I) needed to be. One thing that came from this introspection was a Change Control Board, or CCB. Team members were used to solving problems on their own and not having to make a pit stop, pitch their idea, and wait for someone else's approval. In order to keep a lid on scope creep and gold plating, and to keep track of great ideas we couldn't take advantage of immediately, a CCB was necessary. Our CCB is both formal and informal, structured enough to handle changes in complex projects, but flexible enough to approve changes that can add value right away.

Once the methodology and processes were in place and my colleagues and I started to follow a structured plan, we began to have little project management wins. We started to shrink how far behind schedule we had been. Then we started to meet our deadlines, which eventually led to us meeting our project schedule as a whole. Completed projects began to cost less. We were still over budget, but less and less. Soon we were meeting all project costs, which eventually led to us coming in under budget for our entire fiscal-year portfolio. Our stakeholders' frowns and grumbles turned to smiles and praise. My team could clearly see the value of project management. Over time I gained their buy-in, a big win for me considering they had been used to running without a project management plan for so long.

From 2007 to 2009, I improved upon and streamlined our early structure, methodology, and processes. When the main theater renovation came around in late 2009, it was a chance to showcase what I had developed and show what media-engineering project management was all about.

Essentially, the intent of the main theater project was to remove all the old stuff and put in new stuff. The space was important; it was our only theater and could not be structurally changed. The schedule was critical; the theater was regularly used to support production and therefore could not be out of commission for more than a few days. It would be a technological powerhouse in a 140-seat space, including a first-of-its-kind dual-powered screen system. The screen system was the crown jewel and the one feature regularly touted as the driving factor behind the project. This system would allow the studio to have, in addition to a 2-D standard screen, a 3-D stereoscopic screen, a key piece of equipment for all technologically advanced movie theaters. And we wanted to get these two types of powered screens to fit in a space originally engineered for one.

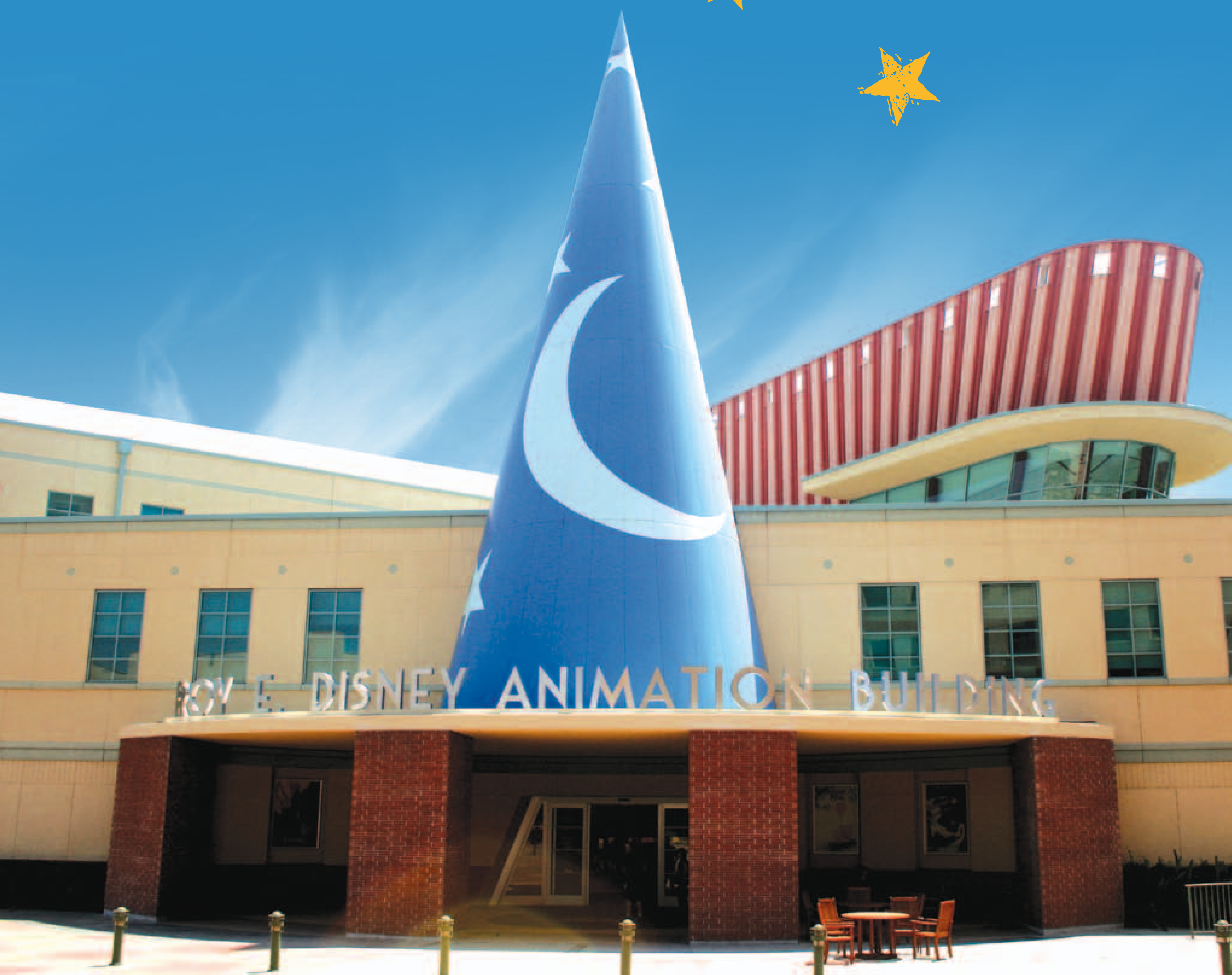
Unlike a fixed screen, which is hung on the wall like a giant portrait (this is what you usually see in a commercial movie theater), a powered screen is housed in a massive metal box weighing around 700 lbs. The metal box contains the screen, which is wrapped around a huge roller, and a motor that powers the roller to raise and lower the screen. The box is anchored into the ceiling, in a fly space. The need for two of these boxes in one space created a significant design challenge, but the project delivery team worked it out, and a screen company custom-made what we envisioned. Our biggest hurdle cleared, it seemed we were on our way to project victory. All we had to do was follow the plan.

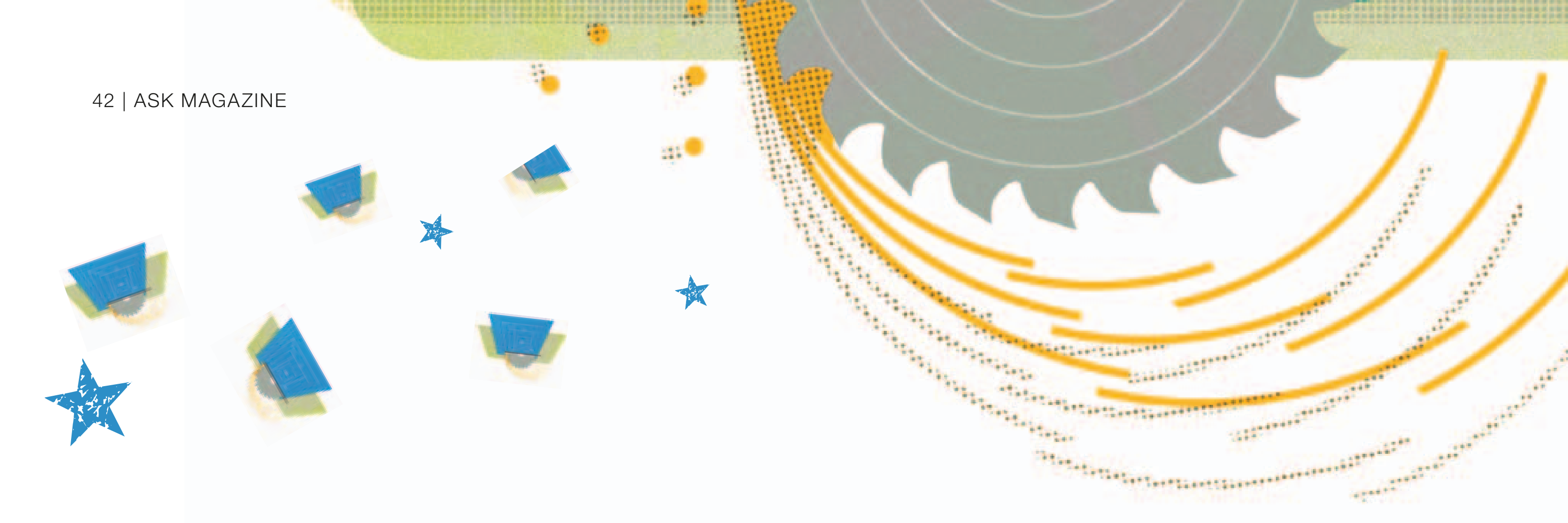
After months of talking and theorizing, the day of installation arrived. I should have known the day wasn't going to go well when the contracted demolition and install crew showed up with no hauling equipment and maybe two hammers among them.

Once all my crews (demolition, construction, electrical, audio/visual technicians, HVAC, fire safety, clean up) were settled and demolition started, I got a call from building security that my screens had arrived. I stepped outside and saw a massive flat-bed trailer with two long, wooden boxes strapped to it. The whole thing seemed to be as long as two city blocks! The delivery crew hauled the boxes into the lobby and the install crew started breaking everything open. Things seemingly under control, I stepped away from the scene for a moment to take care of paperwork. About thirty minutes later, the install crew lead was at my desk telling me there was a problem with the metal boxes that house the powered screens. Each box measured 30 feet and 10.5 inches long. But the screen wall inside the main theater measured only 30 feet and 7 inches long. Each box was 3.5 inches too big.

The crowning piece of the whole show, the one-of-a-kind, custom-made, initiating force behind the project didn't fit. On the way to project victory, we had taken a major detour into a project nightmare.

THE TEAM LOOKS TO YOU, THE PROJECT MANAGER, FOR DIRECTION IN TIMES OF TROUBLE. IF YOU ARE SCATTERED AND FRANTIC, THEIR CONFIDENCE IN YOU AND YOUR ABILITY TO RESOLVE THE PROBLEM SUCCESSFULLY WILL GREATLY BE DIMINISHED.





While I plan for as many risks as possible with the help of the project delivery team, I know it's impossible to account for every risk. Realizing this early in establishing a project management methodology, I had developed a risk-mitigation plan for unknown risks that would help reestablish order during a time of chaos. The eight-step plan is

1. Remain calm.
2. Halt the entire project or just the affected work momentarily and let everyone take a break.
3. Immediately gather the resolution team, which consists of the project manager and any of the people who can offer solutions; meet privately.
4. Assess risk impact.
5. Brainstorm solutions.
6. Choose a solution.
7. Obtain project sponsor approval.
8. Communicate the solution to the entire team, resume project, resolve risk.

This process works for the kind of projects I manage. While these specific steps may not work for everyone's projects, some of them should be widely useful. Remaining calm is a good general principle. Panic is not a useful approach to any problem. The team looks to you, the project manager, for direction in times of trouble. If you are scattered and frantic, their confidence in you and your ability to resolve the problem successfully will greatly be diminished. Stopping the affected work is also a valuable rule, since acting before you understand the problem or its solution is likely to make things worse. And quickly identifying and gathering the individuals who can help makes sense in most situations; you need the right people on hand to help make the right decisions. Not everyone needs to be involved in solving the problem. Whatever the details of your plan are, having some kind of plan in place to handle unanticipated risks will always work in your favor.

Following the eight steps, the resolution team and I came up with a solution for handling the problem. When we looked at the two sets of design drawings, we noticed the actual screens were the correct dimensions on both sets. On one set of drawings, however, the box dimensions were incorrect. We pulled open the boxes and found over seven inches of empty space on the motor side. An electrical crewmember grabbed a buzz saw and safely cut off the excess. Now the screen boxes are up in the ceiling of the main theater, nestled into a perfect fit, and they haven't caused any trouble since.

It wasn't until after the solution was being implemented that the manager, the project engineer, and I met to talk about how the trouble originated. We never pointed fingers during project implementation, since there was still a lot of work to be done, and a negative crew is less effective than a happy one. After many discussions and honest assessments of points of failure, we determined that the main cause of the risk were the erroneous sets of drawings the manufacturer gave to the project delivery team. Each drawing showed a different measurement. When I would call the manufacturer with one set of drawings, they'd confirm the measurements I was talking about. But when the engineer called the manufacturers using the other set, the manufacturer would confirm that as well. And because the project delivery team got both drawings from the same manufacturer (who is still a very reputable and trusted source), we assumed they were identical copies and didn't think to compare the sets.

That is the worst part about project management. The smallest detail, one incorrect measurement, a seemingly harmless assumption left unverified, can spell disaster for a project you've been planning for months or years.

I know the old saying is, "measure twice, cut once," but sometimes something (usually a very small thing) slips through the cracks. For those times, having a pre-planned response will help minimize a negative impact or eliminate it altogether.

That's what I learned. That, and always have a buzz saw on hand. ●

**TARALYN FRASQUERI-MOLINA** is a project manger in media engineering for Walt Disney Animation Studios. She leads projects and project teams focused on developing, retrofitting, and integrating media technologies into existing buildings and system infrastructures. She is a member of the Project Management Institute, Los Angeles chapter; the current virtual headmaster of online resource gantthead University; and was a speaker at NASA's Project Management Challenge 2011. You can reach her on Twitter, @PML33T.

# Delivering Clean, Affordable Power

BY BO SCHWERIN

Imagine you are about to be dropped in the middle of a remote, inhospitable region—say the Kalahari Desert. What would you want to have with you on your journey back to civilization? Food and water, of course, but you can only carry so much. A truck would help, but what would you do when it runs out of gas? Any useful resources would have to be portable and—ideally—sustainable.

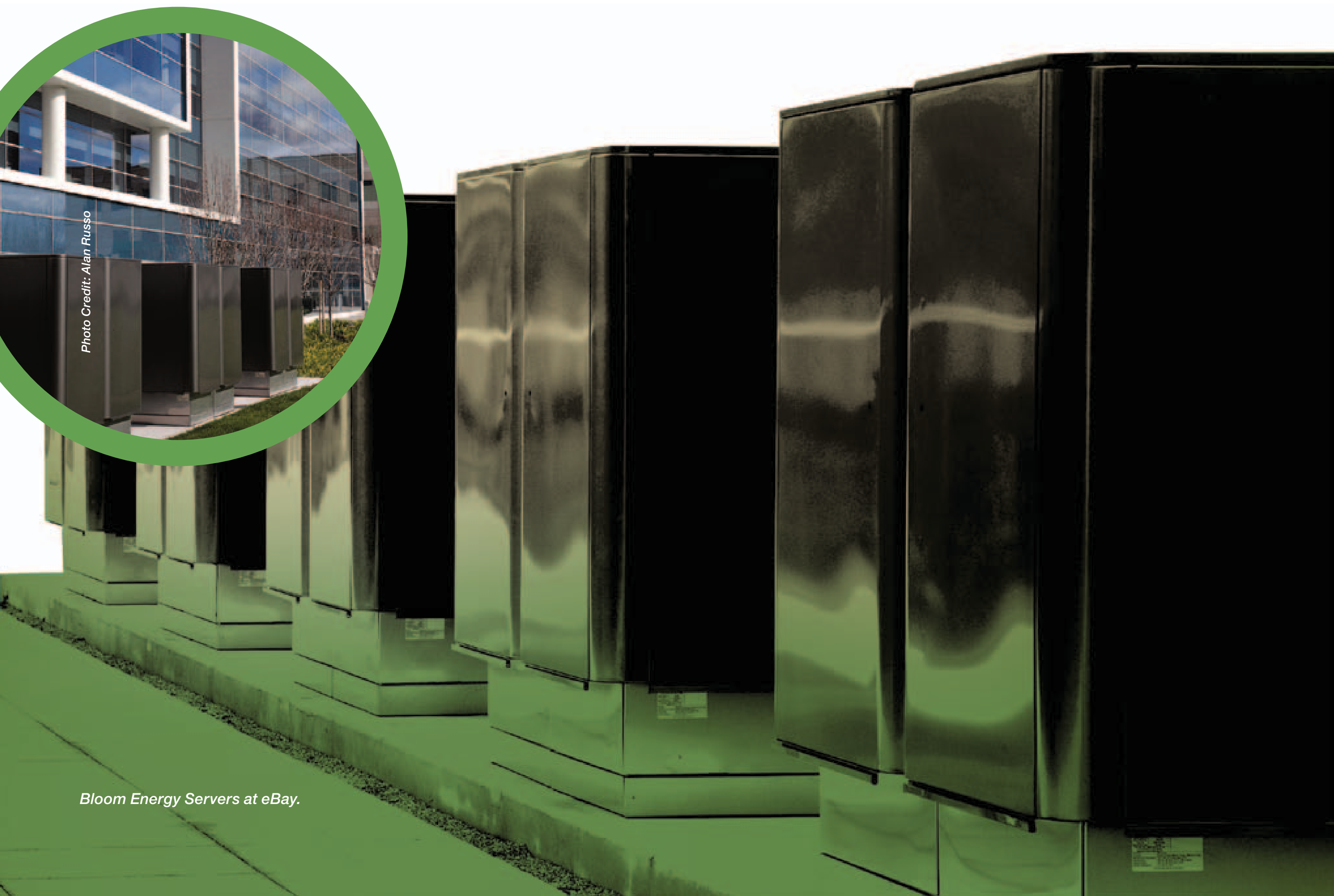


*Photo Credit: Alan Russo*

*Bloom Energy Servers at eBay.*


Photo Credit: Jakub Mosur

*Ceramic fuel cells coated with special inks are at the core of the Bloom Energy Server.*

Astronauts on future long-term missions would face similar circumstances as those in this survivalist scenario. Consider, for example, a manned mission to explore the surface of Mars. Given the extreme distance of the journey, the high cost of carrying cargo into space, and the impossibility of restocking any supplies that run out, astronauts on Mars would need to be able to "live off the land" as much as possible—a daunting proposition given the harsh, barren Martian landscape. Not to mention the lack of breathable air. Another consideration is fuel; spacecraft might have enough fuel to get to Mars, but not enough to return. The moon is like a day trip on one tank of gas, but Mars is a considerably greater distance away.

In the course of planning and preparing for space missions, NASA engineers consistently run up against unprecedented challenges like these. Finding solutions to these challenges often requires the development of entirely new technologies. A number of these innovations—inspired by the extreme demands of the space environment—prove to be solutions for terrestrial challenges as well. While developing a method for NASA to produce oxygen and fuel on Mars, one engineer realized the potential for the technology to generate something in high demand on Earth: energy.

## Partnership

K.R. Sridhar was director of the Space Technologies Laboratory at the University of Arizona when Ames Research Center asked him to develop a solution for helping sustain life on Mars. Sridhar's team created a fuel-cell device that could use solar power to split Martian water into oxygen for breathing and hydrogen for use as fuel for vehicles. Sridhar saw potential for another application, though. When the NASA Mars project ended in 2001, Sridhar's team shifted focus to develop a commercial venture exploring the possibility of using its NASA-derived technology in reverse—creating electricity from oxygen and fuel.

On the surface, this sounds like standard hydrocarbon fuel-cell technology, in which oxygen and a hydrocarbon fuel such as methanol flow into the cell where an electrolyte triggers an electrochemical reaction, producing water, carbon dioxide, and electrons. Fuel cells have provided tantalizing potential for a clean, alternative energy source since the first device was invented in 1839, and NASA has used fuel cells in nearly every mission since the 1960s. But conventional fuel-cell technology features expensive, complicated systems requiring precious metals like platinum as a catalyst for the energy-producing reaction. Sridhar's group believed it had emerged from its NASA work with innovations that, with further development, could result in an efficient, affordable fuel cell capable of supplying clean energy wherever it is needed.

In 2001, Sridhar's team founded Ion America and opened research and development offices on the campus of the NASA Research Park at Ames. There, with financial backing from investors who provided early funding to companies like Google, Genentech, Segway, and Amazon.com, the technology progressed and began attracting attention. In 2006, the company delivered a 5-kilowatt (kW) fuel-cell system to The Sim Center, a national center for computational engineering, at The University of Tennessee–Chattanooga, where the technology was successfully demonstrated. Now called Bloom Energy and headquartered in Sunnyvale, California, the company this year officially unveiled its NASA-inspired technology to worldwide media fanfare.

## Stackable, Clean Energy

Bloom Energy's ES-5000 Energy Server employs the planar solid-oxide fuel-cell technology Sridhar's team originally created for the NASA Mars project. At the core of the server are square ceramic fuel cells about the size of old-fashioned computer floppy disks. Crafted from an inexpensive sand-like powder, each square is coated with special inks (lime-green ink on the anode side, black on the cathode side) and is capable of producing 25 watts, enough to power a light bulb. Stacking the cells—with cheap metal-alloy squares in between to serve as the electrolyte catalyst—increases the energy output: a stack about the size of a loaf of bread can

THE TECHNOLOGY'S PLUG-AND-PLAY MODULAR ARCHITECTURE ALLOWS USERS TO GENERATE MORE POWER BY SIMPLY ADDING MORE SERVERS, RESULTING IN A "PAY AS YOU GROW" SCENARIO IN WHICH CUSTOMERS CAN INCREASE THEIR ENERGY OUTPUT AS THEIR NEEDS INCREASE.

power an average home, and a full-size Energy Server with the footprint of a parking space can produce 100 kW, enough to power a 30,000-square-foot office building or 100 average U.S. homes.

Solid-oxide fuel cells like those in Bloom's Energy Server operate at temperatures upward of 1,800°F. The high temperatures, efficiently harnessed by the system's materials and design, enable the server to use natural gas, any number of environmentally friendly biogasses created from plant waste, or methane recaptured from landfills and farms. Fuel is fed into the system along with water. The high temperatures generate steam, which mixes with the fuel to create a reformed fuel called syngas on the surface of the cell. As the syngas moves across the anode, it draws oxygen ions from the cathode, and an electrochemical reaction results in electricity, water, and only a small amount of carbon dioxide—a process that according to Bloom is about 67 percent cleaner than that of a typical coal-fired power plant when using fossil fuels and 100 percent cleaner with renewable fuels. The server can switch between fuels on the fly and does not require an external chemical reformer or the expensive precious metals, corrosive acids, or molten materials required by other conventional fuel-cell systems.

The technology's plug-and-play modular architecture allows users to generate more power by simply adding more servers, resulting in a "pay as you grow" scenario in which customers can increase their energy output as their needs increase. The server also offers the benefits of localized power generation; the servers are located on site and off the grid, providing full-time power—as opposed to intermittent sources like solar and wind—without the inefficiencies of transmission and distribution, Bloom says. Future servers may even return to the original NASA function of using electricity to generate oxygen and hydrogen. The company envisions feeding electricity from wind or solar power into its servers along with water to produce storable hydrogen and oxygen. The server could then use the stored gasses to generate electricity during cloudy, low-wind, and nighttime conditions. Stored hydrogen could even be used to provide fuel for hydrogen-powered cars.

Bloom quietly installed its first commercial Energy Server in 2008, and since then its servers have generated more than 11 million kilowatt hours of electricity, along with a corresponding 14-million-lb. reduction in carbon dioxide emissions, which the company says is the equivalent of powering about one thousand American homes for one year and planting one million trees.

Sridhar believes it will be another five to ten years before Bloom's technology becomes cost-effective for home use. At that point, he sees the server as a solution for remote and underdeveloped areas in need of power. He says the company's mission is "to make clean, reliable energy affordable to everyone in the world."

"One in three humans lives without power," Sridhar says. "Energy demand exceeds supply." Just within the United States, 281 gigawatts of new generating capacity—the output of 937 new 300-megawatt power plants—will be necessary by 2025 to meet national energy demands, according to the U.S. Energy Information Administration. The Bloom Energy Server may soon offer an environmentally sound option for meeting that challenge, a solution derived from the demands of space exploration.

"NASA is a tremendous environment for encouraging innovation," says Sridhar. "It's all about solving problems that are seemingly unsolvable. After realizing we could make oxygen on Mars, making electrons on Earth seemed far less daunting. We're grateful to NASA for giving us a challenge with serendipitous impact for mankind." ●

**BO SCHWERIN** is an award-winning author and works at the NASA Center for Aerospace Information as the editor for NASA's annual *Spinoff* publication.

*Team members prepare to lift FASTSAT from its shipping container at Kodiak Launch Complex on Kodiak Island, Alaska.*

*Photo Credit: U.S. Air Force/Lou Hernandez*

BY

"Fast" is the word that best describes Tom Simon's experience working at Marshall Space Flight Center on the Fast, Affordable, Science and Technology Satellite (FASTSAT), a microsatellite designed to carry six small experiments into space. Having served as a Space Shuttle subsystem engineer and a research and development project chief engineer at Johnson Space Center since 2001, Simon went to a spaceflight project where the whole team could stand around the satellite. Working on a small team with a quick schedule, Simon saw nearly every major production phase while assisting the project's chief engineer in the fabrication and testing of the spacecraft.

# FAST LEARNING

BY MATTHEW KOHUT

Simon came to FASTSAT as a participant in the Systems Engineering Leadership Development Program (SELDP), which provides opportunities for a small class of high-potential candidates to develop and improve their systems engineering leadership skills and technical capabilities. A core feature of the program is a hands-on developmental assignment away from a participant's home center in a work context that differs significantly from his or her past experience. In Simon's case, FASTSAT fit the bill.

The objective of the FASTSAT project was to demonstrate the capability to design, build, and test a satellite platform that would allow researchers from government, academia, and industry to conduct low-cost scientific and technology experiments on an autonomous satellite in space. The project was in itself an experiment in lean, affordable development.

FASTSAT is intended as a multigeneration effort with future launches of the satellite bus with different experiments on board. The first FASTSAT was called HSV-01 (Huntsville-01) and had

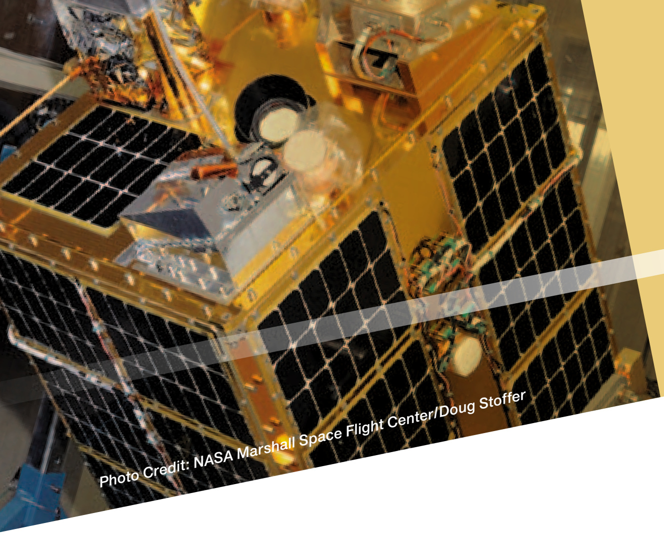


Photo Credit: NASA Marshall Space Flight Center/Doug Stoffer

One of FASTSAT's mission objectives is to demonstrate its ability to eject a nanosatellite from a microsatellite while avoiding re-contact with the FASTSAT satellite bus.

a mass of approximately 100 kg. (Future FASTSAT satellites can now be produced by NASA's partner, Dynetics.) HSV-01 was launched as a piggyback payload on an Air Force Space Test Program launch vehicle. HSV-01's payloads included Marshall's NanoSail-D, the first-ever solar sail of its size to unfurl in low-Earth orbit. From Simon's perspective, the team learned a lot carrying out the project at a manned spaceflight center.

The difference in scale from the Space Shuttle program Simon had worked on for four years changed his approach to learning. "If I had a question about how we mate to the launch vehicle with the satellite, I knew exactly who to talk to," he said. "The family size of the project allowed the advantages of a co-located R&D [research and development] effort even when we applied it to the development of a spacecraft."

FASTSAT also operated completely differently from the systems he'd encountered earlier in his career. "There were almost no moving parts, and no fluid systems," said Simon, whose previous experience included working on the shuttle's power-reactant storage and distribution system, which stores and supplies the liquid oxygen and liquid hydrogen for the shuttle fuel cells and crew breathing, and R&D systems to produce propellants on other planets. "My rotation had me focusing now on software and electrical engineering, which meant being outside my comfort zone and learning a lot," he explained. He found himself troubleshooting electrical problems and software bugs. "The day-to-day work was in completely different technical disciplines, which forced me to grow."

As the new kid on the block, Simon found that his colleagues were glad to help him get up to speed. "Even though I wasn't coming in on the same page that they were on, I tried to make it very clear that I cared about the success of the program," he said. "As long as that connection is made, folks don't mind helping you catch up—especially if they see you as someone who can help them, too."

The schedule also represented a new way of working for Simon. FASTSAT had a twelve-month project life cycle. Processes were streamlined to where decisions were made in hours, not weeks. "Most of the projects that I've worked on I've had intended launch dates a few or several years away," said Simon. The FASTSAT team charged hard, from a kickoff meeting in January 2009 to an assembled, fully loaded satellite nine months later.

Working under such a fast-paced schedule shifted his approach to projects. "Every project I join now, I'm going to start with [the perspective of], 'What do we need to do?' and not necessarily, 'What have we always done?'" he said. "I'll never be the same again."

To keep pace with the schedule, testing took place nearly every day. "We had to basically get to the test phase earlier than any of us usually get to it, and let the data speak for itself," Simon said. During the thermal-vacuum test, the team was reviewing the output signal from the flight transceiver and noticed a discrepancy that likely would have led to a failure. "One thing I learned from this project is that even if you're trying to do things affordably and quickly, you don't skip these meat-and-potatoes tests," he said. "We could have spent six months analyzing the system, and we never would have found the transceiver issue. Instead, in a few days of testing, we found it."

As the project wrapped up and awaited launch, Simon drafted a lessons-learned document for the team: "I tried to keep it very concise. What was the issue? What did you do to fix it? How did it turn out? And it included a contact name to find out more. Rather than turning it into a giant bound book, I wanted to keep it fairly short." He also organized the lessons by disciplines such as project management and systems engineering to make it user-friendly for readers.

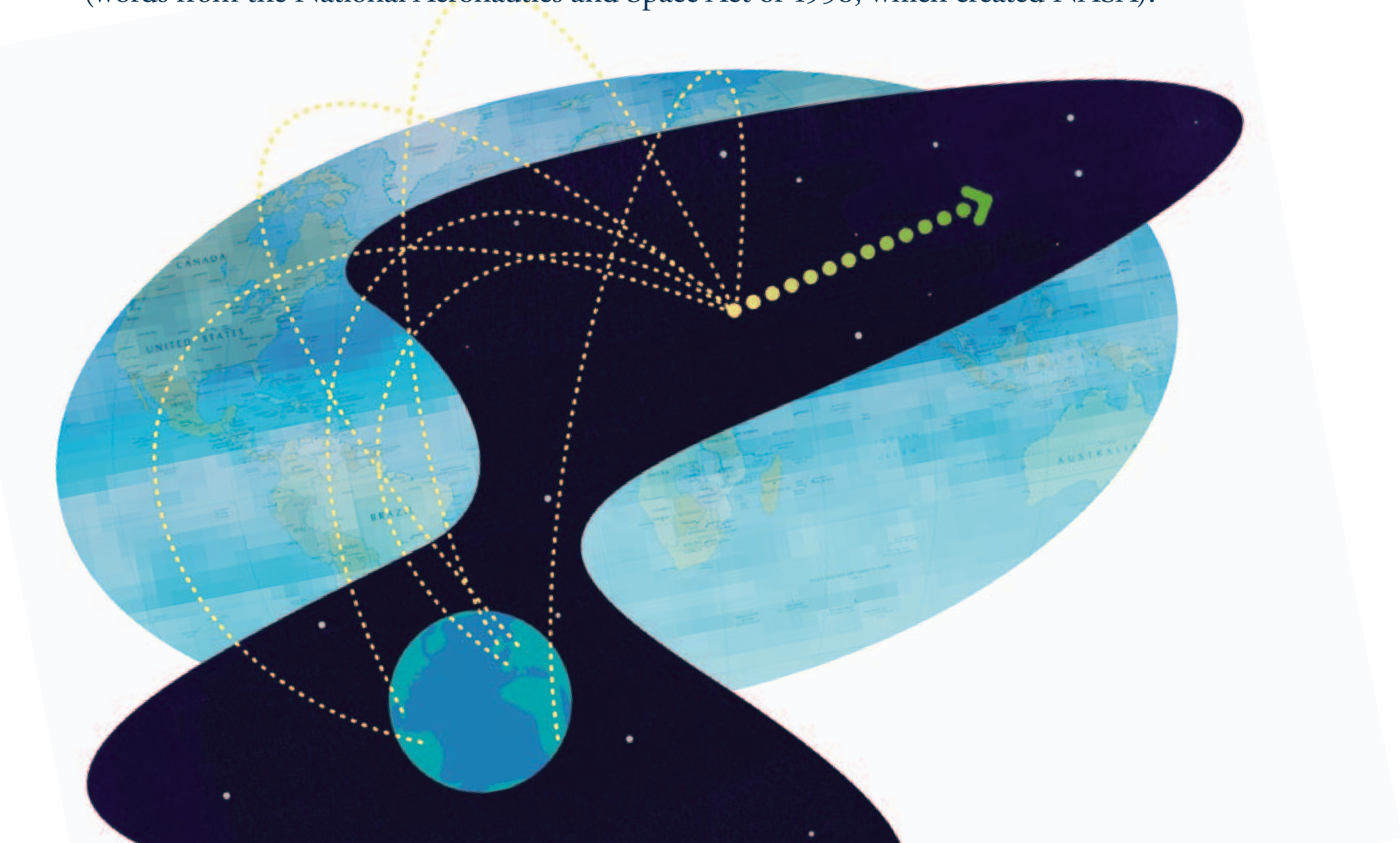
Simon saw the lessons-learned document as a resource for future work at NASA's manned spaceflight centers. "Once the shuttle is retired and the station is complete, there are going to be a lot of people working on systems that need to be approached differently than the way we've worked in the past," he said. Many of the lessons he captured went directly into the draft systems engineering management plan he wrote for potential future FASTSAT satellites, such as HSV-02. "Until you've gone through a build like that," he said, "it would be impossible to predict all the lessons up front."

Working on FASTSAT—a robotic, non-human satellite—helped Simon fill a gap in his experience between working on the shuttle and R&D work earlier in his career in a lab setting. "I don't think they [the SELDP team] could have picked a better assignment, team, or organization for me," he said. "If the first ten years are any sign, I'll be learning every day until I retire." ●

# International Partnerships for Space Exploration

BY KATHY LAURINI

The year is 2050. The vicinity around Earth has become a vibrant economic sphere. Physical sciences and medical research in space are driving innovations that enable companies to offer new products that improve our quality of life. Tourists spend summer vacations beyond the atmosphere. Humans and robots are working together to service the space-based assets on which the global economy continues to depend. Beyond Earth orbit, we have established an outpost on the planet Mars—a visiting research station where scientists from around the world come to pursue answers to questions about Mars's atmosphere and climate changes to better understand the future of our own planet. People visit the moon from time to time to service a deep-space observatory or extract a precious resource. We are prepared to mitigate the risk of dangerous asteroid collisions with our planet. In short, we have extended our human presence across the solar system "for the benefit of all mankind" (words from the National Aeronautics and Space Act of 1958, which created NASA).



NATIONS WITH EMERGING SPACEFLIGHT PROGRAMS SUCH AS INDIA AND SOUTH KOREA WILL BE IMPORTANT PARTNERS IN THE FUTURE.

That human spaceflight brings worldwide benefits of knowledge, innovation, and inspiration is widely recognized both within the United States and around the globe. That view recognizes fifty years of human spaceflight achievements and the thriving international partnerships that built and operate the International Space Station (ISS). There is international consensus that the next step will be a global partnership for human exploration of our solar system, and that the time to start planning for this future is now.

NASA wants to continue to lead in human spaceflight. Our partners count on us to lead. How can we lead in this environment where we rely on international partner contributions to accomplish the basic mission? What can we do to ensure NASA can lead effectively? I hope to provide some useful insights, gained over thirty years of working with international partners on the Space Shuttle, ISS, and Constellation programs. I offer some lessons that I hope help managers to ensure their international programs or projects are successful.

## NASA's Strategic Plan

The 2011 NASA Strategic Plan establishes extending and sustaining human activities across the solar system as one of the agency's six strategic goals. This long-term goal calls for the development of an integrated architecture and capabilities for safe crewed and cargo missions beyond low-Earth orbit. The strategic plan recognizes that human presence cannot be extended without the capabilities and resources of our international and commercial partners. By including the importance of expanding international partnerships in its overarching strategy, NASA recognizes the increased complexity of future missions and challenges us to define and build the necessary partnerships.

To me, expanding our international partnerships means building stronger relationships with the partners we have today and looking for opportunities to build new partnerships. I believe we must succeed in both areas if we want to lead the effort to extend and sustain human presence in space.

There are two keys to strengthening our existing partnerships. First, we must remain reliable partners, following through with our obligations and informing partners early when we have issues. Second, as we plan for the future, we should involve them in the exploration-planning process. Consulting them and incorporating their ideas and capabilities in the development of an integrated architecture will bring robustness to the missions we plan together. This is happening today within the Human Exploration and Operations Mission Directorate, which is working to develop a human-spaceflight Global Exploration Roadmap. As part of this effort, representatives from twelve space agencies are working on mission scenarios of expanding human presence, with Mars as a driving long-term goal. All the current ISS partner agencies are engaged and contributing.

Nations with emerging spaceflight programs such as India and South Korea will be important partners in the future. The work on the Global Exploration Roadmap is one example of initiatives that we will need to build lasting relationships with them, like those we have with our ISS partners.

## Some Lessons Learned

In my experience, programs and projects with international agencies are most likely to be successful when you and your international counterpart are committed to the joint project. Understanding the specific programmatic and technical complexities and developing strategies to jointly manage them is important. While you may control the most significant portion of the budget needed for success, the investment of your partner is probably as great or greater, as a proportion of his agency's overall budget. You and your counterpart should commit to maintaining regular communication, establishing timely decision-making mechanisms, and trusting each other to raise issues as early as possible. With these high-level considerations in mind, here are some other, more specific, things to look out for and think about.

### *Create Opportunities to Build Relationships*

In 1993, the decision was made to expand the space station partnership to include the Russians. Bringing this new partner, whom many remember as an old adversary, into the program changed many things. When the Russians joined, the original space station partners—NASA, Canadian Space Agency (CSA), European Space Agency (ESA), and Japan Aerospace Exploration Agency (JAXA)—had been working together for more than five years under NASA's leadership to settle requirements, define interfaces, distribute functions, and deal with other aspects of the cooperative venture. NASA's relationship with CSA and ESA, based on shared shuttle-program experience, was very strong. Our relationship with JAXA was developing well.

NASA program managers defined a phased approach to bring the Russians on board. Phase 1 involved cooperative initiatives within both NASA's and Russia's individual operational programs. NASA astronauts were to fly to the Mir space station. Russian cosmonauts were to fly on the Space Shuttle. The Space Shuttle was to fly around and eventually dock with Mir. Each of these missions involved a lot of planning, meetings, travel, and expense. You could argue that the benefits we gained from any individual mission may not have justified the cost. Taken together, however, those Phase 1 activities allowed us to build relationships necessary to continue leading the ISS program and working well with Russian partners. Engineers, managers, and astronauts spent time in Russia; many learned Russian and began to understand Russian culture both at work and outside work. We learned how the Russians made decisions, solved problems, and found creative ways to fund their effort during a difficult time in Russia, after *perestroika*.

There were also more modest opportunities to learn about one another and build trust. They included demonstration of ISS-related technologies, defining and validating interface standards, and joint development of precursor capabilities.

***Lesson 1:*** Create large and small opportunities for people to build relationships, understanding, and trust.

### *Don't Assume It Has to Cost More to Partner*

People like to say it will cost more to partner than to do it all alone. It doesn't have to be this way. It is true that there will be some additional costs associated with working internationally, and you must pay attention to export control and International Traffic in Arms Regulations. But a significant cost driver is the level of oversight assigned to all the critical design and development activities of your partner or partners.

Long experience working with our traditional partners has shown us that we can rely on them to deliver excellent products. Let's use this experience to streamline how we work together. In the early days of the space station program, we went through a very time-consuming process of examining the design and construction specifications of our partners to be sure they met or exceeded our standards. This process took man-years to complete and resulted in a discipline-by-discipline understanding of their approach to requirements definition, design, testing, and verification.

***Lesson 2:*** Recognize that past experiences of NASA with traditional partner agencies will provide a good basis for building the relationships and trust needed to execute your project successfully and cost effectively.

### *Understand the Cultural Differences*

Differences in culture within the work environment and outside work will exist between you and your partner agencies. Understanding and working effectively with the differences will help make your joint program or project successful. Within the work environment, what are roles and responsibilities of key players? How do they make decisions? Who decides? For bigger projects, embedding a technical liaison is a good idea. I served in this capacity for the ISS program. By being collocated with ESA, I developed a deep understanding of their work culture and the relationships among ESA countries, as well as with NASA. That knowledge helped us overcome some challenges early in the ISS program.

Understanding and respecting the national culture is also important. People from different countries have different ways of looking at things and different ways of expressing their opinions or desires. For example, the Japanese will typically avoid directly expressing a negative answer. When JAXA colleagues say "that will be difficult," it usually means it's impossible and I'd be wasting my time trying to lessen the burden of a particular approach and should instead start looking for a compromise. Being familiar with the differences can avoid misunderstandings and make interactions more effective.

***Lesson 3:*** Take the time to understand the relevant cultures of your partners, both work and national cultures.

## The Shared Future of Space Exploration

International partnerships will be important to NASA's human spaceflight future. We need to lead—and partner—effectively. Establishing early, critical-path roles for our partners will be important for them and us, and is likely to lead to increased stakeholder support. Creating effective partnerships that bring their technical strengths, resources, and capabilities to bear will increase the robustness of our architectures in ways that increase the probability of mission success.

In the famous words of Yuri Gagarin: *Poyekhali!*—Let's go! ●

**KATHY LAURINI** is a senior advisor within NASA's Exploration Systems Mission Directorate, where she contributes to the development and implementation of strategies for international partnerships in space exploration. She has thirty years of experience within NASA's human spaceflight effort, including leadership positions within the International Space Station and Constellation programs.

# Exploring Megaplanets

BY DON COHEN

Josh Simpson has been creating planets for more than three decades. The cover photo of this issue of *ASK* shows detail from one of them.

*Photo Credit: Ben Interlande*

*One of Simpson's tektites.*


*Simpson's megaplanets swirl with imagined landmasses.*

He started in the mid-seventies when he was demonstrating glassblowing to eighth graders in Franklin County, Massachusetts, where he has his studio. He found that young teens quickly tired of seeing vases and bowls take shape, so he began making marbles they could take home with them. Then he happened to see Jim Lovell's famous Apollo 8 "Earthrise" photo of the earth from space and the Apollo 17 "blue marble" picture of Earth floating in the blackness of space. The next day, instead of marbles, he began making planets—not known planets, but fantasy planets that might exist, he says, somewhere in the universe.

Since then he has made thousands of them, some less than two inches in diameter, others as large as fourteen inches. The 100-plus-lb. megaplanet at the Corning Museum of Glass is the largest glass sphere ever created by traditional blowpipe methods. Over the years, the planets have become more complex, the varied terrain of their landmasses dotted with sprawling cities and strange shapes that might be organic or might be structures designed by alien civilizations. Sometimes tiny satellites and spacecraft hover in their clear glass skies.

Simpson's fascination with space and distant planets began when he was a young boy and read, by his own admission, an "inordinate" amount of science fiction. The real-life space program, which gave us a new view of Earth and the planets of our solar system, increased his enthusiasm and expanded his vision. Although he had been making glass planets for fifteen years before he met and married NASA Astronaut Cady Coleman, her experience has influenced his work. He pores over the thousands of images of Earth she has taken from the Space Shuttle and the International Space Station. Through Cady, he got access to photographs of the effects of micrometeor strikes on NASA's Long-Duration Exposure Facility, a spacecraft that spent almost six years in orbit to provide data on long-term exposure to the environment of space. He began using a hydrogen torch to try to create a similar effect on some of his planets.

For Simpson, work on the planets (and on his tektites, with their rough, meteor-like exteriors and glowing inner colors) brings together his interests in space exploration, art, and science. The physics and chemistry of glassblowing are a challenge that, he says, "has focused my attention and held me spellbound for over forty years." He works with a molten liquid at 2,100°F that is shaped only by gravity and centrifugal and centripetal forces. At that temperature, it glows orange, its eventual colors "red shifted" by heat. He prizes the chemical interaction between different colors of glass that creates a beach-like third color at the border of his seas and landmasses. He likes the fact that he uses techniques that were developed by glassmakers in the ninth century to create his spaceships. And he has spent thousands of hours trying to approximate the color of Cherenkov radiation—the intense blue glow of nuclear fuel rods in their water bath. (So far, silver in a glassy matrix comes closest.)

For the rest of us, Simpson megaplanets are worlds to explore that suggest the yet-unseen wonders of space and give us at least a small taste of the experience of astronauts fortunate enough to look down on their own planet from orbit. ●

The Knowledge Notebook

# The Burden of Knowledge

BY LAURENCE PRUSAK

Who was the last person who knew everything? That's right, there was a time when this was a legitimate question for pundits in Europe and the early American republic. Ben Franklin was one contender for the title. Other well-known candidates put forward by people who think about this kind of thing include Francis Bacon, Erasmus, Thomas Aquinas, Voltaire … well, you get the idea.

But if we ask whether there is anyone alive today who knows *everything*, the absurdity of the question quickly becomes apparent. How could a single individual possibly master everything about even one subject, let alone everything about everything?

I have a friend who received a PhD in organic chemistry thirty-five years ago. At his oral exam he was expected to have a pretty good mastery of the whole subject, or at least a nodding acquaintance with major issues and experiments across the field. He recently told me that such an attempt today would be the height of folly. Organic chemistry—like so many other disciplines—has grown so large, with so many new players, institutions, countries, and universities involved in so many areas of research, that any one person, no matter how smart and hardworking, can only master an ever-decreasing percentage of the total knowledge in the field.

The burden of the sheer quantity of knowledge in any field is the focus of an interesting paper by Benjamin Jones of Northwestern University. Though it is written in "economese," it is worth the effort to read because it takes a very interesting position on just how difficult it is for individuals to know enough to do innovative knowledge work, especially since to innovate usually means to know (and build on) what is already known about a subject.

Just think for a moment about how many Chinese and Indian scientists today are doing research in organic chemistry that weren't doing it twenty years ago. Or—with the advent of the web—how much research from those and even more remote places is now available easily and cheaply. Who could read all of it even if there were no language issues to overcome? And if you just choose to ignore it, how do you know you aren't wasting your time replicating work already done in Kuala Lumpur or Lima or Delhi?

The only possible way to avoid this pitfall is to work in large teams where the burden of knowledge can be more easily carried by a group. This is exactly what is happening, according to research Jones and others have carried out. More and more patents and scientific and technical papers are being written by ever-larger groups of researchers, each of them mastering enough of the content in a field so that their aggregate knowledge covers most of the relevant ground and reduces the possibility that their output will reproduce work already done by someone else, wasting huge amounts of time, energy, and money.

This phenomenon is not limited to the pure sciences and technology studies. Research on organizational and management issues—a newer subject of formal studies than most sciences—is approaching the same epistemic limits with the same results. More and more of this work is also being done collaboratively.

Some of the implications of this phenomenon are still slow to seep into schools or even into our general culture. The idea of heroic, individual innovators working alone and with intense focus is a very hard image to abandon. And we wouldn't want to let it go completely. Within the context of group efforts, talented and knowledgeable individuals still come up with important new ideas. And our individual contributions to our colleagues and teams still depend on our working hard to master what knowledge we can and thinking hard and creatively about it. But no one can fully master a subject anymore, and that makes all the difference in how we approach problems and what skills and behaviors we need to carry out this new way of working well. The ability to collaborate with a team—sometimes a large team—and understanding how to work with and within a new "division of knowledge" will be more and more critical as we move forward into an age of an ever-increasing burden of knowledge. ●

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# ASK interactive

## NASA in the News

NASA Public Affairs Officer Josh Byerly talked with ground-support personnel and mission officials in Russia and Kazakhstan as they prepared for the landing of Expedition 27 on May 23, 2011. Crewmembers Dmitry Kondratyev, Cady Coleman, and Paolo Nespoli returned home aboard the Soyuz TMA-20 spacecraft while Space Shuttle *Endeavour* and the STS-134 crew were still docked to the International Space Station. Get a behind-the-scenes look at the planning and coordination involved when working internationally: www.nasa.gov/multimedia/videogallery/index.html?media_id=96666621.

## Academy iTunes University

The Academy of Program/Project and Engineering Leadership now offers learning materials on iTunes University that are accessible whether you're on the road or in the classroom. You can download a podcast to listen to on your way to work or watch a short video on a portable device about critical challenges facing today's practitioners. The Academy provides videos and podcasts from thought leaders, master practitioners, and innovative thinkers on a variety of topics including green engineering, policy and politics, systems engineering, leadership development, and international collaboration. Visit the Academy's iTunes U page by typing "NASA APPEL" into the iTunes Store search bar or using the following URL in any browser: itunes.apple.com/us/institution/nasa-academy-program-project/id427161628. If you do not have an iTunes U account, you can install iTunes and create a user ID. Learn how at support.apple.com/kb/HT2731.

## Web of Knowledge

NASA's new video series offers the public a fast and fun way to learn about scientific discoveries and facts about Earth, the solar system, and beyond. Called "ScienceCasts," the videos are created by an astrophysicist and a team of agency narrators and videographers. The format is designed to increase understanding of the world of science through simple, clear presentations. Future episodes will focus on citizen science research, the search for new galaxies, how to watch this summer's Perseid meteor shower, and the causes of recent wild weather events in the United States. To view the latest videos online, visit www.youtube.com/user/scienceatnasa.

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