National Aeronautics and Space Administration

Academy Sharing Knowledge

ask

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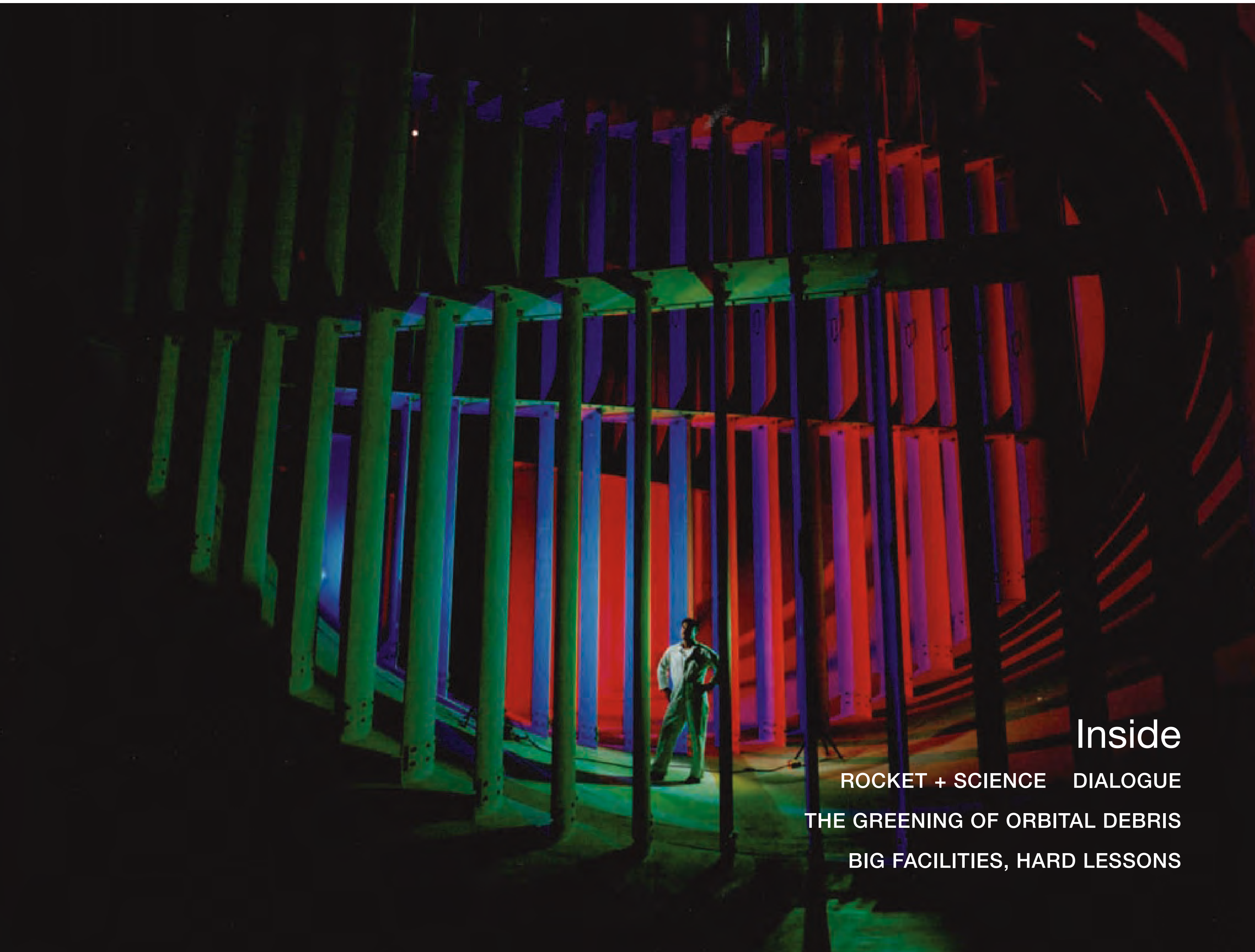

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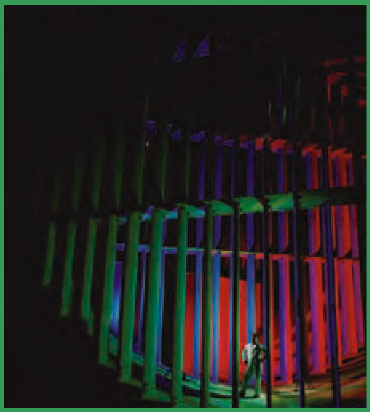

Photo Credit: NASA

ON THE COVER

Turning vanes inside the racetrack bend of the rebuilt 12-Foot Pressure Wind Tunnel at Ames Research Center.

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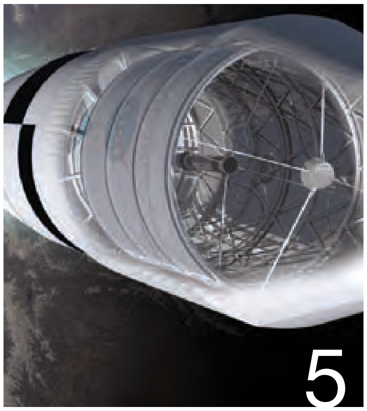

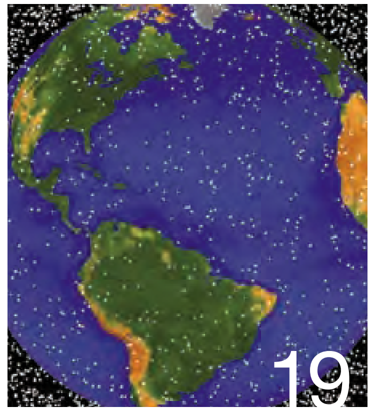

ask

Issue No. 37

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*.

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In This Issue

In his Knowledge Notebook piece ("How Organizations Learn Anything"), Laurence Prusak says that most effective learning comes from hands-on experience combined with reflection on that experience. He notes that many organizations give short shrift to the reflection part. Pressure to move on to the next assignment and distrust of the "soft tools" used to think about work (for instance, conversation and storytelling) stand in the way.

NASA is certainly not exempt from the demands of tight schedules and too much work, but it finds and makes many opportunities for reflection and the kind of experience-plus-reflection learning Prusak talks about. Johnny Kwok's description of the Jet Propulsion Laboratory's Phaeton program ("Phaeton: Learning by Doing") is a good example. The program gives early-career hires the experience of planning and carrying out small payload projects; mentors and milestone reviews guide their reflection on that work. Bowie State University's Satellite Operations and Control Center ("Classes and Spacecraft Operations") similarly combines hands-on work, teaching, and mentoring to prepare students for jobs as NASA employees and contractors.

Karen McNamara views NASA's commitment to learning from another angle, arguing that the agency needs an Office for Planned Learning to identify knowledge opportunities at the start of projects and give them financial support.

Michael Ospring looks at what he has learned from thirty years of project experience in "Big Facilities, Hard Lessons." In his case, too, the thoughtful advice of more-experienced project leaders helped develop his skill and understanding; he is now in a position to pass on what he knows. Ospring suggests that the things that go wrong are especially powerful spurs to thought and learning. That has certainly been true for NASA as a whole, the *Columbia* tragedy being the most recent driver of reflection and reform. In "Still Learning from *Columbia*," Matt Melis details some of the hard work of the team that analyzed the impact of foam on the leading edge of the shuttle's left wing and the continuing value of both their findings and their multicenter collaboration. Nicholas Johnson's "The Greening of Orbital Debris" tells the story of international cooperation and ingenuity applied to the problem of the millions of pieces of space-age refuse that pose a danger to orbiting satellites and spacecraft.

Two articles in this issue of *ASK* are about learning from people outside your own area of expertise. "Rocket + Science = Dialogue" considers the fruitful results of conversations among engineers, designers, and scientists about potential science payloads of the Ares V. And Brook Manville discusses what organizations can learn from recent innovative approaches to solving social problems.

Any learning that does not come from direct experience depends on good communication. In this issue's interview, Rob Strain and Lesa Roe discuss the essential role that open and extensive conversation plays in successful partnerships between their centers. Jean Engle and Brent Fontenot ("Sharing What We Know") describe knowledge management work at Johnson Space Center that includes storytelling as a way to share fifty years of human spaceflight knowledge. And the success of the Flight Readiness Review process ("Getting to 'Yes'") depends absolutely on full and open communication among those deciding whether a mission is safe to fly.

Don Cohen
Managing Editor

From the APPEL Director

The Shuttle: Image of an Organization

BY ED HOFFMAN

The shuttle has been the dominant image of an entire generation of human spaceflight, shaping NASA's missions, organization, and self-image for nearly thirty years.

When I came to NASA in 1983, missions couldn't get to space without the shuttle; everything had to fly on it. To make the most of its reusability, the agency discontinued support for expendable launch vehicles. The shuttle set the technical requirements for everything NASA launched into space. Its payload bay and orbit bounded the designs of a generation of spacecraft. It transported communications and science satellites and Department of Defense payloads to space. It enabled on-orbit servicing of modular spacecraft, most notably the Hubble Space Telescope. It defined the parameters for the construction of the International Space Station.

The shuttle's failures changed us. The *Challenger* accident forced us to ask hard questions about who we had become and confront behaviors like the "normalization of deviance," identified by sociologist Diane Vaughn. We recognized the risk posed by our dependence on the shuttle as the nation's only launch vehicle. Missions designed for shuttle launch, such as the Cosmic Background Explorer, had to find alternate routes to space.

NASA made changes in roles, responsibilities, processes, and procedures, and the failure affected the organization in myriad indirect ways. To take one small, personal example, Deputy Administrator J.R. Thompson's initiative to strengthen the agency's project management capability led to my work with the Program/Project Management Institute, a fledgling project management training program. Today's Academy of Program/Project and Engineering Leadership is a descendant of the agency's response to *Challenger*.

After *Columbia*, we again redefined roles and responsibilities, and set up new lines of authority to ensure that dissenting opinions would be heard. We also redoubled our efforts to make better use of lessons learned and best practices.

Attending an STS-119 Flight Readiness Review last year, I saw a process that was thorough, inclusive, and respectful. Among the participants I spoke with after senior leaders decided not to fly until a technical problem was more fully understood, there was disappointment about the short-term outcome, but also a sense that the process had worked well. The entire shuttle community learned from the rigorous investigation that had taken place.

Perhaps the highlight of my career to date was receiving a Space Flight Awareness Award, which included the opportunity to see a shuttle launch. It remains one of the most moving experiences of my life. There is no greater motivator than the awe-inspiring sight of a shuttle launch coupled with the knowledge that it represents the cumulative efforts of thousands of individuals working millions of hours.

We are now preparing to imagine NASA without the shuttle. What will shape our missions, our organization, and our self-image next? The answer will depend on the challenges that define the agency's vision and mission. When President Kennedy challenged NASA to send a man to the moon and bring him home by the end of the decade, he said that goal would "serve to organize and measure the best of our energies and skills." The next phase of human space exploration will also demand the best of our energies and skills.

Whatever we do next, it will be grand. ●

Image Credit: NASA

Artist's concept of the Ares V heading into orbit with a see-through image of an 8-meter monolithic telescope beneath the payload shroud.

Rocket + Science = Dialogue

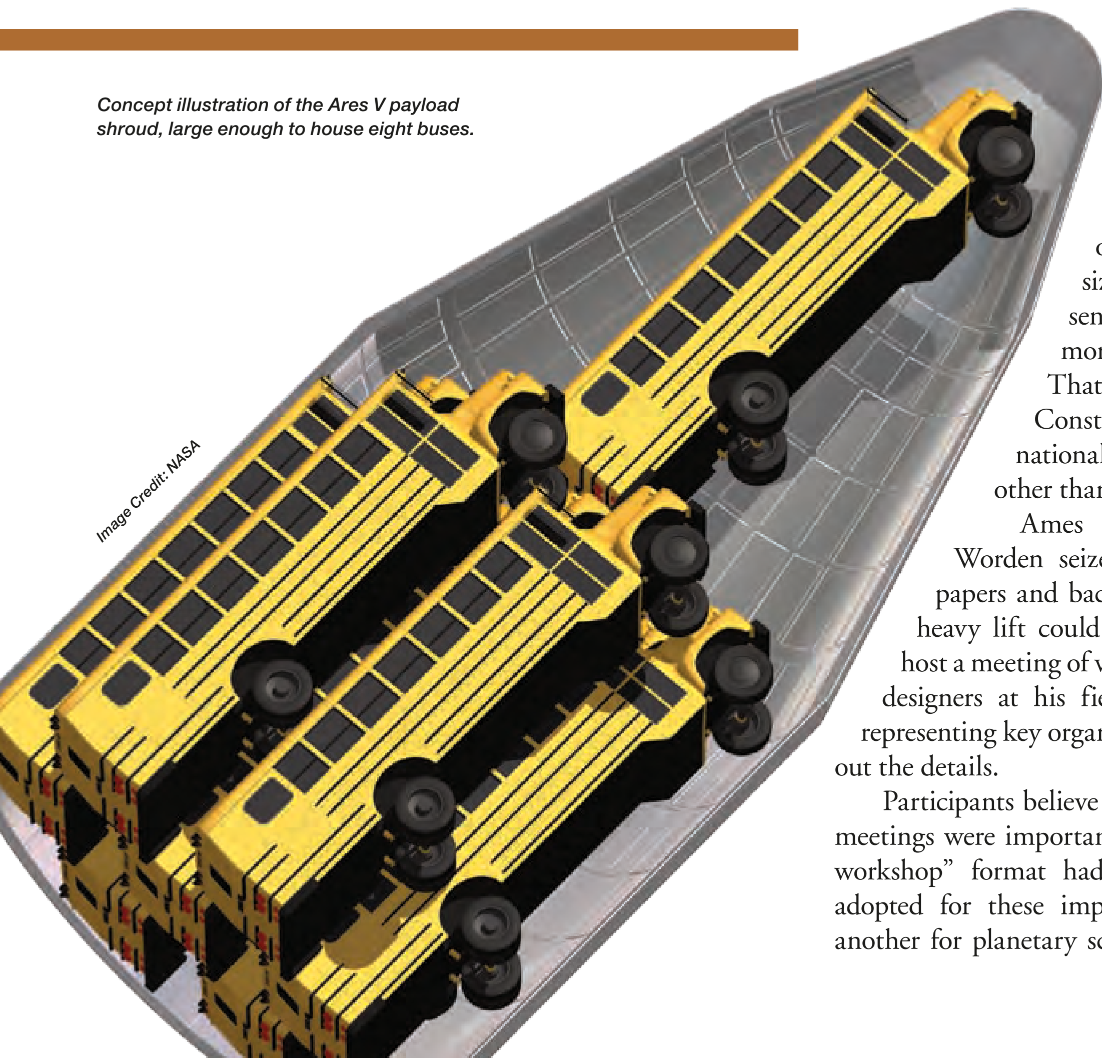
BY BRUCE MORRIS, GREG SULLIVAN, AND MARTIN BURKEY

It's a cliché that rocket engineers and space scientists don't see eye to eye. That goes double for rocket engineers working on human spaceflight and scientists working on space telescopes and planetary probes. They work fundamentally different problems but often feel that they are competing for the same pot of money. Put the two groups together for a weekend, and the results could be unscientific or perhaps combustible.

Fortunately, that wasn't the case when NASA put heavy-lift launch-vehicle designers together with astronomers and planetary scientists for two weekend workshops in 2008. The goal was to bring the top people from both groups together to see how the mass and volume capabilities of NASA's Ares V heavy-lift launch vehicle could benefit the science community.

Ares V is part of NASA's Constellation program for resuming human exploration beyond low-Earth orbit, starting with missions to the moon. In the current mission scenario, Ares V launches a lunar lander into Earth orbit. A smaller Ares I rocket launches the Orion crew vehicle with up to four astronauts. Orion docks with the lander attached to the Ares V Earth-departure stage. The stage fires its engine to send the mated spacecraft to the moon.

Standing 360 ft. high and weighing 7.4 million lbs., NASA's new heavy lifter will be bigger than the 1960s-era Saturn V. It can launch almost 60 percent more payload to translunar insertion together with the Ares I and 35 percent more mass to low-Earth orbit than the Saturn V. This super-sized capability is, in short, designed to send more people to more places to do more things than the six Apollo missions. That kind of heavy-lift capability, the Constellation program believes, would be a national asset potentially useful to endeavors other than human spaceflight.



Concept illustration of the Ares V payload shroud, large enough to house eight buses.

Ames Research Center Director Dr. Pete Worden seized on ideas presented in some early papers and background discussions, recognized what heavy lift could mean to science, and volunteered to host a meeting of vehicle engineers, scientists, and payload designers at his field center. An organizing committee representing key organizations and players was set up to work out the details.

Participants believe that both the venue and format of the meetings were important to their success. Worden's "weekend workshop" format had already proved successful and was adopted for these important summits: one for astronomy, another for planetary science. Scheduling a weekend meeting

The Ares V lifts off in this artist's illustration.

was probably the only way to quickly bring together busy key managers and scientists whose calendars are always full. And it guaranteed the commitment of attendees. "As Pete likes to say, only serious people come to a weekend workshop," said Dr. Stephanie Langhoff, Ames chief scientist and head of the organizing committee for both workshops.

Meeting of the Minds

The first workshop, April 26–27, 2008, was devoted to astronomy. Ares V designers from the Marshall Space Flight Center spoke first on Saturday morning, giving an overview of the Constellation program and a detailed look at the Ares V and its capabilities. Astronomers followed in the afternoon, presenting eight concepts for observatories to study the universe in several regions of the electromagnetic spectrum. After a full day Saturday that ran into the early evening, the discussion continued unofficially at a nearby restaurant. Sunday was devoted to breakout sessions to determine what breakthrough astronomy might be enabled by Ares V and what kind of payload environments developers would need from Ares V.

The exchange was uniformly congenial, perhaps partly because the stakes were not very high. Ares V was early in its concept-definition phase. The science community was making no commitment to a launch vehicle; it was merely invited to discuss the possibilities for a heavy-lift launcher.

"It's easy to be agreeable and collegial because there's no real money being spent," mused Harley Thronson, associate director for Advanced Concepts and Planning at Goddard Space Flight Center. "And astronomers recognize astronomy is a small field. We cannot be a significant player in how launch vehicles are designed. The commercial and military interests are much more important to determine how launch vehicles are built. Astronomy has to be opportunistic."

Nonetheless, there is natural tension between the two groups, telescope designer Phil Stahl said. Astronomers want to launch ever-bigger telescopes, which requires a large-volume payload shroud, while the Constellation program, which is funding heavy-lift development, needs large payload mass. The fundamental problem, Stahl said, is that the larger shroud would reduce payload mass for the lunar mission, and the total height of the Ares V is limited by the height of the Vehicle Assembly Building at Kennedy Space Center.

"Right now, neither side is in a position to say that they can modify their baseline designs," Stahl said.

The basic question posed to scientists attending was what they could do if the existing limits on mass and volume were removed: Does Ares V enable breakthrough science not possible with any other launcher? What demands would large telescopes and planetary probes place on the Ares V and associated launch infrastructure? What technologies and environmental issues need to be addressed to facilitate launching such large payloads?

The advantage of heavy lift was easily illustrated. The revolutionary Hubble Space Telescope's main light-gathering mirror is 2.4 meters in diameter. The forthcoming James Webb Space Telescope is 6.5 meters across and relies on a complex system of folding mirrors for deployment. The Ares V 10-meter-diameter shroud would permit a simpler, monolithic 8-meter aperture without complicated deployment mechanisms. The payload community made clear it would like the same environments and capabilities—cleanliness, venting, temperature control, continuous nitrogen purge, vibrations, G loads, acoustics, pad access—inside a heavy-lift shroud as it has in the Space Shuttle and expendable launchers, explained Langhoff, who co-authored the final reports from both workshops.

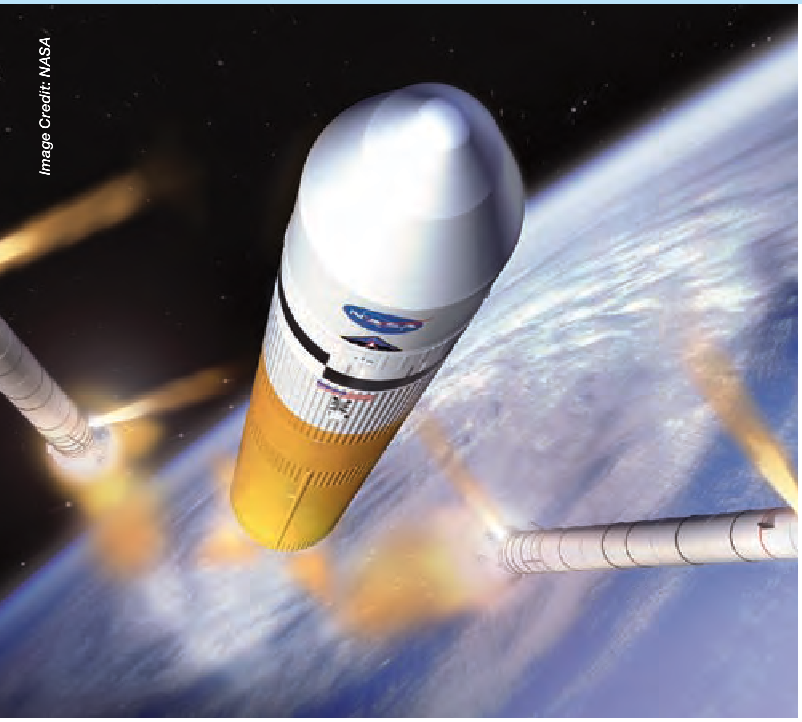


Illustration depicting booster separation from the Ares V.

"The purpose of the workshop was not so much to solve those problems, but to find where the problems lay," Thronson said. "Early on, all sides need to know what the opportunities are, what Ares V potentially could deliver, and there were clearly some limitations; but before you solve them, you've got to find them."

The planetary sciences workshop followed on August 16–17, 2008, again at Ames. The payload community's concerns were much the same as those of the astronomy community, but with an added desire for accommodating capabilities such as radioisotope generators and a cryogenic escape stage. In the planetary science arena, the Ares V capability enabled deep-space, planetary sample-return missions impossible on existing launch vehicles. Most tantalizing to Jet Propulsion Laboratory planetary scientist Tom Spilker was the idea of a sample-return mission to Saturn's moon, Titan, to look for organic and prebiological molecules. For such a mission, cleanliness from payload shroud encapsulation to the launchpad would be a hard requirement.

Stahl posed perhaps the most thought-provoking question of the workshops and led a breakout discussion on the subject of whether the mass and volume capabilities of Ares V might reduce payload complexity and thereby reduce the usual development and operational risks associated with big, so-called "flagship-class" space science payloads.

"We spend a lot of time making very small, high-performance science instruments," explained Gary Martin, director of the New Ventures and Communications Directorate at Ames. "In theory, you could use more off-the-shelf components and not have to spend so much making science instruments so small, if you had the volume and mass margins of an Ares V."

Dan Lester, an infrared astronomer with the University of Texas at Austin, could easily visualize that theory becoming reality with heavy-lift capability. His concept for an infrared telescope requires it to be folded like origami inside an existing launcher. Ares V would change that, he said.

"Now it requires a lot of pieces and a lot of folds and a lot of actuators and a lot of latches," Lester said. "And all these things have to work in order for your telescope to deploy. All the tests for all the folded stuff adds up to a quarter to a third of your cost—perhaps a billion dollars. The simpler you can make your telescope, the fewer things that have to be tested."

For scientists, it was an unusual chance to tell rocket designers what they need instead of designing to the constraints imposed by existing vehicles.

Insights and Connections

"It really is a sort of novel management tactic to do something like this, to get people who don't necessarily normally talk to each other talking," Lester said. "It's kind of a culture change for the science community to do stuff like that. We never thought about having the opportunity to give advice to people designing a new space-transportation architecture. They weren't making any promises but they were saying, 'As we're doing this, we want to make sure we don't do something really stupid and design a launcher that works fine for going to the moon, but has only 98 percent of the capability for launching big telescopes.' I think we came away with just a little better understanding. I think it was really very fruitful."

Participants in both the astronomy and planetary science workshops felt they gained useful insights that will help optimize a new heavy-lift capability. The Ares team's main performance standard is mass, Lester observed. It "opened their eyes" to learn that many of the astronomy ideas for Ares V used only 40 to 70 percent of the mass capacity but 100 percent of the volume. Ares Projects Planning Manager Phil Sumrall agreed, saying that, while lunar studies indicated an increase from 27.5 ft. in diameter to 33 ft. was desirable, the advantages to "other uses" helped finalize the decision at the expense of payload mass. Sumrall, notably, can now tick off payload requirements as easily as he does rocket jargon like "I_{sp}" (specific impulse) and "delta V." Lester was heartened to learn that it wouldn't be a huge obstacle to change the shroud, perhaps with modular components, to accommodate the largest scientific payloads.

PARTICIPANTS IN BOTH THE ASTRONOMY AND PLANETARY SCIENCE WORKSHOPS FELT THEY GAINED USEFUL INSIGHTS THAT WILL HELP OPTIMIZE A NEW HEAVY-LIFT CAPABILITY.

During a breakout session at the planetary workshop, Spilker was surprised to learn that the Ares V Earth-departure stage engine was designed to operate for 500 seconds and would be tested to that standard. "For a planetary spacecraft, you might need to back off on the thrust and run it for a longer time," he explained. "Going in, I had no idea that was going to be a consideration. We started learning all the nuances of design that need to be thought about."

There may have been some skeptical scientists in the audience, Lester said, but none who wanted to be left out if heavy lift becomes a reality. The workshop format ensured certain topics were surfaced and then allowed participants to explore them in detail.

"In some ways, it's serendipitous," Spilker mused. "Like anytime when you start a large project, it takes a while to wrap your arms around all the things that need to be done. Rather than thirty minutes for presentations and five for discussion, there was more time for open-forum discussion. Then there was time for panel discussions and breakout groups to discuss in a less structured format various aspects. We had several breaks and lunches where we all stayed together. If you wanted to talk to somebody and didn't talk to them, it was probably your fault."

Less tangible but perhaps more important impacts may be found in the business cards scientists and engineers exchanged during the unusual meetings. "Now we know who to call if we have a question," Sumrall said. ●

Electronic copies of the Ares V science workshop final reports can be downloaded from event.arc.nasa.gov/main/index.php?fuseaction=home.reports.

BRUCE MORRIS manages the Exploration and Space Systems Office at Marshall Space Flight Center, and he leads Ares V project activities for assessing Ares V use for non-exploration applications.

GREG SULLIVAN, an aerospace engineer and a principal with the Jefferson Institute, has more than thirty years' experience in program management, flight testing, and technology development.

MARTIN BURKEY supports NASA's Ares projects as a technical writer with the Schafer Corp.

PLANNING FOR

BY KAREN M. McNAMARA

When I started at NASA, I never dreamed of being responsible for the science preservation and recovery of a mission, let alone something that even NASA had never attempted before. I didn't expect the assignment as Johnson Space Center mission lead for Genesis to come just two months after I'd located my new office in Building 31. And I didn't expect to be asked to take up Stardust immediately on the heels of Genesis. But it happened, and I accepted both. The first—with its reentry problem—was a dramatic, heart-wrenching experience. People have penned volumes about what should, could, and may have been learned from the Genesis experience. Thankfully, I haven't been asked to add to that lot. In fact, I want to shift the focus here away from "lessons learned" to a consideration of what I call "planning for learning." That concept can be understood by examining the circumstances of the Stardust sample-return capsule and, more specifically, its heat shield.

In early 1999, NASAs Stardust spacecraft was launched on a seven year mission to collect interstellar dust and materials from Comet Wild 2 and return the samples to Earth, where they could provide information about the early evolution of the solar system and the composition of comets. In 2006, the capsule containing this precious cargo entered the atmosphere at just over 28,000 mph, the highest reentry speed of any man made object. At peak heating, the nose of the heat shield was required to withstand temperatures as high as 2,500°C. It was one of the most amazing sights I have ever seen. The shield was made of Phenolic Impregnated Carbon Ablator, or PICA. Developed at Ames Research Center, the material won the 2007 NASA Government Invention of the Year award in recognition of its performance on the Stardust mission. In addition to its ability to effectively manage the effects of high reentry temperatures, PICA is much lighter than the Avcoat shield used on Apollo spacecraft.

Given its performance and light weight, PICA has tremendous promise for use on other spacecraft. It is a potential boon to engineers who always struggle to limit the mass of their designs. These characteristics made it an early candidate for heat protection on the new Orion crew capsule. After considerable study, the Thermal Protection Systems Advanced Development Project at Ames recommended Avcoat over PICA for the Orion heat shield because significant technology development was required

LEARNING

Photo Credit: NASA

NASA s Stardust sample return capsule is seen with heat shield intact after it successfully landed at the U.S. Air Force Utah Test and Training Range.

before the successful implementation of PICA could be assured. Specifically, the large size of the Orion capsule would preclude using one solid PICA casting for the heat shield, as was done on Stardust. The added complexity of casting PICA in sections and developing adhesives that could meet the thermal and mechanical requirements of reentry were identified as important long-term goals, but the risk that additional development posed to the Orion project cost and schedule was too great.

Still, it has been acknowledged that PICA does have a promising future in spacecraft design. (It is scheduled to fly on the Mars Science Laboratory mission in 2011.) The Stardust mission provided an opportunity to develop good technical data that could have supported the use of the material on Mars Science Laboratory and future missions. In some regards, it was an opportunity we missed. After reentry, the Stardust heat shield was in fact carefully retrieved, preserved, and studied in great detail. One of my many unexpected responsibilities at NASA was to "curate" the returned Stardust spacecraft hardware. In that role, I was able to schedule the postflight analyses in the order of least-to-most destructive—in effect, planning for learning.

There was and is much we can learn from the study of the Stardust heat shield and capsule. Unfortunately, the information we could obtain from it was incomplete because detailed, accurate measurements of its thickness and surface characteristics were not obtained before flight. The preflight verification test for shield thickness consisted of micrometer readings taken at only two points on a shield 89 cm in diameter. This was sufficient to ensure adequate performance but not to get reliable information on recession (the amount of material burned away during reentry), which of course requires accurate data about the original as well as the final thickness of the shield.

Photo Credit: NASA Ames Research Center/Dean Kontinos

NASA Ames researchers at the Johnson Space Center curation facility with the recovered Stardust sample return capsule heat shield.

Not Part of the Mission

Why wasn't that potentially valuable preflight analysis done? Simply because learning about the performance of the shield was not part of the mission plan. Stardust was a science mission under the Discovery Program. Budgets and schedules for such missions tend to be tight, and no time or money was set aside for research or engineering endeavors external to the scope of the mission. No one had responsibility for that kind of learning.

About a year before launch, people from NASA's thermal-protection community did suggest that the Stardust team install active instrumentation on the shield so they could monitor PICA's performance. If they had made their request years earlier and the instruments had been built into Stardust's design, budget, and schedule at the beginning of the project, it probably could have been done. But at that late date the added cost and time it would have required were not available, and the risk of adding mass, complexity, and making design changes so close to the launch date was unacceptable. Not adding instrumentation was the right call by mission management. But even low-cost, no-risk data gathering (for instance, photographing the shield to have a record of its surface characteristics) was not done before flight. No one thought of doing that or had the responsibility to see that it was done.

Project teams sometimes are responsible for capturing lessons learned at the end of missions; sometimes a small fraction of the budget is set aside for that mission requirement. Those lessons have great value, but the learning they provide is retrospective and often reactive. Postmortem reflection misses important knowledge that could be gained by planning for learning at the start of missions. The key to such planning is to ask and answer the relevant questions—What can we learn from this mission that could be useful to future programs? What do I wish I knew now?—early on and then devote thought and resources to the task of devising the technologies and processes that would make that learning possible. In the case of Stardust, for instance, that would have meant doing better preflight heat shield measurements.

An Office for Planned Learning

I have already mentioned an important reason this does not happen: people understandably focus on their primary mission and devote their limited time and resources to ensuring its success. Another factor is that team members often lack the broad perspective needed to understand which elements of their projects might provide knowledge that other programs would find valuable. They may not even know what missions are being planned at other centers under the auspices of other mission directorates. (Stardust was, of course, a Science Mission Directorate project; Orion is part of an Exploration Systems Mission Directorate program.) Orion's high visibility means that probably everyone at NASA knows about it; the Stardust

SELECTING MISSIONS AND PROGRAMS WHERE ENHANCED TECHNOLOGY POTENTIAL WARRANTS INCREASED MISSION OR PROGRAM INVESTMENT REQUIRES CALCULATIONS ABOUT THE POTENTIAL VALUE OF THE LEARNING AND THE RISK TO MISSION COST, SCHEDULE, AND SUCCESS.

thermal-protection system team would be excited to share what they learn with Orion. But most project team members are not likely to spend much time thinking about how they can contribute to another mission directorate's program. They already have to contend with too little time and money!

What we need, I believe, is an Office for Planned Learning (OPL): a new small organization at NASA Headquarters that has a global overview of past, current, and future work throughout the agency and is responsible for supporting the development of program knowledge that can benefit other programs, projects, or directorates. This would be more rigorous than so-called "cross-pollination," which assumes the transplanting ideas or individuals will somehow ensure that valuable knowledge is preserved and shared. This office would be responsible for detailed knowledge of organizational and program technologies, with the ability to synthesize the detail into a larger image of the agency and its goals.

Selecting missions and programs where enhanced technology potential warrants increased mission or program investment requires calculations about the potential value of the learning and the risk to mission cost, schedule, and success. Where that calculation favored an investment in learning, OPL would provide financial support and a dedicated liaison to help the program build learning-related activities and technologies into its initial project goals, schedule, and budget. Of course, this needs to be done in the earliest phases of mission development. The kinds of things that did not happen on Stardust because they were "no one's job" would happen because they would be the shared responsibility of the OPL liaison and designated project team members. Planned learning would become one of the project's explicit requirements.

Good communication between the agencywide office and individual programs and projects would be essential to make this work. People working within projects would be the source of information the office needs to develop its perspective on what knowledge will have broad value. Once the office synthesizes and prioritizes these opportunities, it will be OPL's responsibility to communicate that perspective to the project teams to make clear why the knowledge-gathering activities are worth their time and effort. Some of the communication from project teams may be appropriate "pushback" to establish the limits of learning-work that might threaten the mission's success. It is likely that such an office would have a small full-time staff and numerous rotational openings to provide the most timely infusion of technology awareness both within the programs and within the office.

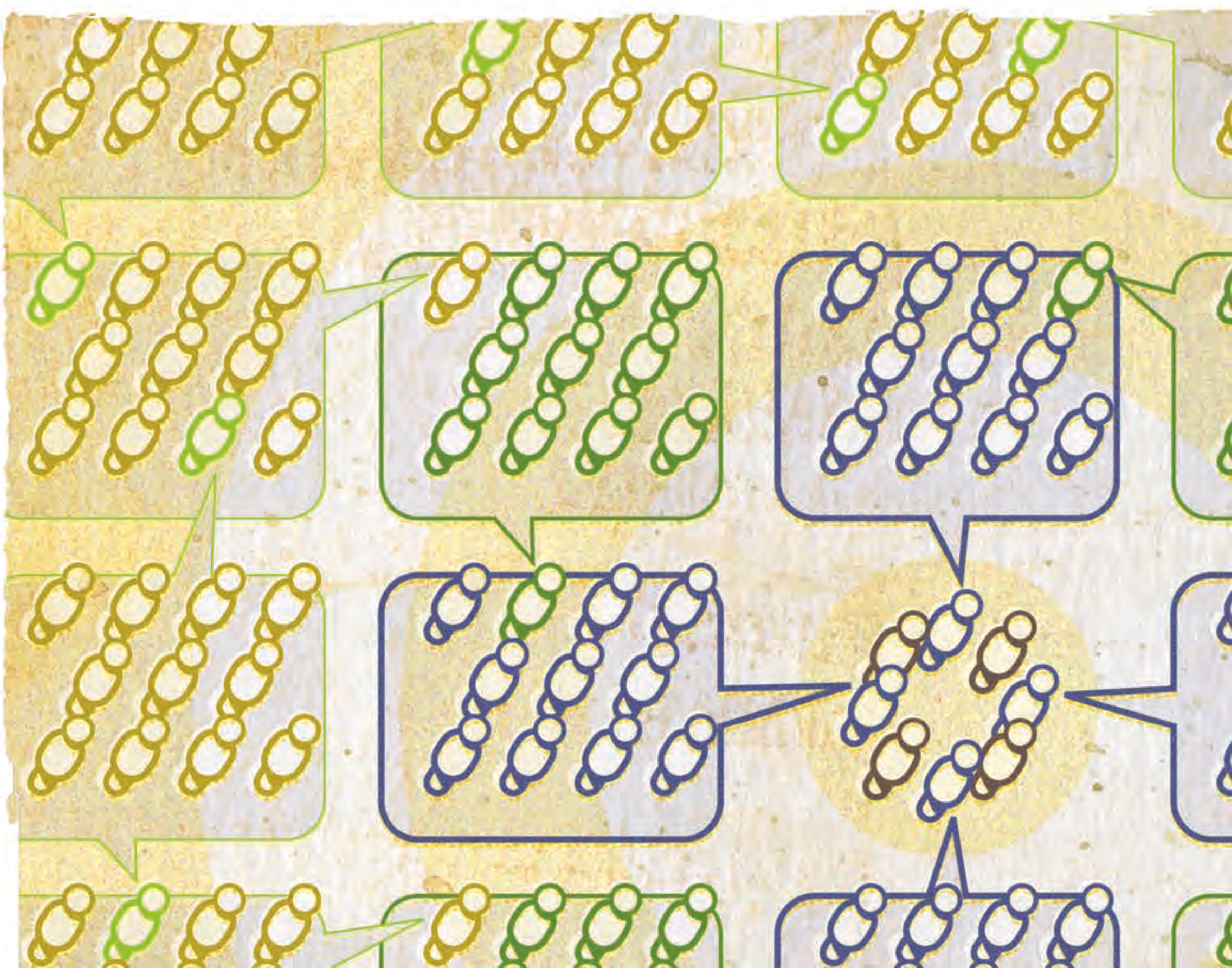
In a perfect world, there would be would be enough money and time to make planning for learning an important part of almost every NASA project. We don't work in that world. We will continue to miss some learning opportunities because we lack the resources to take advantage of them. But I believe the kind of attention to learning I have described here will repay our investment in it many times over. Planning for learning early in the lives of our projects and programs can produce knowledge that will contribute to the success of our most demanding and ambitious future missions. Planning for learning is proactive, and proactivity is critical to the success of our mission at NASA. ●

KAREN M. McNAMARA is currently the New Missions Space Exposed Hardware curator at Johnson Space Center. She served as the Johnson mission and recovery lead for the Genesis and Stardust missions, and she was the Genesis curator from 2001 through 2005.

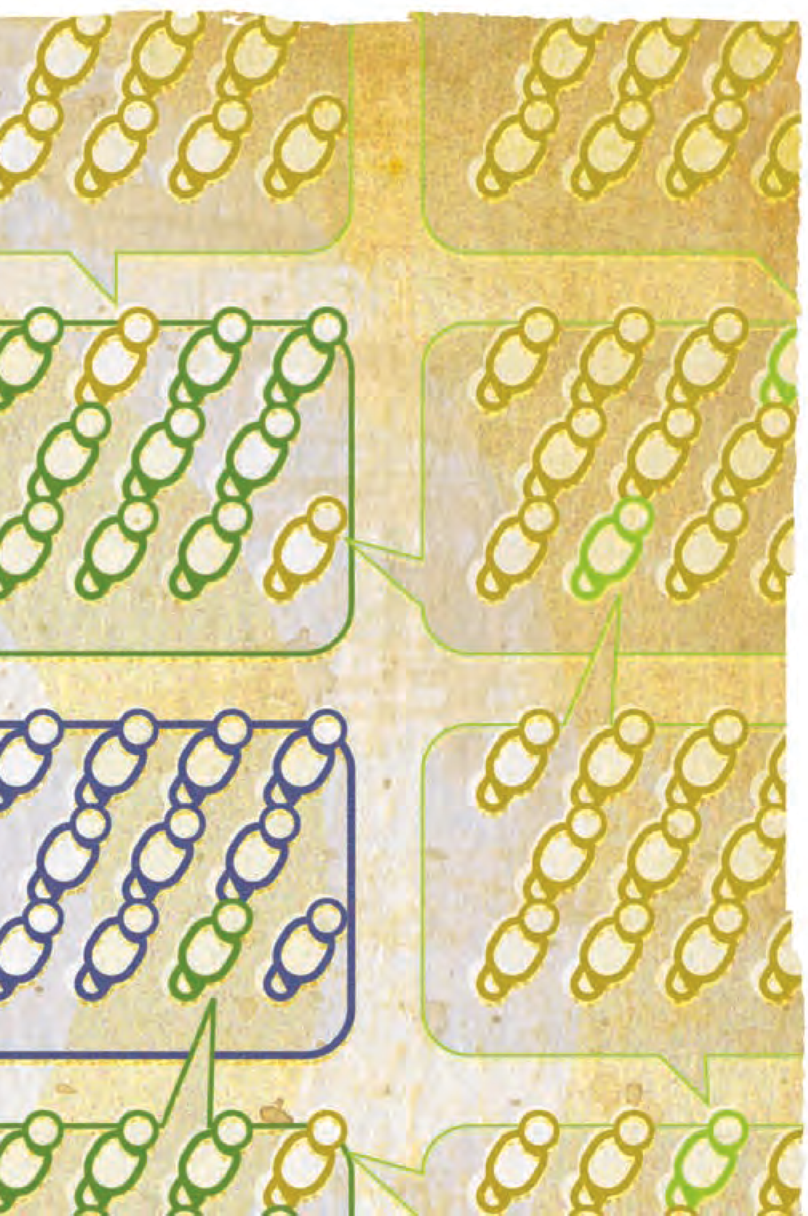
Sharing What We Know

BY JEAN ENGLE AND BRENT FONTENOT

In the fall of 2006, Center Director Michael Coats created the new position of chief knowledge officer at the Johnson Space Center. The purpose of the position was to develop a comprehensive knowledge-management program that would identify and capture fifty years of human spaceflight knowledge and make it readily available to current and future generations.



Johnson was the second center to recognize the need for a chief knowledge officer. Dr. Ed Rogers has been the chief knowledge officer at Goddard Space Flight Center for the past six years. Rogers openly shared Goddard's knowledge management program and learning philosophies with us at Johnson.



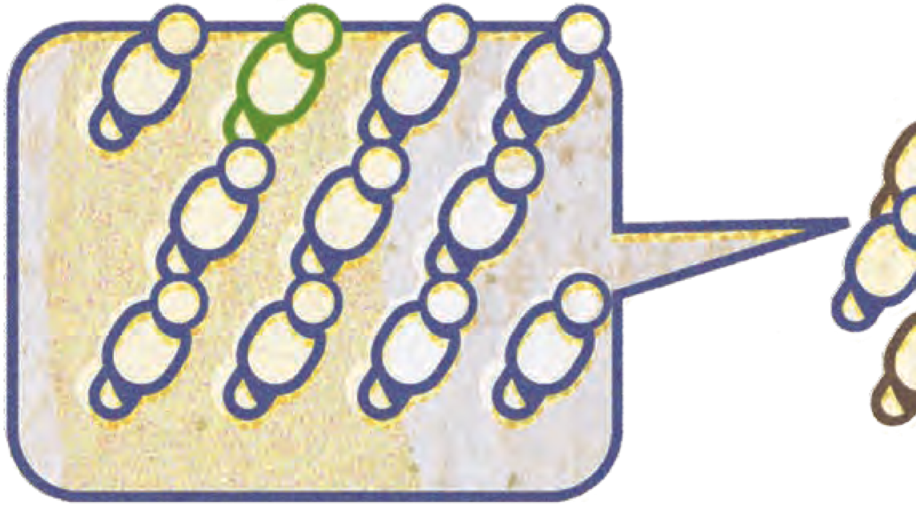
The two centers are different and so are their approaches to knowledge capture. Goddard has focused on case-study development and pause and learn; Johnson began with the capture of lessons learned and an infusion process along with a centerwide knowledge-management assessment. As the Johnson program developed over time, however, the centers recognized that their approaches are complementary and their ultimate goals are the same—to use a variety of means to facilitate knowledge sharing.

Creating a Program

We were reluctant to define a knowledge management program without knowing what was already working well. To identify existing knowledge-management activities at the center, Johnson did a comprehensive knowledge-management maturity assessment in the spring of 2007. The four-month process included interviews and focus groups across all Johnson organizations to determine maturity in three key areas: people, technology, and process.

The results were encouraging. Knowledge sharing was deeply integrated into several parts of the organization. The center as a whole saw the importance of managing organizational knowledge but did not necessarily know how to do so effectively.

In parallel with the assessment, the chief knowledge officer spent months benchmarking knowledge management at twelve organizations, including government, commercial, and aerospace entities, searching for best practices, lessons learned, and driving forces for knowledge capture. What we learned dramatically changed our perception of what our own program should entail. Rather than imposing one centerwide process for capturing and sharing lessons learned, for example, we followed the lead of the Department of Energy's distributed learning methodology, allowing organizations to capture, share, and infuse lessons in ways that worked for their particular cultures. We also learned that information technology can be an enabling capability for knowledge capture and sharing, but should not be the primary focus of a successful knowledge-management program. The most effective knowledge sharing happens person to person.



Guided by the assessment and benchmarking, we defined the Johnson Organizational Learning program and put it in place in May 2008. Key goals included the following:

- To foster a culture of sharing of information, knowledge, and best practices
- To recognize that learning is not uniform
- To capitalize on proven processes and methods
- To appreciate the value of shared collective knowledge

Along with the goals, we established key requirements for each organization:

- Establish expectations for knowledge sharing
- Promote knowledge transfer and collaborative sharing
- Establish local learning processes and procedures for lessons learned, best practices, and transfer of tacit knowledge
- Develop an organizational learning plan consistent with local processes, procedures, and practices
- Identify, document, validate, infuse, and disseminate lessons learned into critical processes
- Provide a point of contact for each organization's learning activities

The integrating body for organizations to share and learn from each other is the Knowledge Management Steering Committee, comprising representatives from each organization. We carefully considered how to create a structure formal enough to support sharing but not so rigid that it might stifle the flow of information. Encouraging sharing of best practices from group to group is an ongoing challenge. Participation varies depending on the topic for the meetings or information being shared. In general, we see less participation from organizations where knowledge capture and sharing are more ingrained. As at all NASA centers, sharing for the sake of sharing is not part of our day-to-day work. Making it integral to work requires time and focus.

Key Concept

To measure progress, we developed a simple concept to allow us to focus on specific areas and give us an easy way to explain the knowledge management program internally and externally. Three interconnected factors allow for the maximum transfer of knowledge and learning: what you know (tacit knowledge gained through experience, training, etc.), who you know (your social network), and what everyone else knows (explicit knowledge that has been codified and made available in knowledge bases).

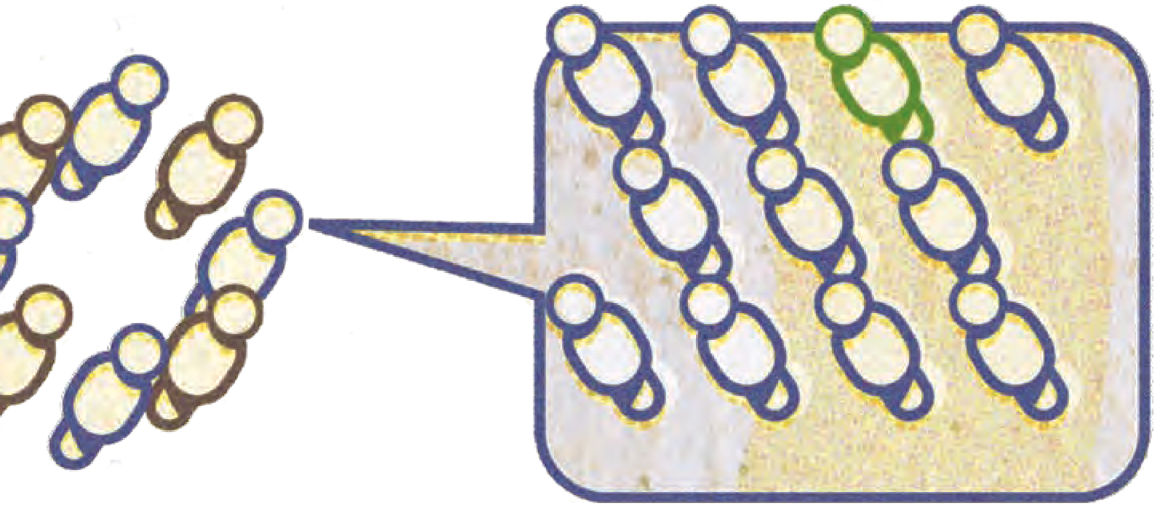
We have developed and implemented specific projects for tacit and explicit knowledge. Future plans will focus on the social-network aspects of our program as we explore agency and center collaboration tools such as NASA Spacebook.

Sharing What We Know Through Storytelling

Although codified knowledge is valuable, the people-to-people transfer of knowledge from subject-matter expert to learner provides essential context, filling gaps that explicit knowledge always leaves. Storytelling is one of the most powerful ways to communicate context.

At Johnson, storytelling happens in a variety of ways, under names including "brown-bag lunches" and "lunch and learn." Although valuable, most sessions have been publicized only by word of mouth, local fliers, or e-mail within a specific workgroup or team. Few are recorded or documented for future use. We wanted to develop a centerwide program that would feature experienced individuals in technical and institutional programs and projects telling stories that are applicable to a large cross-section of the center. Each session includes questions and answers and is videotaped to be available to the center (and anyone else with "nasa.gov" network access).

Associating storytelling with another center or a NASA milestone is one way to increase relevance. In May 2009, just before the beginning of hurricane season, three individuals from the emergency response team at Johnson did a storytelling



session on preparing for, riding out, and recovering after the devastation of Hurricane Ike in September 2006. They shared and expanded on lessons that had been captured in the center's Hurricane Ike report earlier in the year. About fifty-five people attended this event and 225 have downloaded the electronic version of the session.

In July, our storytelling program focused on the Apollo 11 fortieth anniversary events and included multiple sessions with panel discussions featuring subject-matter experts from many Apollo systems and subsystems. Over a three-day period, more than two thousand attended and over a hundred more accessed the online sessions. In August, nearly two hundred people heard Maj. Gen. Joe Engle, NASA astronaut and X-15 pilot, share lessons from the X-15 that were applied to the Space Shuttle—a session presented before the fiftieth anniversary of the first flight of the X-15. This e-mail shows the kinds of valuable connections between people the sessions can create:

> First, thank you for your presentation yesterday. It was great to hear you mention the STAs [shuttle training aircraft]. I was the project engineer on the STAs from 1985 to 1995. Anyway, if you have the time, I would like to talk to you about your experiences as they relate to my task to determine crew survival methods for the new Orion and Constellation program. In our case, crew survival starts after all the hazard controls inherent to the design and test of the vehicle have failed, much like an Apollo 13 situation. I start with a bad day and assess what we can do to get the crew home safely given what is available. If this is of any interest to you, please let me know and we can schedule a time to talk at your convenience.

To obtain speakers for our sessions, we have tapped the rich field of experts in the Johnson NASA Alumni League chapter for several of our sessions. In addition, requests for topics and speakers have gone through *JSC Today*, a daily e-mail with information and tidbits from around the center sent to more than ten thousand recipients.

To help ensure that we are providing a valuable service, we have established an online feedback form that can be used by attendees or those who watch videos of the sessions. The feedback has been excellent and has suggested valuable changes such as adding an outline, moderator, and structure, especially for events with multiple participants.

IN JULY, OUR STORYTELLING PROGRAM FOCUSED ON THE APOLLO 11 FORTIETH ANNIVERSARY EVENTS AND INCLUDED MULTIPLE SESSIONS WITH PANEL DISCUSSIONS FEATURING SUBJECT-MATTER EXPERTS FROM MANY APOLLO SYSTEMS AND SUBSYSTEMS.

Although we keep tabs on how many people attend each session and download video or MP3 files, we measure success by how we connect current employees to experts, many of them no longer at the center. After the first session in March 2009, "Wisdom and Lessons Learned from the Johnson Propulsion and Power Division," the chief for the current propulsion division, William Hoffman, invited the participants back to Johnson to share their knowledge with his entire division. Connecting the newer generations with individuals who were at NASA when the early manned spaceflight programs were being developed is an opportunity for invaluable knowledge transfer.

ALLOWING ORGANIZATIONAL VARIATION IN HOW LESSONS ARE CAPTURED AND SHARED WHILE INTEGRATING SEARCH CAPABILITY HAS PROVEN TO BE MORE ACCEPTABLE TO THE USER COMMUNITY THAN TRYING TO FORCE TRANSFER OF LESSONS FROM EXISTING SYSTEMS TO A CENTERWIDE ONE.

Sharing What Everyone Else Knows

Responsibility for the center's lessons-learned program was transferred from the chief engineer to the chief knowledge officer in the spring of 2007. Local learning and sharing were happening more than we had thought. Surveying existing lessons-learned activities at Johnson, the Center Lessons Learned Data Manager identified twenty-seven separate repositories and processes. Collection methods, verification and storage processes, and outputs were often specialized for the division or branch they supported. Rather than change existing practices, we want to support and leverage them as much as possible.

Experience had taught us that a lessons learned process that is separate from how an organization or team learns or operates will not work. During benchmarking, we found anecdotal evidence suggesting that 95 percent of lessons learned are applicable only at the local level. The challenge is to identify and collect the 5 percent that have wider applicability. To capture and share that 5 percent, we created criteria to guide organizations. In the case of the center's report on Hurricane Ike lessons learned, for instance, we were able to identify, codify, and share broad lessons from organizations including procurement, center operations, and information technology. Submitted to the agency's Lessons Learned Information System (LLIS), this material was voted the number-one "lesson" in the LLIS for 2009.

An integrated search function lets a user search the more than thirty-five internal and external lessons learned and case-study collections in the lessons learned library at once. In the past, a user would have to identify and search each collection individually or do a global search at the center level, which would return results from hundreds of sources—processes that were too laborious to be of value to most users.

Allowing organizational variation in how lessons are captured and shared while integrating search capability has proven to be more acceptable to the user community than trying to force transfer of lessons from existing systems to a centerwide one.

Where Do We Go Next?

On the horizon, though in its infancy, is an activity modeled after National Public Radio's StoryCorps project, which we are calling "JSC Voices." It will give our workforce a chance to produce their own ten- to twenty-minute movies about their NASA experiences. We will provide the platform for sharing firsthand personal experiences by hosting the DVDs on our Web site and advertising them to the center. Our goal is to find new ways to inspire people to record and preserve the stories that matter to them and capture the courage, humor, trials, and triumphs of an incredible range of voices.

Additionally, we teamed up with the Center Shuttle Transition team to capture memories and experiences of the final flights of one of our greatest programs. During each Space Shuttle launch viewing in the Teague Auditorium, we ask employees to take a few moments to share shuttle memories on camera, telling us about the first launch they saw or the feeling of accomplishment that came from seeing the hardware they helped build turned on in space. They provide the memories, and we provide the camera to record them and a way to share the memories with others.

Over time, we have seen that learning and sharing happen differently across a diverse, innovative, and creative workforce. Allowing individuals and teams to transfer knowledge in ways that have meaning to their culture is the most effective path to success. ●

JEAN ENGLE is the chief knowledge officer at Johnson Space Center, a position she has held since 2006. Her previous experience includes chief information officer from 2000 to 2006 and deputy center information technology security manager, both at Johnson.

BRENT FONTENOT has been an aerospace engineer at Johnson Space Center for thirty years. Currently he serves as the lessons learned manager at Johnson, where he also manages the storytelling program.

The Greening of Orbital Debris

BY NICHOLAS L. JOHNSON

Like most technological advancements, the space age has left a sea of refuse in its wake. Spread throughout near-Earth space, this man-made orbital debris, ranging from micron-sized particles to intact launch-vehicle stages tens of meters in length, has accumulated to a point where it now threatens the safety of human spaceflight and the reliable operation of hundreds of robotic satellites.

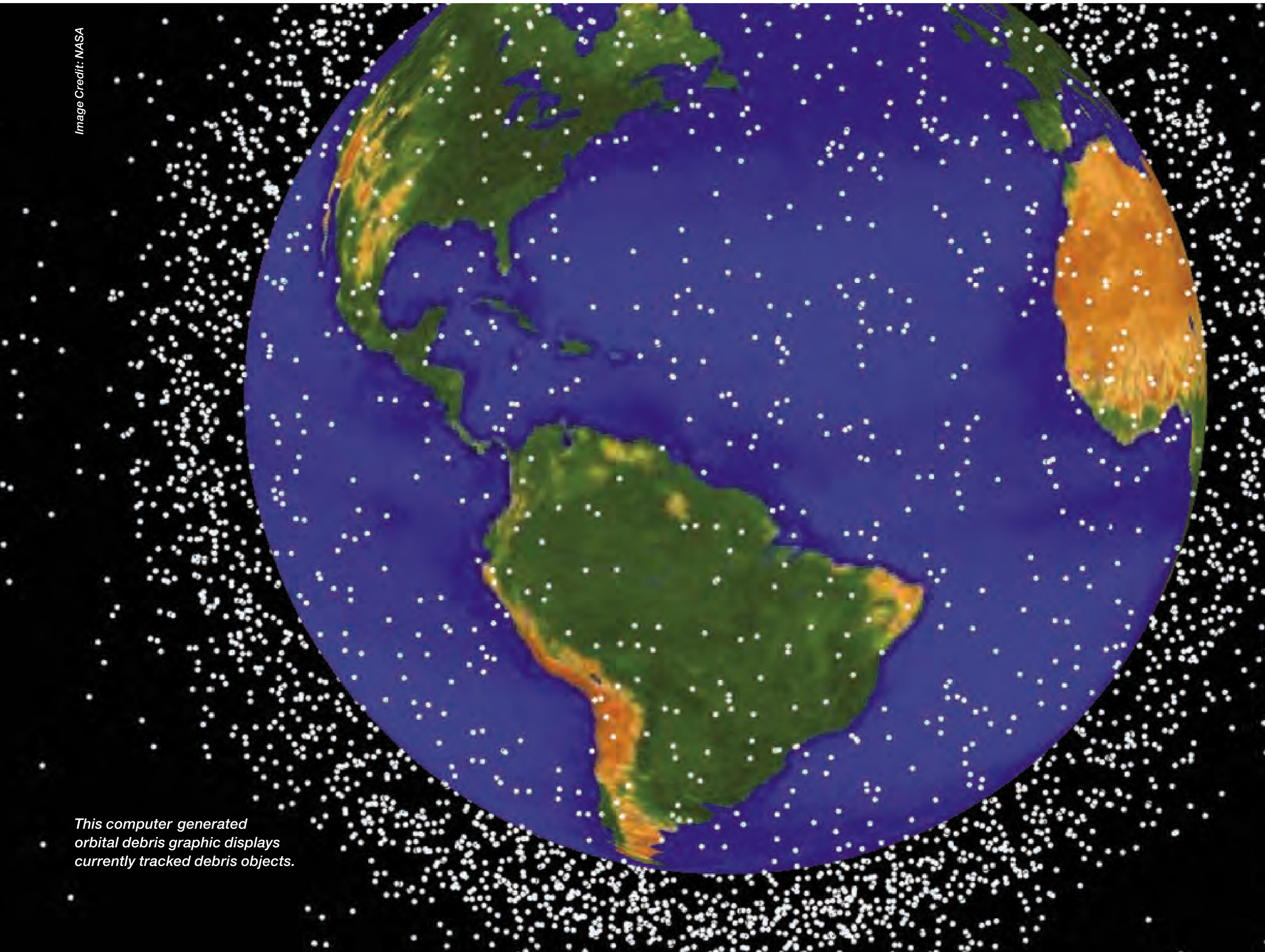


Image Credit: NASA

This computer generated orbital debris graphic displays currently tracked debris objects.

The main propellant tank of the second stage of a Delta 2 launch vehicle landed near Georgetown, Texas, on January 22, 1997. This approximately 250 kg tank is primarily a stainless steel structure and survived reentry relatively intact.

During 2009 both the International Space Station and the Space Shuttle had to conduct evasive maneuvers to avoid colliding with orbital debris. NASA's Cloudsat satellite, part of a multisatellite Earth-observation network to monitor the planet's environment, also had to alter course to prevent a potential collision, as did several commercial spacecraft.

Due to the extremely high relative velocities of space objects, typically 10 km per second or more in low-Earth orbits, even small debris can impair or terminate a spacecraft's mission. Most robotic and piloted satellites are vulnerable to debris as small as 5 mm in size. Today, such debris number in the millions.

In response to the growing threat of orbital debris, NASA pioneered the development and implementation of orbital debris–mitigation guidelines and requirements, starting in 1995 after more than a decade of elaborate orbital debris measurements and projections of the debris population's evolution. Each NASA space program and project must prepare a detailed orbital debris–assessment report in conjunction with its preliminary design review and critical design review milestones. This process seeks to minimize the generation of orbital debris during deployment, operations, and post-mission disposal.

At the direction of the White House, in 1997 NASA teamed up with the Department of Defense to create U.S. Government Orbital Debris Mitigation Standard Practices, based upon the existing NASA debris-mitigation guidelines. The principal elements of these standard practices seek to

1. control debris released during normal operations,
2. minimize debris generated by accidental explosions,
3. reduce risks to operational spacecraft via flight profiles and vehicle designs, and
4. plan for the safe post-mission disposal of spacecraft and launch-vehicle stages.

After a multiyear coordination with the U.S. aerospace industry, these practices were adopted in February 2001. Since orbital debris is a problem for all space-faring nations and organizations, however—and one that cannot be solved solely by the United States—international agreement to limit the creation of orbital debris is necessary. Consequently, NASA took a leading role in establishing the first set of international orbital debris–mitigation guidelines, which were produced in 2002 by the Inter-Agency Space Debris Coordination Committee (IADC), an association of the national space agencies of ten countries as well as the European Space Agency. In 2007 the United Nations adopted its own orbital debris–mitigation guidelines, consistent with the U.S. and IADC standard practices and guidelines.

Implementing these mitigation measures can be simple or complex. In the initial decades of the space age, little thought was given to the release of miscellaneous hardware in orbit, particularly during launch and deployment phases. Springs, covers for sensors and motors, spin-up yo-yos, remnants of explosive bolts, and similar objects were frequently left in Earth orbit. Today, many missions are debris-free by design. For example, sensor covers are hinged or attached to the vehicle by short tethers. When instances of unexpected debris occur after a launch, an investigation is undertaken to identify the source of the debris and to institute corrective measures.

Prior to 2007, accidental explosions of abandoned spacecraft and launch-vehicle stages were the principal source of hazardous orbital debris. Residual propellants and pressurants were found to be a leading cause of the fragmentations. Battery explosions were also the source of numerous debris. To prevent these explosions, passivation—the removal of all stored energy—of spacecraft and launch vehicles at the end of a mission is now widely practiced by the international aerospace community. As a result, this source of orbital debris has been markedly curtailed.

Since the 1970s, NASA studies have shown that in the long term the principal source of orbital debris will be accidental satellite collisions. This assessment was underscored in February 2009 when a collision between an operational U.S. communications satellite and a defunct Russian communications satellite produced more than two thousand large and tens of thousands of smaller, yet still hazardous, debris in the worst accidental satellite collision in history.

To reduce the potential for future accidental collisions, the post-mission orbital lifetimes of spacecraft and launch-vehicle stages in low-Earth orbit (below 2,000 km altitude) should be limited to

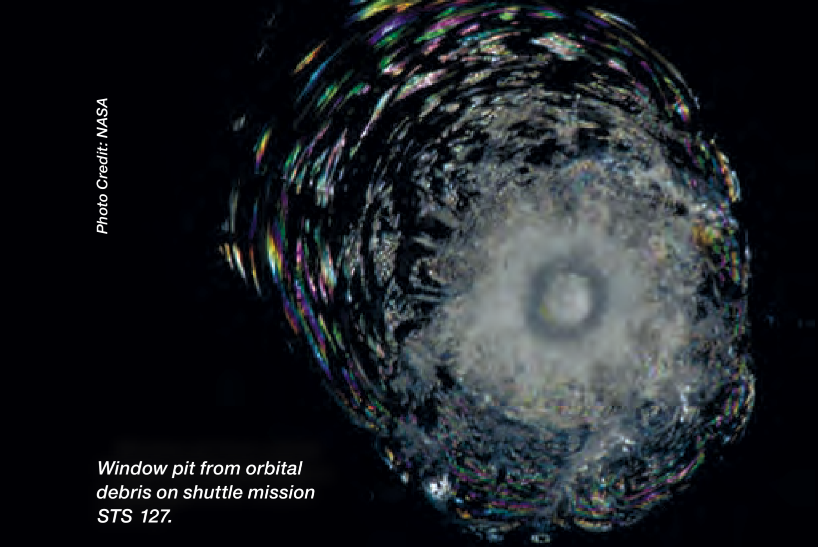


Photo Credit: NASA

Window pit from orbital debris on shuttle mission STS 127.

ORBITAL DEBRIS IS NOT ONLY A POTENTIAL HAZARD TO SPACE OPERATIONS; REENTRY CAN ALSO POSE A RISK TO PEOPLE AND PROPERTY ON EARTH.

twenty-five years or less. This guideline was first devised by NASA and later adopted by the U.S. government and other foreign space agencies. In 2005 NASA maneuvered its Earth Radiation Budget Experiment Satellite and its Upper Atmosphere Research Satellite to lower orbits to accelerate their fall back to Earth and to reduce their potential for being involved in accidental, debris-producing collisions. In 2008 the Department of Defense performed similar maneuvers for its GEOSAT Follow-On satellite, as did France with its SPOT 2 satellite in 2009.

For satellites in very high orbits, maneuvers to low altitudes are not feasible. Geosynchronous satellites at an altitude of nearly 36,000 km should be placed in disposal orbits that will remain at least 200 km above the geosynchronous orbital regime. Such maneuvers, which normally require less than 10 kg of propellant, are now performed by the majority of geosynchronous spacecraft.

Orbital debris is not only a potential hazard to space operations; reentry can also pose a risk to people and property on Earth. On average, one known man-made object falls back to Earth each day. Most of these objects are small fragments and burn up during reentry. Components of spacecraft and launch-vehicle stages that do survive are statistically likely to land in the water or on large, sparsely populated areas, such as Siberia, the Australian Outback, or the Canadian tundra.

However, by encouraging or requiring space system operators to limit satellite stays in low-Earth orbit, the number of reentries of spacecraft and launch-vehicle stages will increase. Again based upon NASA analyses, NASA, the U.S. government, and some foreign space agencies attempt to limit human casualty risks from reentries to 1 in 10,000 per event.

For vehicles that might pose greater risks, two options are available: directing a controlled reentry over a broad ocean area or designing the vehicle to be more completely destroyed during reentry. This is normally accomplished by component redesigns and material selection. For example, lower-melting-temperature materials like aluminum are much less likely to survive reentry than higher-melting-temperature materials like titanium, stainless steel, or beryllium.

NASA strongly promotes a "design for demise" philosophy when developing or procuring new satellites. Satellite survivability is first addressed by the preliminary design review milestone, at which time surviving components are identified and modified, if feasible. The Goddard Space Flight Center leads engineering efforts to develop satellite components that will demise, including propellant tanks and reaction-wheel assemblies, objects which historically have survived reentry.

Green engineering and operations are essential to preserving the near-Earth space environment for future generations. The U.S. and international aerospace communities have been proactive in addressing the threat of the increasing orbital debris population and the risks to people and property from reentering debris. NASA has led this activity by first devoting resources to thoroughly understand the technical issues and then by developing effective and acceptable policies and guidelines. NASA has also worked closely with the international community to ensure that the U.S. aerospace industry is not placed at an economic disadvantage as a result of implementing orbital debris–mitigation measures.

In the future, remediation of the near-Earth space environment (that is, the removal of large spacecraft and launch-vehicle stages) might be necessary to prevent the uncontrolled growth of the debris population due to accidental collisions. In December 2009, NASA and the Defense Advanced Research Projects Agency jointly sponsored the first international conference on the removal of debris from Earth orbit. The technical and economic challenges of orbital debris removal remain daunting, but NASA scientists and engineers are up to the task. ●

NICHOLAS L. JOHNSON is the NASA chief scientist for orbital debris at Johnson Space Center.

Featured Invention:

NASA Modeling Innovations Advance Wind-Energy Industry

Aerostar s wind turbines are stall regulated, a feature enabled by the Viterna model.

Photo courtesy NASA Spinoff

BY BO SCHWERIN

One morning in 1990, a group of Glenn Research Center employees arrived to find their workspace upended by an apparent hurricane. Papers were scattered, lights blown out. All eyes turned to the door connecting the office to its neighbor: a 20-foot wind tunnel.

The employees did not know it, but they had Dr. Larry Viterna to thank for the state of their workspace. An innovation by the NASA researcher may have led to the accidental trashing of their office, but it would go on to benefit the entire field of wind energy.

Viterna joined NASA in 1977, when growing anxiety over fuel costs and environmental impacts led the U.S. government to explore alternative and renewable energy sources. Prior to the formation of the Department of Energy, the government turned to other agencies to develop solutions. Glenn had a history of energy research stemming from its work in fuel-efficient aeronautics during World War II and in alternative fuels and related aerospace engines at the start of the space age in the 1950s. When Viterna joined the center, it had already assumed the lead role in the nation's wind-energy program. NASA's goal was to develop technology for harnessing the wind's power and transfer it to private industry.

"Our center had an expertise in propellers, propulsion, rotating equipment, and power systems," making Glenn a natural choice for the job, explained Viterna. The center's efforts, he said, ultimately laid the foundation for much of the wind technology and industry that exist today.

Glenn constructed its initial experimental 100-kilowatt (kW) wind turbine at the center's Plum Brook Station facility in

For more than twenty years, NASA's 4-megawatt WTS-4 wind turbine held the world record for maximum power output.

Photo courtesy NASA Spinoff

1975. The Mod-0 turbine was a two-bladed, horizontal turbine. By 1978, the 2-megawatt (MW) Mod-1, the world's first multimegawatt wind turbine, was developed—capable of providing electricity to thousands of homes. Successive experimental models (thirteen in all) were built throughout the country. Viterna noted that these were also record setting in size and output; the 4 MW capability of the WTS-4 turbine, built in 1982 in Medicine Bow, Wyoming, was not surpassed for about twenty-five years.

"That's how far ahead the program was in terms of developing this technology," Viterna said.

NASA's efforts led to other industry innovations that are standard today. As Glenn researchers explored ways of reducing the weight and cost of turbine structures, they developed steel tube towers that replaced the rigid truss towers traditionally used. "Today, virtually every large wind turbine uses a steel, tubular tower, which was novel technology at the time," said Viterna.

Despite the advances made by the NASA-led program, there were still significant challenges. "One of the key things then and now is to accurately predict the forces exerted on a wind turbine," Viterna said. On a basic level, wind turbines use the same forces that allow airplanes and helicopters to fly. Wind blowing over the turbine's blades, or airfoils, creates lift that turns the blades, spinning a shaft that connects to an electricity-producing generator. When engineers first began to model the impact of these forces on wind-turbine airfoils in high-wind conditions, they would produce results that were off by at least 50—and sometimes as much as 100—percent.

The problem was that wind turbines, unlike most other airfoil-based systems, operate at a high angle of attack—the angle formed between the chord of an airfoil and the direction of the airflow. (A chord is an imaginary line through an airfoil's cross-section, joining the tip of the trailing edge to the center of the leading edge.) In airplanes, when the angle gets too large, the laminar air flow that typically hugs the wing begins to detach and become turbulent, reducing lift and increasing drag; at a certain point, the plane stalls and drops out of the sky. Wind turbines, especially in high-wind conditions, can routinely stall, limiting the ability of the turbine to produce electricity. The inability to properly predict stall behavior, actual aerodynamic loads, and the relationship between wind speed and power in wind turbines led to inefficient designs and costly failures. At the time, there was a significant lack of research and data in this area, Viterna explained, as well as "three-dimensional effects going on that we had no way of calculating or even measuring."

In 1981, using data previously collected from an old Danish turbine, coupled with test data gathered by fellow NASA researcher Robert Corrigan from the Plum Brook turbine, Viterna developed a model that took into account three-dimensional effects and predicted stall behavior with far greater accuracy than previous methods.

The model was not well accepted by colleagues in the wind-energy field, Viterna recalled. "I almost got laughed off the stage when I presented it," he said, explaining that the model violated existing theories that used two-dimensional airfoil data. Viterna, however, continued to employ the model, even using it in 1991 to improve Glenn's Icing Research Tunnel, designed to study the

By shaving the Icing Research Tunnel's wooden fan blades according to the results of Dr. Larry Viterna's model, Glenn engineers boosted the tunnel's top wind speed by more than 130 mph.

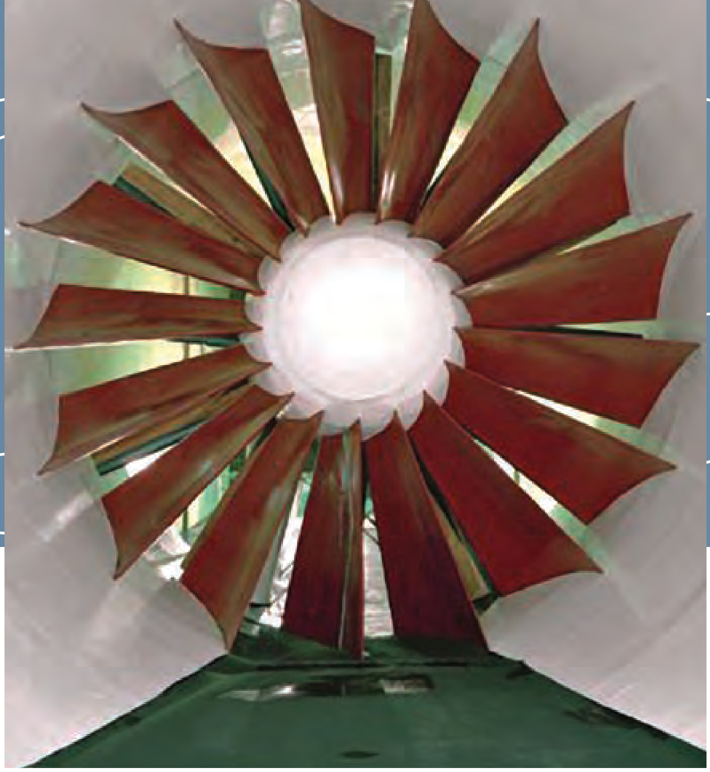


Photo courtesy NASA Spinoff

effects of ice buildup on aircraft. Based on the model's results, Viterna suggested that slightly shaving down the wooden fan blades could boost the tunnel's 299-mph capability. During a nighttime test, the wind tunnel's pressure release door flew open, sending 400-mph winds ripping through the adjoining work area. (The tunnel's new upper limit after implementing Viterna's model: 430 mph.)

The surprise Viterna's coworkers encountered the following morning was on par with what Viterna experienced during a random Internet search nearly twenty-five years after inventing his model. In 2005, long after the easing of the energy crisis and shift of the wind-energy program to the Department of Energy, Viterna, now in Glenn's Office of Strategic Management, was searching the Internet when he began to come across multiple references to the "Viterna method" by experts in the wind-energy field. He discovered his initially criticized model had, within a decade of its creation, quietly become the established method of modeling the performance of wind-turbine airfoils under high angles of attack—stall conditions.

"It had become, and still is, the most widely used stall model in the United States," said Viterna, who along with Corrigan recently received a "Space Act Award" from NASA's Inventions and Contributions Board, as well as the Agency's inaugural "Blue Marble Award" at its Environmental and Energy Conference.

Among the many who use the Viterna method is the Department of Energy's National Renewable Energy Laboratory's National Wind Technology Center (NWTC), located in Boulder, Colorado. In 2005, the center added the Viterna model to its design-code software suite for horizontal-axis wind turbines, the most popular variety of turbines in use today.

"Viterna's model does a very effective job of estimating stall behavior on inboard sections of the blade and how it varies along the blade's span," said Dr. Sandy Butterfield, wind program chief engineer at the NWTC. "Even though it was invented in the 1980s, it remains a model used by engineers predicting performance and loads for wind turbines."

The NWTC suite—which offers design and analysis software tools for use in achieving worldwide certification of wind turbines—incorporates Viterna's model in its FoilCheck preprocessor. FoilCheck allows users to generate airfoil tables and compute dynamic stall parameters for use in NWTC's AeroDyn software library, which enhances the center's YawDyn, FAST, and ADAMS turbine simulators. The entire suite is available to private industry for free, which has enabled wind-turbine manufacturers like Westport, Massachusetts-based Aerostar Inc. to use Viterna's method to help craft their products.

The Viterna method is finding applications beyond horizontal wind turbines; Viterna has discovered his once-mocked model is now employed for vertical wind turbines, wind tunnels, and even underwater turbines that make use of tidal energy to produce power. In the meantime, NASA continues to be involved in the advancement of wind energy; Glenn, for example, is supporting the plans of Cuyahoga County, Ohio, to establish on Lake Erie the world's first freshwater, offshore wind-turbine site.

The agency can also expect to see its early work experience a resurgence, predicted Dr. Butterfield of the NWTC. "As the industry moves forward and becomes more competitive and broad, you will see efforts to explore lower-cost, more structurally efficient machines, and that's when people will begin to capitalize again on that good work NASA did in the early 1970s and 1980s," he said. It seems likely that Viterna's and NASA's pioneering work will continue to play a significant role, given the nation's ambitious energy goals: the Department of Energy has outlined a plan for generating as much as 20 percent of the country's energy from wind power by 2030. ●

This article was originally published in NASA's Spinoff 2009.

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

Photo Credit: NASA/Jim Grossmann

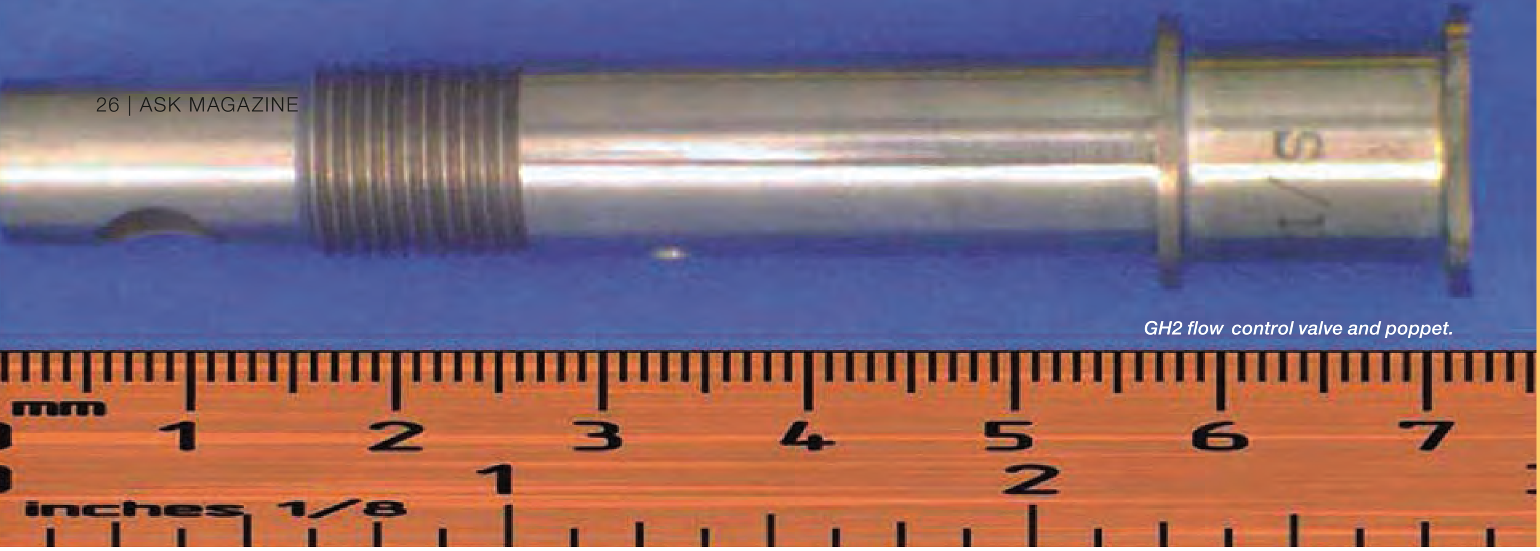
After sunrise at the Shuttle Landing Facility at Kennedy Space Center, the wheels on space shuttle Endeavour *are lowered before its move to the Orbiter Processing Facility. On December 19, an X ray of the orbiter showed evidence of a problem with a poppet, a kind of tapered plug that moves up and down in the valve to regulate flow.*

GETTING TO "YES"

THE FLIGHT READINESS REVIEW

BY MATTHEW KOHUT AND DON COHEN

As its name suggests, a Flight Readiness Review, or FRR, gives teams responsible for various elements of a NASA flight mission an opportunity to ensure technical questions raised at earlier reviews have been adequately dealt with and to raise concerns about anything else that might affect mission success. Typically held about two weeks before a scheduled launch, the reviews gather team members in one meeting room, where they report on their areas of responsibility and, at the end of the session, express their judgment in a "go" or "no-go" flight decision. Most often, technical issues that could affect the flight are studied and resolved by engineers before the meeting; their work is reviewed and discussed and the session usually ends in a unanimous "go" decision.



GH2 flow control valve and poppet.

Photo Credit: NASA

STS-119, the March 2009 *Discovery* flight to the International Space Station (ISS), was an exception. Getting to a positive launch decision took three FRRs, including a marathon second session, where frustratingly incomplete technical data led to uncertainty, some disagreement, and, finally, the decision that STS-119 would not be declared ready for flight. This unusual experience vividly demonstrated that the FRR process worked as intended, providing an open forum for voicing and examining concerns about flight safety and success and a focal point for rigorous technical work.

A Broken Valve

On November 14, 2008, as *Endeavour* rocketed skyward on STS-126, flight controllers monitoring data noted an unexpected hydrogen-flow increase from one of the shuttle's main engines. Since three flow-control valves (one per engine) work in concert to maintain proper pressure in the hydrogen tank, one of the other valves reduced flow to compensate for the valve that malfunctioned.

Understanding the causes and implications of the failure was essential to the safety of future shuttle missions. Management would have to promote and ensure open communication among the multiple organizations involved in the shuttle program so that all relevant information would be available to decision makers with the responsibility to approve or delay future shuttle flights.

"We knew at least on paper the consequences could be really, really bad, and this could have significant implications for the orbiter fleet and, most urgently, the next vehicle in line. Depending on where the vehicle landed, we wanted to get these inspections done and some X-rays done as quickly as we could," said John McManamen, chief engineer of the Space Shuttle Program.

Shuttle and ISS program managers preferred launching STS-119 prior to mid-March so it would not interfere with the March 26 mission of the Russian Soyuz to transport the Expedition 19 crew to the ISS. If the launch was delayed until after the Soyuz flight, interdependencies in the schedule would require a reevaluation of other future launches.

STS-126 touched down at Edwards Air Force Base on November 30 after unfavorable weather conditions at Kennedy Space Center led flight controllers to divert the landing to California. This delayed work until December 12, when the shuttle was ferried back to Kennedy aboard a specially equipped 747.

A December 19 X-ray showed evidence of a problem with a poppet, a kind of tapered plug that moves up and down in the valve to regulate flow. Inspection determined that a fragment had broken off, the first time such a problem had occurred during flight, although there had been two similar failures in the early 1990s during testing of a new set of flow-control valves for *Endeavour*.

There were a total of twelve flight-certified valves in existence: three in each shuttle, and three spares. Simply buying more was not an option—these custom parts had not been manufactured in years, and NASA had shut down its flow-control valve acceptance-testing capability.

The FRR

With the launch scheduled for February 19, the program scheduled a Flight Readiness Review for February 3. At that review, it quickly became clear that the engineering and safety organizations felt that significant work needed to be done before a sound flight rationale could be established. Steve Altemus, director of Engineering at Johnson Space Center, summarized the knowledge gap from the Johnson engineering community's point of view: "We showed up at the first FRR and we're saying, 'We don't have a clear understanding of the flow environment; therefore, we can't tell you what the likelihood of having this poppet piece come off will be. We have to get a better handle on the consequences of a particle release.'" The most important outcome of the meeting was the establishment of new lines of inquiry that could lead to better understanding.

On February 6, the launch was delayed until February 22.

Technical Analysis

Analysis of the cracked valve showed that the failure resulted from high-cycle fatigue (in which a material is damaged by

BILL MCARTHUR, SAFETY AND MISSION ASSURANCE MANAGER FOR THE SPACE SHUTTLE AT THE TIME, SAID, "THE FACT THAT PEOPLE WERE WILLING TO STAND UP AND SAY, 'WE JUST AREN'T READY YET,' IS A REAL TESTAMENT TO THE FACT THAT OUR CULTURE HAS EVOLVED SO THAT WE WEREN'T OVERWHELMED WITH LAUNCH FEVER …"

numerous cycles of stress). This raised several questions. Had STS-126 presented an unusual environment, or was another valve likely to break in normal flight? What would be the worst-case consequences of a break? Engineers needed to determine the probable size and the maximum size of a loose particle, understand how it would move through the propulsion system, and what the system could tolerate without experiencing a potentially catastrophic rupture in its lines.

Teams worked on the problem from multiple angles, including materials, structural dynamics, computational fluid dynamics (CFD), and fracture mechanics. Initial efforts relied on visual inspection and nondestructive evaluation (NDE) techniques, including scanning electron microscopy. The microscopes could see small cracks only after the poppet was polished, however, and polishing invalidated the flight certification of the hardware. "A polished poppet could upset the flow balance of the valve, rendering it unusable for flow management. In this case the valve could get stuck in the high- or low-flow positions, which could cause a serious issue in flight," said Steve Stich, the orbiter project manager. "In order to ensure that a polished poppet was properly balanced required testing using the system that had been shut down at the White Sands Test Facility in the late nineties. So we were in a bit of Catch-22 situation with respect to performing the best possible NDE."

The Orbiter Project authorized impact testing at Glenn Research Center, Stennis Space Center, and the White Sands Test Facility to learn more about whether a fragment of a broken poppet would puncture the pressurization lines downstream of the valve. The data from these tests and other analyses contributed to a probabilistic risk assessment of the entire flow-control valve hydrogen-repress system. At the same time, the CFD analysts figured out the velocity and spin of a given-sized particle as well as the probable path it would travel through the elbow-joint turns in the pipe.

As data began to come in from these tests, the program decided to convene a second FRR on February 20, although some members of the engineering and safety organizations expressed doubts about the timing of the review.

One NDE technique that was initially dismissed was an eddy-current system, because the size of the probe head was too large for the valve.

The Marathon FRR

The second FRR for STS-119 lasted nearly fourteen long hours, and the outcome was not clear until the end. "It was much more of a technical review than typical Flight Readiness Reviews. There was a lot of new data placed on the table that hadn't been fully vetted through the entire system. That made for the long meeting," said FRR Chairman Bill Gerstenmaier.

Well over a hundred people were in the Operations Support Building II at Kennedy Space Center, seated around the room in groups with their respective organizations as technical teams made presentations to the senior leaders on the FRR board. Some participants believed that the analysis done on the potential risk of a valve fragment puncturing the tubing that flowed hydrogen from the external tank to the shuttle main engines showed that the risk was low enough to justify a decision to fly. Others remained concerned throughout that long day about the fidelity of the data, and that they didn't know enough about the causes of the valve failure and the likelihood and risk of its occurring again.

Despite the tremendous amount of analysis and testing that had been done, technical presentations on the causes of the broken valve on STS-126 and the likelihood of recurrence were incomplete and inconclusive. Unlike at most FRRs, new data, such as computations of loads margins that couldn't be completed in advance, streamed in during the review and informed the conversation. A chart reporting margins of safety included "TBD" (to be determined) notations.

Doubts about some test data arose when Gene Grush received a phone call from Stennis informing him that the test program there had used the wrong material. "I had to stand up in front of that huge room and say, 'Well there's a little problem with our testing. Yes, we did very well, but the hardness of the particle wasn't as hard as it should have been.' That was very critical because that means that your test is no longer conservative. You've got good results, but you didn't test with the right particle," he said.

NASA Chief Safety and Mission Assurance Officer Bryan

Space Shuttle program and mission managers meet for a Flight Readiness Review of STS 121.

Photo Credit: NASA/Kim Shiflett

O'Connor remarked, "Gerst [Gerstenmaier] was absolutely open. He never tried to shut them [the participants] down. Even though he could probably tell this was going to take a long time, he never let the clock appear to be something that he was worried about."

Toward the end of the meeting, Gerstenmaier spoke about the risks to the ISS program and to the shuttle schedule of not approving *Discovery*'s launch. A few participants perceived his comments as pressure to approve the flight. Others saw it as appropriate context-setting, making clear the broader issues that affect a launch decision. After he spoke, he gave the groups forty minutes to "caucus," to discuss what they had heard during the day and decide on their recommendations. When they came back, he polled the groups. The engineering and safety organizations and some center directors in attendance made it clear that they did not find adequate flight rationale.

Bill McArthur, safety and mission assurance manager for the Space Shuttle at the time, said, "The fact that people were willing to stand up and say, 'We just aren't ready yet,' is a real testament to the fact that our culture has evolved so that we weren't overwhelmed with launch fever, and people were willing to tell Bill Gerstenmaier, 'No, we're no-go for launch.'"

As the participants filed out of the meeting, Joyce Seriale-Grush said to Mike Ryschkewitsch, "This was really hard and I'm disappointed that we didn't have the data today, but it feels so much better than it used to feel, because we had to say that we weren't ready and people listened to us. It didn't always used to be that way."

New Information

Charles Bryson, an engineer at Marshall Space Flight Center, used his eddy-current probe equipment with a relatively large probe head to inspect a poppet and his inspection, confirmed by other analysis, indicated that the eddy-current inspection technique showed promise in finding flaws. Propulsion Systems Engineering and Integration Chief Engineer at Marshall Rene Ortega told colleagues from the Materials and Processes Problem Resolution Team about Bryson's eddy-current inspection results. Ortega helped arrange for Bryson to examine several poppets at Boeing's Huntington Beach facility. Bryson then worked collaboratively with a team from Johnson led by Ajay Koshti, an NDE specialist with expertise in eddy-current investigations. Koshti brought an eddy-current setup with a better response than Bryson's, and together they arrived at a consistent inspection technique.

"Once we were able to screen flaws with the eddy current and there wasn't a need to polish poppets with the process," Ortega explained, "we had a method by which we could say that we … thought we're pretty good at screening for non-polished poppets."

Engineers had found that some of the smaller flaws identified in the poppets didn't seem to be growing very fast. "Through that exercise, we came up with the suggestion that, 'Hey, it doesn't look like these flaws are growing out very rapidly in the flight program, and with the screening of the eddy current we can probably arrive at a flight rationale that would seem to indicate that those flaws being screened by the eddy current wouldn't grow to failure in one flight,'" Ortega said. The eddy-current technique was not a silver bullet, but in conjunction with the other techniques and test data, it provided critical information that would form the basis for sound flight rationale.

The Final FRR

With the results from the test programs all now supporting a shared understanding of the technical problem, there was wide consensus among the community that the third Flight Readiness Review, on March 6, would result in a "go" vote.

"By the time we eventually all got together on the last FRR the comfort level was very high," said O'Connor. "For one thing, everybody understood this topic so well. You couldn't say, 'I'm uncomfortable because I don't understand.' We had a great deal of understanding of not only what we knew about, but what we didn't know about. We had a good understanding of the limits of our knowledge as much as possible, whereas before we didn't know what those were."

The FRR board agreed and STS-119 was approved for launch on March 11. After delays due to an unrelated leak in a liquid hydrogen vent line, *Discovery* lifted off on March 15, 2009, and safely and successfully completed its mission. ●

INTERVIEW WITH

Rob Strain and Lesa Roe

BY ED ROGERS

Ed Rogers, chief knowledge officer for the Goddard Space Flight Center, recently sat down with two center directors—Rob Strain of Goddard and Lesa Roe of Langley Research Center. He asked them about collaboration, partnerships, and how their centers are learning to work well together.

ROGERS: Both of you come with some industry experience and knowledge of other NASA centers. What do you bring to the center director job that can help NASA and your respective centers meet the challenge of complex partnering?

STRAIN: I think that our missions in the future will all entail partnership involvement because of the size of the missions, the nature of international research, and the capabilities that industry and academia bring. The fact that I've had different sorts of roles in different organizations might help me see those multiple perspectives a little better.

ROE: My background includes working at multiple NASA centers—Johnson, Kennedy, and now Langley—which gives me an interesting mix in that it includes both space and research centers. I have also worked in industry. So I, like Rob, am able to think about multiple perspectives when I look at a challenge. I also see the tremendous value that the diversity of different organizations brings. Their solutions to problems are far superior to ones provided by isolated thinking.

STRAIN: I agree. Say, for example, we're having a difference of opinion with somebody—another center, a partner in academia, a big-name PI [principal investigator], or an international partner. I start with, "What do you think they're thinking? If you were in their shoes, how would you view this?" I would push to

> “SAY, FOR EXAMPLE, WE’RE HAVING A **difference of opinion** WITH SOMEBODY …. I START WITH, “WHAT DO YOU THINK **they’re thinking**? IF YOU WERE **in their shoes**, HOW WOULD YOU **view this**?” ”

the point where I’ll ask people to make the case for the partner. If we have an external PI, for instance, I want them to think about, why do you suppose he’s angry, or why do you suppose she has this issue? Or if we’re debating issues on performance with a contractor, are they having problems with us? Often the answer is, “Hmm, I didn’t think about that.” Well, if you were them, what would you do? They go through this process, and then they say, “Okay, now I know what to do.”

ROE: Rob and I have a very similar approach when someone brings a problem up, especially a problem with another center or a partner. You have to put yourself in their shoes to find the best way forward. It is very easy to wallow in how bad the other organization is, but that gets you nowhere fast! It is very important to me to get all perceptions out in the open, jointly come up with a plan, and hold ourselves accountable to the plan.

ROGERS: It seems that there is some competition among centers, but it’s also in their best interest to cooperate. How do you deal with the competitive nature of NASA work?

ROE: We are always looking to develop partnerships with other centers on projects whether there is competition or the work is directed to a particular center. Just as with industry, centers will sometimes partner or be competitors depending on the requirements for a specific opportunity. In either case, we are trying to assemble the best team and contribute in a way that will make the project successful. Mission success is NASA success—everyone really believes that inside. We just need to make sure we don’t let the way we organize ourselves get in the way of the commitment our people have to mission success.

STRAIN: It’s important to remember that we’re not only competing intramurally within NASA, but also with industry and academia, and that keeps us sharp. I think if we didn’t have some component of competition, we might wake up one day and not be on that leading edge. I wouldn’t argue that we should swing down that continuum too far, because competition has an unproductive side, too. The place we've arrived at recently, where a good portion of the work is assigned and a smaller portion is competitive, strikes me as about the right balance.

ROGERS: Partnering between Goddard and Langley is not new. How have you approached Goddard in your current partnership on CLARREO [CLimate Absolute Radiance and REfractivity Observatory]? Are you applying lessons in this area of cooperation learned from past missions and, if so, how are you applying them?

ROE: Carefully [laughing]. We have had some hugely successful partnerships with GSFC [Goddard], but after our CALIPSO [Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations] experience—where many lessons were learned the hard way—we wanted to start out right with the next joint mission. When it came along, Rob and I decided we needed some face-to-face discussions followed up with a memorandum of understanding defining roles and responsibilities. We had some sessions with both centers' senior management teams, where we put all the concerns, fears, perceptions on the table. The teams worked to negotiate each center's roles and responsibilities, with the focus on using each center's capabilities to maximize the probability of project success. We documented them in the MOU [memorandum of understanding] between the centers, which was reviewed and signed by both centers' senior management teams. We are also committed to holding all team members fully accountable for implementing the partnership agreed to in the MOU.

STRAIN: We actually wrote case studies on CALIPSO and STEREO [Solar TErrestrial RElations Observatory] that focus on the team-management aspects of the project, and we've learned some important lessons. CALIPSO, a mission jointly managed by Goddard and Langley, was marred, like STEREO—a mission run with APL [Applied Physics Laboratory]—by interorganizational strife. So when Goddard and Langley ended up in a partnership again, I called Lesa, and we had our organizations spend an entire day together to let it all hang out. I think it was therapeutic for everyone, if a bit awkward, but that's how the real lessons get applied and not buried in half-truths. CALIPSO and STEREO are both successful missions, but everyone agreed that the way we got there left much to be desired. I'm sure we won't get it perfect this time, but we're certainly going to try to apply as many lessons as we can up front.

ROE: People at Langley and Goddard are applying the lessons we learned from CALIPSO, but this is not a situation where you can assign an action, check the box, and you are done. It is going to take focus by Rob and me and our leadership teams to make sure there is no fallback. During our Langley/GSFC meetings, we specifically discussed challenges we faced in our collaboration on CALIPSO. These ranged from unclear roles and responsibilities to poor communication between center senior management and with Headquarters. In the past, unclear roles generated confusion within the project team and mistrust between center leadership. We worked extremely hard to avoid these unproductive situations in crafting current partnerships, particularly for the CLARREO mission. We have had a fully integrated team leading up to MCR [mission concept review] involved in the design of the mission. Specifically, we organized the science team with a deputy project scientist at GSFC and scheduled biweekly telecons between the Langley Science director and the Goddard Earth Science Division director. This already has paid off during the discussion of a sensitive decision concerning adding an instrument to CLARREO. By working closely with GSFC management ahead of time, we were able to reach a joint recommendation that has been accepted by Headquarters. I sincerely believe we have established a strong partnership on CLARREO where everyone is focused on mission success. Both organizations have worked hard at clear and frequent communication at all levels, and we have made tremendous progress.

ROGERS: The lessons you two are talking about are not the usual lessons learned; you are talking about teaming and communication. Are people receptive to paying attention to these "soft" lessons?

STRAIN: Totally. When we actually got into how to execute this new mission, Langley brought their team up, and at first it was "you did this" and "you did that" and "we didn't appreciate that." Like I said, we really let it all hang out. And at the end people said, "Oh, I see your point," and, "Well, yeah, I wouldn't do it that way but I see your logic." Our MOU includes a behavior clause. Lesa and I put in a clause about how we expect people to behave so that when the project gets into the thick of things, people will say, "The agreement wasn't just you do this and I do that," but, "This is how people ought to behave and follow some protocol." There were some hard feelings left from previous missions. We said, "We can relive this, or we can do it differently." I think we all decided to do things differently.

ROE: I agree with Rob. In addition to specifying the roles, we had to replan the project as agency requirements evolved and changed—the CALIPSO project began during the "faster, better, cheaper" era at NASA. What Langley proposed as a PI-led mission with limited insight and oversight of contractor activities and a partnership with CNES [the French Space Agency providing the spacecraft and one instrument] began to change after the Mars Polar Lander and Mars Climate Orbiter failures. One thing we are trying to apply with CLARREO is that the proposed resources must match the project plan, which must be consistent with current agency policies and requirements. Another lesson is recognizing the resources needed to manage a complicated partnership itself. With CALIPSO, we probably underestimated the added complexity and challenges of the partnership with CNES. Cultural differences, time zone differences, communication issues, ITAR [International Traffic in Arms Regulations], etc., led to many long telecons and meetings between the NASA and CNES teams to develop requirements and ensure they were met. That effort takes resources, and we want to plan for that kind of need in future partnerships. Although CLARREO may not have an international partner, we will be partnering with Goddard and maybe other centers, other government agencies such as the National Institute for Standards and Technology, universities, and industry. We must ensure that the project organizational structure and staffing plan account for the complexity driven by these partnerships and contracts and budget for them. Finally, leadership must focus the team on mission success beyond just center success. With CLARREO I believe the senior leadership at both centers is working very effectively and paying great attention to ensure each center is focused on mission success. We bring the best, most appropriate capabilities from each center to bear in order for CLARREO to be successful. We are committed to building a dedicated, highly motivated Langley/Goddard CLARREO team.

ROGERS: Where else do you see exciting partnerships shaping the future for NASA?

STRAIN: I'm excited about what Wallops is bringing, not just to Goddard—though that is great—and not even just to NASA, but to the broader community, because they will do commercial, scientific, and military missions at price points we don't have access to today. Orbital Science picked Wallops to be the place where they're going to develop their new rockets for crew resupply and also for Taurus 2.

ROE: We've had numerous successful partnerships with Wallops, including the recent Max Launch Abort System test for the new crew exploration vehicle. We utilize the Wallops Unpiloted Aerial Vehicle runway and range to conduct important flight controls research for the Aeronautics Research Mission Directorate. We also recently had a highly successful flight of a first-of-its-kind inflatable reentry vehicle on a sounding rocket from Wallops. This was the first flight demonstration of a technology that could enable the landing of much larger systems on Mars or returning spacecraft to Earth. So we have collaborated with Wallops to utilize their flight-test capabilities for research- and technology-demonstration activities. This is a great example of taking advantage of the capabilities at both centers to do something neither could do alone.

STRAIN: Lesa is absolutely correct—Wallops is a great example of getting more done by collaboration. Wallops could be for NASA, the commercial community, and the military the resource for cheap, midsize access to space, at price points of $50 million or $60 million, not the current $200 million. They've always done good work with balloons and suborbital missions. They're very clever—they can do more with a dollar than anyone else, I think, at NASA. They pride themselves on it, and I love what they're doing. It's great being connected with Wallops, Virginia, and Langley. I think together NASA is a better place by having different ways of doing things all for the same goal: to better understand our Earth, our solar system, and ultimately our universe. ●

The CALIPSO and STEREO case studies mentioned are available on the Office of the Chief Knowledge Officer Web site at www.nasa.gov/goddard/ocko.

The Revolution of Social Innovation: Emerging Lessons for Large, Complex Organizations

BY BROOK MANVILLE

Finding new sources of inspiration and creative ideas is easier said than done—mandates to just "start thinking outside the box" are hardly the answer. The innovating organization looks constantly to often unfamiliar models and sources of inspiration, challenging itself to understand when and how someone else is "changing the game"—and what it might mean for them. Breakthrough ideas come when someone dares to look beyond the predictable boundaries of "how we normally work in our industry." One source of new thinking still unfamiliar to most organizations is the emerging field of "social innovation."

The Rising Tide of Social Innovation

Social innovation has captured the imagination and enthusiasm of legions of young, new professionals and is drawing millions of philanthropic dollars to its pioneers. It is spawning thousands of new Web sites and bloggers; some state governments and the Obama administration are authorizing special funding for it; colleges and universities are establishing new degrees and academic programs about it. It is generally shaking the traditional assumptions and operations of the nonprofit sector. Some fresh thinking from this rising revolution may be an opportunity for others who are not themselves "social innovators"—even leaders of major enterprises not necessarily in the business of "saving the poor." So what might be learned from this evolving phenomenon? Are there lessons about innovation for any organization?

Social innovation is a developing set of new approaches to solving social problems, born out of the frustration and persisting shortfall of traditional nonprofits' efforts to address the problems of society. Social innovators believe that such problems can be tackled by bringing entrepreneurial thinking and market-based problem solving to social issues, novel and transformative approaches to change the status quo, and strategic efforts to spread success. Some social innovations—the charter school movement, microfinance, the "fair trade" branding movement are examples—have become well known, but there are also now thousands of smaller organizations capitalizing on new approaches to solving social ills, creatively bringing to bear business strategies or new uses of technology or some "turn-it-on-its-head" new process to tackle homelessness, declining crop yields in the fields of Kenya, shortages of supplies in U.S. urban schools, or the lack of sanitation in rural villages in India.

For leaders seeking new sources of creative thinking and new ways to create value, social innovation can be a promising arena from which to learn. Like the social innovator, leaders of large and complex organizations face seemingly intractable problems they need to solve despite barriers such as the morass of bureaucracy, too little funding, and a shortage of motivated people. Imagine your own organization today: are your challenges any more pressing and difficult than motivating underpaid teachers in an urban school, providing clean water to poor villagers living in the squalor of lands polluted by animal waste, or preparing former prisoners for a productive return to society?

Obviously each successful individual case has its own structure and strategies, but we can identify a few themes of potential application to any organization seeking to create its own innovative approaches.

Simple Technology Often Wins

How many projects in large, complex organizations become large and complex because of this or that huge IT investment intended to bring together and analyze all the information needed by different users in every different configuration possible? Many large projects are delayed, run overbudget, or even ultimately fail when the key problems might have been solved by a simpler approach, using less but more targeted technology—typically everyday technology already in the hands of users. Social innovators, who normally lack the resources and infrastructure for complex systems, often call upon what is literally at hand—for example, collecting and distributing market prices over cell phone SMS messages to poor farmers in Africa, allowing them to bypass exploitative middlemen and gain more profit for their work in the fields, or distributing basic health information to indigent villagers about infection, HIV, and maternal care using the same simple medium, as the Grameen Foundation does.

In other words, consider simple and basic solutions to capture value faster and cheaper. African fields in many countries are now being irrigated without electricity or complex machinery by simple bicycle-like pedal pumps. Charles Best, a U.S.-based social innovator, created a minor revolution in funding supplies for poor public schools with the elegant idea of allowing teachers themselves to post specific needs for their classrooms on his "Donors Choose" Web site; donors can browse through the advertised needs and in a simple and targeted way provide money for calculators, new books, or basic furnishings for underequipped classrooms. Before "Donors Choose," funding for school supplies was caught in the bureaucracy of district budgets and complex allocations; that's not gone away,

… INNOVATIONS ARE SPREAD BY PEOPLE-TO-PEOPLE RELATIONSHIPS, WITH IMPACT GROWING MORE THROUGH THE INFORMAL TRANSFER OF VALUES AND KNOWLEDGE FOCUSED ON A SHARED MISSION THAN FORMAL INFRASTRUCTURE.

but entrepreneurial teachers can now cut through the red tape and rapidly get what they need, thanks to the small-scale philanthropy of private donors—brokered through a basic Web site open to the public.

Breaking Silos with Hybrid Approaches

The bureaucracy of large organizations stifles projects and frustrates customers with the all-too-common cry of "not my department"—when in fact the solution to a problem or the opportunity to be captured is all about putting the ideas of different departments together. Managers become frozen by the mind-set that they must control all that reports to them and work around all that does not; similarly, most believe that there is one way of doing things within an industry or unit that defines how that enterprise works and differentiates it from other enterprises. The hardware people make hardware, the software people make software, and never the twain shall meet. Yet when they do meet, wonderful things can sometimes happen.

Social innovators create often unpredictable value by jumping across traditional categories and breaking silos with cross-domain thinking and collaboration, combining unexpected entities, processes, or multiple approaches to problems in a new composite solution. The citizens of Nairobi long believed that public sanitation, when it existed at all, was the province of the not-very-efficient municipal authorities—until a social entrepreneur named David Kuria created a successful network of pay toilets combined with related small businesses in the slums of the city. Co-designed with members of the community, featuring innovative design and operations that also provide energy recycling and reuse of waste for farming, the "IKO" toilets have become profitable community institutions, funded not just by users but also investors and retailers who use the sites to set up adjacent micro-businesses such as shoeshining, retailing, and phone-card sales.

The citizens of Mumbai until recently despaired about their hopelessly inefficient municipal ambulance service, but with the launch of an entrepreneurial nonprofit organization "1298" (the telephone number of the new service), they now have a separate, high-quality response that combines a state-of-the-art call center and information-technology tracking with a network of privately maintained emergency medical vehicles. 1298 uses an innovative business model whereby better-off patients cross-subsidize less-well-off patients on an ability-to-pay basis, and prices further vary depending on the quality of the hospital the patient desires. Another innovative hybrid organization is the "Partnership for Quality Medical Donations" (PQMD), a consortium of pharmaceutical and medical-supply companies that work with relief organizations serving needy populations around the world; the manufacturers combine their product know-how and supply with the nongovernmental organizations' (NGO) distribution and on-the-ground knowledge of community health organizations to create an integrated end-to-end supply chain. The unique partnership thus provides access to donated pharmaceuticals and other health-care supplies for people in need all around the world. In these and many other cases, new value is created by bringing together often unfamiliar partners or processes, spanning boundaries embodied in traditional categories of industry or service.

Leveraging Networks for Scale

PQMD is an example of another common strategy in much of social innovation—using networks and a range of "softer" or more informal relationships to spread programs and create more impact. The combined networks and relationships of all the NGOs in PQMD provide much greater reach and distribution than any single organization, and more than all the pharmaceutical manufacturers can hope to achieve on their own; the heart of the consortium is a set of core values and a commitment to mission that binds the different networks of the members into an integrated whole.

Root Cause, a social-innovation consulting and research organization, has created a path-breaking funding marketplace in Boston (the "Social Innovation Forum"), bringing together donor-investors and their networks of socially minded colleagues with rising community innovators who need knowledge, visibility, and operating capital to advance their work in health, education, and other human services. Thanks to these networks, much more funding is now available to the social entrepreneurs

of metropolitan Boston; other municipalities have expressed interest in the model, and Root Cause is building networks to support the spread of the innovation.

Another network-building story can be found in the Nyala Dairy Cooperative in Kenya. The cooperative, aided by pioneering work of the social-innovation consulting organization TechnoServe, built a wide range of community networks and for-profit business relationships (leveraging both commercial and traditional tribal relationships) to make its dairy the hub of a much larger commercial and social center. The network expansion now brings more economic prosperity to an increasingly large population in the region. Teach for America, the social innovation of Wendy Kopp that recruits and places "best and brightest" graduating college students in poverty-stricken urban and rural school districts, continues to build its impact not just through the development of its corps of teachers, but also through networks of alumni who collect and share best practices and help recruit future members. In these, and thousands of other cases, innovations are spread by people-to-people relationships, with impact growing more through the informal transfer of values and knowledge focused on a shared mission than formal infrastructure.

Mission-Driven Performance and the New Kind of Leadership

The motivating power of mission is another critical attribute of social innovation. Though nonprofits have long called on the shared values and shared purpose of noble missions to engage volunteers and staff, social innovators up the ante. Leaders of social innovation seek solutions that are more rapid, measurable, and disruptive; they make the call to mission a deep and penetrating part of all that they and their organizations do. At the same time, the leadership style of social innovators is neither messianic nor ego-driven; depending on networks, rapid problem solving, and widely distributed learning and change, the best socially innovative leaders share responsibility within their organizations and across the networks they call upon and do all they can to replace hierarchy with purpose-driven collaboration.

That style of leadership is further enhanced by social innovation's insistence on measurable performance, accountability, and transparency. When all are committed to mission and results, and when all engage in new ways of working and solving problems in order to break through persisting, complex barriers, there is no tolerance for the pomp of position or the hoarding of knowledge or authority for personal gain. The common themes of these innovators are not "me" but "us," not "glory" but "impact." Thus the comment of Charlie Brown, the leader of Ashoka's open-source social-solution network, Changemakers.net: "There are better ways to change the world than building a personal empire."

A Challenge for All

Not all problems or opportunities are suitable for social innovation, nor is social innovation a panacea for all that ails humanity or a particular organization. But more and more organizations adopting the social-innovation approach are getting traction in problem arenas long written off as hopeless. At the same time, like other revolutions through history, this one may be as valuable for the broader and longer-term effects it catalyzes as for the immediate change it brings. We may hope and pray that creative social innovation finds new and better ways to educate children, provide better health and living conditions for the poor, and make a dent in ending domestic violence or global pollution. If it also serves to inspire leaders in any organization to work in new, better ways, it may deservedly live beyond the excitement of the moment. ●

BROOK MANVILLE consults to "socially minded organizations," including many social innovators, as Principal of Brook Manville, LLC. Based in Washington, D.C., he can be reached at brook@brookmanville.com.

Phaeton: Learning by Doing

BY JOHNNY KWOK

Recent graduates working at the Jet Propulsion Laboratory (JPL) face a familiar dilemma: project managers want individuals with experience, but how do you get the necessary experience if your lack of it prevents managers from hiring you? JPL has inaugurated a training program to address this problem.

HOW DOES ONE TRAIN AN EARLY-CAREER HIRE TO BE ASSERTIVE AND YET BE HUMBLE, TO LEAD AND TO FOLLOW, TO COUNT ON SENIORS FOR ADVICE AND YET BE AN INDEPENDENT THINKER, TO EARN RESPECT WHEN EVERYONE KNOWS YOU ARE AN EARLY-CAREER HIRE?

It was around Halloween in 2007 when Benjamin Solish, who had been employed at the lab for about six months, drew the short straw among his peers and fired off an e-mail to JPL Director Charles Elachi.

"Dear Dr. Elachi," it began, "as you may know, the X PRIZE Foundation recently released a challenge to the engineering community to send a rover mission to the moon. Our team, all early-career hires at JPL, is excited to answer that challenge." Early-career hire is a designation for employees less than three years out of college.

The e-mail contained a request to use JPL facilities to compete in the Google Lunar X PRIZE and mentioned that this would be a chance for younger employees "to gain valuable end-to-end experience on a small-scale mission, which would greatly benefit our future work at JPL." It was signed "The Phaeton Explorer Team," followed by the names of seven early-career hires.

To their surprise, the Phaeton Explorers received an e-mail back from Elachi requesting to meet with them. During the meeting, Elachi channeled their shoot-for-the-moon enthusiasm into creating a one-of-a-kind training program that would achieve their original objective. After several months of brainstorming and iterations with upper management and Elachi, the Phaeton Program was born.

The group's recommended approach for the program included developing small payload projects with a life cycle of about two to three years and start dates separated by about one year. Participants would be assigned multiple positions on Phaeton projects in different phases of each mission's life cycle—projects would mimic JPL flight projects but be staffed by early-career hires, including key management positions. Each year the program would solicit early-career hires who would devote half to three-quarters of their time to the program for a period of up to eighteen months. The plan also called for a Phaeton advisory board to annually select project concepts, and for the recruiting and funding of mentors.

With an institutional blessing, committed training funds, and a dedicated facility, the Phaeton Program office was formed in June 2008. Six concepts were evaluated based on criteria that included technical feasibility as a project managed by early-career hires, cost and schedule risks, diversity of hands-on experience, and relevance to JPL/NASA mission statements. Two projects were selected to proceed to Phase A definition. A call for applicants was issued. Out of a potential pool of two hundred eligible early-career hires, seventy applications were received and about twenty people were selected.

One of the selected projects is Phaeton Mast Dynamics (PMD), a collaboration with Caltech and the NuSTAR project, a high-energy X-ray telescope scheduled for launch in August 2011. PMD will measure and characterize the dynamic behavior of the 10-meter boom of the telescope. "During my career at JPL, I've been exposed to a lot of Phase C and D work, but I have never been given the opportunity to be involved in Phase A and B work," said project manager Lauren Halatek of the measurement systems group. "Phaeton is a great learning experience," Halatek said. "I have a lot more respect for those who have been here a long time and make it look so easy." PMD plans to deliver the payload to NuSTAR in March 2010.

The second selected project proposed furthering the technology of terrain-relative navigation using a yet-to-be-determined suborbital vehicle as a carrier for the payload comprising imaging and inertial reference units. The group was struggling with the affordability of the suborbital vehicle when JPL received notification of the training opportunity called Hands-On Project Experience (HOPE), issued by NASA's Science Mission Directorate, the Office of the Chief Engineer, and the NASA Academy of Program/Project and Engineering Leadership. HOPE's training objectives are exactly what the Phaeton program is designed to accomplish. Furthermore, it provides for a sounding rocket from Wallops Flight Facility. What luck!

True to the intent of Phaeton as a training program, the focus of this group of early-career hires was redirected toward proposal and formulation training instead of implementation training. In addition to proposal classes, the early-career hires were assigned roles in proposal definition and production and matched with mentors with relevant experience. The effort paid off with the selection of the winning proposal in April 2009, called Terrain Relative Navigation and Employee Development (TRaiNED). TRaiNED will be launched in June 2010.

"The Phaeton Program gave a group of early-career hires an opportunity to learn the JPL formulation process from a group of senior, experienced mentors," said Don Heyer, the project manager for TRaiNED. "The fact that we won just makes it even more rewarding."

With these two projects completing in 2010, another project was selected in June 2009 for Phase A concept definition: the Optical Planetary Access Link for space station. This project will validate optical acquisition and tracking algorithms and mechanisms intended for use on Mars by placing an instrument on the International Space Station.

More Than Engineering and Science

The Phaeton experience isn't limited to the lab's early-career engineers and scientists.

"Phaeton was designed for the development of both technical and business professionals," noted Hosanna Aroyan, project resource analyst and business administration manager for Phaeton. Aroyan, also an early-career hire, believes learning to manage the business components of flight projects through Phaeton will pay dividends for the lab over time: "A business professional that understands and can communicate the needs between line and project management is important. Phaeton, through the participation of actively involved mentors, allows for that development to occur early in our career."

"As the Phaeton training lead, it's my task to create a curriculum of classes, tours, field trips, and observational opportunities to complement their hands-on experience. This has provided me with a clearer understanding of JPL's project life cycle and all that's involved in making each step happen," said Betsy Riley, who is an early-career hire from Professional Development in the Human Resources Department.

Supplying business and flight-project experience to early-career hires was a complex notion that came from the ground up. "When you first get to the Lab, you get pigeonholed into one area," said Solish, one of those who worked early on to develop the Phaeton concept and is now a systems engineer for TRaiNED and an advisor to the Phaeton Program. "Phaeton is not just networking; it's understanding how the Lab is put together and how it works," he said.

Darren Michaels was working on a conceptual design of analog circuits for the future Europa Orbiter when he was selected as the lead electrical engineer on PMD. "In fifteen short months we have turned a basic napkin-drawing concept into a real flight instrument. Now, as the flight hardware evolves, we even have the opportunity to problem-solve some anomalies that came up during flight environmental tests," he explained. "These are real tasks and situations that all projects experience, and it is very exciting to go through the full experience so fresh out of college. Where else can new hires obtain such comprehensive training on building and delivering spacecraft payloads?"

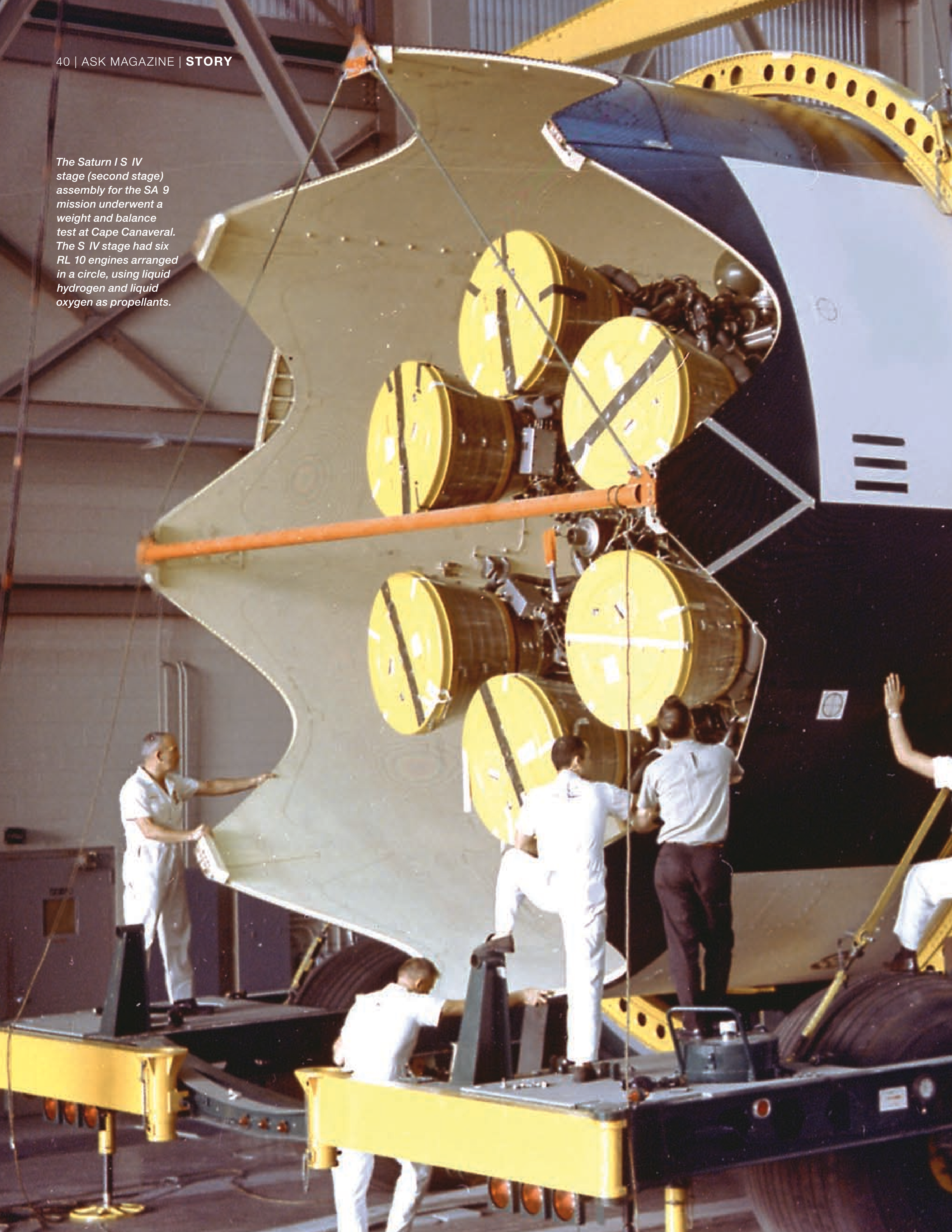
The fulfillment of being part of the Phaeton Program is not limited to early-career hires. "It is an amazing experience working with such talented new engineers," said Calina Seybold, the senior engineer who is the systems engineering mentor for TRaiNED. "An especially gratifying moment came after the TRaiNED HOPE proposal was submitted, when I was presented with a thank-you card containing a handwritten note from each member of the early-career hire team."

There are challenges in managing a training program of this nature. I found myself frequently having to remind supervisors and early-career hires that this is not just a training program. There are schedules, deliverables, and cost commitments. Although I found no shortage of mentors for technical training, it is much harder to find mentors to guide the early-career hires to develop leadership skills. How does one train an early-career hire to be assertive and yet be humble, to lead and to follow, to count on seniors for advice and yet be an independent thinker, to earn respect when everyone knows you are an early-career hire? And yet, in the past eighteen months, I have seen this group of early professionals mature in their skill and thinking, gain each other's respect, and establish lifelong camaraderie.

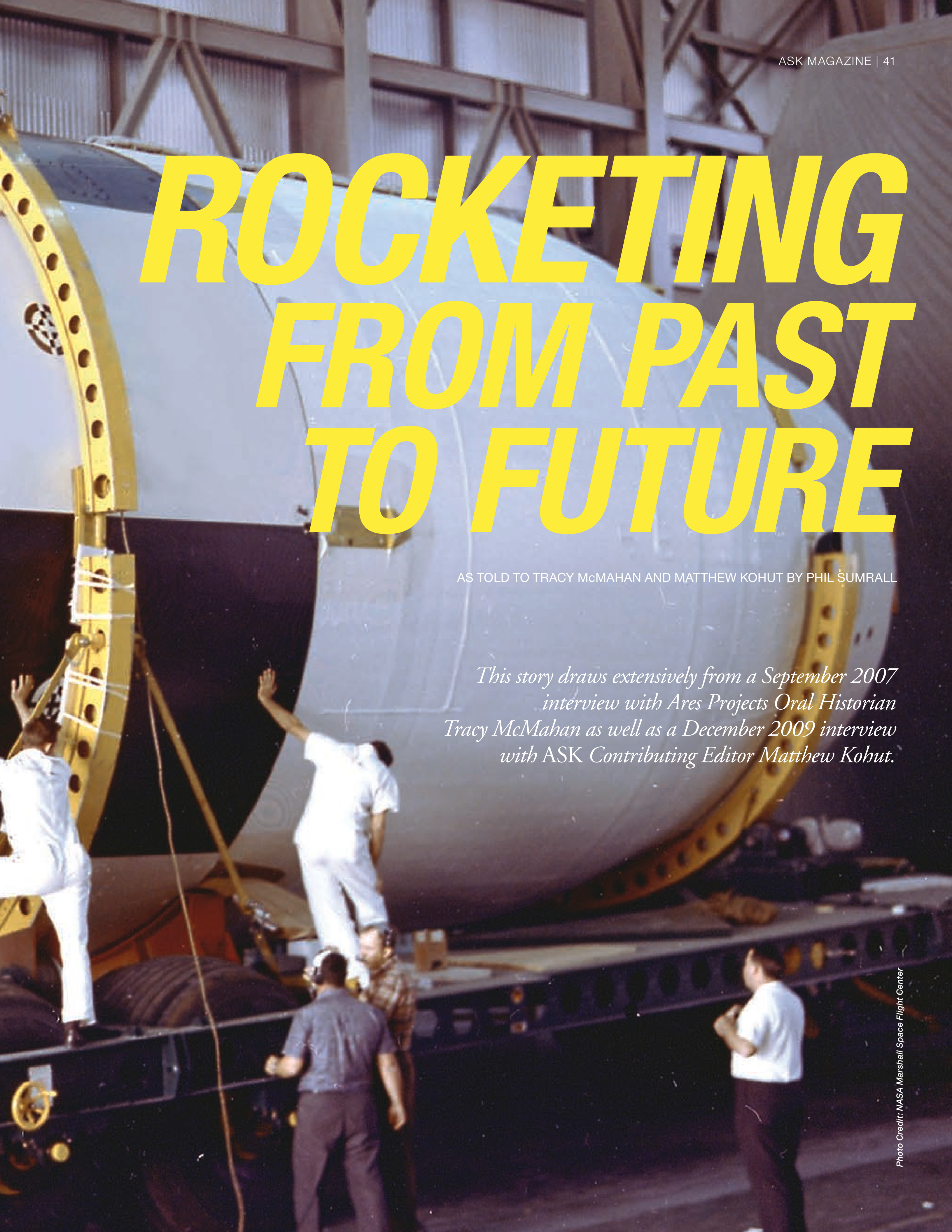
Although the idea to compete against industry for Google's $30 million prize purse was rebuffed, the Phaeton Explorers won another prize. They became the catalysts to developing future leaders for JPL and beyond. ●

For more information about the Phaeton Early-Career Hire Development Program, visit phaeton.jpl.nasa.gov.

JOHNNY KWOK is the assistant director for formulation in the Engineering and Science Directorate at the Jet Propulsion Laboratory. In addition to being the program manager for Phaeton, he oversees activities in workforce planning, concept development, and costing.



The Saturn I S IV stage (second stage) assembly for the SA 9 mission underwent a weight and balance test at Cape Canaveral. The S IV stage had six RL 10 engines arranged in a circle, using liquid hydrogen and liquid oxygen as propellants.



ROCKETING FROM PAST TO FUTURE

AS TOLD TO TRACY McMAHAN AND MATTHEW KOHUT BY PHIL SUMRALL

This story draws extensively from a September 2007 interview with Ares Projects Oral Historian Tracy McMahan as well as a December 2009 interview with ASK *Contributing Editor Matthew Kohut.*

Photo Credit: NASA Marshall Space Flight Center

The Saturn V vehicle (SA-501) for the Apollo 4 missions stands on the Crawler Transporter Vehicle. The Apollo 4 mission was the first launch of the Saturn V launch vehicle.

Photo Credit: NASA Marshall Space Flight Center

A Chance Encounter at the Barbershop

I was fortunate enough to accidentally meet Dr. Wernher von Braun on a Saturday morning in the early spring of 1962 at a downtown barbershop in Huntsville, Alabama. I was waiting my turn, and Dr. von Braun came in and happened to sit down next to me. He had a number of papers in his hands, and he was thumbing through more papers in his briefcase.

He worked for a while—I would say a half hour or so—and then he put his papers away, closed the briefcase, and struck up a conversation. Of course, I knew immediately who he was; he had no idea who I was. He was very, very friendly, very charming. He asked me what I was doing, and when I told him I was teaching math and science in a local private school, he asked about what classes I had taken in college, what I had studied, what my major was, and that sort of thing. I was amazed at how curious he was about everything.

He wanted to know every course that I had taken, basically what the courses covered and what kind of grade I had made and so forth. We had a lot of time to wait, and he interviewed me pretty thoroughly, and at the end of it he said, "Well, have you ever thought about working in the space program?"

I answered honestly that I had not. He said, "Well, if you ever decide that you would like to work in the space program …." He gave me a name and phone number and said to call this individual. "Tell him that you and I have talked, and that I thought there was a place for you at Marshall Space Flight Center," he said. At that time, I was not seriously considering changing careers. However, a few months later in June, after the school year was out, there were reasons that I decided I perhaps didn't want to return for another year.

I called the personnel office and eventually talked with the individual who Dr. von Braun had recommended. Turned out he was the director of the personnel office at Marshall, and he arranged an interview the next day with Helmut Bauer, who worked in the aeroballistics area. He told me that they would offer me a job, and I was called by personnel the very next day and formally offered the job. I reported to work the second of July 1962.

Engineering Then and Now

I worked primarily on the Saturn V, and looking back on it now, we just didn't have good analytical tools at all. It was very primitive. For example, one of the things that I worked on was dynamic stability and wind response. The vehicle is not a rigid body. It may look rigid, but it bends, and that little bit of bending corrupts the signals to the rocket-control sensors. The vehicle may be going absolutely straight, but if it's slightly bent, the sensor may think it's deviating from its path and try to bring it back on course. When it does that, it may cause it to bend more, and may start an oscillation that, instead of damping out, builds up. Couple that with the fact that you have propellant tanks that are quite large, and the propellant sloshing in those tanks creates enormous forces, which in turn can cause the vehicle to bend. It is all a complex set of system interactions.

I was working for Helmut Bauer, who was considered one of the foremost experts in modeling propellant slosh. We had to build analytical models, and we had relatively crude computers compared with what we have today. We just didn't have the tools to make complex models.

We built the Dynamic Test Stand facility, which at the time was the tallest self-supporting structure in the state of Alabama. We built that so we could put this gigantic Saturn V in there and excite it and actually measure its bending characteristics. From that, we would validate the analytical models and design the control systems. Today we have discussions about whether we even need to build the large, structural test articles for ground-vibration testing because our models are that good. Back in the Saturn days, we built these large test facilities and all the structural articles and did the best we could analytically, and we still weren't confident we had it right. The power of the models that engine designers have today is just beautiful.

We test a lot in the wind tunnel now, and a lot of what we do is calibrate and validate the computational fluid dynamics, which would not have been possible in those days because we didn't have the computational capability to build very sophisticated models; aerodynamic flows are very complex and require extremely large and fast computers. We find now that we can avoid a lot of wind-tunnel tests with the aerodynamic analytics that we generate through computational fluid dynamics. That's just one example of how far the models have come in the past several years.

Lessons of Apollo

The Saturn I was a very large vehicle, at that point the largest vehicle that had ever flown. From it we learned a number of lessons that we still apply today. We built the Saturn I primarily out of existing materials. That is, we took the H-I engines that already existed for another application within the Department of Defense, we took the RL-10 engines that already existed for the Centaur, and we took the tooling that existed for building some of the ballistic missiles. The Redstone missile that was developed at Marshall had a 70-inch-diameter tank. The Jupiter, a later variant, had 105-inch-diameter tank. With the Saturn I, we developed what we call the cluster concept. That's part of why it was so dynamically difficult. We took that 105-inch Jupiter tank and used the Redstone tooling so we could build the Jupiter tank quickly and at lower cost. Then we built eight of the Redstone 70-inch-diameter tanks and clustered those around that center core Jupiter tank. The center core and four of the 70-inch tanks contained liquid oxygen, and the other four contained the RP-1 (rocket propellant 1), a rocket grade of kerosene. That's what we fed to the H-I engines on the Saturn I.

Engineers and technicians at the Marshall Space Flight Center placed a Saturn V ground test booster (S IC D) into the dynamic test stand. The 300,000 pound SI C stage is being lifted from its transporter into place inside the 360 foot tall test stand.

Photo Credit: NASA Marshall Space Flight Center

By clustering tanks that were made from existing tooling, using engines that already existed for both that and the upper stage—we used the RL-10s on the upper stage—we were able to put together the Saturn I primarily using existing things. We're doing that today in the Ares I and Ares V: taking things that already exist and putting them together in a new and creative way.

I think the most important lesson we learned from Saturn V is the importance of robustness. In the spring of 1968, we flew the second Saturn V. We called it SA-502. SA-501, which was the first flight of the Saturn V, had been a nearly flawless example of how a big launch vehicle should operate. But we had a whole myriad of problems on the second vehicle. We experienced a severe first-stage oscillation in the thrust. It would go up and down in a way that caused the vehicle to be periodically in compression. We called it the pogo effect because it goes up and down like a pogo stick.

Photo Credit: NASA

The 327 foot tall Ares I X test vehicle, brightly lit against the night sky, rides aboard a crawler transporter for the 4.2 mile trip to Launch Pad 39B.

Then, during second-stage flight, we had the experience of having to shut down an engine because we were getting an indication that there was a potential catastrophic failure, so we sent a command to shut the engine down. It had five J-2 engines, and we sent a command to shut down the problem engine before it catastrophically failed. To be sure, we sent a second command from a different source to make sure it shut down. Unfortunately, the wiring to the engines was wrong, and so instead of shutting down that engine, we shut down the opposite engine, which was a perfectly good engine. Instead of having five engines, we had only three, yet the mission continued.

When we got into the burn of the S-IVB, the third stage, there was a fuel line that began to shake violently and cause some oscillations, and we actually threw off one of the spacecraft lander adapters—the SLA, as we call it—the spacecraft lunar excursion module (LEM) adapter, and one of those panels failed. So, we had pogo in the first stage, we had an engine out in the second stage and cut off a wrong engine, had this oscillation in the third stage, and had a structural failure in the spacecraft LEM adapter. All those problems, and yet we still made it to orbit.

We had the decision to make whether we were going to fly another test flight of the Saturn V vehicle, unmanned, or whether we would put people on the next one. Now, remember, we had just had all these failures. Although we limped into orbit, we'd had a lot of near disasters. But we had enough robustness in the system, we thought we understood the failures, and we corrected all those things. We added accumulators on the first stage to take care of the pogo problem. We made sure that the wiring was right on the second stage. We changed the attachment of the line that had oscillated on the third stage, and then made a structural change to the SLA. We had all those things fixed, and we had enough confidence in that vehicle's robustness that we committed to send humans. That was Apollo 8. We're trying to build that same kind of robustness into the Ares family today.

Finally, I would say we learned the importance of safety from the Apollo program. We had the tragic fire on the launchpad during the checkout of Apollo I that took the lives of Gus Grissom and Ed White and Roger Chaffee. Although that particular failure had nothing whatever to do with the Saturn, it was part of the Apollo program, and all of us felt that very deeply. That moved us all very much.

I think that today, safety is our number-one criterion. When we picked the launch vehicle that we today call Ares I, we analyzed many concepts and picked the Ares I on the basis that it was the safest of all. Our goal is to make the Ares I ten times safer than any launch vehicle ever flown. We are continuously learning from our past and improving the designs of our future systems. ●

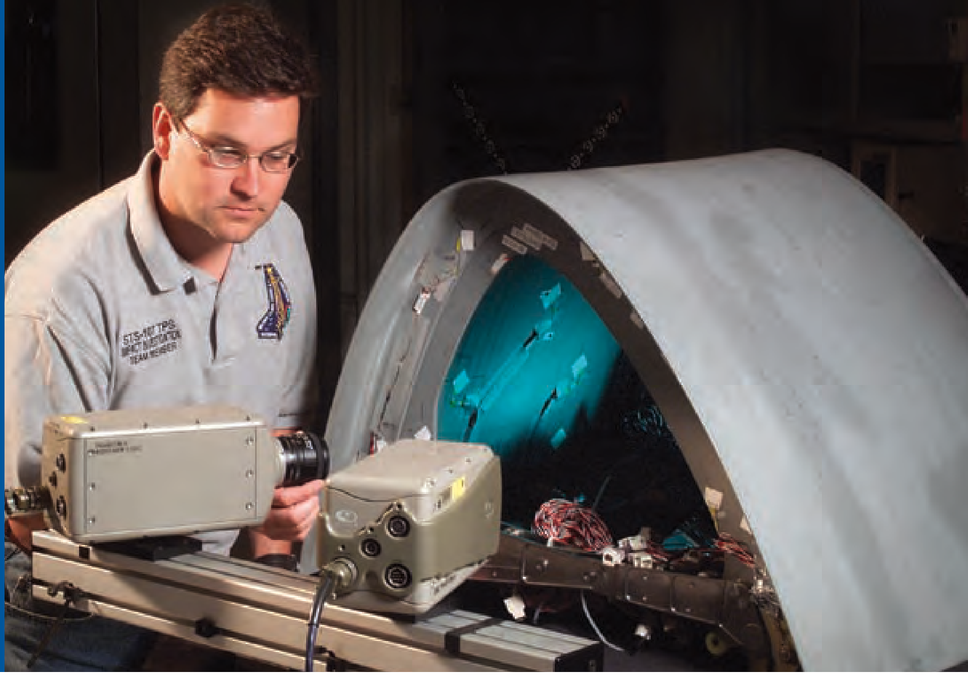
Still Learning from *Columbia*

BY MATT MELIS

On February 1, 2003, Space Shuttle *Columbia* and her crew were lost during reentry. In the months following, a nationwide team of experts from NASA, industry, and academia, spanning dozens of technical disciplines, was assembled to investigate the causes of the tragedy.

Mechanics Jeff Hammel (left) and Jim Sexton (right) prepare a ballistics impact gun for testing as aerospace engineer Mike Pereira looks at a computer monitor that will display photos of the blast taken by a high-speed camera.

Photo Credit: NASA



(Left) Duane Revilock sets up a high speed digital camera in Glenn s Ballistics Impact Laboratory to aid in testing the orbiter leading edge.

(Right) A test engineer inspects the hole created during full scale testing of the orbiter leading edge.

Photo Credit: NASA

Launch imagery and forensic reconstruction of the orbiter provided the evidence that enabled the *Columbia* Accident Investigation Board to determine the root cause of the accident. A piece of insulating foam had separated from the orbiter's external fuel tank bipod attachment eighty-one seconds into the STS-107 launch, causing a breach in the thermal-protection system on the left wing's leading edge. This breach allowed superheated air to penetrate and erode the aluminum structure of the left wing, which ultimately led to the breakup of the orbiter.

As the shuttle was being designed, the program team knew the metal bipod attachment connecting the orbiter to the external tank would require either heating or insulation to prevent large, and undesirable, ice deposits forming on it prior to launch. Building safety into a system—in this case, mitigating a threat from ice—might produce unintentional risks that could go unrecognized even after hundreds of flights or perhaps an entire flight program. Choosing to use foam insulation on the bipod attachment introduced a critical design flaw into the system, one that would not be fully understood until more than twenty years after the shuttle's first flight.

The board concluded its investigation with a full-scale impact test that recreated the foam strike on *Columbia* in order to demonstrate that event as the most likely cause of the tragedy. Despite months of newly acquired experience in testing and analysis on the orbiter wing's leading edge, dozens of engineers and technicians were still unprepared to witness the 16 x 17–inch hole created when 1.67 lbs. of foam hit the leading-edge article during the full-scale test. Their surprise and disbelief can be clearly heard in video documenting the test, emphasizing that a complete and rigorous test program is necessary to fully understand the capability and weakness of any given flight system—and that even seasoned experts can't completely rely on their intuition once outside the bounds of their experience.

Working as One NASA

Prior to the loss of *Columbia*, NASA had performed limited debris-impact testing on shuttle structures and had no "physics-based" software-prediction tools to analyze such events. Physics-based software does what the name implies: it incorporates the laws of physics and engineering principles into the equations that make up computational tools. The agency did have significant expertise in impact physics at the Glenn and Langley research centers, but it was rooted in propulsion and airframe aeronautics research efforts, which were not typically partnered with NASA's spaceflight programs.

After the accident, the shuttle program chartered an independent team of experts in impact analysis and testing from Glenn Research Center, Langley Research Center, Johnson Space Center, and Boeing to identify and develop rigorous, physics-based approaches to predict impact damage to orbiter tiles, leading edges, and structures. This team would also provide materials and impact-testing support to the STS-107 accident investigation and Return-to-Flight programs.

Coordinating from the orbiter office at Johnson, our core group performed much like a football team: teammates with clearly defined jobs to do. Glenn was responsible for an enormous amount of impact testing, developing material models and then ensuring they would function correctly once integrated into the analysis software. Langley conducted materials tests and performed validations on the models from Glenn. Once the methods were accepted, Boeing would carry out what we called "production runs," performing hundreds of analyses on shuttle components to ensure we were safe to fly and able to survive any debris strikes that were expected on a shuttle launch.

The team was highly effective from its inception, in large part due to having been assigned a well-defined set of milestones and goals to accomplish for the program. We were empowered to work independently, and we were allowed to do our jobs unencumbered by administrative burden. We certainly had plenty of e-mail in our inboxes and spent hours on teleconferences—constant communication that was necessary for our work.

Travel played a valuable if not critical role in building and maintaining the team's effectiveness. Since we lived in different

Photo Credit: NASA Glenn Research Center

… A COMPLETE AND RIGOROUS TEST PROGRAM IS NECESSARY TO FULLY UNDERSTAND THE CAPABILITY AND WEAKNESS OF ANY GIVEN FLIGHT SYSTEM … EVEN SEASONED EXPERTS CAN'T COMPLETELY RELY ON THEIR INTUITION ONCE OUTSIDE THE BOUNDS OF THEIR EXPERIENCE.

parts of the country, we would convene four to five times a year at one of the centers. Not only did we accomplish a lot of work at these meetings, but we also reaffirmed the trust and confidence we had developed with one another. Trust is a crucial component in high-functioning groups that depend on each other to achieve a common goal, and I believe it is established most effectively face to face.

In a true "One NASA" sense, our multicenter analysis team would work together for nearly five years developing the sophisticated analysis capability the shuttle program uses today for making flight-rationale decisions. Through both personal and programmatic associations made in the years following *Columbia*, the expertise and capabilities existing at Glenn and the other research centers are now much more recognized and accessible by the flight centers. Several engineers at Glenn and Langley are still assigned to the shuttle program, further highlighting their recognized value to the program.

This expanded awareness of our expertise has also led to other efforts within NASA. We continue to advance jet engine fan-containment technology in the ballistic lab at Glenn to make our aircraft safer. Our analysts are also contributing to the development of NASA's new Orion crew capsule for human spaceflight by helping design seats for the astronauts that will help them avoid injury in the event of a hard landing. Our advances in knowledge and technology during our Return-to-Flight efforts will most certainly continue to support the agency's future aeronautics and spaceflight programs.

Advances in Technology

As often is the case with ambitious programs like Return to Flight, the development and maturation of new technologies are greatly accelerated. In fact, this occurred as a consequence of the ballistic impact-testing efforts.

The advent of digital photography dramatically improved NASA's ability to accomplish its goals on the accident investigation as well as the Return-to-Flight program. High-speed digital cameras, largely unavailable and cost prohibitive just a few years before, were used extensively in both these efforts and provided near-instantaneous playback of any event they recorded. We used sixteen cameras to document the full-scale leading-edge test at rates of up to 30,000 frames per second—an unprecedented use of digital high-speed cameras.

Since the development of the digital still camera, a technique called "stereo photogrammetry" had come into practice. It accurately measured deformations on objects by using a pair of digital cameras to observe a test article from two points of view. Just as we sense depth using both our eyes, so can a pair of cameras—but with the added benefit of allowing us to apply mathematics to the images to compute precise displacements, stress, and strains for engineers.

It was a natural progression to apply these principles to the high-speed cameras being used to record the impact tests, and the NASA Glenn Ballistic Impact Lab worked closely with a commercial vendor of this technology to adapt the capability to use high-speed camera images. Once developed, this capability was critical for validating our analysis models. The technique was so successful that it was used on some of the full-scale leading-edge tests as well. Six years later, this technology is

SINCE WE LIVED IN DIFFERENT PARTS OF THE COUNTRY, WE WOULD CONVENE FOUR TO FIVE TIMES A YEAR AT ONE OF THE CENTERS. NOT ONLY DID WE ACCOMPLISH A LOT OF WORK AT THESE MEETINGS, BUT WE ALSO REAFFIRMED THE TRUST AND CONFIDENCE WE HAD DEVELOPED WITH ONE ANOTHER.

standard equipment in labs doing high-speed work both within and outside the agency.

The Rest of the Story

Early in 2009, the Orbiter Thermal Protection Group at Kennedy Space Center contacted us to inquire about getting some of our high-speed test video to present to their organization and enhance their understanding of debris-impact phenomena on their systems. Rather than provide only the movies, I offered something a bit better: a two-hour seminar summarizing the accident and describing how ballistic-impact research played a critical role in supporting the investigation and the Return-to-Flight effort.

More than fifty people attended that first seminar, and their response was so positive that I was asked to return to Kennedy to speak to all the technicians and engineers in the thermal-protection group. Over the next several months, I would present eight times to more than three hundred people who work on the shuttle orbiter.

Feedback from the attendees affirmed two things. First, sharing our story was extremely valuable and worthwhile to the workforce. I presented dozens of high-speed impact-testing movies from our work—impacts on tiles, reinforced carbon-carbon, windows, the external tank structure—materials that every tech and engineer attending saw or handled daily. They were captivated by the impact movies and the damage that could be caused by lightweight foam or a tiny piece of tile-gap filler. They also felt a sense of satisfaction as they learned how much effort the impact team had put into safeguarding their thermal-protection systems. There was a very strong sense of community and pride knowing what their teammates at the other centers had done to help make the orbiter safer.

Second, I became aware that creating such presentation materials for knowledge sharing, teaching our lessons learned, and preserving the agency's history is invaluable to NASA as well as to our stakeholders. After the experience of speaking at Kennedy, I concluded it would be worthwhile to adapt our team's story to video to permanently preserve it for future generations. Dozens of individuals with the debris-impact team worked tirelessly for more than two and a half years to overcome immense technical challenges to get NASA back to safely flying. Their story is worth knowing.

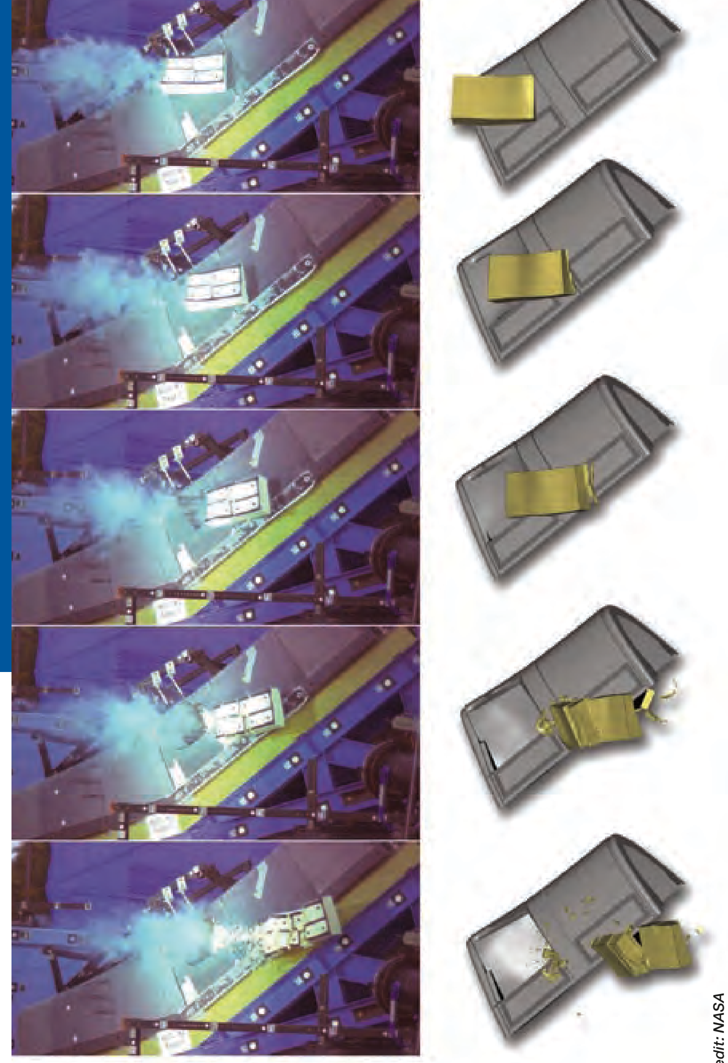


Photo Credit: NASA

Comparison of the LS-DYNA predictions with high-speed video of the full-scale test.

The shuttle is not unique in having dormant design flaws. They are inevitable in complex systems: aircraft, air traffic control, nuclear power plants, and even today's financial systems are some examples. It is the job of those who tend to these systems to identify and resolve such flaws to ensure safety and mission success. To our credit, we've collectively done a commendable job. Our shuttle fleet flies safer than it ever has. Better imagery, better engineering, and more sophisticated analysis tools, as well as effectively learning from our past lessons, are just a few contributing factors. Nevertheless, in the business of spaceflight, we cannot relax until the wheels stop on the last vehicle to return home. *Columbia* will always be a painful, yet necessary, reminder for us to stay vigilant, always on the lookout for what lies hidden. ●

MATT MELIS has been an aerospace engineer at Glenn Research Center for twenty-six years. As part of NASA's outreach efforts, he frequently presents his team's story to technical and nontechnical groups alike through the NASA Speakers Bureau. For more information, contact Mr. Melis directly at Matthew.E.Melis@nasa.gov.

Big Facilities, HARD LESSONS

BY MICHAEL OSPRING

Three years after a catastrophic accident at the National Full-Scale Aerodynamic Facility, the large wind tunnel at Ames Research Center, it was time for a second unplanned shutdown. John Perry and I had watched the facility's dynamic pressure during testing for several minutes. At less than two-thirds of the required pressure, the structure was already close to redlining. We needed to stop the integrated system test for two months and spend several hundred thousand dollars to reach design speed. That was the first time I wanted to quit my job, and it wouldn't be the last. But for every tough challenge I've faced during my thirty-four years at NASA, I've gained some important lessons. In this case, taking responsibility for a problem can be as rewarding as it is challenging.

Getting Our Feet Wet

Five years after that shutdown, I was working on the 12-Foot Pressure Wind Tunnel (PWT) Restoration Project. At the time it was the largest American Society of Mechanical Engineers Division 2 pressure vessel ever constructed in the country. We needed to fill it with water for three separate hydrotests—a total of more than five million gallons of water. We presented the review committee with a probabilistic calculation concluding that the magnitude 5.1 earthquake required to fail the columns would not occur during our testing. The numbers showed it was beyond reasonable expectation for such an event occur during the ten-day period we had planned for tests. However, once we had five million gallons of water in the primary vessel, we realized that we didn't wish to experience an earthquake of any magnitude. Statistics are useful when considering other people or other times. When it's you and now, statistics don't matter. Following a suggestion from our project manager, Harry Gobler, we stayed the weekend to complete all three hydrotests before Monday morning.

During the course of the 12-Foot PWT project, we needed to create control screens for the first fully automated wind-tunnel facility within NASA. The controls contractor had run into a cash-flow problem because he had underestimated the necessary design time. Again following Harry's advice, I flew to the contractor's facility for an off-the-record Saturday meeting to discuss the issues face to face. I learned the contractor's funding issue on my job would bring unneeded and unwanted attention from his corporate headquarters. With great struggle, I managed to get a change order approved to cover the fully justifiable costs. Once the contractor believed that I needed his expertise and didn't want him to lose money, we came to trust each other fully. This single incident reversed all my cultural training about contractors and partnering. I learned that the majority of contractors, apart from a few gold-diggers, are hardworking people trying to make a profit. When treated fairly, they produce excellent results.

During the earlier design effort on the same project, we needed to make important decisions about how to split our twelve construction-work packages for procurement. Two of these packages were so technically complex that our previous project manager, Nancy Bingham, decided to try a relatively unused procurement strategy that would result in a short list of technically qualified bidders, who could then bid against each other. When the Acquisition Division told us that Ames never did business this way, Nancy brought in a copy of the Federal Acquisition Regulations and put it on a stand in the middle of the project office. When anyone made a definitive statement in a meeting about acquisition, we would simply go to the project office and look it up, chapter and verse.

What we found was that many objections to our unconventional ideas were personal and subjective, but not prohibited by the Federal Acquisition Regulations. The boxes we had been confined to because of our lack of experience with large procurements began to melt away. At the end of the 12-Foot PWT project, we had successfully acted as the prime contractor, issuing and managing twenty separate contracts that totaled more than $101 million. Our group of relatively young engineers became a group of seasoned contracting officer's technical representatives (or COTRs) in just a few short years. With constant encouragement to think for ourselves and take responsibility, we were able to gain significant experience in a short amount of time. Having the courage to push boundaries and ask questions allowed us to find strengths we didn't know we had.

Photo Credit: NASA

HAVING THE COURAGE TO PUSH BOUNDARIES AND ASK QUESTIONS ALLOWED US TO FIND STRENGTHS WE DIDN'T KNOW WE HAD.

Rewinding the Coils

Before long, I faced impending failure on another project. As part of the Unitary Modernization project to upgrade the Unitary Plan Wind-Tunnel Facility, we were rewinding four large alternating-current motors, each one capable of 65,000 horsepower. Two years into the rewind, several coils began to fail at the contractor's plant during a high-potential test at 10,000 volts. They kept splicing the failed coil strands, assuring me of the high quality and robust nature of the repair. "We use this repair in industry all the time," declared the contractor.

Our team had an experienced motor designer, Andy Spisak, who told us the splices would not work and that we needed to make design changes. After more than twenty coil failures, I walked into Harry's office and said I didn't know what to do. "I've been waiting for you to admit the failure, because I need your expertise to solve the problem," Harry said. "Here's the plan."

We flew to Houston a few weeks later and asked the contractor to conduct one last "winner-take-all" high-potential test on each of the motor stators in the presence of the contracting officer. If any of them passed, we would pay for newly designed coils for that particular stator rewind. If any of them failed, the contractor would have to pay. Harry was betting every dollar of his project's contingency fund that the other stators would fail.

After some negotiation, we set the test parameters. Within two hours, every stator failed. Although we lost a year and a half, the contractor paid the majority of costs for correctly redesigned coils. When I asked Harry how he knew that the motor stators would fail the high-potential test, he said, "I didn't. But it seemed like a good bet, considering the technical expertise of the team. If it didn't work out, I was willing to deal with the consequences."

I learned that sometimes you don't know the answer, but you may have to make a very important decision with incomplete data. The key is to surround yourself with competent people and listen to them.

As we were getting ready to start the facility in 1998, the contractor warned us that the proprietary control software for the main drive system was not designed with Y2K in mind. Since the four main drive motors had a capability of 180 megawatts at full power, a software glitch was potentially catastrophic. The controls contractor could redesign the software, of course,

View looking upstream at the 135,000 horsepower drive system comprising six parallel fans that power the National Full Scale Aerodynamic Facility.

… SOMETIMES YOU DON'T KNOW THE ANSWER, BUT YOU MAY HAVE TO MAKE A VERY IMPORTANT DECISION WITH INCOMPLETE DATA. THE KEY IS TO SURROUND YOURSELF WITH COMPETENT PEOPLE AND LISTEN TO THEM.

Upstream view of the 15,000 horsepower variable pitch fan inside the 12 Foot Pressure Wind Tunnel.

Photo Credit: NASA

Photo Credit: NASA

One of four alternating current drive motors, rated 65,000 horsepower each, just before installation into the Unitary Wind Tunnel.

at an added cost and considerable lost time. Peter Graube and Mark Phillips, two of NASA's controls engineers, approached me with an idea. "We can rewrite the software ourselves, put it on a PC, and provide our own configuration management," they said.

The best part was it could be done in eight weeks. Although Harry was skeptical, he asked me, "Do you believe them? Can they do it?" Without enough money to pay the contractor, or any other plan to deal with the problem, it didn't seem like we had any alternative. I learned one of the most valuable people lessons from what happened next.

Peter and Mark rewrote the software. They installed and tested it in eight weeks, exceeding my expectations but not their own. I learned that passionate people are easy to manage. All you have to do is give them responsibility and tools, trust them to do their jobs, and get out of their way.

Many Stories, Many Lessons

There are dozens of untold stories, but the real value is in the lessons I have learned. The best lessons seem almost obvious now that the struggle of learning them is far behind. My personal short list includes the following:

- The project is always more important than any individual desires. Everyone can be replaced, and that includes me.
- A project lives or dies with its people. You must surround yourself with trustworthy people who want to be part of a team.
- People want to be trusted. Trust them until they have twice shown themselves untrustworthy. And always be willing to take the first hit.
- Make hard decisions in the quickest, fairest manner possible and explain your rationale. People want a decision and will respect one made out of fairness if it is explained to them.
- People need to be informed. If not informed, they will assume the worst. Communicate freely and often, and empower others with your information, rather than empowering yourself. Never allow gatekeepers to manage the flow of information.
- Teach people to give and take criticism on a non-personal level. Most technical issues can be sorted out in candid, informal sessions.
- People want and need to be heard. Listen to everyone, on their terms, when they are ready to share.
- "Good enough" is always better than "optimum." Meet the requirements and move on, because you will need the resources in other places.
- Most roadblocks are unnecessary. Never let someone without responsibility for cost or schedule try to influence yours.
- Test your authority and encourage others to do the same, which means they will be testing you.
- Give people your blessing when they think for themselves, even if it causes you some personal pain.
- Find a way to include everybody. People work much harder when they have some responsibility. Make their failures your problem and try again.
- Keep meetings small. Hardworking people don't want to meet. Non-workers love to meet.
- Find a mentor and pick his or her brain. Make sure it is someone who is not impressed with you, so they can be honest.

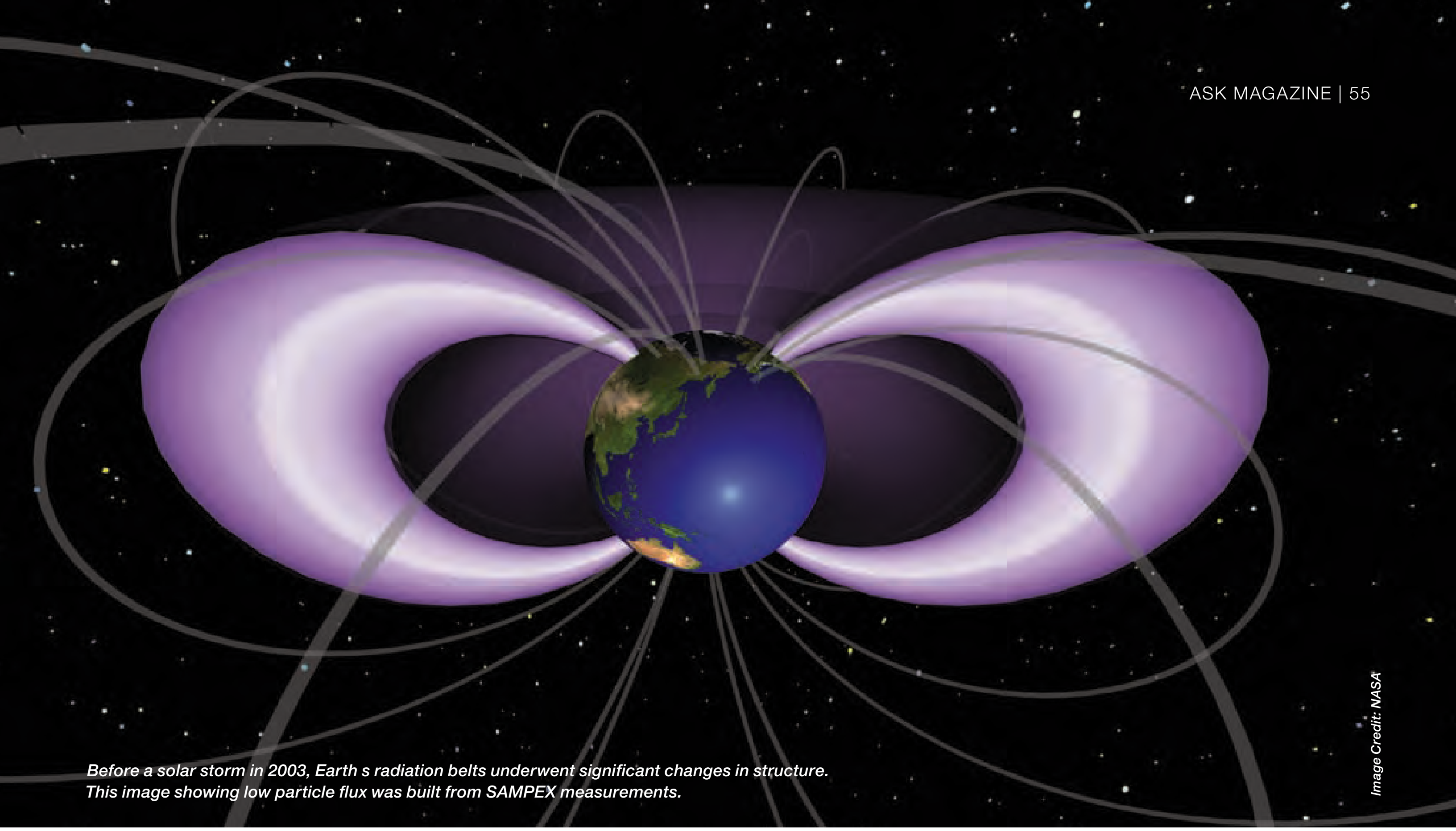
These lessons were learned on the job in painful circumstances over a long period of time. Some of them were the outcome of direct personal failures, which leads to perhaps the best lesson of all: having our worst perceived scenario happen sometimes results in a pearl of great value. ●

MICHAEL OSPRING is a mechanical engineer with thirty-four years of experience in design and analysis of wind-tunnel models, large facilities, ground-support equipment, and aircraft. He has served as engineering manager on several large facility modifications and currently acts as a group leader for mechanical design.

Classes and Spacecraft Operations

BY LEIGH GATTO AND TODD WATSON

A yellow caution flag pops up on the monitor with the message, "Battery Voltage to Temperature Ratio Is Out of Limits!" "That's okay," mathematics senior and certified spacecraft analyst Darrell Washington tells computer science senior and certified command controller Kevin Gross. "We just changed the V/T ratio on the spacecraft this morning, so we expect to see that flag." It is just another day on campus and another real-time contact with an orbiting NASA satellite.



Before a solar storm in 2003, Earth s radiation belts underwent significant changes in structure. This image showing low particle flux was built from SAMPEX measurements.

Located on the campus of Bowie State University in suburban Washington, D.C., the Bowie Satellite Operations and Control Center (BSOCC) has been training students in real-time satellite flight operations since 1996. This innovative program combines a rigorous series of mission control certifications with daily flight operations for NASA's Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX). The SAMPEX spacecraft collects data on solar and galactic radiation and is controlled from the university's mission operations center. Students take part in almost all aspects of flight operations while pursuing three progressively advanced levels of mission control certification. Along with their work in the BSOCC, they also carry a full-time schedule of college classes in science and technology.

Building the BSOCC

The idea for the BSOCC took shape in the mid-1990s, when former Goddard Space Flight Center Director Joe Rothenberg wanted to reduce the operating costs of extended-duration science missions by using university-based control centers and student participation. Bowie State University, one of the nation's oldest Historically Black Colleges and Universities, has had a long and productive relationship with Goddard. Just six miles northeast of Goddard, its campus was a logical place to install a mission operations center. NASA's Leigh Gatto, the Small Explorers mission director at the time, was asked to build the facility and move SAMPEX flight operations to Bowie State University.

"When we first began building the facility, we had no money and no place to go," explained Gatto. "At the time, Dr. Nagi Wakim was the Associate Provost of Bowie State University and a steadfast supporter of the BSOCC concept. Together, Nagi and I lobbied Bowie State and Goddard for resources. We applied for and won seed money from the Goddard Director's Discretionary Fund. We also convinced the university to section off a corner of the campus's main library to build the ops center. With initial resources acquired, we met with the SAMPEX principal investigator. Together we were able to convince him that his spacecraft would be well cared for under the watchful eyes of university students."

Mission oversight and student training are currently performed by Todd Watson, a Honeywell employee who functions as both satellite engineer and center director. Watson was a part of the BSOCC from the very beginning, one of the first group of trainees in 1996. After the company he worked for went out of business, he enrolled in Bowie State's computer science graduate program and one day happened to see a poster advertising for NASA flight-control candidates. "I was astonished that there was such a program on campus and went right over to apply," he said. He completed all the certifications, was hired by Honeywell, and eventually took on leadership of student training and flight operations.

The BSOCC concept calls for the university to provide the facility and the student stipends, while NASA provides the spacecraft, control center equipment, and one full-time flight operations professional. The BSOCC's certification program is based on the training used by the Small Explorers program at Goddard and was developed by Honeywell.

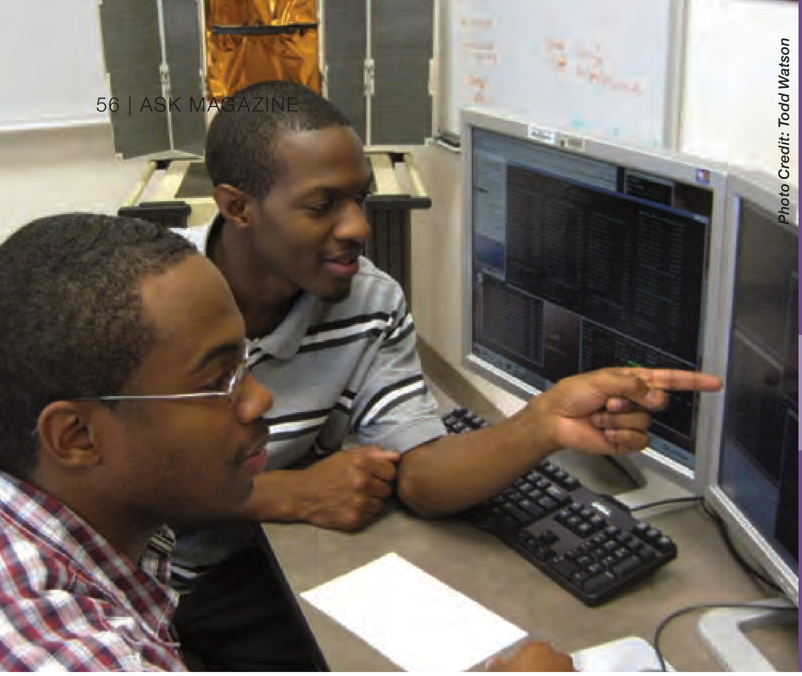


Photo Credit: Todd Watson

Bowie State University students Darrell Washington and Kevin Gross at the controls during a NASA satellite contact.

BSOCC Missions and Technology

SAMPEX was launched into low-Earth orbit in 1992. The spacecraft has four scientific sensors designed to study solar energetic particles, anomalous cosmic rays, galactic cosmic rays, and magnetospheric physics. Mission data is delivered to scientists at the Aerospace Corporation in El Segundo, California.

The Wide-field Infrared Explorer (WIRE) performed a four-year experiment in asteroseismology (a science concerned with the structure of variable stars) while being controlled from the BSOCC. That experiment was concluded in 2008.

Along with being the primary control center for these missions, BSOCC has served as a backup control center for NASA's Submillimeter Wave Astronomy Satellite and its Transition Region and Coronal Explorer (TRACE). BSOCC recently hosted TRACE operations for two weeks while satellite operations were moved into a new facility at Goddard.

In BSOCC, students also take part in the mission support work that goes along with flying satellites. The Bowie State facility has undertaken several ground-system upgrades, helped test and implement Goddard Mission Services Evolution Center technology, and performed numerous ground-station proficiency and engineering tests. Approximately forty students have been certified in the program, and nearly ninety flight control certifications have been awarded. About half these graduates now work in the aerospace industry, most of them with NASA and its contractors. BSOCC students have a 100 percent college graduation rate.

In 2003, the BSOCC moved from its original location in the campus's main library to a much larger facility in Bowie State's new computer science building. The program added flight operations for a second mission, the WIRE spacecraft, which performed stellar seismology observations until the spring of 2008. SAMPEX, staying remarkably healthy over its long lifetime, has remained BSOCC's primary mission. It continues to provide valuable data to the scientific community while ensuring the futures of dozens of students.

BSOCC's Training Program

Since the beginning of the program, training has centered on mission controller certification. It takes two years, including one summer, to complete the three levels of command controller, mission planner, and spacecraft analyst. The command controller learns how to set up and take real-time satellite contacts while monitoring the receipt of data from the NASA tracking stations. During a contact, the command controller sends commands to the spacecraft and ensures that telemetry—comprising attitude control, engineering, and science data—is properly downlinked to the ground station.

The mission planner learns how to build the "command loads" that are uplinked to the spacecraft during real-time contacts. Command loads contain instructions for the satellite to follow when it isn't in contact with controllers on the ground—such as turning the transmitter on or off and cycling power for the scientific sensors. The mission planner also verifies the schedules of contacts with the NASA tracking stations, ensuring that minimum requirements for viewing-period duration and spacecraft elevation are met.

The spacecraft analyst is the final and most advanced level of mission control certification offered in BSOCC. The analyst helps oversee the activities of the command controller and the mission planner and is responsible for identifying spacecraft anomalies and starting the process of resolving them. The analyst must understand the satellite's subsystems, including power, thermal, attitude control, communications, computer, and payload. He or she should be able to identify any anomalous conditions with either the ground system or the spacecraft.

Training includes classroom sessions, hands-on experience, and independent study. After passing a long list of skill demonstrations, the trainees must pass a written test for each certification. Students work and train in the facility between classes and have adequate opportunities to participate in real-time satellite contacts. The control center normally teems with activity; in addition to operating satellites, the students take part

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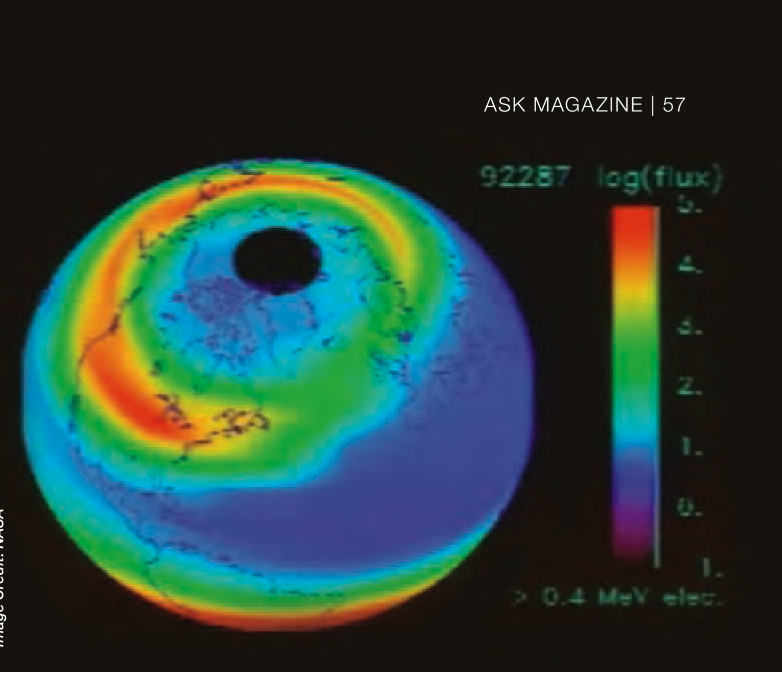


Image Credit: NASA

SAMPEX s Proton Electron Telescope instrument captured these energetic electron fluxes over the North Pole between July 1992 and July 1993.

in mission-support tasks such as data trending and spacecraft anomaly investigation.

Occasionally a fully certified student will still have time to work in BSOCC before graduation. Along with acting as peer mentors to the newer interns, these advanced students may be assigned special projects involving satellite subsystem research or creating and editing computer scripts and programs.

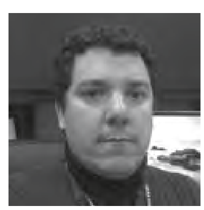
The Present and the Future

One student, Alicia Scott, worked in the BSOCC while earning her master's degree in computer science. Since graduation, she has worked at Goddard for NASA contractors Honeywell and SAIC, where she has participated in mission support for the Terra, Tropical Rainfall Measuring, and Hubble missions. Scott said, "I was able to apply everything I learned in the BSOCC to the daily operation of the Terra mission at Goddard. It was a great relief to the management team that I was already knowledgeable of the basics involved in mission operations. The most critical thing I took from the BSOCC was the importance of communication between members of the operational team. The most effective procedures and commands for spacecraft ops result from good communication. The three levels of certification at the BSOCC allowed me to view operations from different standpoints and to focus on one aspect at a time. Once I started my job with the Terra mission, it was easy to combine all these standpoints into one position. I was performing all duties learned at BSOCC and was better able to focus on anomaly recovery and error prevention, which is essential to the life of a mission."

Miquel Moe completed the BSOCC certifications as an undergraduate in math and engineering. He is now an electronics engineer for NASA at Goddard, where he leads the screening of electrical components for the design phase of the ICEsat-2 mission. Moe believes the BSOCC training helped put his career on track. "First and foremost, BSOCC provided me a quality, real-life work experience while allowing me to focus primarily on my undergraduate studies," he explained. "The skills I acquired working for BSOCC have made me very attractive to employers such as the National Oceanic and Atmospheric Administration and NASA Goddard, for whom I now work. Not only do I understand the engineering aspect of space missions, I also understand the scientific, data acquisition, and spacecraft-commanding aspects. This knowledge paid me great dividends in the past as an intern working on the Geostationary Operational Environmental Satellite project, and it will continue to pay off in my future as an employee."

With its fully equipped mission control center, the BSOCC is well positioned to take on new projects for NASA. As more students take advantage of this unique training, the pool of talent available to the local aerospace community will increase. Current BSOCC student and mathematics major Darrell Washington put it this way: "With BSOCC on my résumé I know that there's someone out there who will take an interest." ●

LEIGH GATTO is the technical director for the Independent Verification and Validation (IV&V) Program. During his eighteen years with NASA, he has served in numerous positions with Goddard, Wallops Flight Facility, IV&V, Johnson Space Center, and NASA Headquarters. Prior to joining NASA, he spent nine years in the U.S. Air Force and received his BS from the University of Maryland and his MS from Johns Hopkins University.



TODD WATSON joined Honeywell Technology Solutions, Inc., as a systems engineer in 1998 and has managed the BSOCC program since 2000. He holds a BS degree from the University of Maryland–College Park and did postgraduate studies in computer science at Bowie State University.

The Knowledge Notebook

How Organizations Learn Anything

BY LAURENCE PRUSAK

During the late 1930s, several researchers working on the West Coast noticed something interesting occurring during the manufacturing of aircraft bodies. Whenever a new design or model was manufactured, building the second one always took considerably less time than the first one had. The third iteration took less time than the second. (Before long, of course, those time savings leveled out.) The learning needed to build the aircraft more efficiently was learned by the workers and the organization itself in the process of building them. Now, this sort of insight will not come as a big surprise to many readers. In fact, Adam Smith in *The Wealth of Nations* remarked on the same phenomenon after watching nails being made in eighteenth-century workshops; his observations became the foundation of his theory of the division of labor. Planes are much more complex than nails, however, and the cost of building them is much greater, so the efficiencies observed in the aircraft factory and the idea they suggested began to attract serious research attention after World War II.

That was when operation-research analysts working at the Rand Corporation began writing papers and developing equations for understanding in a more quantifiable way exactly what goes on during this type of learning process. This work was codified and given more analytic heft by Ken Arrow, a highly influential Nobel Laureate economist now at Stanford. Arrow's paper, "Learning by Doing," was published in 1962. It aroused great interest among economists, but it wasn't exactly a great success among the "training" bureaucracies in organizations—all the many managers responsible for promoting organizational learning. They were still wedded to the rather limited and less valuable type of learning that takes place predominantly in classrooms or (later) facing one's computer monitor.

This was a great pity and has caused much waste of money and time. Arrow gave academic rigor to the idea that people and the organizations they work in learn mostly by doing, that active participation is the best teacher. The learning-curve theory, made popular (and profitable) by some management consultants in the seventies, was the direct result of this work. It holds that the time required to complete a task decreases as the task is repeated, that the amount of improvement decreases over time, and that the rate of improvement can be predicted with reasonable and useful accuracy.

These lessons were very slow to catch on for several reasons. One is that Arrow used some psychological studies as well as economics and they hinted at the fact, now more emphasized in practice, that one needs reflection to really understand and learn from one's experiences. Though some learning perhaps comes from repetition alone, most of it doesn't happen in that purely automatic way. Giving employees the time and tools (including "soft" tools like storytelling and discussion) to reflect on what they have learned from the process of doing work is still a rare phenomenon in the workplace. Our management methods and styles work against institutionalizing any form of activity that cannot be readily quantified. Many managers are more comfortable with a quiz showing whether people have grasped the lessons of a training session than the less tangible understanding gained by telling or listening to a story about work.

The other main reason for this gulf between what is now known about how people learn and how we use such knowledge is a commercial one. Many vendors and consultants sell various and sundry offerings dedicated to making organizational learning more efficient and (they claim) more effective. While some of these products and services are potentially useful, many are based on the idea that there are easy technical fixes to what is a very human and somewhat complex activity that can only be very partially mediated by technologies.

Now that economists are perhaps starting to more readily accept the findings of learning theorists and psychologists and this knowledge is filtering down into more popular business thinking, we may start to see a more nuanced and realistic understanding of organizational learning emerge. If leaders really come to accept and support the understanding that the most valuable learning comes from action and reflection, we could see a great increase not only in project productivity but in innovation and the spread of useful and valuable knowledge throughout organizations as well. ●

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NASA in the News

NASA s Kepler space telescope, designed to find Earth size planets near sun like stars, has discovered its first five exoplanets, or planets beyond our solar system. "These observations contribute to our understanding of how planetary systems form and evolve from the gas and dust disks that give rise to both the stars and their planets," said Principal Investigator William Borucki of Ames Research Center. Known as "hot Jupiters because of their high masses and extreme temperatures, the new exoplanets range in size from similar to Neptune to larger than Jupiter. Estimated temperatures of the planets range from 2,200 to 3,000 degrees Fahrenheit, hotter than molten lava and too hot for life as we know it. All five of the exoplanets orbit stars that are hotter and larger than Earth s sun. To learn more about this discovery and the Kepler mission, visit www.nasa.gov/mission pages/kepler/main/index.html.

Learning and Development

The Academy of Program/Project and Engineering Leadership (APPEL) has updated its curriculum offerings. The APPEL Program Management and Systems Engineering development structure includes three major components: core curriculum, in-depth courses, and outside-the-classroom development experiences. Evaluating the quality and results of this curriculum—and providing for its continuous improvement—is a high priority of the APPEL team. For more information, visit www.nasa.gov/offices/oce/appel/curriculum/curriculum.html, or view the master schedule and registration information at www.nasa.gov/offices/oce/appel/curriculum/schedule/292.html.

Web of Knowledge

As NASA continues to set new goals and launch challenging missions in the new year, the agency also took time to review its discoveries and accomplishments during 2009. Among the top accomplishments for the year are the discovery of water on the moon, the successful test flight of the new Ares I-X launch vehicle, and the appointment of a new administrator. Read about these milestones and more at www.nasa.gov/externalflash/YIR09/index.html.

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NASA Headquarters
300 E Street SW
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