National Aeronautics and Space Administration

Academy Sharing Knowledge

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WINTER | 2013

Inside

THE THERMAL DESIGN CHALLENGE

SOLVING CHALLENGES THROUGH MASS COLLABORATION

THE TOOTHBRUSH HACK

Photo Credit: NASA/Drew Noel

ON THE COVER

As the planned successor to the Hubble Space Telescope, even the smallest of parts on the James Webb Space Telescope will play a critical role in its performance. “Actuators” are one component that will help Webb focus on some of the earliest objects in the universe. Pictured is the Webb engineering design unit’s primary mirror segment, coated with gold by Quantum Coating Incorporated. The actuator is located behind the mirror.

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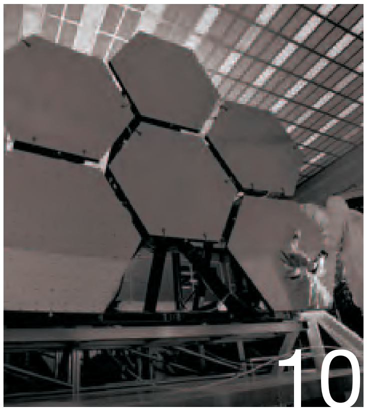
Contents



ask

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Staff

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

In her reflection on seven years of learning and writing about NASA projects ("What I've Learned from NASA"), *ASK* editor Kerry Ellis identifies adequate testing as an essential contributor to mission success. She cites "test as you fly, fly as you test" as a guiding principle: that is, design tests that will mimic expected flight conditions as closely as possible and then try to make sure actual flight conditions stay within the limits that testing has shown to be safe. Some of the articles in this issue of *ASK* emphasize the value of thorough, thoughtful, and sometimes creative testing.

Mike Menzel makes the importance of testing clear in his discussion of designing hardware that will keep the James Webb Space Telescope, or JWST, cold ("The Thermal Design Challenge"). Because JWST is an infrared telescope, even a miniscule amount of solar heat would interfere with observations. And because the telescope will be situated a million miles from Earth, no Hubble-style repair missions will be possible—they have to get it right the first time. So Menzel's team tested and retested a full-scale model of JWST's core area and a one-third scale model of the sunshield to track down potential problems and refine their design.

A team at the Applied Physics Laboratory devised new vibration-testing equipment for the Van Allen Probes to make sure the spacecraft would survive the stress of launch ("Radiation-Ready with a Little Rock 'n' Roll"). And the information the probes are returning about the Van Allen radiation belts should help refine testing for future orbital missions by improving our understanding of how much radiation they will have to withstand.

Thorough testing invites failures that will reveal the flaws and limitations of systems. It's one illustration of the point Laurence Prusak makes in "The Knowledge Notebook"—that failure is a great teacher. He sees the reluctance of people in many organizations to admit and analyze failure as a lost opportunity for valuable learning (and of course unacknowledged errors are likely to be repeated).

Given the rigors and complexity of NASA missions, problems will sometimes occur no matter how much testing has been done. When they do, project teams devote all their attention and ingenuity to fixing or finding ways to work around them. Haley Stephenson describes one example in "The Toothbrush Hack." When a stuck bolt prevents astronauts from replacing an important switching unit on the space station, a team on Earth swings into action, quickly improvising tools needed to solve the problem from a toothbrush and other materials available on station.

Ellis's "What I've Learned" article also points to good communication as a requirement for project success. That's a familiar *ASK* theme and several articles in this issue focus on it. For instance: in the interview, Alan Lindenmoyer talks about the importance of knowledge-sharing and trust-building conversation with NASA's commercial partners; Lars Schnieder and Susanne Arndt discuss how to reduce ambiguity so written requirements clearly communicate what is being required ("Reducing Natural-Language Ambiguities in Requirements Engineering"); and Jay Grinstead ("The Soft Skills of International Project Management") considers the special challenges of communicating effectively with NASA's international partners.

Don Cohen
Managing Editor

From the Academy Director

Toward Knowledge Resilience

BY ED HOFFMAN

Eleven years ago, the Government Accountability Office (GAO) issued a report about NASA's effectiveness—or lack of effectiveness—as a knowledge organization. Conducting its audit in the aftermath of the failures of the Mars Polar Lander and the Mars Climate Orbiter, GAO found "fundamental weaknesses in the collection and sharing of lessons learned agencywide." GAO concluded that, "NASA needs to strengthen its lessons learning in the context of its overall efforts to develop and implement an effective knowledge management program."

The GAO report spurred a new focus on knowledge across NASA. Many centers and mission directorates either initiated or formalized existing knowledge management efforts. This was a start, but it did not solve the issue overnight. Following the *Columbia* accident a year later, the *Columbia* Accident Investigation Board wrote that, "NASA's current organization … has not demonstrated the characteristics of a learning organization." The persistence of the problem showed that knowledge effectiveness depends on more than just systems for sharing lessons learned or best practices. It also requires an open culture in which people can speak openly about what they know without fear of retribution. There was more work to be done.

Today, NASA is a different organization than it was a decade ago. The importance of knowledge has been recognized throughout the agency. When tough programmatic decisions arise, leaders such as Chief Engineer Mike Ryschkewitsch encourage capturing those stories as case studies or articles that include rich context and quotes from multiple practitioners with divergent views. Painstaking efforts have been made to document the closeout of Space Shuttle and Constellation to preserve the invaluable knowledge developed in the course of those programs. Every center and mission directorate has either a chief knowledge officer or a point of contact to serve as the advocate for the knowledge needs of the organization's practitioners. Cross-agency support organizations such as the NASA Safety Center and the NASA Engineering Network foster knowledge exchanges that connect practitioners throughout the agency. These interwoven threads are helping create a resilient knowledge organization.

We are not there yet. Knowledge is not universally accessible across organizational lines. Half the NASA workforce is eligible for retirement and could walk out the door with critical knowledge that has not yet been passed on to others. Young professionals at the other end of the career path have had fewer opportunities than previous generations at NASA to get hands-on experience.

So there is plenty left to do. But it has been a decade of real progress. ●

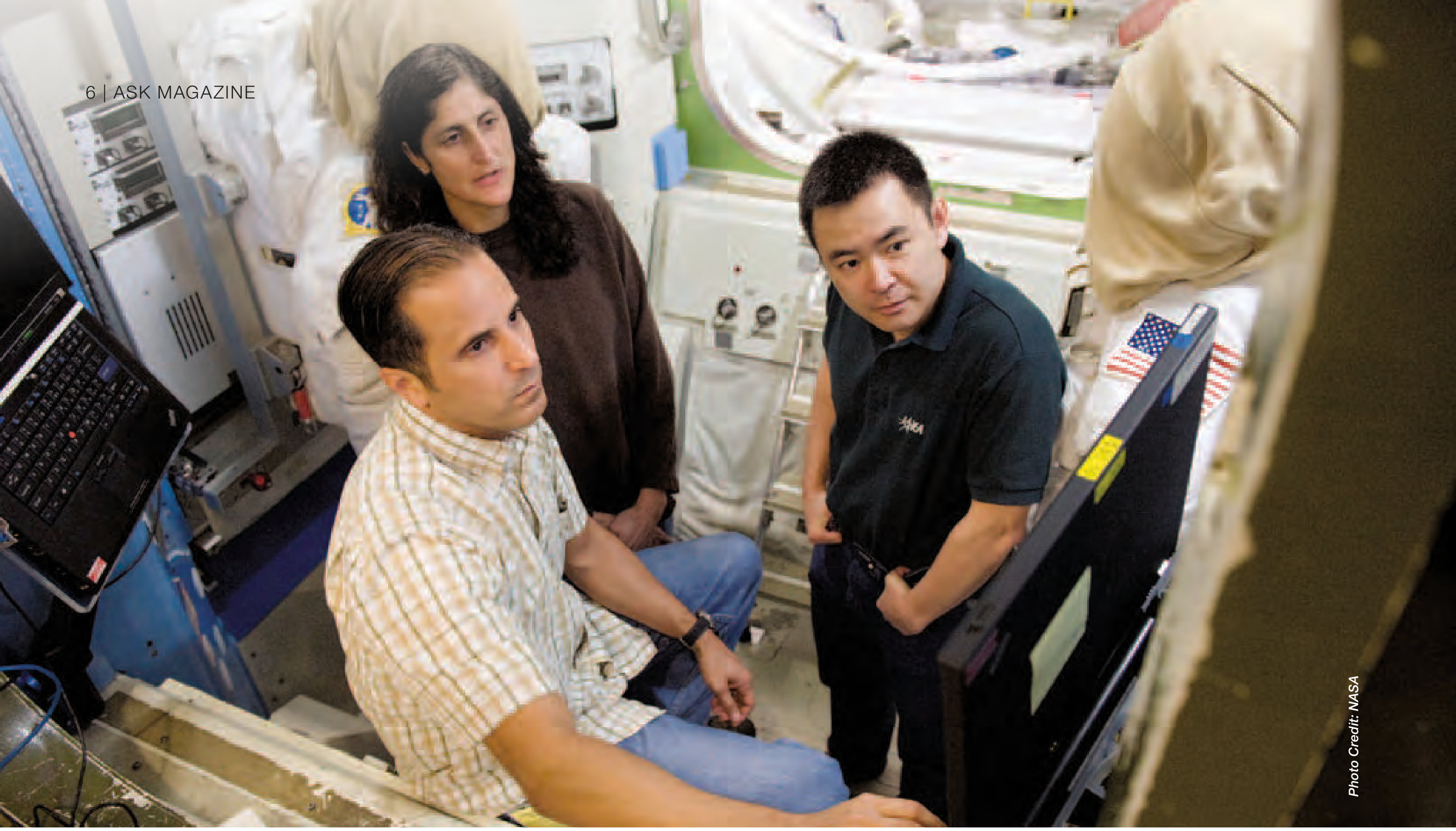
THE TOOTHBRUSH HACK

BY HALEY STEPHENSON

Collaborative problem solving, a jumper lead, and a toothbrush turned around an unsuccessful late-August spacewalk.

Photo Credit: NASA

NASA Astronaut Sunita Williams appears to touch the bright sun during a third session of extravehicular activity. Williams and Japan Aerospace Exploration Agency astronaut Aki Hoshide (visible in the reflections of Williams' helmet visor) completed installation of a main bus switching unit.



NASA Astronauts Sunita Williams and Joe Acaba (left), and Japan Aerospace Exploration Agency Astronaut Akihiko Hoshide, participate in an extravehicular-activity planning and preparation session in an International Space Station mock-up/trainer in the Space Vehicle Mock-Up Facility at Johnson Space Center.

On Wednesday, August 30, 2012, NASA Astronaut Sunita Williams and Japan Aerospace Exploration Agency Astronaut Akihiko Hoshide were tasked with replacing a malfunctioning main-bus switching unit (MBSU) on the center segment of the International Space Station (ISS), called the Starboard-0 truss. The MBSU is one of four 220-lb. boxes responsible for routing power from the ISS solar panels to the U.S. and Russian segments. The uninstallation went smoothly, but the replacement did not. One of the two bolts required to secure the new unit properly got stuck.

During several attempts to drive the bolt down, the crew observed debris inside the bolt receptacle. They attempted to clean it, but the bolt still refused to cooperate. After eight hours and seventeen minutes, Williams and Hoshide temporarily secured the MBSU and returned to the station's interior, completing what became the third-longest extravehicular activity (EVA) in history.

The unsuccessful MBSU installation meant the ISS was running at 75-percent power, prompting NASA to initiate power-mitigation plans, which were robust enough to maintain ISS operations. However, the urgency to fix the problem stemmed from Canadarm operator and NASA Astronaut Joe Acaba's scheduled return to Earth. With the desire to complete the MBSU's installation with the current crewmembers, who had direct experience with the task and EVA configuration, NASA wanted to resolve the issue sooner rather than later.

The "Big 12" and Team 4

The story of the MBSU began in October 2011, when it stopped communicating with the computers onboard station. While the unit was still functional and routing power as it should, it would need to be replaced. The MBSU is one of twelve items whose failure would render the space station "zero fault tolerant." In other words, if one of the "Big 12" failed and then another item failed, maintaining research operations would become complicated. In the event the second failure happened to be another Big-12 item, the U.S. segment could be lost completely.

ISS Flight Director Ed Van Cise is part of the team dedicated to developing contingency EVAs for items on the Big-12 list and worked on the plans for the MBSU replacement. In August 2012, Van Cise served as the lead flight director on EVA 18, during which the crew would remove and replace the unit. "That, of course, did not go very well," Van Cise said.

"The EVA was approximately six and a half hours in and my management was already pulling together the groundwork for what we call a 'Team 4 Effort,'" said Van Cise. In mission control, there are three teams, each covering an eight-hour shift. Team 4 is called in when extra support is needed. "Pretty much everybody needs to drop what they're doing and we throw every resource we need at the problem," he said. "That was Thursday night. My role after that was lead for developing our response to the problem."

There were three main challenges to address, Van Cise explained. First, how would the team fit another EVA into an already-packed expedition schedule? Second, once they find time in the schedule, how do they install the MBSU properly? Third, what is the next worst failure if they are unable to install the MBSU? In other words, what else might go wrong and how should they prepare for it?

One group was assigned to find time in the expedition schedule for the additional EVA; the rest of the team tackled the last two issues. After several briefings, the likely problem on the MBSU emerged: the bolt was getting stuck on the metal shavings and debris the crew reported. To fix it, the crew needed to clean and lube the bolt threads.

"The first place you start is, OK, if I had this problem at home, what would I do?" said Van Cise. "My response to things like this is just go get my big torque wrench and torque it real hard, and if it breaks I go get a new one. The problem is that in space we can't run to the hardware store and buy a new nut if it breaks.

"When you throw out options like that, then you start thinking up alternatives. We needed to [lube] the threads, and we needed to clean them out. How would we do that?" he continued. Specific tools for these jobs didn't exist on station, so they had to be invented.

Tools for the Job

Inside Building 9 at Johnson Space Center, Victor Badillo, an operations support officer and sixteen-year NASA veteran, was part of the team responsible for figuring out how to clean the bolt receptacle. "In situations like this, part of our job is to see what tools we have and try to imagine different uses for them," said Badillo. "We were wondering if we could make our own brush: a wire brush to clean out the bolt receptacle."

Badillo and another team member started making prototypes. Badillo grabbed a 4-gauge jumper lead identical to one found on ISS, removed the insulation from one end, and frayed the wires inside, creating a brush. The team liked what Badillo developed and improved upon the tool by using EVA tape to make the flimsy lead firm and finding ways to ensure the crew could grab and maneuver the tool with their oven-mitt-like gloves.

Another team worked the lubrication challenge. After surveying the inventory on station, the team settled on using a toothbrush to lubricate the bolt threads. A quick trip to the drug store and the team was ready to start testing the two types

Japan Aerospace Exploration Agency Astronaut Aki Hoshide participates in a third session of extravehicular activity. During the 6-hour, 28-minute spacewalk, Hoshide and NASA Astronaut Sunita Williams (out of frame) completed the installation of a main bus switching unit that was hampered by a possible misalignment and damaged threads where a bolt must be placed. They also installed a camera on the International Space Station's robotic arm, Canadarm2.

Photo Credit: NASA

of toothbrushes onboard ISS: name-brand and bargain-brand. The name-brand brush had a bend in the neck that interfered with it accessing the threading. The bargain-brand fit, but the full-length brush bent too easily, so the team had to cut it down to make it stiffer and less likely to snap.

The tools also had to be EVA-ready, meaning they needed to be tethered and able to survive the extreme cold. Once members of the astronaut office and the safety office tested the wire brush and the toothbrush, performing evaluations such as a 30-lb. pull-test to ensure the toothbrush wouldn't come off its EVA handle, they declared them ready for use.

But their work wasn't done. "We're not only trying to put together the tools, but also thinking about the techniques for using them and writing concise yet detailed procedures of what the crew needs to do in order to build these things and also use them," explained Jeff Stone, an operations support officer who worked the toothbrush challenge. For the toothbrush, Stone and his team pared down the procedure to two pages.

By Saturday morning, the team had ready for the crew their procedures and tools: a wire brush made out of a jumper lead and a modified bargain-brand toothbrush.

The Next Worst Failure, Almost

Even with the tools, everyone had to consider the next worst failure. If Williams and Hoshide couldn't remove the bolt or drive it all the way down, the team would have to resort to removing the MBSU at its cooling plate, bringing everything inside station, and trying to fix the box.

"That would have been a big deal," said Stone. "[The unit] is designed to be changed out, but we don't have a spare cold plate on orbit. We could send one on a subsequent cargo mission, but in order to do that there would be a whole lot more logistics, planning, and training."

Fortunately, this did not come to pass. On Wednesday, September 5, Williams and Hoshide conducted another spacewalk. They cleaned and lubricated the receptacle and threads, drove down the bolt, and successfully installed the MBSU.

From the beginning, the goal was to successfully assist the crew. There was no finger pointing and no turf wars, explained Van Cise. Just find a solution and implement it. "It was neat to be at the head of pulling that whole team together and watch them do all their great work. It was fun. Now that I've slept, it was fun," laughed Van Cise.

"I think there's a good parallel to a hack-a-thon-type event," said Stone. "You just get everybody who might have an interest in a particular challenge together so they can talk about it, brainstorm, have this common experience, and implement this creative, innovative approach to solving a problem."

"It's not always one person who works one particular task," added Badillo. "We have a lot of talented people here, but when you put them all together on one problem, it's amazing what we accomplish."

Photos courtesy of Victor Badillo

Images of the jumper cable modified to create the wire brush tool.

Hindsight

Almost immediately after the second EVA, team members approached Van Cise to ask when their lessons learned meeting was to take place. "One of the things we work really hard on is going and asking what surprised us, why, and how can we prevent it from happening again," said Van Cise.

One lesson that came to light pertained to a specialized technique for installing hardware like the MBSU, Van Cise explained. On previous spacewalks, crews used an installation technique called "dithering" to replace ISS batteries, which have a similar two-bolt installation configuration to the MBSU and require a crewmember to be on the end of the fully outstretched robot arm on station. Dithering involves carefully wiggling the unsecured end of a piece of hardware while drilling down a bolt on the other end. The technique relieves any structural loads from building up between the bolt threads and receptacle, and mitigates the movement generated by the astronaut from travelling down the outstretched arm.

For EVA 18, "We didn't anticipate having any issues installing the box since we were not going to be in the arm configuration that called for the special dithering technique," Van Cise said. "We learned afterward that dithering is needed for installing this type of hardware regardless of being on the arm or not."

After realizing the technique was needed for the MBSU, it is likely that other similarly configured hardware on the ISS will, too. "We are now examining the remaining Big-12-type boxes to see if they will require similar installation techniques or if there are problems we should anticipate when replacing this sort of hardware in the future," Van Cise added.

Where the Know-How Lives

When asked how NASA knows how to solve problems like this, Van Cise replied, "We train hard not only on failure recognition and resolution, but also on how to think ahead to the implications of the next possible failure and how to protect for it. We have a culture of developing creative solutions, bred out of the mind-set that failure is not an option. For a flight controller, when you're not on console and hear that something failed, you feel bad for the team that is dealing with the issue. That said, on the inside you're wishing you could be there, helping to resolve it. This is a key tenet to our training and what it means to be a part of mission operations—not just for ISS but for any program we support."

Part of the Johnson Mission Operations Directorate's mantra is "plan, train, fly," explained Van Cise. Lessons learned are documented and folded back into planning and operations, but also training for crews and flight controllers. They are built into everything. "This way, we don't just have to rely on someone like Kieth Johnson, lead EVA officer, remembering the horror stories and telling them to the other people on his team," said Van Cise.

The other parts live in IT systems like databases. "The operations team, the engineering team, and the [operations support officers] all have their own databases," he said. With this setup, one possible concern is that the solution to a problem could live in an operations database where an engineer might not think to find it. "How do we put things in a visible place where everybody can find the information?" asked Van Cise. Fortunately, a robust, cross-database search capability mitigates this risk.

Stone, who joined NASA in 1989 and has worked events like this on programs such as shuttle throughout his career, explained that this is just business as usual. NASA trains for situations like this. "We prepare people to have the right mind-set. You try to train so much that the initial reaction is instinctive on how to start handling a problem," said Stone. "That was another neat thing to see. We hadn't seen this problem before, but we kind of already knew what we needed to do to make it better.

"We try to remind ourselves that at any given time our actions or our decisions could have the ultimate consequences," he said. "Keeping that in the front of our minds, trying to analyze a situation, and actively learn the lessons and apply them in the future is just part of the way we operate." ●

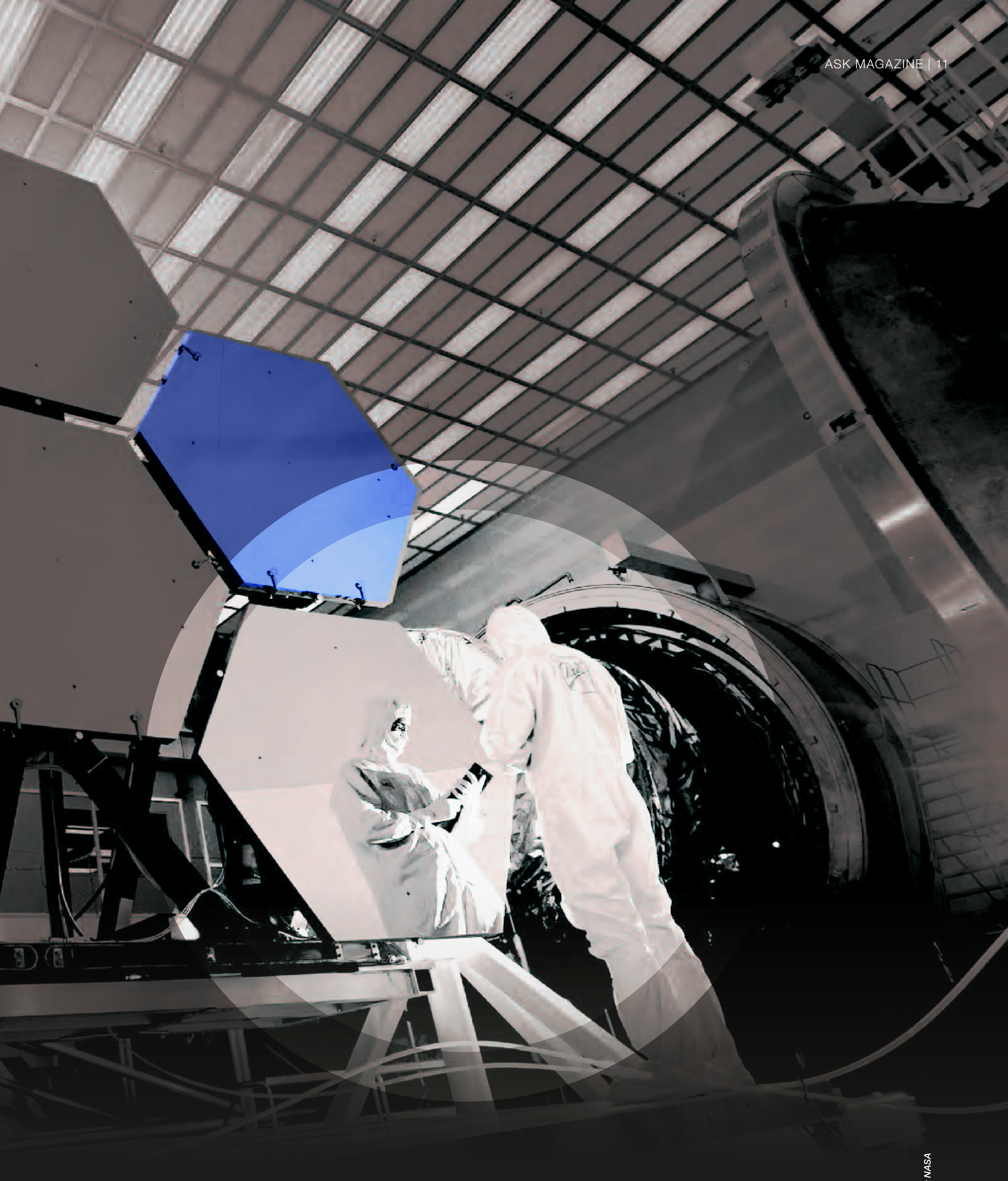
A fisheye lens attached to an electronic still camera captured this image of NASA astronaut Sunita Williams during the mission's third session of extravehicular activity.

Photo Credit: NASA

THE THERMAL DESIGN CHALLENGE

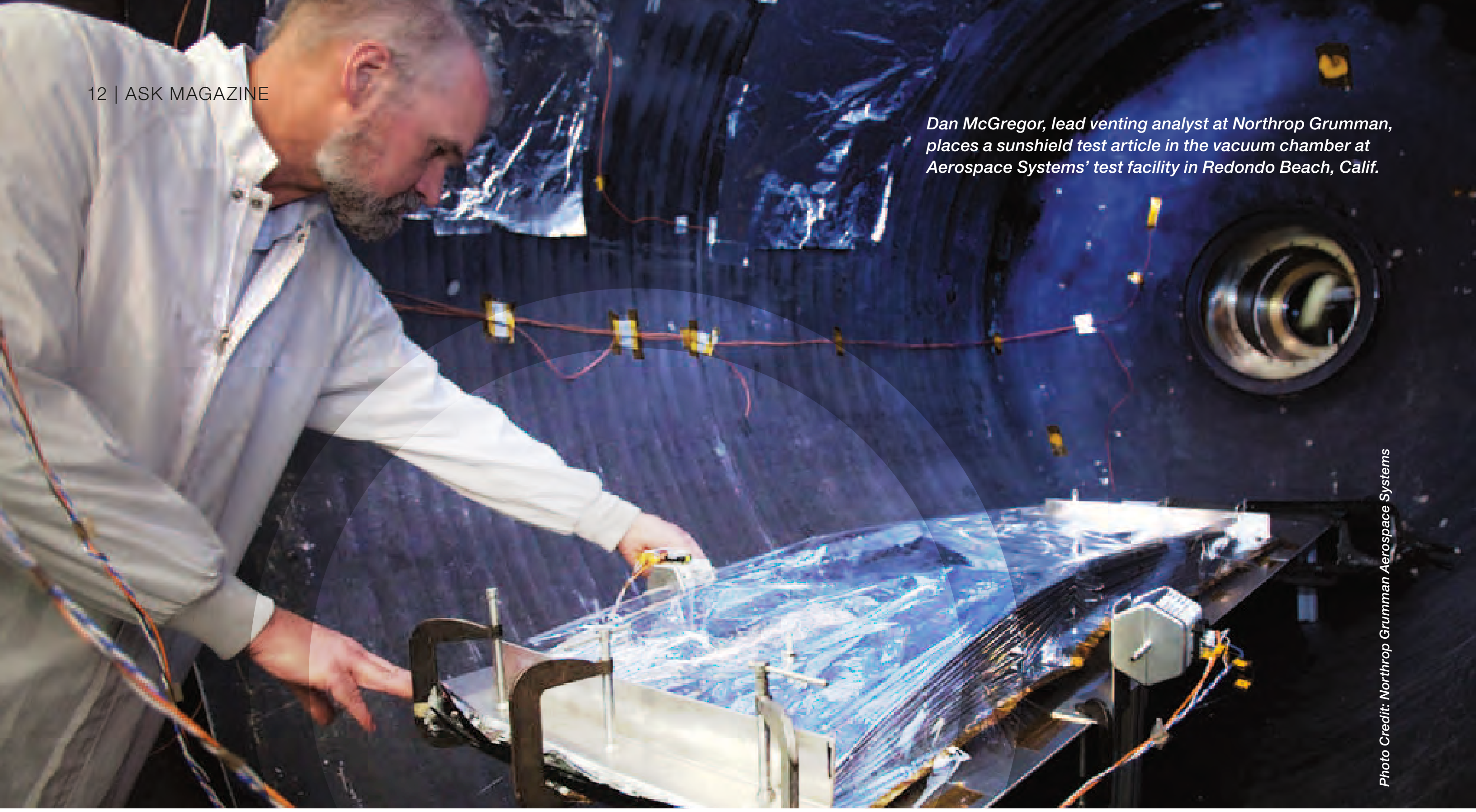
BY MIKE MENZEL

The James Webb Space Telescope (JWST), scheduled for launch in 2018, is expected to show us the most distant galaxies that formed in the early life of the universe. To do this, it has light-gathering capability unprecedented in a space telescope—its 6.5-meter-diameter mirror has more than six times the light-collecting area of Hubble's mirror. Also, it is designed to "see" mainly infrared radiation so it can detect the red-shifted radiation of early stars and make out stars and planets that are hidden from visible-light telescopes by clouds of gas and dust.



Technicians at Marshall Space Flight Center completed a series of cryogenic tests on six James Webb Space Telescope beryllium mirror segments at the center's X-ray and Cryogenic Facility. The mirrors were subjected to extreme temperatures dipping to -415°F, permitting engineers to measure in extreme detail how the shape of the mirror changes as it cools.

Photo Credit: NASA



Dan McGregor, lead venting analyst at Northrop Grumman, places a sunshield test article in the vacuum chamber at Aerospace Systems' test facility in Redondo Beach, Calif.

Photo Credit: Northrop Grumman Aerospace Systems

Because infrared is essentially heat, JWST's telescope and instruments must be extremely cold so those faint signals from distant objects will not be overwhelmed by the "noise" generated by the heat of the telescope and instruments themselves. To maintain the required low temperature—around 40 K or approximately -233°C—JWST will be located in deep space, about a million miles from Earth, with a sophisticated system of shields and radiators to cool down the hardware to prevent solar radiation from heating the telescope and instruments.

The challenge to JWST's thermal design group has been to design and test the hardware that will keep the instruments of this very large observatory at a very low temperature despite being in an environment where it will constantly be bombarded with 200,000 watts of solar energy—and to provide enough design margin to be certain the thermal design will work. With JWST a million miles away, a Hubble-style repair mission is out of the question. If the thermal design fails, so will the mission.

This task can be accomplished without radically new technical innovation. The basic principles of the sunshields and radiators have been used before. But the extremes of the temperature requirements and the constraints imposed by mass and budget limitations have made this a daunting task.

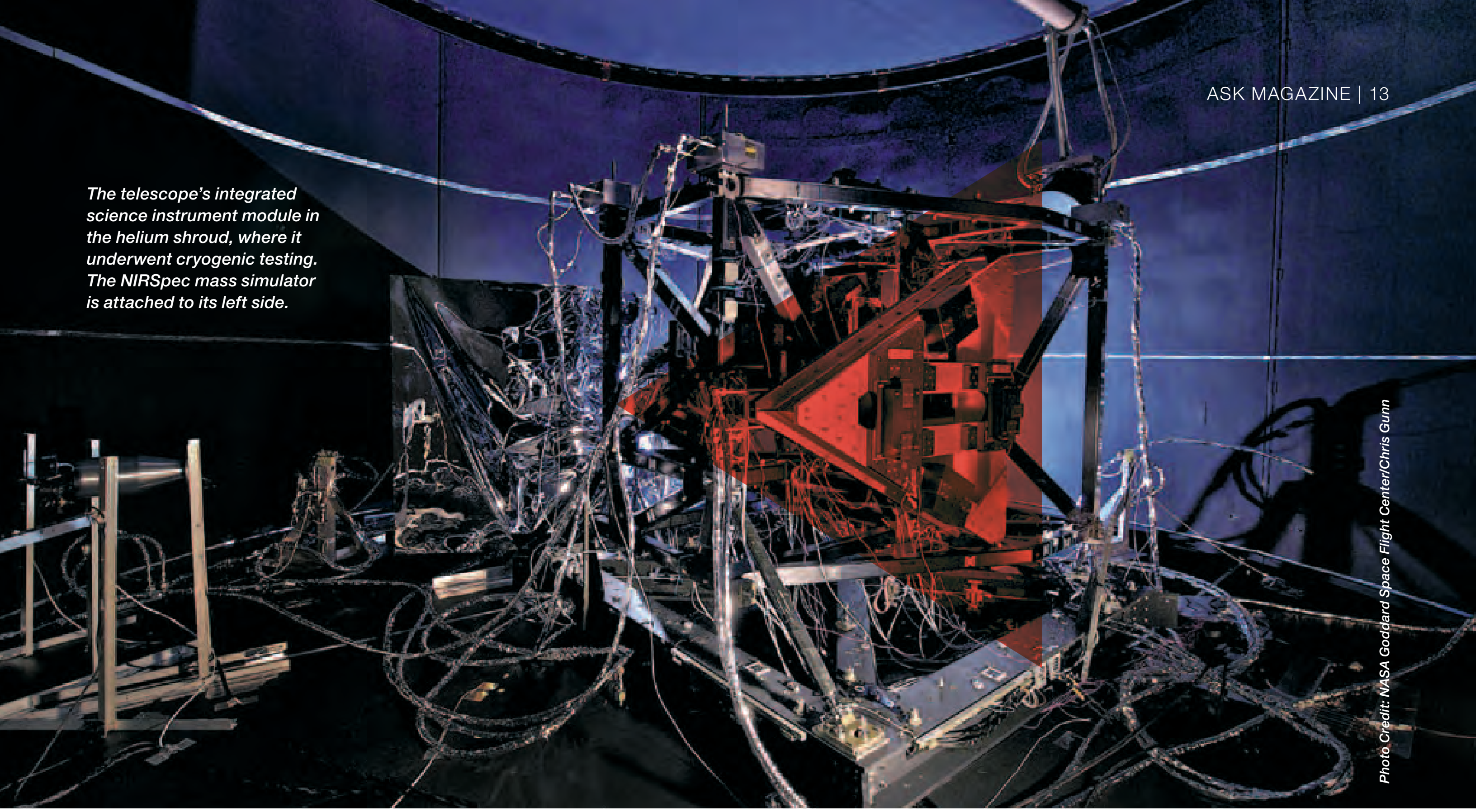
Previous cryogenic space hardware had masses of not more than about 500 kg; JWST needs to cool over 3,700 kg. Not only did we have to make sure that no more than 1 watt of the 200,000 watts of solar energy would get through JWST's heat shield, we had to fully understand the paths that 1-watt seepage would take to "sneak" around from the hot side to the cold side of the observatory, tracking down to tens of milliwatts to determine where to place the thermal shields and radiators that would disperse most of that residual energy.

The extreme vigilance required is hard to describe. We went into extraordinary detail in analysis and design, not wanting to overestimate the thermal insulation needs of JWST (and spend more mass and budget than necessary), but guarding against unjustified optimism that would increase the risk of underperformance.

Experience and Cooperation

The prior experience of team leaders Keith Parrish and Shaun Thomson from Goddard Space Flight Center and Perry Knollenberg from Northrop Grumman was essential to ensuring a robust thermal system. Through their past experience, they understood the risks and challenges of designing a passively cooled cryogenic system. People who have done cryogenic work before—even if less demanding work than JWST requires—have a feel for how much margin is needed and how much difference a seemingly tiny variation in temperature can make. Newcomers to the field are likely to underestimate both. These team leads understood the critical cryogenic demands and reminded the team to "concentrate on detailed heat-flow diagrams and follow the milliwatts."

Members of the JWST team also had prior large-telescope experience from working on the Hubble, Chandra, or Spitzer telescopes. Part of the Hubble experience—being a member of a "badgeless" system team where contractors and civil servants worked side by side, not concerned about which organization signed their paycheck—proved essential to the JWST work.



The telescope's integrated science instrument module in the helium shroud, where it underwent cryogenic testing. The NIRSpec mass simulator is attached to its left side.

Photo Credit: NASA Goddard Space Flight Center/Chris Gunn

While updating the observatory thermal-integrated models with results from engineering and component tests soon after JWST's critical design review in April 2010, the team determined that interface characteristics between components was not adequately represented in the models. Many of the problems found in the detailed heat-flow map did not lend themselves to be cleanly allocated to discrete-element product teams because they resided in the interfaces between these elements and had to be addressed at an overall system level. In other words, they could only be solved by a badgeless team concerned not with ownership of the individual elements but with responsibility for the system as a whole.

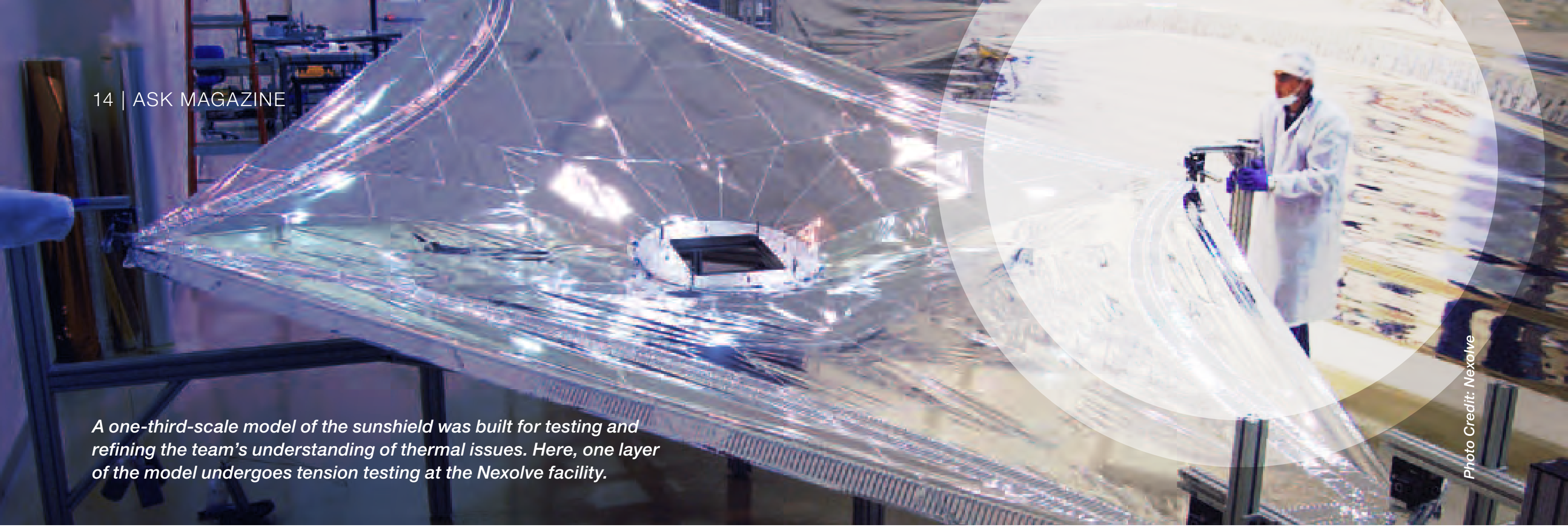
That meant bringing together people from a variety of organizations. The JWST program is an international collaboration with Goddard as the mission lead and contributions coming from the European and Canadian space agencies. In addition, Goddard holds contracts with Northrop Grumman as the observatory contractor, with Ball Aerospace as telescope subcontractor, and with the University of Arizona. An effective systems team required participation from all these teams without parochial interests getting in the way.

That multiplicity of players and the typical separations caused by the way money and work orders flow in the organizations meant that we had to avoid the dangers of so-called "stovepiping"—groups carrying out their assigned tasks more or less isolated from one another. The telltale signs of stovepiping are groups saying, "Just tell us our requirements and let us design the element," or, "Leave us alone to provide an optimized product." But the sum of optimized elements rarely adds up to an optimized system.

A stovepiped organization can obstruct solutions that involve give and take among elements to optimize systems performance as a whole—the kind of teamwork we needed for the thermal design. Stovepipes also can obscure problems, either because a subgroup's decision to solve a problem on its own keeps it hidden from the larger team or because the people who could recognize a problem are not party to essential "global" information. Finally, stovepipes hinder a program's ability to form cross-organizational teams that draw on the people best able to address problems regardless of where they are located.

To get rid of stovepipes and their negative effects, we were able to consolidate systems engineering for JWST under a common Goddard-led team. For many members of the team, this was an unfamiliar way of working, but in the case of the thermal systems team, the transition was extremely smooth. This was due in part to the urgency of solving the thermal problems and in part to the professionalism of the thermal leadership and the thermal team as a whole. We got the skills we needed to solve our thermal-engineering problems by creating a unified thermal-engineering group of people from Goddard, Northrop Grumman, our science teams, and the product teams (optical telescope element, integrated science-instrument module, and sunshield). Members of the group were not co-located, but they traveled a great deal and met almost daily during periods of the most intense work.

Working closely with the science communities that will use the observatory was also essential to getting the design right. We needed to understand the sensitivity of mission science objectives to subtleties of observatory performance. Some science instruments are inherently more sensitive to the noise of



A one-third-scale model of the sunshield was built for testing and refining the team's understanding of thermal issues. Here, one layer of the model undergoes tension testing at the Nexolve facility.

Photo Credit: Nexolve

higher detector temperatures. Working with the scientists, the thermal team made what may appear to be minor tweaks to the design but which resulted in higher margins for the instruments that needed it the most.

We worked hard to keep international teams and scientists informed of progress and problems during a weekly teleconference. (We also held science group briefings every three months.) That communication and the team's focus on the health of the program as a whole has led to important cooperation. One example is our getting scientists to agree on that proposal to keep the margins high on JWST's most-sensitive instruments by lowering the margin a bit on the less-sensitive ones. In part, this agreement was facilitated by giving scientists time to analyze the issue. In larger part, it built on the connection and trust that already existed.

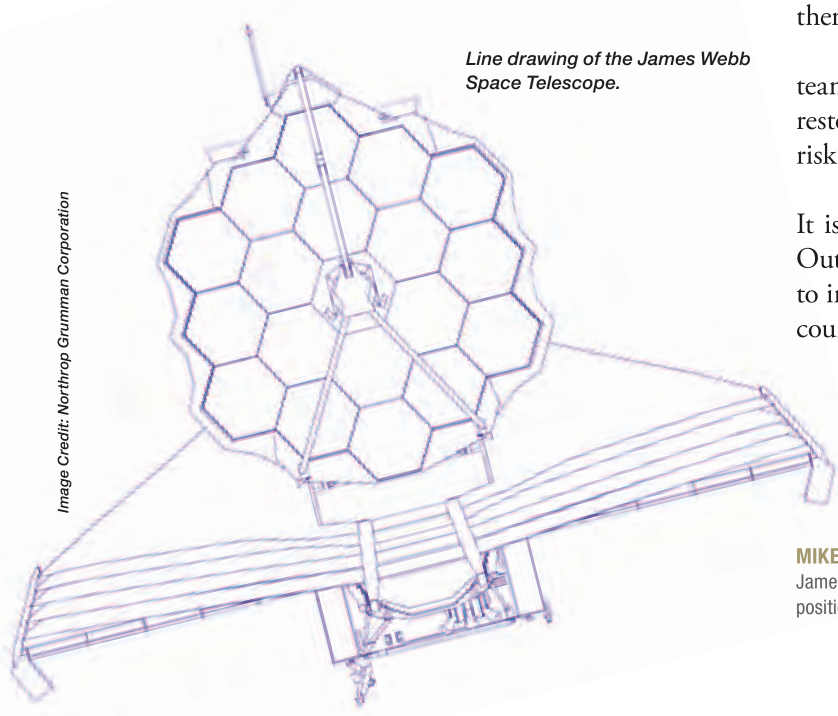
Testing, Learning, Fixing

To ensure our understanding of the thermal issues, we built a one-third-scale model of the sunshield and a full-scale model of the observatory's core area (the complex transitional region between the warm and cryogenic portions of the observatory). As we tested those models and refined our understanding of the thermal issues, we discovered more and more potential threats to our thermal goals, reducing margins to levels we could not accept.

Since March 2011, our Return to Green (RTG) thermal-recovery effort employed our best cryogenic experts to "follow the milliwatts" in an exhaustive effort to identify thermal threats and develop a strategy that gives us the margins we need without burdening the system with unneeded and costly protection. It would be hard to overstate the subtleties of the work. For instance, we had to make sure that our radiators have the best possible view to the cold of space. A 40-K radiator that "sees" a 100-K heat shield would have to be larger than one that has no obstructions to deep space to shed the heat it absorbed from that "warm" shield. The team conducted some of the most detailed thermal analyses ever performed for any spacecraft, keeping careful account not only of these view factors, but also of the way in which the absorptive and emissive properties of these radiators and their environments varied with the wavelength of thermal radiation.

At the conclusion of the RTG thermal-recovery effort, the team produced a revised thermal architecture that not only restored the appropriate margins after addressing all the known risks, but also gained a 27-kg mass savings.

Thermal design is an absolutely critical element of JWST. It is one of many systems that must work together flawlessly. Outstanding teamwork, extensive expertise, and commitment to implement practices that eliminate institutional barriers that could hide risks are instrumental in ensuring that they willl. ●



Line drawing of the James Webb Space Telescope.

Image Credit: Northrop Grumman Corporation

MIKE MENZEL is the NASA mission systems engineer for the James Webb Space Telescope at Goddard Space Flight Center, a position he has held since he joined NASA in June 2004.

Solving Challenges Through Mass Collaboration

BY NICK SKYTLAND

One of the things astronauts who have had the privilege of traveling to space talk about when they return is what it's like to see Earth from space, and the orbital perspective this brings. They talk about what it means to live in a world where we are more interconnected and dependent on one another than ever before, and how it shifts their thinking. They talk about what Astronaut Rusty Schweikart first observed in 1969 on Apollo 9: a world where our boundaries disappear, our problems overlap, and we realize the solutions are not one nation's alone.

People all over the world—here, in Tokyo—participated in the 2012 International Space Apps Challenge.

Photo Credit: Fumi Yamazaki

OVER THE NEXT COUPLE OF YEARS, I REALIZED MANY OF THE ASSUMPTIONS WE HAD AS A GOVERNMENT ABOUT HOW TO ENGAGE CITIZENS IN SPACE EXPLORATION WERE WRONG. OR AT LEAST WRONG GIVEN THE CHANGING ENVIRONMENT.

Although only about five hundred people have had the chance to physically experience this orbital perspective, the rest of us are starting to share this experience thanks to technology. We now live in an age where it's possible for a record-setting eight million of us to watch Felix Baumgartner jump from the edge of space live on the Internet. We can take a photo on Mars and stream it to a mobile device nearly anywhere in the world just minutes later.

As people around the world become more technologically literate and experience this orbital perspective themselves, they will want to participate more directly in government affairs, and with a purpose much bigger than space exploration. I know because I was one of them.

Finding a Way to Contribute

Like many others in my generation, I wanted to work at NASA. I wanted to be the guy who flew in space. But the problem I had was I grew up in North Dakota—pretty much as far away from a NASA center as you can be in America—and had no connection to NASA. No one in my family had ever attended college, and I was destined to be an auto mechanic or a farmer. Thankfully, I had a teacher in kindergarten who was equally inspired by space exploration and invited the rest of us to watch an upcoming Space Shuttle mission live on national television.

That was the day that tragedy struck the crew of *Challenger*.

Though I didn't realize it at the time, it was also the day that changed my life's trajectory. It's the day I realized I wanted be part of the solution to the grand challenges of our time—the ones that required the collective vision of us all. At the time, the only way I knew how to participate was to work at NASA. So that's what I set out to do.

Years later I had an opportunity to work at NASA. I packed myself up, drove as fast as I could 2,000 miles across country and showed up months before anyone had a work assignment for me. I was ready and waiting. I wanted to be put in the game.

One month after I started at NASA full time, Space Shuttle *Columbia* broke up over the Texas skies. I spent my first few months walking around the fields of East Texas picking up the broken dreams of our nation and thinking about how risky and unforgiving space exploration can truly be.

While I was in East Texas, I noticed the other people who were there. There were forest rangers and firefighters. People who drove across the country to participate in what we were doing. Thousands of people were helping NASA. They gave everything they had—their time, their talent, their resources—to participate. It was the largest mass collaboration I had ever seen.

The *Columbia* recovery effort was a testament to what people can do if given the proper resources and permission to work together. People around the world were willing to contribute to NASA. They wanted an opportunity to do that, but we weren't set up well to do it.

Collaborating on a Larger Scale

Over the next couple of years, I realized many of the assumptions we had as a government about how to engage citizens in space exploration were wrong. Or at least wrong given the changing environment.

It's true citizens want to participate in NASA's mission, but they want to do so on their terms, using common technology. They want not only to read about the Mars Curiosity rover, they want to drive it while sipping coffee in their pajamas somewhere in Idaho and thinking about how this might contribute to something locally relevant to them.

Thankfully, technology is opening doors so everyone can collaborate with government to help shape solutions to the grand challenges of our times: the ones that require not only government participation but participation by us all.

What this means for governments worldwide is participation is no longer limited to showing up to vote on election day, expressing concern by protesting about a cause, or accepting a government job. There are now ways to participate directly in government.

Admittedly, engaging citizens is something that is not easy to do. Although government has always been a platform for collective action (at least in the United States), the problem is it's never been an efficient one at connecting people together for a common purpose and scaling their participation in a focused and useful way. But thanks to technology, connecting people to what we do inside government does not have to be complex. It is not rocket science.

Here's the key: it's not just about individual participation; it's about mass collaboration. It's about creating platforms that allow us to take advantage of the exponential power of what happens when a thousand eyes look at our toughest problems and we collectively develop a solution.

Mass collaboration is possible today because of the Internet and our place in history. Technology enables the creation and application of ideas at scales previously unimaginable, in a focused way. There are many good examples of mass collaboration at work today. If masses can peer-produce an operating system, write an encyclopedia, or co-create the Icelandic constitution, we should carefully consider what might come next.

Mass Collaboration at NASA

I have the privilege of leading a team of entrepreneurs and technologists who are focused on considering what comes next for government, specifically at NASA. Our core team consists of only four people, but we have been able to engage thousands in NASA's mission by applying our experience in mass collaboration. We focus on scaling collaboration, using information technology to exponentially multiply the impact on the agency. This starts with the agencywide open-government plan that lays out the entire vision, with more than one hundred initiatives that include open software, open data, and technology, and highlighted initiatives like general robotics and collaborative spaces.

In implementing NASA's plan for open government, we quickly learned the agency has never really had an effective way to engage citizens on such a scaled and relevant way, so we set off to create one.

U.S. Embassy Jakarta partnered with NASA to bring the International Space Apps Challenge to Indonesia April 21–22, 2012, at high-tech cultural center @america.

Photo Credit: U.S. State Department/U.S. Embassy Jakarta, Indonesia

A team in San Francisco puzzles over The Pineapple Project, a software challenge to apply climate data to agricultural planning, during the 2012 International Space Apps Challenge.

Photo Credit: Elizabeth Sabet

Our vision was to engage people around the world in NASA's mission and create a mechanism for them to collectively develop new solutions to challenges facing us here on Earth and in space. We have experimented with developing online platforms, leveraging our networks and social media, and partnering with industry leaders to plan technology development events all with the goal of connecting more people to what NASA is doing. This experience culminated in an event we first hosted in April 2012 called the International Space Apps Challenge.

The International Space Apps Challenge took place in twenty-five countries and resulted in more than one hundred solutions to challenges offered by NASA and its partners. It was the largest government-led mass-collaboration event to date, and a testament to what people can accomplish together if given the permission, opportunity, and resources. After 48 hours, more than 2,000 people around the world collaborated to develop new technology that had never existed before.

Two of my favorite innovations to come out of last year's Space Apps Challenge are ExoAPI and Strange Desk. ExoAPI offers data from Kepler via an application programming interface (API) to make the data readable. NASA doesn't have many APIs, but we have a lot of data, so we anticipate solutions like this setting the standard for what we might be able to do with the many terabytes of data we collect through our space missions in the future.

Strange Desk is an app that allows people to crowdsource observations of strange things—for example, weird weather, black swans, or dead bumblebees. The idea is if you have people around the world recording this information, you can see trends at a macro level that you might not have noticed before. The app is a great example of how citizen science can be applied to solving NASA challenges.

The International Space Apps Challenge demonstrated that the creativity and innovation that used to take place primarily behind closed doors within large institutions is increasingly taking place by people connected together online. The solutions developed were so impressive, and the demand to do another event so strong, we decided to host a second International Space Apps Challenge April 20–21, 2013. (See "*ASK* Interactive" on p. 56 for additional information.)

The International Space Apps Challenge has inspired other government agencies to consider nonmonetized collaboration to help address technical needs. We recently advised the Peace Corps on the creation and implementation of their own innovation challenge. The Peace Corps Innovation Challenge was held on December 1–2, 2012, in cities around the world. We are also helping with two other mass-collaboration events—Random Hacks of Kindness and the National Day of Civic Hacking—which will focus on improving our communities and the governments that serve them around the United States.

There are many challenges that need to be solved, and we believe that governments need to continue to be bold, to take risks, to do what intimidates most others, like when we went to the moon or landed a rover on Mars. We need to do the things that not only inspire our nation, but our world. We can't do this alone. Solving the grand challenges of our time will require all of us. Just imagine what we could do together if we all shared an orbital perspective. We could improve our cities, reshape our economy, develop game-changing technology, improve outdated, outmoded, inefficient government—at all levels. After all, once you see Earth from space, you realize we are all in this together. ●

Portions of this article have been adapted from the TEDxHouston talk, "We're in This Together," given on November 3, 2012.

NICK SKYTLAND is the program manager of the Open Innovation Program at NASA Headquarters, where he leads a team of entrepreneurs and technologists who are responsible for directing the agency's open government plan and digital government strategy, with goals toward releasing more high-value data sets online, pushing forward the use of open-source technology, and creating participatory opportunities to engage citizens in NASA's mission.

SHARING EXCITEMENT EXPLORATION

BY AMBER STRAUGHN

Photo Credit: NASA Goddard Space Flight Center/Bill Hrybyk

Lead scientist Amber Straughn and observatory manager Paul Geithner answer questions during James Webb Space Telescope Night at the NASA Goddard Visitor Center on August 26, 2010.

On a small farm in the Middle of Nowhere, Arkansas, the sky was beautiful at night. Looking up at all those stars is how I became interested in astronomy as a child. Later on, Hubble began to release its beautiful images, which made me start asking those big science questions, such as, "How are those stars formed? How did we get here? What all is out there?" Years later, I'm able to study some of these intriguing questions thanks to my work at NASA.

Technicians and scientists check out one of the Webb telescope's flight mirrors in the clean room at Goddard Space Flight Center. Wavefront-sensing technology was used to measure the shape of each mirror and has spun off into ophthalmology, where it has been used to more perfectly measure the topography of the human eye.

Photo Credit: NASA/Chris Gunn

FINDING TIME AND BUDGET TO COMMUNICATE FREQUENTLY CAN BE A CHALLENGE, BUT IT'S SO IMPORTANT AND REWARDING. THE SCIENCE MISSION DIRECTORATE REQUIRES A MINIMUM OF 1 PERCENT OF ALL MISSION FUNDING GO TO EDUCATION AND PUBLIC OUTREACH.

I first got hands-on experience with Hubble during my graduate studies several years ago, when I used data from its ultra-deep field as part of my dissertation work at Arizona State University. Later, I was able to work with Hubble's wide-field camera 3, which was installed during the last servicing mission in 2009. With that instrument and several others, we gave Hubble new eyes, extending its capability into the near infrared and also the ultraviolet. This allowed us to look at the universe in greater detail and learn more about the universe around us.

Although Hubble's new instruments extend its capability into the near infrared, in order to push the boundaries and answer the biggest astronomy questions of our day, we need a much larger telescope that also extends into the mid-infrared. Not only does this help us peer through dust, as in the case of newborn stars inside their dusty cocoons, but it also gives us a better view of distant galaxies.

For example, when we look at ultra-deep-field images from Hubble, we find the most distant galaxies in those images are tiny red dots. The light we receive from these distant galaxies has been shifted to longer wavelengths by the expansion of the universe—the more distant, the redder their light. In order to see them, we need to see light that is redder, and that's exactly what infrared light is. That's one of the big reasons the James Webb Space Telescope (JWST) was designed to be an infrared telescope: it will detect the very first galaxies to be born in the early universe.

In addition to improving our vision of these distant galaxies and learning more about how stars form, JWST will also reveal more about how galaxies assemble over time and expand our study of exoplanets—planets orbiting other stars outside our solar system. With this, JWST will study every phase of our universe: from the very first galaxies to form more than 13 billion years ago to the very recent formation of planets that could be capable of supporting life. JWST will observe the universe near its distant edge, and also in our own "backyard" as it helps us learn more about objects within our own solar system.

Succeeding in building this new telescope is only part of our mission—of any NASA mission. Another important component of what we do is outreach, telling people what we're doing and why.

Successful Outreach

Since what we do at NASA involves complex engineering of one-of-a-kind missions, explaining the intricacies of what we do in a way that's easy to understand is important not only to maintain support for the mission, but also to engage people in what we're doing.

To engage an audience, first they have to be interested in what you have to say. One of the great things about astronomy is it's something the public is interested in and captivated by. The sky is beautiful; the images we get back from Hubble are inspiring and appeal to the public. Astronomy is a good starting point for getting the public interested in science and technology in general. And once you have that entry point, it's easier to expand upon the engineering required to build these big missions and do the great things NASA does.

Kids and adults alike are drawn in by the captivating images from Hubble, Spitzer, and all the other space telescopes, as well as the cutting-edge technology that goes into building them. Additionally, discussing spin-offs of our technology that apply to their everyday lives helps keep them engaged.

One of the really cool examples of technology spin-off with JWST involves the way we ensure the mirrors are perfect. We used a technology called wavefront sensing to measure the shape of each mirror, and this technology has spun off into the medical field of ophthalmology. Ophthalmologists have used it to more perfectly measure the topography of the human eye.

Another spin-off example involves JWST's cryogenic application-specific integrated circuits (ASICs). ASICs are very small and can contain an entire circuit board's worth of electronics. These circuits were installed on Hubble as part of its advanced camera for surveys, and JWST's investments enabled these circuits to be programmable, which was important when the camera needed to be repaired. This became a case of "future heritage," where a program in development invents a technology for a program well into operations.

Behind-the-scenes photo from the filming of the"Hubble Gotchu!" segment from Late Night with Jimmy Fallon.

Photo Credit: NASA/Maggie Masetti

NASA Astrophysicist Amber Straughn demonstrates the cold environment where the Webb telescope will be by dipping flexible rubber surgical tubing into liquid nitrogen in a demonstration video.

Photo Credit: NASA

And those are just two examples of spin-offs that come from the big, bold research-and-development efforts that go into building our huge missions. There are thousands more.

These are ways to structure successful outreach communication, but I think the most important thing is to be enthusiastic about what we're sharing with the public. Excitement is contagious, and I truly love my job. Ever since I looked up at those Arkansas skies I wanted to be involved with studying the universe, and I find sharing my personal story is a great way to convey my enthusiasm for what we do. It's also a great way to engage students, showing them one path into space exploration. It's important for the future of our country to get kids interested and educated in science, technology, engineering, and math—and on the path to making new discoveries in the future.

One question I often get about JWST specifically is why it looks the way it does. Indeed, it is an odd-looking telescope. One generally thinks of tubes and circular mirrors when they envision a telescope—Hubble is of this design, of course. But the answer to that question is we are building it to function optimally for what it's designed to do: observe in the infrared. Because of this, its mirrors and instruments have to be shielded from the sun (hence the tennis-court-sized sunshield). People are always fascinated by the design of this observatory.

Finding time and budget to communicate frequently can be a challenge, but it's so important and rewarding. The Science Mission Directorate requires a minimum of 1 percent of all mission funding go to education and public outreach. It's a good structure because it allows us to do the great things that get the mission science out not only to students and teachers but also the general public. Creating stunning visuals is one aspect of that. We have a team here at Goddard Space Flight Center who put together stunning visuals, videos, and imagery to go along with the story of the science, which really helps draw in the audience and communicate the science on a deeper level.

Social media has become another of the primary means by which we communicate news, and we have a great team here at Goddard that ensures we are on the cutting edge of new media and new communication.

I'm so glad that part of my official mission duties include communication and outreach. I've been fortunate to be involved in some cool, quirky things. We filmed with a crew from *Late Night with Jimmy Fallon* a couple years ago for their "Hubble Gotchu!" segment. They were here all day, and we got to do a funny rap video about NASA that aired on the show. That got a lot of attention and response, and it was a fun and positive experience overall.

These are only a few examples of how to engage others in what we do at NASA. It's important to do because our missions wouldn't exist without support and interest from the community. And it helps engage the next generation so they can continue exploring wherever we leave off. Who knows what JWST will teach us along the way, and where we'll go as a result of what we learn? The only thing we can be sure of is we will need future explorers to take us there. But making sure they're involved to ask the next big questions of tomorrow takes communication today.

AMBER STRAUGHN is a research astrophysicist in the Observational Cosmology Laboratory at Goddard Space Flight Center and serves as the deputy project scientist for James Webb Space Telescope education and public outreach.

INTERVIEW WITH

Alan Lindenmoyer

BY DON COHEN

Originally a co-op student at Goddard Space Flight Center, Alan J. Lindenmoyer has worked on human spaceflight programs for more than thirty years. In 2005, he was appointed manager of the Commercial Crew and Cargo Program, which manages Commercial Orbital Transportation Services (COTS), at the Johnson Space Center.

COHEN: Why was the Commercial Orbital Transportation Services program created?

LINDENMOYER: The Commercial Crew and Cargo Program was established in late 2005 as part of the U.S. Space Exploration Policy to promote the commercial space industry. Shortly after Mike Griffin came on board as administrator, it was clear to him that we needed to provide significant opportunities for U.S. private industry to demonstrate capabilities that could possibly meet our needs. We have obligations to service the space station with cargo and crew resupply over its service life, but we were retiring the shuttle. We would have loved to have gone to a catalog and been able to order up cargo-delivery services to the station, but they didn't yet exist in the U.S. The COTS challenge was to provide initial seed money and technical support to help industry develop those capabilities so that ultimately we could purchase them. We used our Space Act authority to enter into public–private partnerships, which we called Commercial Orbital Transportation Services, or COTS, agreements.

COHEN: To help them develop in a different way from the traditional NASA approach?

LINDENMOYER: We know very well how to define requirements, hire a prime contractor, and pay the full cost of developing a spaceflight capability. Our challenge was to take the experience, lessons learned, and the technologies we've developed over the last fifty years and make them available to industry to help generate this new capability. Instead

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of the traditional approach of writing requirements and hiring a contractor, we decided to become a lead investor and a consumer of services. We had to learn how to become an investor instead of a technical director, a partner providing financial and technical assistance. We wanted to do it not only to meet NASA needs but for a larger public purpose.

COHEN: How did you choose the industry partners?

LINDENMOYER: The first step was to put together program goals and objectives and the evaluation criteria. This wasn’t to be a handout; it wasn’t to be a grant. It was to be a competitive award of agreements with industry that would reduce the cost of access to low-Earth orbit, which is key to opening new markets and helping build a vibrant space-transportation industry. We would facilitate the demonstration of cargo and crew space-transportation capabilities with the goal of achieving safe, reliable, and cost-effective access to low-Earth orbit. We said we would focus on cargo demonstrations first and then would discuss the possibility of extending our agreements or establishing other agreements for crew transportation.

COHEN: Attracting non-NASA customers depends on reducing the cost.

LINDENMOYER: Absolutely.

COHEN: So what would allow these companies to reduce cost?

LINDENMOYER: We identified a range a capabilities of interest to NASA, not a firm set of requirements to meet. Companies could choose which capabilities to provide. Traditionally we write requirements, we direct their implementation, and companies build what we ask for. We wanted to provide flexibility for these companies to innovate and optimize their systems to the maximum extent possible to reduce cost. If the result was a capability that only the government could afford, that wasn't going to meet our objectives.

COHEN: Was choosing the winning companies difficult?

LINDENMOYER: We competitively selected a portfolio of companies we had the highest level of confidence could achieve those capabilities. We went about it in a very rigorous way. Instead of scoring proposals the way we usually do, we had to find a new way to evaluate because companies weren't all going to meet the same set of requirements. Everyone was planning to do something different. Some might propose developing pressurized cargo; some would talk about unpressurized carriers; some would talk about doing crew transportation; some would propose cargo return and others wouldn't. We allowed companies to bid on any combination of these capabilities. We kept the requirements to a minimum. The only firm requirements we insisted on were with the interfaces to the space station. Obviously if companies elected to do a demonstration to the station, they had to meet the physical- and data-interface requirements and comply with our safety requirements. Once the vehicle enters the control zone of the space station, there is no compromising the level of safety. They weren't required to go to the station, but if they elected to attempt to do that, we said we would make it available and help with the integration of their vehicle to the station. Those were the only firm requirements we had; everything else was goal related. We had a healthy competition. We wanted to level the playing field so that both emerging companies and established companies could compete equally and fairly.

COHEN: How did you go about evaluating those different proposals?

LINDENMOYER: We evaluated three elements of the proposals: the technical approach, the business plan, and the cost—not so much the relative cost of one proposal to the other, but our confidence in the ability of the organization to complete the demonstration effort within the proposed cost. This became another important characteristic of our program. We would not be paying the full cost of the demonstration. It was to be a shared-cost effort. If the company was confident that they could develop a capability that could be used for other customers, they should put skin in the game and share the cost risk with us. The business plan was very important. NASA is not accustomed to evaluating a company's business plan, so we hired a venture-capitalist consultant to help us. He helped write a request for a business plan. We didn't know how to ask for one, let alone evaluate one. Our consultant helped us ask for what we now know are the standard elements of any business plan: business strategy, market assessment, governance structure, management team, sources of financing, revenue, and projections of cash flow and expenses. We had to be educated to evaluate all that information because a company that didn't have a viable business wasn't going to help us no matter how good the technical accomplishments. We also wanted to build a portfolio of companies. Competition is a very important element of keeping cost and price down.

COHEN: And if more than one succeeded …

LINDENMOYER: If they succeeded, we wanted to be able to be the customer for multiple companies. Another thing we learned was that new ventures like this don't all succeed. In highly complex ventures, maybe one out of ten gets all the way to the end. We knew it would be best to include as many as we could in our portfolio, knowing that they may not all make it. If we get at least one by the end, that would be good. Having multiple capabilities would even be better.

COHEN: How many companies were initially selected?

LINDENMOYER: We had approximately $500 million available over five years to invest in these companies. We picked two companies in 2006 to share the $500 million and kept just 3 percent—$15 million—for our program operations. We wanted to make sure that the majority of resources were in the hands of the companies. We picked two: Space Exploration Technologies (SpaceX) and Rocketplane Kistler (RpK).

COHEN: Has setting goals rather than establishing requirements encouraged innovation?

LINDENMOYER: It absolutely has, but we weren't necessarily looking for new technologies. We shouldn't expect companies to develop cutting-edge technology. It's NASA's

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job to do that. We wanted to share our technology and let industry operate and develop capabilities in new and effective ways. That's what we saw with SpaceX. They have developed a new medium-class booster using standard liquid-fuel technology—kerosene and liquid oxygen. That technology was not new, but they were able to develop their engines, put together the first stage, second stage, and a capsule spacecraft in very cost-effective ways. That was the strategy of their company: to develop reliable low-cost access to space. It wasn't a new technology, but it sure was a new way to do business.

COHEN: How did they keep costs down?

LINDENMOYER: They controlled costs by doing a majority of the design and development in house. That was the SpaceX innovation. Rocketplane Kistler's concept was to develop a reusable launch system. They also were using liquid-fueled engines, but they wanted to have a fly-back booster that would land and be turned around and quickly reused. That was their innovation. We were planning to invest up to $207 million; their program required another $500 million at least. Their challenge was to raise that financing up front. Unfortunately, they weren't able to get there. We knew that was a risk going into this partnership, so we made a financial milestone one of our progress gates up front, stating they needed to raise at least one round of financing before we continued. They chose to combine all three rounds of financing and raise $500 million in one round. We were very patient with RpK and gave them every opportunity to succeed but we recognized that it just wasn't going to happen. The market took a downturn and financing dried up for that level of investment. Within about a year, we had to disengage with that agreement and quickly turn around a second competition to invest the balance of our funding.

COHEN: So one benefit of the milestones was telling you when to call it quits.

LINDENMOYER: Milestones were key in many ways. They were fixed price and predefined. We found that they were an extremely effective way to incentivize cost control and schedule. They were getting reimbursed after the fact, after they completed a milestone. They had to keep their costs to a minimum, and they had to work as quickly as possible in order to get the payment.

COHEN: After you ended the RpK agreement, did you look for other partners?

LINDENMOYER: Within four months we had re-competed the second round of COTS demonstrations, had an entirely new set of proposals and concepts to evaluate, and awarded our second-round agreement to Orbital Sciences Corporation.

COHEN: How hard was it for NASA to learn how to manage these new relationships?

LINDENMOYER: We had to learn how to become a trusted partner. We did this with a very small group. My program only averaged about ten people in the program office. I assigned a project executive to each company who would be the lead in the day-to-day interface with the company. The project executives had a deputy and the support of a safety and mission assurance officer. That was it for the primary team. Then we assembled a team of technical experts from across the agency, the COTS advisory team. There were about one hundred people across thirty technical disciplines. If the company needed help with a particular issue, we would call on an expert in that field. We also used them to help us review the progress of a company. They helped both us and the companies on an as-needed basis. We had the same level of insight into how the company was operating and what decisions they were making that a member of the board of directors would have. We developed that relationship over the years and had a great deal of insight both technically and financially into the operations of the companies. That helped give us confidence that they could succeed even though there were tough times and delays and challenges.

COHEN: What was working with SpaceX like?

LINDENMOYER: We had frequent reviews with SpaceX. The milestones came quickly in the beginning. We also had at least quarterly management reviews where we engaged in a lot of interaction. My project executive and his technical support spent a good deal of time out at the company's factory. We held multiple technical interchange meetings. A lot of time was spent face to face; a lot of team building went on. That evolved into a very good relationship, where there was a lot of learning on our side on how these companies operate in such an agile manner, and they were learning from us what was important in terms of safety and reliability.

COHEN: Was it hard to break the habit of very strict oversight?

LINDENMOYER: Our COTS advisory team certainly had an initial expectation of getting volumes of documentation and engineering data. But we worked differently. In some cases our commercial partners didn't provide a great deal of written documentation. A lot of their work was done with analysis of models and databases. Rather than spending a great deal of time documenting, they would manipulate their models and look at the data directly. We eventually got accustomed to that, but it certainly was a change for us.

COHEN: Are there ways in which NASA might copy SpaceX's more agile approach?

LINDENMOYER: SpaceX is very vertically oriented, with relatively few subcontractors and suppliers. They had the ability to make almost all the decisions they needed right there in the company, with some decisions delegated down to the responsible engineers. They were able to take chances and do rapid prototyping. If something didn't work out, they would turn around and try something else. Our programs don't typically have that flexibility. We have many subcontractors and international partners; one small change here can affect something else somewhere else. We're also dealing with very expensive science instruments and human safety. Another point is, when we commit to do a program, you can be assured that, given time and money, NASA will deliver. For our COTS partners, it just may not happen. So the circumstances are completely different. I wouldn't say one is better than the other. Their ability to make quick decisions is maybe something we could learn.

COHEN: Have there been things in this experience that surprised you?

LINDENMOYER: Early on, I was pleasantly surprised by how much this new way of doing business was embraced by leadership at all levels at NASA. The other thing that pleased me was the patience that was shown by all our stakeholders and other organizations. They understood that this is complex work; there are going to be challenges and delays, just as there are in any space development program. They were able to be patient and believe that this investment will have a good payoff. Members of Congress and their staff and members of the administration recognized that performing not exactly according to plan was part of the deal. If we got to the point where we thought it

“WE wanted to share OUR TECHNOLOGY AND LET INDUSTRY operate and develop CAPABILITIES IN new and effective ways.”

wasn’t going to be successful, we needed to make that call and move ahead in a different manner, which we did in reference to RpK.

COHEN: Are there differences in how NASA works with SpaceX and Orbital?

LINDENMOYER: SpaceX is a small emerging company; Orbital Sciences is a much more traditional large company. They use two different models. We’re more accustomed to working with companies like Orbital. Here’s a small emerging company with new in-house capabilities versus a large contractor with multiple suppliers using heritage hardware. That was part of the deal, too—having a balance of risk in our portfolio. A larger, more established company was considered to be the lower risk. But it had higher cost, too. We certainly got the payoff from SpaceX. Back in 2008, we awarded actual service contracts to Orbital and SpaceX, which was the second phase of the program. SpaceX has concluded its first operational service mission. Orbital is getting very close to doing a demonstration and is planning a supply mission next year.

COHEN: How has the agreement with Orbital been going?

LINDENMOYER: The agreement started a year and a half later than our agreement with SpaceX, but they’re very close to fielding their capability. There is a brand new launchpad at Wallops Island. A lot of people don’t know that we have a very capable launch complex there in Virginia. The vehicle is rolled out; it’s undergoing wet dress-rehearsal testing now and hopefully by early next year we’ll see the maiden flight of a brand new vehicle and its spacecraft.

COHEN: What is it called?

LINDENMOYER: The launch vehicle is Antares. The spacecraft with its pressurized cargo carrier is called Cygnus.

COHEN: How did the decision to use Wallops come about?

LINDENMOYER: That was completely up to Orbital. They originally proposed to launch out of Cape Canaveral, but during our negotiations they had discussions with Florida and Virginia about state incentives to help them develop their launchpad capabilities. Virginia offered very strong incentives. Orbital asked us if we would be OK if they switched to Wallops and we said, "That's your business decision."

COHEN: So what is the future of the program?

LINDENMOYER: We started with cargo demonstrations that evolved into an operational commercial cargo service. We always planned to follow on with crew-transportation demonstrations. Our program started the commercial crew-development activity back in 2010. We received $50 million of Recovery Act funding to begin our crew partnerships. We executed another competition and awarded five Space Act agreements with companies to take the first steps toward developing crew-transportation capabilities. In 2011 we were appropriated another $300 million for a second round of commercial crew-development agreements. At that point, commercial crew activities transitioned to a separate new program managed out of the Kennedy Space Center. I believe the success of our COTS partnerships is largely responsible for the support we received for crew. Now we're at the point where we have one commercial provider on board servicing the space station, another preparing to fly, and we're considering other commercial opportunities to meet human exploration goals in a cost-effective manner. ●

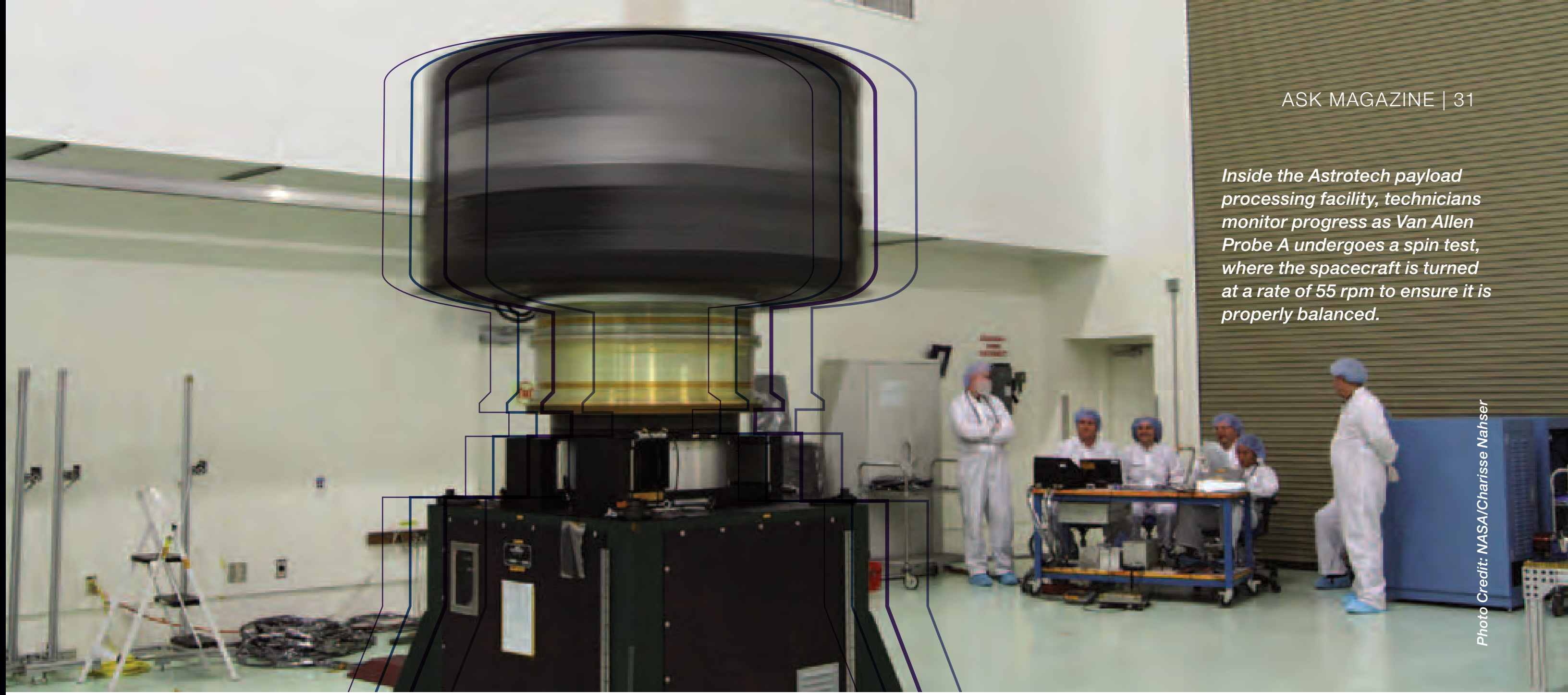
RADIATION-READY WITH A LITTLE ROCK 'N' ROLL

BY KERRY ELLIS

Radiation is one of many hazards in space exploration. It causes electronics to fail, degrades sensitive instrumentation, and affects astronaut safety—just a few of the things NASA protects against when launching missions to space. And our planet is surrounded by radiation: most notably the Van Allen belts. To help us better understand the generation, intensity, and variability of the radiation belts and how they and Earth are affected by space weather, the Radiation Belt Storm Probes—renamed the Van Allen Probes—were launched in August 2012.

Using a black light, a technician closely inspects one of NASA's Van Allen Probes. Black-light inspection uses UVA fluorescence to detect possible microcontamination, small cracks, or fluid leaks.

Photo Credit: NASA/Kim Shiflett



Inside the Astrotech payload processing facility, technicians monitor progress as Van Allen Probe A undergoes a spin test, where the spacecraft is turned at a rate of 55 rpm to ensure it is properly balanced.

Photo Credit: NASA/Charisse Nahser

The term "space weather" might conjure up ideas about asteroid hail or gale-force winds, but the winds in space are different from those we experience on Earth. The gases that blow are ionized, and their bluster affects our planet in strange—and magnetic—ways, such as disrupting satellite communications. When space weather intensifies, populations of charged particles trapped in the radiation belts also intensify, becoming swirling clouds that react in unpredictable and surprising ways. But how much do these changes affect our space technologies and astronauts? And how do the changes occur?

To answer that latter question in particular, two probes are needed. This allows the mission to not only measure how much radiation increases during a space-weather event, but how long it takes for us to feel the effects, and whether the effects are from one event moving through the belts or from different events altogether.

Nicky Fox, deputy project scientist, explained the logic behind this strategy in a NASA feature about the probes: "If you imagine having two buoys in the ocean, and one goes up, and comes down again, you don't know anything about what caused that to go up and down. If both of them go up, then you know you've got a very big feature that is affecting both of them at the same time. If one goes up, then the other goes up, you can measure how fast that wave has traveled between them, and what direction it's going in. And if only one goes up and comes down again, then you've got a very, very localized feature that didn't travel anywhere.

"So in order to be able to really understand what is going on [with] these very fine-scale features in our radiation belts, we have two spacecraft to do that," she said.

And both probes have to survive these intensified waves of radiation multiple times.

"Radiation is bad for electronics," Jim Stratton, mission systems engineer, explained as part of an educational video series on the mission's Applied Physics Laboratory (APL) site. "If you just flew your computer through the radiation belt, it really wouldn't work. It would damage the hard drives. The processor would constantly … reboot itself."

Since the Van Allen Probes have to safely transmit data about big radiation events, the team took extra precaution to ensure such failures wouldn't affect the spacecraft. Andy Santo, deputy project manager, explained some of the precautions the team took to protect the sensitive instruments. "For example … we covered each solar panel with a thin slab of glass … to protect from the radiation," he said. "The electronics are very susceptible to radiation, so we put a slab of aluminum over the very sensitive pieces."

Adding these protective measures also adds mass, which can affect any project's budget, either through the direct cost of materials or by requiring a larger launch vehicle to lift the heavier spacecraft. Many space missions are overdesigned in this way to ensure spacecraft can survive large radiation events without failing. Engineers hope the Van Allen Probes will tell them if they're overdesigning too much.

"Often people just have to overdesign because they don't know what the radiation is really like, so you just have to take the worst thing you think you're going to have. Sometimes you don't predict that enough, and you get a big storm and it kills the spacecraft. Other times you overdesign, you have more mass than you really needed, and you could have saved money by producing a simpler spacecraft," said Fox. The data from the Van Allen Probes will help the mission team improve models of the radiation environment in low-Earth orbit, so future missions will have a better idea of what the environment is like and can design their spacecraft with more accuracy.

In addition to these radiation models, the team plans to create physics-based models to help forecasters predict space-weather events and warn astronauts and spacecraft operators about impending hazards.

THE DATA FROM THE VAN ALLEN PROBES WILL HELP THE MISSION TEAM IMPROVE MODELS OF THE RADIATION ENVIRONMENT IN LOW-EARTH ORBIT, SO FUTURE MISSIONS WILL HAVE A BETTER IDEA OF WHAT THE ENVIRONMENT IS LIKE AND CAN DESIGN THEIR SPACECRAFT WITH MORE ACCURACY.

The identical Van Allen Probes will follow similar orbits that will take them through both the inner and outer radiation belts. The highly elliptical orbits range from a minimum altitude of approximately 373 miles to a maximum of approximately 23,000 miles.

Image Credit: NASA/Johns Hopkins University Applied Physics Laboratory


Photo Credit: NASA/Kim Shiflett

Technicians attach a solar array with its associated science boom to Van Allen Probe B at the Astrotech facility.

The Twin Spacecraft Challenge

Building two of everything can be a blessing and a curse. In the case of the Mars Exploration Rovers, it allowed the team to halve the testing time, putting one rover through one set of tests and the second rover through another. But building two spacecraft can also add time, as well as money and mass. With extra mass to shield electronics from radiation already required for the Van Allen Probes, keeping overall mass in check was vital. Especially since both spacecraft would launch on the same vehicle.

"The challenges of designing a mission with two spacecraft is basically double the work," said Fazle Siddique, from the mission design and navigation team. "Each spacecraft has its own trajectory, and we have to run each spacecraft through its own science requirement validation …. Also, because it's a twin spacecraft mission going up on one rocket, we have to make sure the launch-vehicle provider drops off each spacecraft in its correct orbit. And part of our early operations is doing some maneuvers to make sure the spacecraft don't hit each other."

Maneuvering both spacecraft in their respective orbits is further complicated by the boom system implemented on both probes. To decrease the risk of interference from onboard electronics, some science measurements will be taken by instruments located at the end of long booms, some 164 feet away from the body of the spacecraft. Because of these booms, rotating each spacecraft has to be done slowly and accurately to avoid any changes in trajectory.

"When you have long wire booms, it tends to make it a very stiff system. When I say stiff, it's like a spinning top where once it's spinning, it doesn't want to change its orientation," Santo explained. "So for us to change the orientation of a system with these long booms takes a lot of time and very small pulses because we don't want the system to react in a way we can't predict." Since the fully deployed wire-boom configuration could not be fully tested on the ground, preflight verification of performance required a tremendous amount of sophisticated analyses of the dynamics of the system.

Before they could place the probes in their proper orbits, however, the team needed to ensure the spacecraft would survive the journey there. To help decrease risk during mission development, the team at APL set out to create a new test on site to ensure both spacecraft would survive the launch.

Shake and Bake

For any mission to succeed, the spacecraft must survive the vibration of launch and the environment of space. To ensure this, engineers put the hardware through a series of tests—what they refer to as "shake and bake."

"We call it shake and bake, to put it simplistically, because that's essentially what we do," said Hadi Navid, environmental test facility supervisor at APL. "We always do the vibration test, which simulates the launch environment, and then we do what is called the thermal-vacuum test, which simulates the post-launch or on-orbit environment." Thermal-vacuum testing ensures hardware can survive in the harsh environment of space by rapidly heating up and cooling elements several times.

In the past, APL has had to transport spacecraft to other facilities for the vibration-testing portion of the shake and bake. This not only adds time to the development schedule—as the team has to wait for hardware to travel to the testing facility—but also cost. Transporting hardware also increases risk that something might be damaged in transit. To address these problems, APL set out to create a new test that would enable them to shake the Van Allen Probes on site.

Many vibration tests are done using acoustics in a reverberant chamber: sound is blasted at the walls and the sound waves bounce back onto the spacecraft to set it shaking. Because these chambers tend to be large and specialized, and APL wanted to keep the testing in house, the team began to

Near Kennedy Space Center, technicians inside the Astrotech payload processing facility use a crane to position the Van Allen Probes spacecraft A for stacking atop spacecraft B.

Photo Credit: NASA/Jim Grossmann

THE CHALLENGES OF DESIGNING A MISSION WITH TWO SPACECRAFT IS BASICALLY DOUBLE THE WORK …

explore direct-field acoustic testing. Essentially, they would turn the speakers around.

"Since it's somewhat of a new test method, we had to first qualify it to make sure it was satisfactory to our analysts, to our sponsor, and at the same time make sure that our facilities could support it," said Navid. "What it does essentially is uses speakers and subwoofers to simulate the sound field within the launch vehicle's fairing."

And that sound field is very loud, even outside the ring of speakers. So loud, the team had to make sure not only their hardware would be safe, but their facilities would be, too.

"We made sure that the overhead lights and things that are … in the ceiling are covered up, that there's extra screws, and we have netting in place," said Ken Turner, lead vibration test engineer. "And after each test run we go out and inspect our facility."

Once they confirmed the facility could handle direct-field acoustic testing, the team had to convince everyone involved that the hardware would survive as well. Gordon Maahs, senior structural engineer, explained that this took a lot of coordination to achieve: "We had sound technicians come in. We worked with the facilitators from the Vibration Lab. We had to talk to scientists that had instruments on the test. And we had to give everyone a basic understanding of just how the test works. It took months of work, but it was great to work with all these different people in different fields to get it to come together."

But before any actual hardware entered the ring of speakers, mechanical engineer Simmie Berman explained that they first created a mockup to undergo the testing. Loaded with sensors to obtain measurements, it allowed the team to ensure this new way of testing wouldn't harm their spacecraft. "The mockup is just a four-sided aluminum structure made of honeycomb and 8020, which is like Legos for big kids," she said. "It's the approximate height and width of the actual [probe] structure. On the spacecraft itself we taped I think fifty-nine accelerometers on different locations all over to collect data."

Facilities and mockups tested, APL was ready to expose the Van Allen Probes to the 143 decibels inside the ring of speakers. The sound was so loud, the team had to shut off the speakers after twenty seconds to allow them to cool down for an hour, according to Maahs. "… Just imagine standing in front of a rock concert speaker a foot away at full blast," he said. The sound is about twice as loud as the actual launch, so if the probes survived the speakers, the team was positive they would survive the launch.

Which they did on August 30, 2012, when the Van Allen Probes successfully launched on their two-year mission as part of NASA's Living with a Star program. So far, they have revealed the sounds of "chorus" radio waves emitted by particles in Earth's magnetosphere and captured energetic events that reveal the sun's influence on space weather is even greater than scientists had thought. This information, and what the probes reveal over the next two years, will help keep future missions and astronauts safer from the effects of our turbulent Van Allen radiation belts. ●

Interviews were originally conducted by APL and can be found at vanallenprobes.jhuapl.edu/mission/conversation/overview/index.php.

NASA's current arc-jet test capabilities have worked well—like for this testing of the Mars Science Laboratory entry, descent, and landing instrument—but will not meet the most demanding requirements of future missions. This is why NASA has partnered with CIRA to use the Italian agency's Scirocco facility, the newest, largest, and most advanced arc-jet facility in the world.

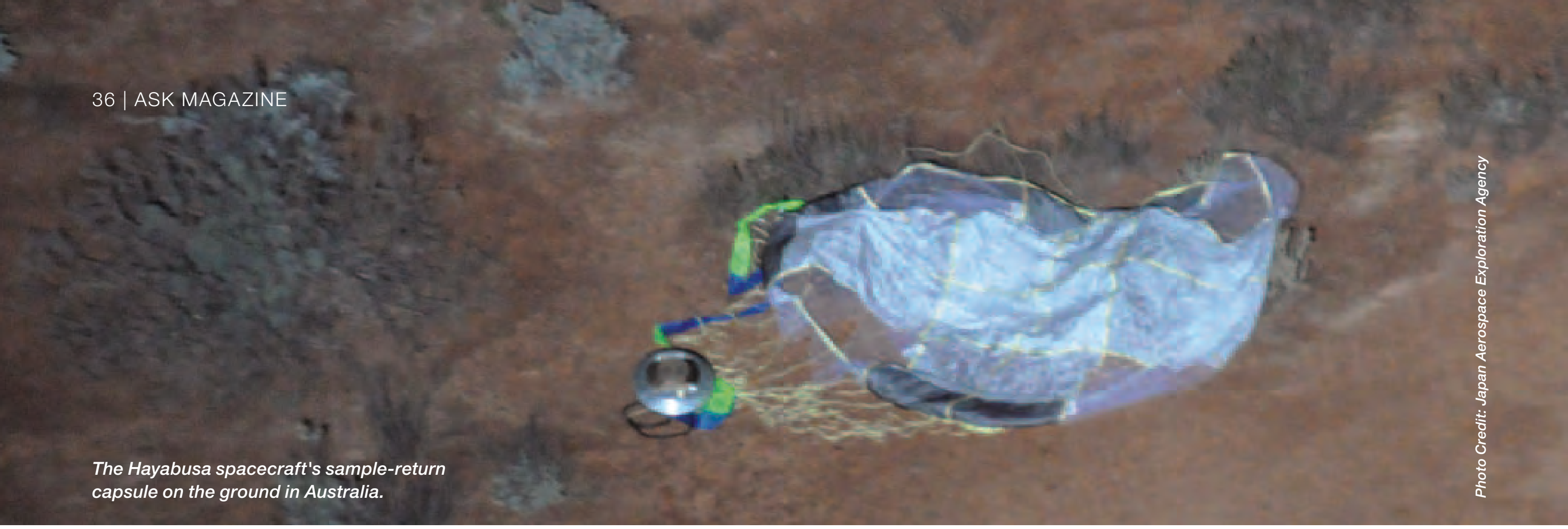
Photo Credit: NASA Ames Research Center

Photo Credit: NASA Ames Research Center

THE SOFT SKILLS OF INTERNATIONAL PROJECT MANAGEMENT

BY JAY GRINSTEAD

When I took the International Project Management (IPM) course at Kennedy Space Center in the winter of 2012, I had already had some experience working with NASA's international partners. In fact it was that work, which introduced me to some of the cultural and organizational complexity of working internationally, that convinced me to sign up for the course and learn more.



The Hayabusa spacecraft's sample-return capsule on the ground in Australia.

I am a research scientist and project manager in the Aerothermodynamics Branch, Entry Systems and Technology Division, at Ames Research Center. From late summer 2009 through 2011, I was project manager for the Hayabusa Reentry Airborne Observation project, an Ames-led international effort to observe and record the atmospheric reentry of the Hayabusa sample-return capsule over Australia on June 13, 2010.

Hayabusa was an asteroid-exploration mission conducted by JAXA (Japan Aerospace Exploration Agency). Its return was a rare opportunity to collect data from the reentry of an atmospheric entry capsule. NASA's DC-8 airborne laboratory was equipped with optical instruments that tracked the luminous reentering capsule. The data are being used to validate simulation tools applied to the design of NASA's future atmospheric entry vehicles. The project had participants from four NASA centers, JAXA, the SETI Institute, and research institutions and universities in the United States, Europe, Japan, and Australia. I assisted NASA's Office of International and Interagency Relations in negotiations with our international partners to secure the agreements that enabled a U.S.-led team of researchers from seven countries to fly a NASA jet in Australian civil air space to observe the reentry of a Japanese spacecraft.

I found that technical discussions with our Japanese partners were easier than the managerial and administrative ones. We all spoke the same technical language, but our different cultures led to some different ways of working. The clearest example came from the Japanese norm of developing group consensus before a decision is made. That made it harder than I was used to to get a quick response to questions and to understand exactly who exercised executive authority for the Japanese team. It meant that things happened a bit more slowly than I was used to and additional correspondence and face-to-face meetings were needed to arrive at a decision. Technical knowledge is important in these partnerships, but it was clear that diplomatic skills are, too.

Insights from the IPM Course

The five-day IPM course confirmed and helped explain my experience on the Hayabusa project and showed me how others dealt with those and similar issues. There were useful descriptions of how different cultures work, videos of actors assuming the negotiating styles typical of various nationalities, and role-playing exercises for the class, which included participants from many of NASA's international partners.

For me, the course confirmed the importance of soft skills in international project work. I learned, for instance, that in working with partners with strong social and familial bonds, it was essential to spend time developing personal relationships before getting down to business—an important lesson for Americans who tend to want to jump in and get to work quickly. The course showed us examples of how the ways of conducting business in another country may seem counterintuitive and even counterproductive or ineffectual to an American. But that's not for us to decide. Those in other countries may draw the same conclusions about how the Americans work. The primary objective of the course was to prepare us to read the unspoken and unwritten language of cultural norms of other countries. Once the motivating forces of international partners are understood, potential frustrations can be avoided and replaced with strategies for success.

Putting the Lessons to Work

My first opportunity to put some of what I learned to work came in July 2012, when I engaged in discussions with the Italian Aerospace Research Centre (CIRA, the Centro Italiano Ricerche Aerospaziali) to secure a contract for NASA's use of their arc-jet facility, Scirocco. Arc jets are high-temperature hypersonic wind tunnels used to test heat-shield materials at conditions that approximate the intense heat of atmospheric entry. NASA's current arc-jet test capabilities will not meet the most demanding requirements of future missions (for example, robotic sample and crewed vehicle return from Mars). The Scirocco facility, patterned after NASA's own arc jets, is the newest, largest, and most advanced of its type in the world.

The purpose of the test series is for NASA to collect performance characterization data at the extremes of Scirocco's operating envelope. The data, along with insight into Scirocco's supporting subsystems, will inform NASA's efforts to expand

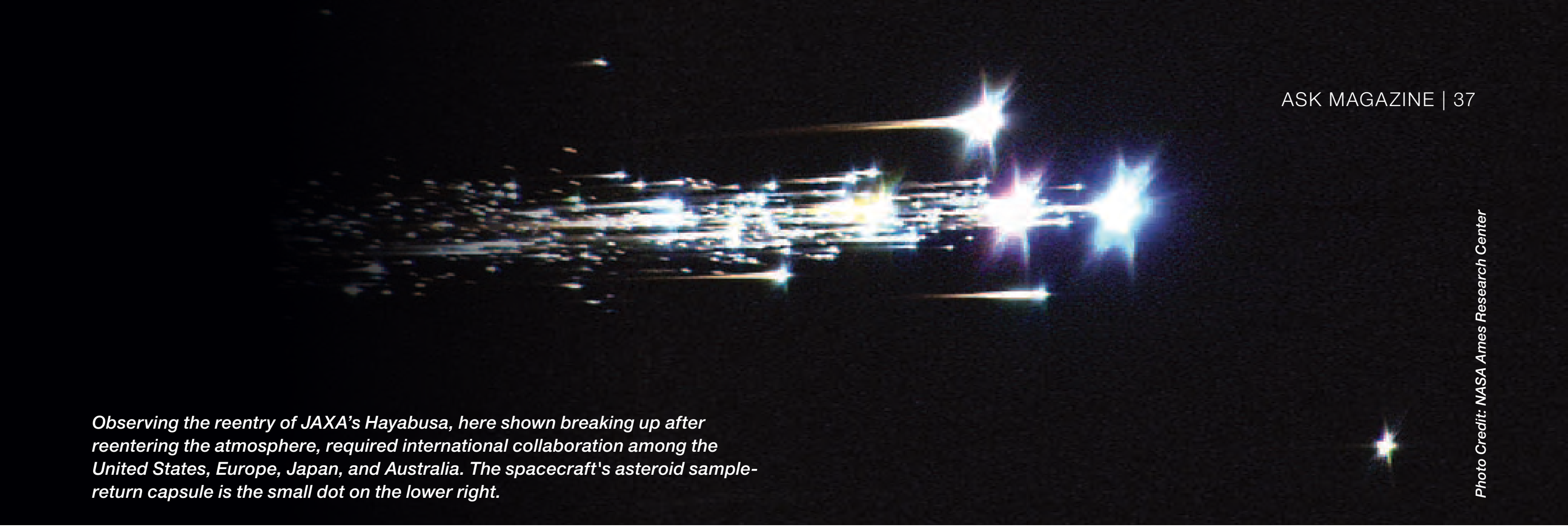


Photo Credit: NASA Ames Research Center

Observing the reentry of JAXA's Hayabusa, here shown breaking up after reentering the atmosphere, required international collaboration among the United States, Europe, Japan, and Australia. The spacecraft's asteroid sample-return capsule is the small dot on the lower right.

its capabilities to meet future requirements. My responsibility was to continue previous high-level discussions between Ames and CIRA regarding the collaboration. The result was a procurement contract awarded to CIRA for testing services with negotiated milestones and deliverables. I got the job partly because I raised my hand—I was enthusiastic about doing more international work—but also, I think, because of my Hayabusa experience and my participation in the IPM course.

The negotiations did not present any significant difficulties: NASA was interested in using the Italian facility; CIRA was interested in finding customers for it. But there was still a lot of work to do to fine-tune the details of a procurement contract: negotiating the scope and schedule of the tests, accommodating on-site NASA observers, sharing relevant facility design documentation, and—most importantly—reaching agreement that CIRA would operate their facility at its design limits.

Developing personal connections before getting down to serious negotiation work proved as important as the IPM course suggested it would be. While the framework of the NASA–CIRA collaboration was established prior to my arrival, I needed to introduce myself and our procurement specialist to the CIRA representatives, and they to us.

All our discussions leading up to contract award were conducted through teleconferences (with a nine-hour time difference between us). We had not met face to face previously, and the initial correspondence with my counterpart at CIRA was conducted through e-mail. Our Italian colleagues all speak English—a skill more common than one might think—which brings peace of mind to those, like myself, who know no Italian. I opened our first meeting with short summaries of who we were on the NASA team, our roles and responsibilities, and how important this collaboration is to Ames and the agency. My counterpart on the CIRA team did likewise, and we spent a few minutes sharing some personal experiences on the easy, shared subject of travel. After that, I described NASA's expectations for the contract discussions and the schedule we needed to keep in order to award before the end of the fiscal year—an immovable deadline.

We met frequently via telecon to develop and refine the test plan and statement of work. Concurrently, the Ames procurement specialist worked with the CIRA business manager to assemble all necessary documentation for NASA to contract with CIRA. Our meetings were suspended for the entire month of August to accommodate the traditional European summer holiday. But negotiations went smoothly, and we were able to award on September 26, 2012—just under the wire.

Conducting business solely through telecons with an international team I had never met presented some peculiar challenges. The cues one acquires visually in conversation were absent, and the accented English of our colleagues was at times hard to parse. The lack of nonverbal feedback on occasion caused confusion. But patience and polite queries to repeat questions or answers often resolved misunderstandings. Though it is a common practice for just about every nontrivial collaborative effort, end-of-meeting summaries and reviews of action items were particularly effective tools in these circumstances to assure both parties that we were in agreement regarding expectations.

I believe that all of us charged with responsibility for collaboration have innate common sense and a desire to act reasonably and rationally. How these characteristics are expressed reflects the culture of both individuals and groups. Establishing a very modest personal connection—even over the phone—can draw groups together with a shared enthusiasm to succeed. That worked for us in the contract negotiations with CIRA. The only thing we lacked in the end was a firm handshake to celebrate our achievement. ●

JAY GRINSTEAD is an aerospace engineer and project manager in the Aerothermodynamics Branch at Ames Research Center. He currently supports atmospheric entry technology-development initiatives for center, agency, and commercial space projects.

Reducing Natural-Language Ambiguities in Requirements Engineering

BY LARS SCHNIEDER AND SUSANNE ARNDT

Interdisciplinary and interorganizational project collaboration is a challenge. One of the most essential tasks in big and heterogeneous projects is requirements engineering, which, done properly, helps master complexity and reduce misunderstanding. Requirements engineering is a communication process that involves understanding and coordinating terminologies from different disciplines. In order to obtain an unambiguous and precise specification of what is required, requirements engineers need to be aware of the potential pitfalls of drawing up requirements in natural language. Requirements engineering needs the support of tools that include models of domain-specific terminologies and conventions about their use to reduce the likely ambiguity and vagueness of requirements expressed in natural language.

Requirements Engineering in Complex Projects

Research and development projects inherently involve a lot of planning and modeling. In general, this work begins with the collection of requirements. These are discussed and modified over time to arrive as far as possible at a requirements specification that is testable, unambiguous, complete, and correct. The project manager of a complex research-and-development project needs to ensure that requirements are adequately administered, guided, controlled, and used throughout the project. For this reason a suitable requirements management process and an adequate tool such as IBM Rational DOORS or IBM RequisitePro need to be in place.

Failure to pay appropriate attention to requirements can have fatal consequences for project success: needs of the user not being met (development of required functions does not happen), resources of money and staff being wasted on unimportant work (for example, on the development of non-required functions), and the greater likelihood of bugs or errors.

Collaboration

The more complex the research subjects or products, the more care and expertise are required to implement them professionally. This includes a rigorous collaborative approach toward requirements engineering.

First of all, researchers of different departments of one organization work together to specify required technical features of the system (intraorganizational collaboration). In addition, external suppliers need to understand the expected deliverable. Customer and supplier need to find a common language (interorganizational collaboration). Complex projects often require contributions from different domains. Since no single domain can completely capture all relevant requirements, experts from various disciplines need to get together—and they must understand each other (interdisciplinary collaboration). This is where the greatest problem lies.

As productive as different perspectives on collaborative requirements engineering can be in an ideal situation, it is difficult to get those benefits in reality. The key to making these collaborations effective is language. Terminology that belongs to one knowledge system is often misunderstood by people who work with another knowledge system. Overcoming the linguistic barriers between these systems is essential.

Ambiguity

Ambiguities are a problem because they can lead to two or more different interpretations of the same word. They are often part of the subconscious, so requirements writers will not necessarily recognize these potential sources of misunderstandings.

There are different kinds of ambiguity. *Lexical ambiguity* refers to single expressions that may be reasonably interpreted in more than one way. One simple example is the German adjective *einfach*, which implies two different meanings. The first meaning refers to the "ease of doing something." A requirement containing *einfach* could be taken to mean, "The sensor shall be easy to install." The second meaning of this adjective refers to the "frequency of an activity." So a requirement containing *einfach* could also be read as, "The sensor shall be installed only once." The second interpretation is not the intended meaning, as often sensors should feature a bracket to reattach them at some other location. Once an ambiguity like this is detected, the author should be guided toward a clear, alternative wording.

Misinterpretation can also result from *syntactic ambiguities*. The syntactical structure of a requirement—for example, when pronouns and relative clauses can refer back to two or more other elements of the preceding sentence—might also lead to different interpretations. In addition there might be *discourse ambiguities*, which are defined as incompatibility between several requirements.

Vagueness

In cases of vagueness, it is difficult to form any interpretation at the desired level of specificity. This is in contrast to ambiguity, where more than one interpretation is evoked.

- Use of the passive voice can prevent a reader from understanding the meaning intended by the author of a

TERMINOLOGY THAT BELONGS TO ONE KNOWLEDGE SYSTEM IS OFTEN MISUNDERSTOOD BY PEOPLE WHO WORK WITH ANOTHER KNOWLEDGE SYSTEM. OVERCOMING THE LINGUISTIC BARRIERS BETWEEN THESE SYSTEMS IS ESSENTIAL.

requirement as it lacks explicit reference to the actor. In contrast to this, the active voice clearly identifies who is performing that action. A sample requirement that reads, "Video streams of critical vehicle movements have to be stored," fails to indicate which technical or organizational entity is responsible for data storage and where the storage will be allocated.

- Use of participles to modify nouns also leaves open the agent of action. A sample requirement that reads, "Installed sensors must measure the weight of the vehicles," leaves open the question of who will install the sensors.
- The use of unspecific adjectives is another likely source of vagueness. For instance, "Components installed in the public road space should have an unobtrusive appearance," leaves open the possibility of interpreting "unobtrusive" in many ways. More detailed requirements that specify a maximum size and a desired color of the components avoid the problem.

Improving the Quality of Natural-Language Requirements

These kinds of problems can be identified by means of strict detection routines. Requirements engineers can then remedy flaws and improve quality. At the DLR (German Aerospace Center), we have taken some steps in this direction:

- An in-depth initial linguistic analysis of the requirements repository identifies a list of critical and ambiguous terms that can serve as a basis for future requirements reviews.
- A prototype terminology management system plug-in for the requirements management tool is under development, which allows for modeling domain-specific terminologies. Using this plug-in, engineers can organize relevant terms according to the semantic relations between them. The plug-in includes ambiguous words and links to the associated different readings they can have. It indicates terms to avoid because of the ambiguity they create.

Future work will be directed to modeling rules for avoiding syntactically ambiguous sentence structures. Together with the detection of lexical ambiguities, this has the potential to significantly improve the linguistic clarity and quality of requirements. Future work will be directed toward the continuous improvement of the current prototype tool. The ultimate goal will be to use the tool for linguistic checks based on both the available terminology and the syntactical rule set.

Early experience has shown that especially the first steps of linguistic analysis and modeling need to be done by experts who are highly aware of potential natural-language problems. It also is clear that correcting faults requires close cooperation between linguists and domain experts whose knowledge is required to recognize and remedy linguistic faults. Terminology and existing syntactical rule sets need to be continually updated for new application contexts. In the future, we expect that requirements engineers will eventually have a tool that will allow them to model their own semantic networks and terminology systems to the benefit of their requirements engineering work. ●

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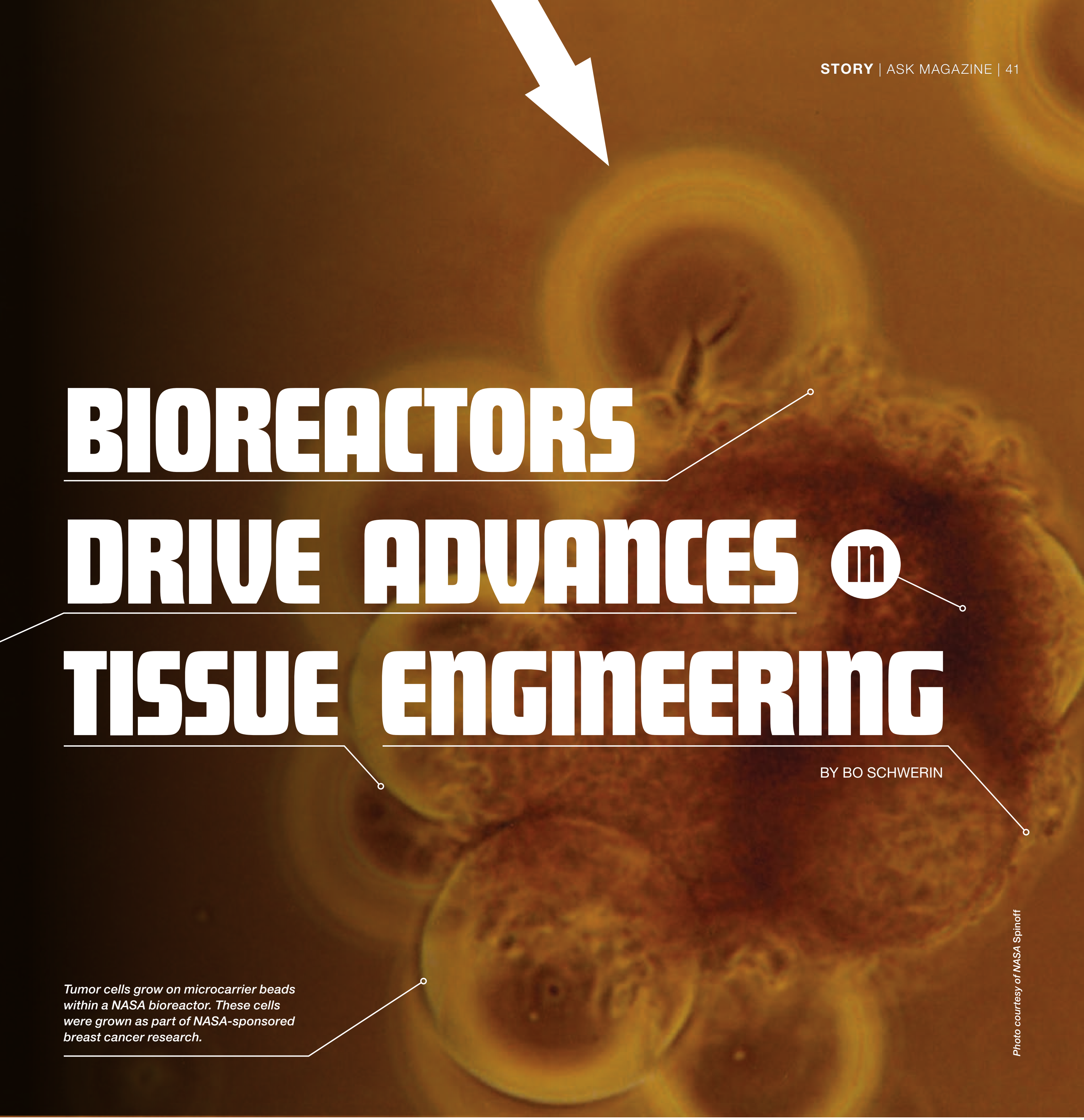
SUSANNE ARNDT works at the Technische Universität Braunschweig, Institute for Traffic Safety and Automation Engineering.



BIOREACTORS DRIVE ADVANCES IN TISSUE ENGINEERING

BY BO SCHWERIN

Tumor cells grow on microcarrier beads within a NASA bioreactor. These cells were grown as part of NASA-sponsored breast cancer research.

Photo courtesy of NASA Spinoff

It was an unlikely moment for inspiration. Engineers David Wolf and Ray Schwarz stopped by their lab around midday. Wolf, of Johnson Space Center, and Schwarz, with NASA contractor Krug Life Sciences (now Wyle Laboratories Inc.), were part of a team tasked with developing a unique technology with the potential to enhance medical research. But that wasn't the focus at the moment: the pair was rounding up colleagues interested in grabbing some lunch.

THE BIOREACTOR'S ROTATING WALL ELIMINATED THE PROBLEMATIC MECHANICAL FORCES THAT HAD DAMAGED PREVIOUS CELL CULTURES …

One of the lab's other Krug engineers, Tinh Trinh, was doing something that made Wolf forget about food. Trinh was toying with an electric drill. He had stuck the barrel of a syringe on the bit; it spun with a high-pitched whirr when he squeezed the drill's trigger.

At the time, a multidisciplinary team of engineers and biologists—including Wolf, Schwarz, Trinh, and project manager Charles D. Anderson, who formerly led the recovery of the Apollo capsules after splashdown and now worked for Krug—was pursuing the development of a technology called a bioreactor, a cylindrical device used to culture human cells. The team's immediate goal was to grow human kidney cells to produce erythropoietin, a hormone that regulates red blood-cell production and can be used to treat anemia. But there was a major barrier to the technology's success: moving the liquid growth media to keep it from stagnating resulted in turbulent conditions that damaged the delicate cells, causing them to quickly die.

The team was looking forward to testing the bioreactor in space, hoping the device would perform more effectively in microgravity. But on January 28, 1986, the Space Shuttle *Challenger* broke apart shortly after launch, killing its seven crewmembers. The subsequent grounding of the shuttle fleet had left researchers with no access to space, and thus no way to study the effects of microgravity on human cells.

As Wolf looked from Trinh's syringe-capped drill to where the bioreactor sat on a workbench, he suddenly saw a possible solution to both problems.

"It dawned on me that rotating the wall of the reactor would solve one of our fundamental fluid mechanical problems, specifically by removing the velocity gradient of the tissue-culture fluid media near the reactor's walls," said Wolf. "It looked as though it would allow us to suspend the growing cells within the reactor without introducing turbulent fluid mechanical conditions."

The three engineers skipped lunch. They quickly built a prototype from components lying around the lab and tested the bioreactor that night using hamster kidney cells (cheaper than their human counterparts). When the team returned in the morning, not much had changed; the cells were all dead. But after running chemical analyses, Wolf and his colleagues realized the cells had died from an altogether different reason than before: They had run out of nutrients because they grew too fast. The new bioreactor was, in a sense, too effective.

The bioreactor's rotating wall eliminated the problematic mechanical forces that had damaged previous cell cultures, creating a constant free-fall effect within the media and suspending the cells in a way very similar to microgravity. As the team discovered means of supplying nutrients and oxygen and removing waste at high enough rates to support the cell cultures, they noticed new structures forming within the bioreactor. While standard human-cell cultures grown in Petri dishes settle into flat layers thanks to gravity, the NASA bioreactor's microgravity mimicry produced very different results.

"These were three-dimensional structures that very accurately represented the way human tissue is structured in the body," said Wolf. The bioreactor performed even better in space, as was later demonstrated by Wolf himself as an astronaut onboard the STS-86 mission to the Mir space station.

"When I first put the space-grown tissue samples under the microscope, I was astounded. With many years of experience culturing tissues, I had never seen any so well organized and with such fine structure," Wolf said. It was another breakthrough moment, he said, similar to when the team first discovered the ability to assemble 3-D tissue on Earth using the simulated microgravity of the NASA bioreactor. Wolf, Schwarz, and Trinh won NASA "Inventor of the Year" honors for their innovation.

Partnership

In 1990, Anderson and Schwarz licensed patents for the rotating-wall bioreactor technology and founded Synthecon Inc. to commercialize the device.

"When they saw what the technology could do, they thought, 'Wow, we really have a better mousetrap,'" said Bill Anderson, Charles Anderson's son and current president of the company. Synthecon's founders saw great potential in the bioreactor not only as a powerful tool for growing healthy cell cultures, but also as an enabler for more effective drug development and production techniques and even entirely new fields of medicine.

Astronaut David Wolf performs maintenance on a NASA bioreactor unit onboard the Mir space station. Experiments conducted by Wolf demonstrated that the bioreactor produces even more effective cell-growth results in space.

Photo courtesy of NASA Spinoff

The problem was waiting for the rest of the medical industry to catch up, explained Anderson. Scientists were satisfied using flasks to culture cells, and drug companies were relying on the resulting two-dimensional cells, unlike any in the human body, to provide them with data for their pharmaceutical compounds.

"The technology was seven to eight years ahead of its time," Anderson said.

While Synthecon worked to demonstrate the potential of the rotating-wall bioreactor, it received significant support from NASA.

"We were fortunate in the early days that NASA saw the importance of the technology and formed a grant program around it," Anderson said. The agency funded researchers from schools like Harvard University and the Massachusetts Institute of Technology to test the device's value for what was then a burgeoning medical field—tissue engineering, seeding an artificial matrix with cells that grow into implantable human tissues. Synthecon provided the bioreactors for these studies, and the results—success growing different tissue types, as well as tumor models for testing cancer treatments outside the body—led to numerous published findings that added relevance to the technology.

"It really helped us stay alive when most small businesses don't get that benefit," said Anderson.

Benefits

Synthecon has since built a portfolio of patents based on the original NASA bioreactor and improved upon the original technology in a number of ways, creating models inexpensive enough to be disposable, as well as automated versions that can change the growth media without stopping the reactor's rotation. Now the company's NASA-developed rotary cell culture systems (RCCS)—an "R&D 100" award-winning technology—are key tools for medical research being conducted around the globe, and the company, bioreactor technology, and original NASA innovators were all inducted into the Space Technology Hall of Fame in 2011.

"It might have been ahead of its time, but our technology is really filling its shoes quickly," Anderson said.

Major pharmaceutical companies, Anderson explained, spend significant amounts of money on drug discovery and now want to test candidate compounds on RCCS-grown, 3-D cells to get a more accurate sense of a potential drug's effects. Synthecon is also scaling up the bioreactor technology for the production of recombinant proteins and antibodies. (Recombinant proteins are expressed from cells containing genetically modified DNA; this is the method used to create human insulin and the hepatitis B vaccine among other vaccinations and disease treatments.) The company has found that an RCCS can churn out multifold more product than standard systems because it treats cells so gently, meaning the cells expressing the proteins do not spend energy on repair, a major drain on their productivity. A 100-liter RCCS can thus generate the same output as a 1,000-liter standard system.

WE WERE FORTUNATE IN THE EARLY DAYS THAT NASA SAW THE IMPORTANCE OF THE TECHNOLOGY AND FORMED A GRANT PROGRAM AROUND IT …

Another developing area of medical research in which Synthecon's NASA technology promises to be a major contributor is regenerative medicine. Much has been made in recent years about the prospects of stem cells to treat conditions as varied as cancer, diabetes, and sickle cell anemia. (In simple terms, stem cells are special cells that can transform into other cell types, offering the potential to replace damaged or malfunctioning cells with healthy ones.) A major obstacle, however, is supply. Synthecon is currently engaged in studies using its RCCS devices to multiply stem cells from umbilical cord blood—a plentiful source without the ethical concerns raised by embryonic stem cells. Cord-blood transplants have already been demonstrated to treat leukemia and other cancers, Anderson said, and the RCCS offers the means to efficiently generate the amounts of healthy stem cells necessary for medical use.

"We think the bioreactor is going to provide a lot of benefit to a lot of patients moving forward," said Anderson. "The applications seem to grow every year."

"I think it is reasonable to say that the fields of regenerative medicine and molecular biology have evolved in the interim years to complement this technology," said Wolf, who says he is proud to see a technology conceived within the government make a successful transfer to the private sector. "We have a very powerful set of tools to make the next set of innovations and contributions to future medical science."

Wolf believes that the lunchtime epiphany that led to the development of the NASA bioreactor is indicative of how true innovation works.

"Innovation is an inherently messy process," he said. "It's based on the correct balance of sticking to the original plan but also being able to appropriately deviate and adapt to new information and discoveries. The future of NASA, our country, and world is depending on this process for ever more innovations for deep-space exploration and for improving life on Earth." ●

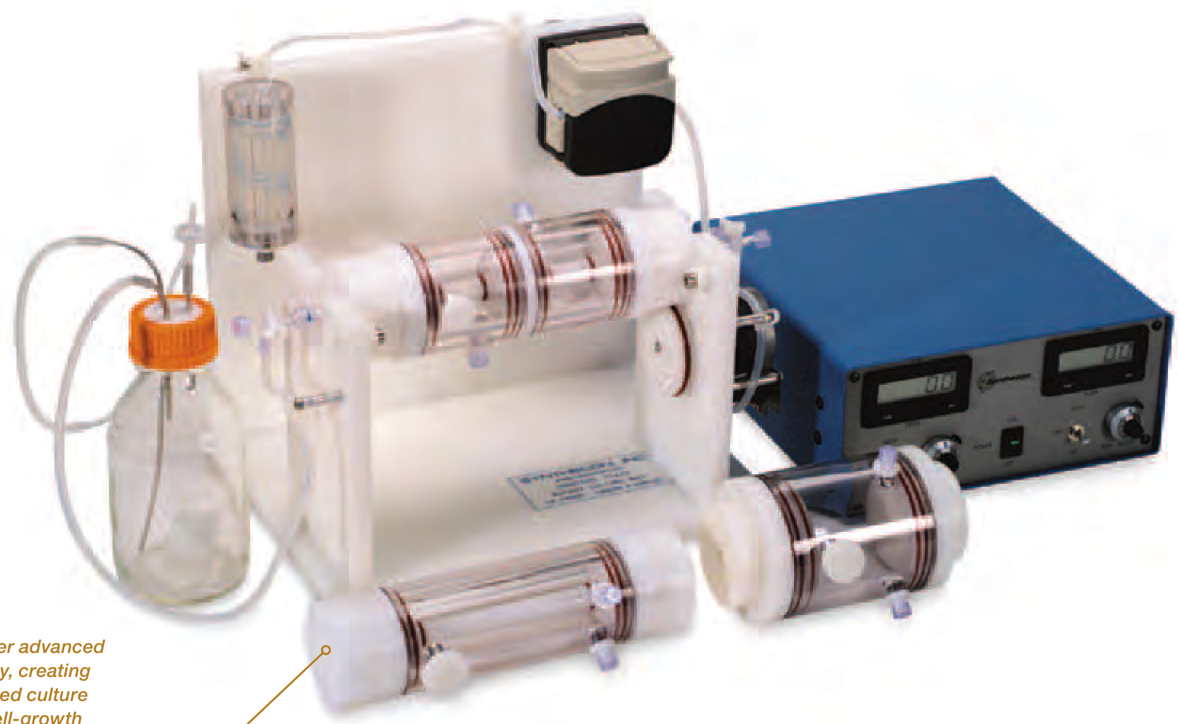


Photo courtesy of NASA Spinoff

Synthecon Inc. has further advanced the bioreactor technology, creating platforms like this perfused culture system that allows the cell-growth medium to be exchanged, sampled, or modified without stopping the bioreactor's rotation and potentially damaging the cells.

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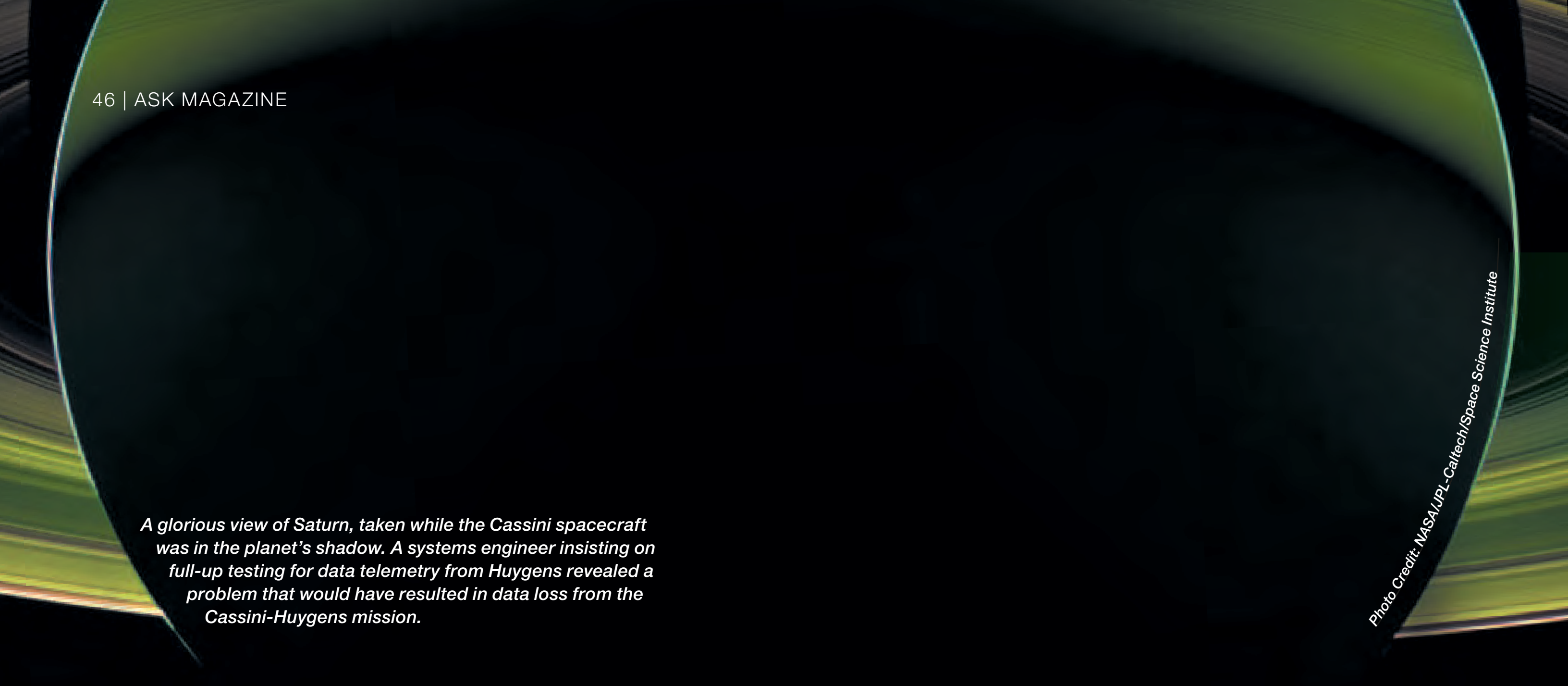
WHAT I'VE LEARNED FROM NASA

BY KERRY ELLIS

Seven years ago, I was hired as an editor for NASA's *ASK Magazine*. Being a rare English major–math minor hybrid and a generally curious sort who liked taking things apart to see how they worked, I was thrilled for the opportunity to get an inside look at NASA.

Robonaut 2 (R2) onboard the International Space Station. General Motors, NASA's partner in R2's development, plans to use the robot to test advanced vehicle safety systems and create safer manufacturing options. This is just one way NASA technology contributes to improved health and safety on Earth.

Photo Credit: NASA



A glorious view of Saturn, taken while the Cassini spacecraft was in the planet's shadow. A systems engineer insisting on full-up testing for data telemetry from Huygens revealed a problem that would have resulted in data loss from the Cassini-Huygens mission.

Photo Credit: NASA/JPL-Caltech/Space Science Institute

I was overwhelmed by how much I didn't know about our nation's aeronautics and space program. Thankfully, there were hundreds of scientists, project managers, and engineers who were as excited to teach me as I was to learn. (There are thousands more I've yet to meet.) And what I've learned is aeronautics and space exploration are hard, much harder than I'd imagined. In addition to that basic truth, I also learned there are important common lessons to be had from these one-of-a-kind missions.

Communication Matters

We've heard this countless times, but every story makes the point in a new way. The underlying message is the same—communicate openly and often!—but how it's delivered can change. I learned that the root cause of most mishaps, be they in hardware, software, or requirements, could be traced back to miscommunication or a lack of communication.

I learned this early with one of the first projects I wrote about for *ASK*: Genesis. Before Mike Ryschkewitsch became NASA's chief engineer, he was the deputy center director for Goddard Space Flight Center and spoke with me about the mission that unexpectedly crash landed upon reentry. He taught me why clear communication trumps heritage hardware in ensuring a mission flies as planned:

> "You can't just say, 'don't install g-switches upside down,' as a lesson learned from Genesis," said Ryschkewitsch …. "There was confusion around what testing needed to be done and what the tests meant. One part of the team understood that repackaging the [Genesis] electronics meant losing the 'heritage' from Stardust. Other parts never clearly understood that, and it was never clearly communicated between those teams." So when one team verified that the switches did what they were supposed to—which to them meant flipping from one orientation to another—another team thought full testing had been done, ensuring the switches flipped *and* made the correct connections.

Falsely assuming communication has occurred or understanding has been reached by all involved is a common problem. It's the reason behind another often-heard adage at NASA: "Trust, but verify." Though I first heard this repeated among systems engineers, it applies to all parts of a project. Everyone is working together to create a successful mission—which can be thought of as a system itself.

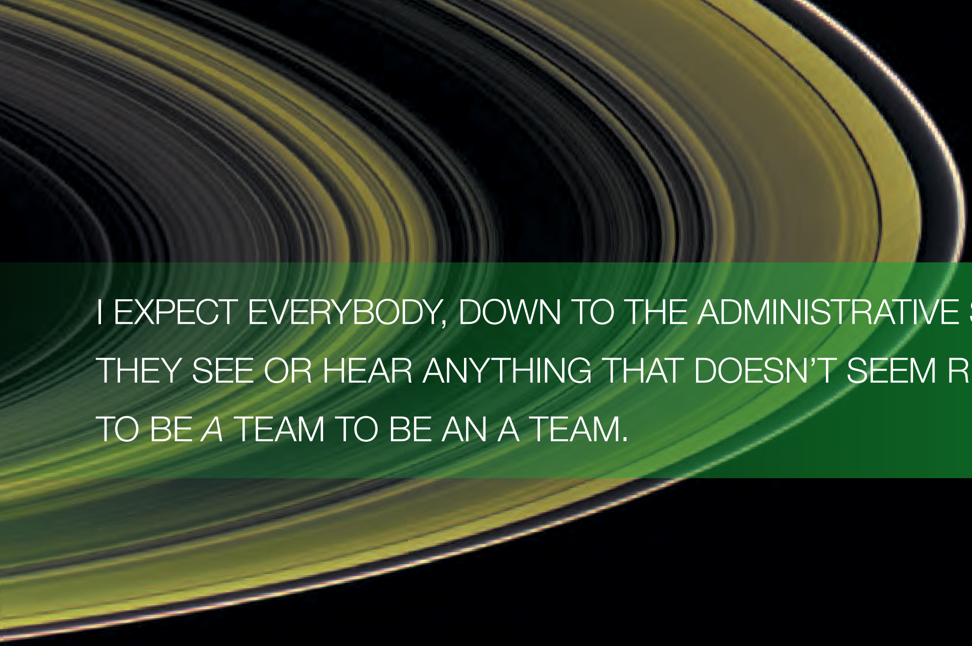
> "I remind everybody constantly that we are all systems engineers," explained [Bryan] Fafaul [from Goddard]. "I expect everybody, down to the administrative staff, to say something if they see or hear anything that doesn't seem right. Remember, you need to be *a* team to be an A team."

Resolving communication issues can help prevent larger, technical issues down the line. Speaking up can be difficult, but not doing so can result in disastrous mission failures.

The type of communication that occurs can also make a difference. While the consensus is to talk often, many agree that face-to-face conversations offer the most benefit, followed by teleconferences, then e-mail. Being able to see people's expressions and hear their voices helps eliminate uncertainty

Photo Credit: NASA

Close-up of the Genesis capsule shortly after return. Miscommunication resulted in misunderstanding about tests performed, which resulted in the capsule's crash landing after reentry.



I EXPECT EVERYBODY, DOWN TO THE ADMINISTRATIVE STAFF, TO SAY SOMETHING IF THEY SEE OR HEAR ANYTHING THAT DOESN'T SEEM RIGHT. REMEMBER, YOU NEED TO BE *A* TEAM TO BE AN A TEAM.

around meaning or motives. It also helps build the trust these collaborations require.

> Ed Rinderle, a Viking programmer, attributed some of Viking's success to the working environment: "We were all gathered in one big bullpen, an open area, no cubicles or partitions. You got to know each other on a different level than had we been separated."

> According to Mike Landis [former NextGen project manager], "Real estate agents talk about location, location, location. From a project manager's perspective, it's communicate, communicate, communicate. It's not just sending an e-mail out, it's sitting down with the line management and researchers, understanding their requirements, and ensuring they have the resources they need to execute our plan."

> "When we actually went to their [Roscosmos] cafeteria and were able to eat with them, sit down with them, that helped," added [Harold] Beeson [an expert on materials flammability in high-oxygen conditions from White Sands Test Facility]. "A meal is always a good thing to share."
>
> The working relationship among the team swiftly improved after that. [David] Urban [microgravity scientist from Glenn Research Center] explained, "We'd built a familiarity, they were relaxing, we had spent some time together and communicated during meetings."

Building trust through communication also relies on following through on commitments—exactly as agreed to. Doing things as stated—whether in conversation or written requirements—also contributes to mission assurance. It's why every piece of hardware and software goes through verification and validation. If you don't thoroughly communicate changes, everyone will operate under the assumptions of what was previously written or heard.

Test as You Fly, Fly as You Test

I first heard this mantra at one of the Academy of Program/Project and Engineering Leadership's Masters Forums, and since then I've heard it repeated often as a core lesson learned from many NASA missions. It seems obvious from the outside—test for the planned mission conditions and operations, then operate according to plan—but the thing about one-of-a-kind missions is the plan always involves the unexpected. (It's tough to plan for discoveries you haven't yet discovered.) And replicating conditions in orbit or deep space on Earth is never easy.

In one instance with Cassini, an engineer insisting on full testing revealed a flaw that would have resulted in data loss:

> The team asked the Goldstone Deep Space Network (DSN) station located near Barstow, California, to transmit a signal to Cassini that would simulate the signal coming from Huygens …. The team would then record the signal on board and play it back to Earth …. They originally proposed using only a carrier signal, but one of the ESA [European Space Agency] engineers, Boris Smeds, pushed to make it a full simulation with telemetry. … "Most people thought this was overkill, but we agreed to let him do it," [project manager Robert] Mitchell says. As it turned out, the carrier signal was received just fine, but the telemetry was not. If they had done no test, or just the carrier test, the team would have lost a significant amount of Huygens' data and would not have known about the problem until after the mission was completed.

We can never solve the problem of "we don't know what we don't know," but by acting on what we *do* know, and testing according to that knowledge, we may be able to oust some of those unknown unknowns before they become problems.

In the projects I've learned about, the factors that most often make or break a NASA mission are the quality of communication and the thoroughness of testing. Getting those two things right goes a long way toward ensuring the technical and operational success of any project.

But no NASA project exists in a vacuum. To compete successfully for scarce funding, missions must make a convincing case for their scientific and societal value, so another vital aspect of project success is stakeholder support. And the biggest stakeholder for NASA is the general public.

Reach Out for Support

Many project managers and systems engineers tout the benefits of networking when problem solving—reaching out to other experts to gain their expertise or insight. A different type of reaching out can have a greater impact in keeping a project going: public outreach. Support from the public, or from scientists wanting new data, can be a strong argument against project cancellation.

> "The reality is that every year you have to defend your program," [Dougal] Maclise [who worked on the solar-powered Pathfinder unmanned aerial vehicle] says. "The best way to keep a program alive is to get the user communities to say they need the data your program provides them. Thus it behooves you to spread your base of support far and wide."

The Environmental Research Aircraft and Sensor Technology program's Pathfinder project appealed to local farmers, children, and universities. Word eventually made its way back to NASA about everything the team was doing to support the local community.

> "Suddenly money that hadn't been available before appeared [from NASA], and this gave the project some extra lift, so to speak, making our attempts at another world-record-altitude flight an even more viable goal," [Jenny] Baer-Riedhart explains.

Getting the public, international partners, and scientists on board gives projects extra voices to fight for mission completion. It can also result in unexpected and beneficial collaborations beyond aeronautics or spaceflight, like when industries learn about new technology created for NASA projects and brainstorm new ways to use it.

Expanding Technology Innovation

One of the most important things I learned working for NASA, and something I think is often lost when the general public thinks about the agency, is how much of what NASA does affects our daily lives. The knowledge obtained by doing these missions does not stay locked inside the government. And I don't mean just the scientific knowledge we gain by studying Earth, other planets, and galaxies.

Because NASA is building one-of-a-kind missions, a lot of new technology gets invented along the way. That technology is reused and repurposed in thousands of ways. Better known as "spin-offs," these innovations are embedded in our local communities. What's surprising is how few people outside the agency realize this.

For example, working in space has allowed NASA engineers to help remote villages obtain clean water.

> "We're working in extreme environments in both cases," said [Dan] Garguilo [a systems engineer at Johnson Space Center]. "When you have to plan project implementation in the developing world, you have a finite amount of money and resources to do the project; it's almost like working in space. You have to plan everything out to the *n*th degree, account for all the tools you're going to need, know what materials are available for you. You have to work efficiently and take your environment into consideration. All these things are similar to when we're working on ISS [International Space Station] or other planetary missions."

Thanks to NASA spin-off technologies, doctors can help diagnose patients located thousands of miles away. Firefighters can put out fires faster. Farmers can remove harmful chemicals from soil. Ophthalmologists can diagnose diseases earlier and more accurately. NASA technology is also responsible for polished brass coating on plumbing fixtures, cordless handheld vacuums, UV blocking in sunglasses, shock-absorbing sports shoes, wireless headsets, and refrigerated display cases at grocery stores. And this is a very small sampling from thousands of examples. What we put in to NASA we get tenfold in return. (See NASA's annual *Spinoff* publication for more examples.)

More to Know

Perhaps the biggest lesson I've learned is no matter how much we know about aeronautics and space exploration today, there's always more to learn. Stories and experience from past and current missions are continuously captured and told to help today's missions and those who will innovate in the future. And every mission has multiple stories—different knowledge and perspectives from everyone who worked on them.

Sharing those stories and that knowledge is why I do what I do every day. Not just for the obvious value of getting that know-how circulating across centers, agencies, academia, and the world, but because I love learning and telling those stories.

What NASA does is amazing. I'm proud to be one small part of it. ●

Viewpoint: Attracting Tomorrow's Engineers

BY AMIR S. GOHARDANI AND OMID GOHARDANI

Dreams of flight have captured the human imagination for centuries. Children worldwide imagine dancing among the stars and soaring into the blue. Will their visions become reality? The dream of flight has motivated generations to experiment with the physical and scientific world, including those children who—against their parents' advice—stretch out their hands from the windows of cars in order to feel the air resistance against their palms. In the early phases of our careers in education, we saw the dreams of flight among the majority of high-school students. Younger generations are always interested in aviation and space sciences. We were asked similar types of questions whether we gave an aviation/aerospace lecture in a school in Tucson, Arizona; Gainesville, Florida; Stockholm, Sweden; or London, England. For many, though, the dream of working in aeronautical and aerospace engineering slowly evaporates and is lost.

Are there underlying reasons for these losses and, if so, how is it possible to avoid them? The answers to these questions are contingent upon two crucial elements: education and research.

Aeronautical/Aerospace Engineering Education

Today, the average aerospace engineering student has a much more comprehensive curriculum than students of only a few decades ago. A combination of novel experimental techniques, more sophisticated computational models, and an overall greater wealth of knowledge provide today's students with a refined tool set to tackle future engineering challenges.

But a basic element of the discipline—lessons to develop mathematical and computational skills—has a negative impact on many, usually during the early undergraduate years. Fear of these subjects is common; the task of overcoming it is so arduous that a notable number of students choose to abandon their aeronautical/aerospace engineering dreams entirely.

Certainly, there should be no compromise regarding the requirements for acquiring essential knowledge and skills. But one of the challenges the educator faces is how to keep students interested even when the heavy clouds of mathematics and sciences blur the view of their goals.

We believe that modern educational approaches such as learner-centered teaching practices can help retain student interest in aeronautical/aerospace engineering. Educators can enhance or abandon traditional lectures by incorporating new interactive tools in their teaching—tools that range from podcasts and audio clips to posters and animations, as well as hands-on experience. For instance, aircraft stall can be taught theoretically as the separation of the airflow from a wing section and a follow-up discussion on the consequence of lift loss. Or it can be experimentally verified in a wind-tunnel setting using smoke visualization and instrumentation to record lift reduction and augmentation. Actually watching a wing section drop is understood more easily and remembered better by students than its theoretical counterpart.

Such additional routes to learning engage the students with these topics without the discouraging fear created by theoretical complexity and abstraction. This step is vital to maintaining a diverse student body capable of meeting the needs of future aeronautical/aerospace sectors.

The Lure of Research

NASA's involvement in various programs for children and young adults and other community-outreach endeavors inspire many youngsters in the United States and other parts of the world.

The bridge between academic studies and research is a golden one for career involvement and advancement. If educators worldwide help students envision the structure of this bridge before its final construction, they have already contributed to a source of inspiration for further progress. Young individuals can be inspired by aeronautical/aerospace research, but they are not drawn to the successful efforts in aeronautics and space exploration as much as they should be. For some students, exposure to research efforts, environments, and outcomes has been marginal at best. Our teaching experiences indicate that giving children the chance to observe aeronautical/aerospace research at early ages means they will tend to follow these subjects more frequently and actively. We see improvements in this regard, but additional efforts would contribute to tomorrow's aeronautical/aerospace workforce.

EDUCATORS CAN ENHANCE OR ABANDON TRADITIONAL LECTURES BY INCORPORATING NEW INTERACTIVE TOOLS IN THEIR TEACHING …

New Skills for Global Projects

Our collective collaborations with NASA, the European Space Agency (ESA), and the European Commission's FP7 program have shown that aeronautical/aerospace research has never been as global as it is now. Project and program management in such an environment requires a new set of approaches that includes personal development and visionary thinking and a variety of skills other than technical expertise. Multilingual skills and insight into cultural differences have a more pronounced role than ever before. Given the dynamic nature of the aeronautical/aerospace industry, unforeseen events such as budget cuts or limited manpower add complexity to the overall implemented management and time management practices. So it is important to attract students whose skills and interests go beyond science and engineering.

The experiences of one of us with a multinational European Commission FP7 program shows that collaboration across borders makes cultural awareness, leadership qualities, communication, and language skills essential. The other author has been involved with the Solar Orbiter mission, in which NASA and ESA jointly aim to address the central question of heliophysics: How does the sun create and influence the heliosphere? The skills needed by the leaders of this project stretch far beyond technical skills.

The success of such projects in the future will depend on the willingness of younger generations to engage with the engineering discipline. Ensuring a bright future for aeronautical/aerospace engineering rests in the decisions made by government entities, policymakers, educational and research institutions, and, perhaps most importantly, by all the individuals who interact with the young men and women who will be the future of aeronautical/aerospace engineering. ●

AMIR S. GOHARDANI is editor-in-chief of the *International Journal of Aerospace Sciences*. In 2012 he joined OHB-Sweden (formerly Swedish Space Corporation Space Systems Division) as a propulsion-procurement manager. Dr. Gohardani graduated with an MS in mechanical engineering from the University of Arizona in addition to an MS in aeronautical engineering and a BS in vehicle engineering from the Royal Institute of Technology, Sweden.

OMID GOHARDANI is an executive editor of the *Journal of Aeronautics and Aerospace Engineering*. Following an MP in aerospace engineering from Cranfield University, United Kingdom, he graduated with a PhD in aerospace engineering from the same institution, where he served as a senior project manager for a collaborative project in aeronautics sponsored by the European Union.

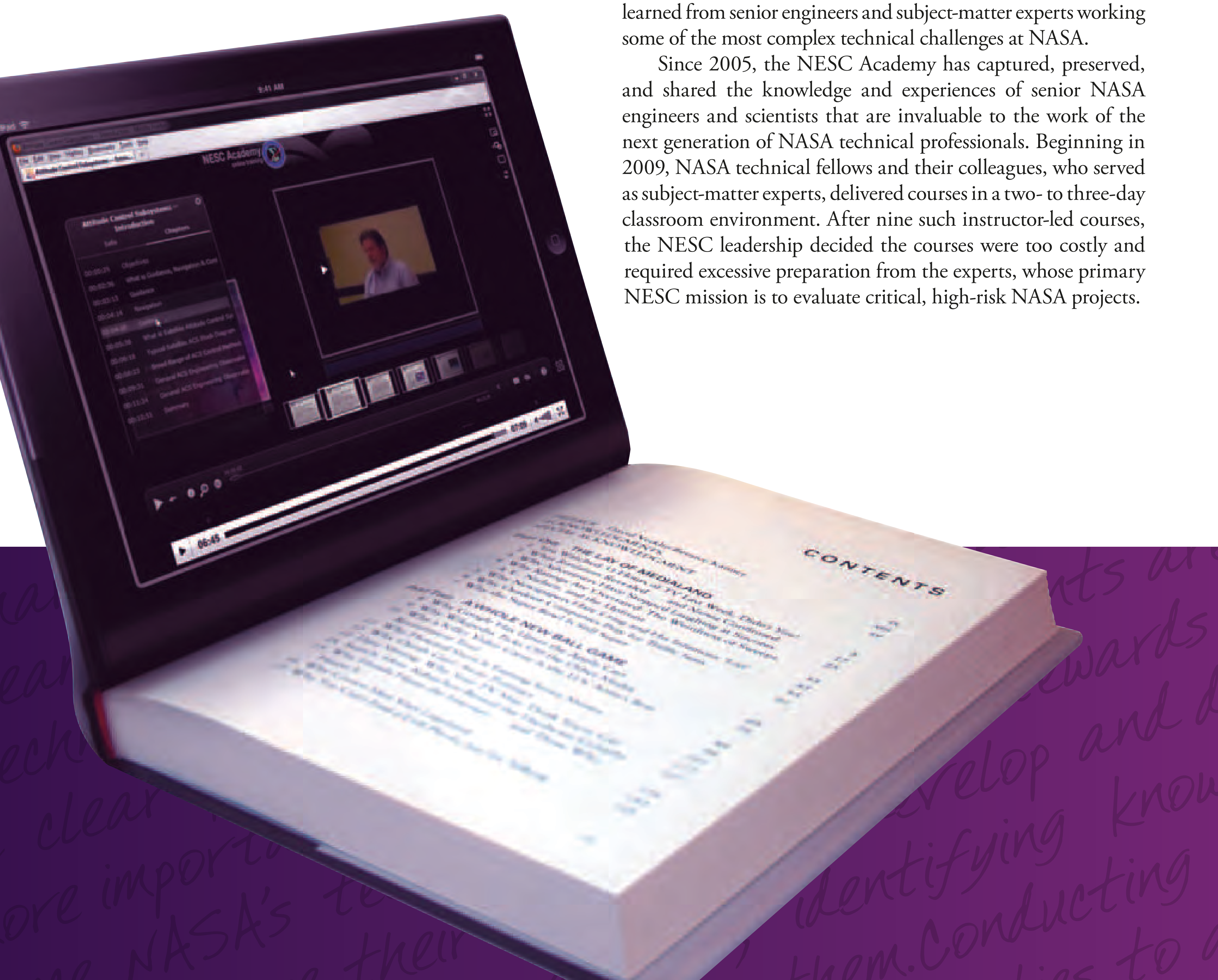
The NESC Academy: Expertise for Tomorrow's Engineers

BY PATRICIA PAHLAVANI

"The only source of knowledge is experience."
— Albert Einstein

The NASA Engineering and Safety Center (NESC) recently implemented the new NESC Academy (nescacademy.nasa.gov), an innovative online academy documenting hundreds of lessons learned from senior engineers and subject-matter experts working some of the most complex technical challenges at NASA.

Since 2005, the NESC Academy has captured, preserved, and shared the knowledge and experiences of senior NASA engineers and scientists that are invaluable to the work of the next generation of NASA technical professionals. Beginning in 2009, NASA technical fellows and their colleagues, who served as subject-matter experts, delivered courses in a two- to three-day classroom environment. After nine such instructor-led courses, the NESC leadership decided the courses were too costly and required excessive preparation from the experts, whose primary NESC mission is to evaluate critical, high-risk NASA projects.



[TECHNICAL FELLOWS] GET IMMENSE SATISFACTION KNOWING THEY ARE PRESERVING TECHNICAL KNOWLEDGE THAT REMAINS VIABLE AND ACCESSIBLE TO THE CURRENT AND FUTURE COMMUNITY OF NASA PROFESSIONALS.

In 2010, the NESC began reviewing and benchmarking modern capture and delivery mechanisms with the goal of reinventing the Academy while reducing costs and lessening the demands on experts' time. The NESC's systems and communications team was given the challenge. The team used the Khan Academy, started by Salman Khan, as a model.[1] The Khan Academy began as short, online courses in science, technology, engineering, and math to tutor remote family members. It has since grown to more than 3,500 micro-lectures, with over 190 million views. The NESC team benchmarked products that could facilitate the effective capture and delivery of the NESC online lessons. The team also collaborated with the NASA Safety Center, which uses Mediasite to capture and stream content to the Internet.

Because NESC's experts are spread across the country, capturing content from remote locations, including a user's desktop, was a challenge. Initially, a "training toolbox" was physically sent to the expert's location. It contained all the software and hardware necessary to record a lesson. A simple PowerPoint plug-in and new server software (Camtasia Relay), which enables lessons capture directly from the user's desktop and transfers the data remotely to the NESC servers, replaced the toolbox. This technology enables remote video capture without requiring travel, complicated data file transfers, and extensive upfront preparation.

Once the NESC's servers receive the video lessons, they are processed using an eleven-step method that includes editing, course-material insertion, export-control review, and closed captioning. To track the processing, the NESC Academy team uses a tool called TrackVia, an online, cloud-based tool configured to monitor progression. It provides workflow, tracking, dashboards, and processing support for all video production.

In 2011, the NESC began collaborating with the NASA Engineering Network (NEN), also within the Office of the Chief Engineer, to provide live, online webcasts. Using Academy hardware, these webcasts give NASA technical fellows and their colleagues the ability to present material remotely to large audiences in real time. Webcasting allows the presenter, moderator, and producer to reside in different locations. Live webcasts are recorded for later viewing. All upcoming and recorded webcasts are available from the NESC Academy web site at nescacademy.nasa.gov/#features=2. To date, the NESC has captured more than 200 videos, with 123 published, that document work across thirteen technical disciplines online. The new online NESC Academy officially launched on September 8, 2012, and has had more than three thousand viewings to date.

The NASA technical fellows are passionate about sharing technical knowledge. They and their discipline teams solve some of the most varied and difficult technical problems at NASA. This experience gives them a clear picture of where their discipline excels and, more importantly, where critical investments are required to advance NASA's technical capability. As stewards of their disciplines, they use their experience to develop and document a state-of-the-discipline assessment, identifying knowledge gaps and proposing strategies to fill them. Conducting reviews and assessments daily, they look for opportunities to address these shortcomings and capture knowledge and experience that might otherwise be lost or forgotten.

At a technical interchange meeting sponsored by the aerosciences technical discipline team, for example, the NESC recognized that there was a wealth of NASA knowledge and experience in the aerosciences discipline of significant benefit to both the commercial crew partners developing the next spacecraft servicing low-Earth orbit and the NASA team tasked with the evaluation and selection of these concepts. The meeting was designed as a series of case studies and briefings outlining flight-development projects, including the shuttle orbiter, HyperX/X-43A, X-38, Ares, Ares I-X, and Orion. Presentations focused on the aerosciences philosophy, strategies, techniques, experiences, and lessons learned in predicting aerodynamic performance, constructing aerodynamic databases, predicting flight environments, and managing uncertainty. Participants included the NESC, Langley Research Center, Johnson Space Center, Ames Research Center, Marshall Space Flight Center, commercial crew partners, the NASA Commercial Crew and Cargo Program Office, and other industry and agency guests.

All the case studies and lectures were recorded. The content is now being placed on the NESC Academy web site.

Since the technical fellows' technical discipline teams consist of experts from all NASA centers, along with other government agencies, industry, and academia, members live and work all across the country. Each team assembles in annual face-to-face meetings to share experiences, strategize discipline advancement, and network. In 2011, at a joint meeting of the aerosciences, flight mechanics, and guidance, navigation, and controls teams, a member with extensive experience in the development of Gemini, Apollo, and the shuttle orbiter gave a presentation entitled "Lessons Learned on Previous Manned Spaceflight Programs That Seem to Have Been Forgotten." While that original presentation was not recorded, an encore presentation to the broader NESC a few months later was captured on video and is available on the NESC Academy site. This is a good example of how engineering knowledge and experience is captured by the technical fellows, in near real time, and preserved by the Academy.

The NASA technical fellow community has enthusiastically embraced the new, user-friendly methodology. They get immense satisfaction knowing they are preserving technical knowledge that remains viable and accessible to the current and future community of NASA professionals. Technical fellows and their discipline teams determine the courses to capture and make available on their NESC Academy catalog. The disciplines and other webcast presenters also suggest future topics.

Classroom courses previously videotaped are now being converted to the new NESC Academy online format, the results streamlined and improved by applying additional editing and cleanup. The content is now more accessible to users than in the past, as there are no prerequisite reading requirements. Of course, in an exclusively online format, the hands-on aspects of viewing hardware and models in the classroom and the back-and-forth dialogue and networking with colleagues and senior professionals are lost. To compensate, all webcasts offer a question-and-answer period at the end of each session. The subject-matter experts answer questions and address issues that were either not addressed or needed clarification. All questions and answers are retained as part of the webcast and are available on the NESC Academy web site and to the communities of practice on the NEN.

An exciting new development is the rebroadcasting of a webcast within university settings, followed by the subject-matter expert connecting to the classroom via Skype to address students' questions live. The NESC team may explore more possibilities of this kind to increase the level of interaction. Currently, the NEN communities of practice serve as the avenue for interacting with other technical professionals and providing feedback on webcasts and other content so that continuous improvement becomes a part of the process.

Amadou Hampâté Bâ, an African ethnologist, famously stated, "… when an elder dies, it's a library burning." With the new approach to capturing and delivering content, the NESC is attempting to preserve NASA's "technical library." In short, there is more to acquiring knowledge than what is in textbooks; knowledge also develops from lived experience, and veteran NASA experts possess decades of knowledge and experience that is invaluable to the aerospace community.

While the NESC Academy has changed, the core mission remains the same: to help senior NASA scientists and research engineers pass on critical technical expertise and problem-resolution skills to the younger workforce to support continuing and future mission success. ●

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1. www.khanacademy.org.

The Knowledge Notebook

Saying the F Word

BY LAURENCE PRUSAK

I'd like to talk about an F word that is probably heard less in most organizations than that other F word—the one you thought I meant. The F word I have in mind is "failure."

I'm sure I needn't belabor the point that most private and public organizations rarely admit their failures. (NASA is of course an exception to this rule. Its failures tend to be front-page news and are endlessly discussed and analyzed inside and outside the agency.) But failure is slowly being recognized as a valuable subject. One can learn a lot from the failure of projects, technologies, states, and virtually any other human endeavor.

There is now a movement within the world of philanthropy and non-governmental organizations to begin to discuss failed activities openly. It is called FAILFaire. Its distinctive punning name is of course deliberate. FAILFaire is all about being fair-minded when talking about things that do not go as planned. It recently held its third annual meeting in Washington, D.C. Representatives of several organizations stood up and discussed in detail projects that went wrong for systemic reasons—not as a result of simple human errors but because of faulty ideas about how things would work.

The meeting was held this year at the World Bank; several people I work with at the World Bank attended. It has been written up in the *New York Times* and on the web. It is also reported that the Bank is having its own internal FAILFaire meeting soon under the transparency initiative the Bank is committed to.

Can you imagine such a meeting being held at the end of a war? Did Japan or Germany do this in any public or private way? Did the United States look closely and openly at what happened in Vietnam? Or, to take a less contentious issue, did any major financial firm try to look carefully at what happened in 2008? What about internal examination of a disastrous merger like that of Time Warner and AOL?

What can one learn from failure? If done with a modicum of sensitivity and good will, discussions of failure are worth their weight in acquired wisdom and improved judgment. As a result of extensive, frank analysis of the *Challenger* and *Columbia* disasters, NASA has developed processes and cultural norms that support greater openness and safety consciousness. But how many other such examples can we name? And if failures are not admitted and discussed, they are likely to happen over and over again.

So what stops this most valuable activity from happening in most organizations? Surely the blame game is at or near the top of the list. In spite of protestations to the contrary, discussing failure is not possible in many organizations because "failure is not an option" and the individuals blamed for the failures that inevitably occur are punished. In those rare cases when failure is discussed, it is usually seen as idiosyncratic and individual, so little learning takes place.

Another reason—perhaps a more valid one—is what philosophers call "causal ambiguity." It is hard to understand the causes of a failure in a complex organization—or even in such a small theater of activity as one's own mind. A story told about the great Elizabethan adventurer Sir Walter Raleigh illustrates this point.

When he was imprisoned in the Tower of London in the early 1600s, Raleigh decided to write a history of the world. Staring out of his prison cell one day, thinking about how to proceed, he saw a man being killed right under his window. Raleigh was appalled. He asked his valets and other servants to find out what had happened. His men were never able to get to the bottom of the crime. That discouraged him from writing his history: if he couldn't even understand what had happened under his own window, how could he possibly understand what happened hundreds of years ago?

Yet a third reason for not discussing failure is fear of putting off donors, patrons, clients, investors, congress people, and anyone else whose support one needs to carry on the work. It is hard to put a good spin on a failure that has potential and real liabilities for stakeholders (even though looking at the failure would ultimately benefit them, too).

Overcoming these barriers to open examination of failure is important because of all we can gain by encouraging such transparency in our working and social and political lives. That is often the only way we can learn things that are not taught or often even considered in our rushed day-to-day lives, and sometimes the only or the best way organizational truth can grow. I think the movement toward transparency and learning from failure is one of the more remarkable trends in recent years. It should be applauded and encouraged. Two cheers for failure! ●

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ASK interactive

NASA in the News

NASA's Nuclear Spectroscopic Telescope Array, or NuSTAR, caught the glow of two black holes lurking inside spiral galaxy IC342, which lies 7 million light-years away in the constellation Camelopardalis (the Giraffe). Previous observations of this galaxy from the Chandra X-ray Observatory revealed the presence of these black holes, called ultraluminous X-ray sources (ULXs).

How ULXs can shine so brilliantly is an ongoing mystery in astronomy. "High-energy X-rays hold a key to unlocking the mystery surrounding these objects," said Fiona Harrison, NuSTAR principal investigator. "Whether they are massive black holes, or there is new physics in how they feed, the answer is going to be fascinating."

Read more about the new image and what it reveals at www.nasa.gov/mission_pages/nustar/news/nustar20130107.html.

International Space Apps Challenge 2013

After a successful event in 2012 that resulted in dozens of innovative solutions, the International Space Apps Challenge is gearing up for its second event April 20–21, 2013. The International Space Apps Challenge is a two-day technology development event during which citizens from around the world work together to address current challenges relevant to both space exploration and social need. To learn more about the event, and register to participate, visit spaceappschallenge.org.

This Year @ NASA: 2012

NASA takes a look back on the many accomplishments of 2012 in an interactive feature showcasing images, articles, and video from the year. Experience again the "seven minutes of terror" when the Curiosity rover landed on Mars, the Space Shuttle's retirement, advancements in commercial space partnerships, new scientific discoveries, and more at www.nasa.gov/externalflash/YIR12. Also watch as those behind these achievements reflect on them and what it took to succeed: www.nasa.gov/multimedia/videogallery/index.html?media_id=157200021.

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