National Aeronautics and Space Administration

Academy Sharing Knowledge

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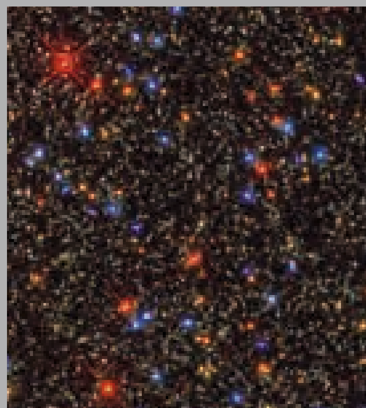

Photo Credit: NASA, ESA, and the Hubble SM4 ERO Team

ON THE COVER

NASAs Hubble Space Telescope snapped this view of a colorful assortment of 100,000 stars residing in the crowded core of a giant star cluster, Omega Centauri, with its new Wide Field Camera 3, installed during the May 2009 servicing mission. The photograph showcases the camera s color versatility, revealing in ultraviolet and visible light a variety of stars in key stages of their life cycles.

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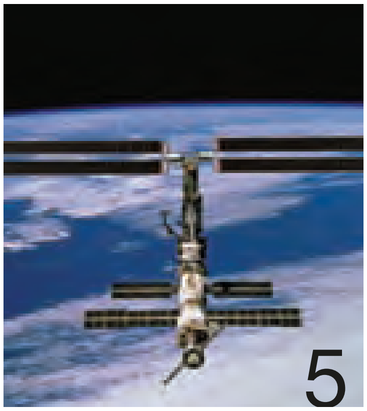

ask

Issue No. 36

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

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

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

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To subscribe to *ASK*, please send your full name and preferred mailing address (including mail stop, if applicable) to ASKmagazine@asrcms.com.

In This Issue

"Looking back and looking forward" is one way to sum up the learning strategies considered in this issue of *ASK*.

Looking back—learning from the past—is a familiar idea at NASA. Program and project teams have long depended on technical documentation of past missions and the advice of "graybeards" to help them solve contemporary problems. Some articles here look at what the past has to offer in interesting ways. Piers Bizony's "Apollo Technology: Back to the Future" effectively dispels the myth that the Apollo mission's computers and other technologies were primitive by today's standards; it suggests how much we can learn from the work that began almost half a century ago. "Son of LEM," by John Connolly, reinforces the point: designers of the new Altair lunar lander have discovered how brilliantly their counterparts in the sixties met the challenge of reaching (and leaving) the moon, and how much their new, larger spacecraft will resemble its predecessor. "What Would Max Do?" (by Dawn Schaible) is the story of a Langley team using principles of simplicity articulated by NASA pioneer Max Faget to build an alternative launch abort system for the new Orion crew vehicle.

The participants in the Systems Engineering Leadership Development Program have been learning from the more distant past. Haley Stephenson ("Gettysburg Addressed") shows how the experience of Civil War generals at the battle of Gettysburg illuminates issues project leaders wrestle with today. The basic factors that define leadership—good communication, analysis of complex situations, trust, decision making—have not changed over time.

These backward looks are part of NASA's preparation for a demanding future. "Fresh-outs" who have recently joined the agency and men and women who are still students today will create new vehicles and instruments for ambitious science and exploration missions in the next decades. Several articles in this issue highlight new programs that will help give them the knowledge and skills they will need. The Hands-On Project Experience (HOPE), jointly sponsored by the Academy of Program/Project and Engineering Leadership and the Science Mission Directorate, gives young engineers and managers an opportunity to carry a small flight project from start to finish. As George Morrow says in the interview, hands-on work is an essential source of deep expertise that cannot be gained in any other way. STEP, the Safety and Mission Assurance Technical Excellence Program, will provide a complete, four-level development program for safety and mission assurance professionals that includes everything from online courses and case studies to on-the-job learning and membership in professional societies. Both of these educational efforts recognize the point Laurence Prusak makes in "The Knowledge Notebook"—that real learning takes time and comes from experience and interaction with others. And in "Nobody's Perfect," Mark Saunders and James Ortiz describe an independent review process that combines learning from experienced veterans with learning by doing real project work.

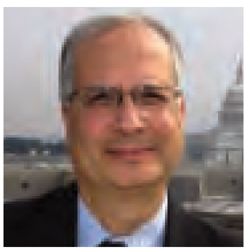
Finally, "In Their Own Words" looks forward to a time when our present is the past a new NASA generation looks back to for knowledge. Tim Howell describes a program to capture the thinking of International Space Station designers: not only what they did but how and why they made those choices and how their technologies really work. Their words provide the kind of rich context that turns information from the past into knowledge for the future.

Don Cohen
Managing Editor

From the APPEL Director

The Conspiracy of Optimism, the Dangers of Pessimism

BY ED HOFFMAN



The traditional tools of project management do not help leaders with one of their most critical jobs: defining reality.

Last summer I took my son to France, and we visited the beaches of Normandy where the D-day landing took place. While we were there, I heard a story about how the day before the landing—after months of planning—General Eisenhower, the Supreme Allied Commander, wrote two letters. One was a message of inspiration that was delivered to every soldier, sailor, and airman who took part in the invasion. The second, written in the event that the invasion failed, said, "If any blame or fault attaches to the attempt it is mine alone."

That's a powerful story, and it speaks to the challenge of leading a complex project. Leadership expert Noel Tichy has said that a leader has to perform two core functions: define reality and mobilize resources. Eisenhower and the other leaders who conceived the D-day landing defined reality as they understood it and conveyed that understanding to everyone involved in the operation. As Supreme Allied Commander, Eisenhower understood how perilous the conditions would be for the troops storming the beaches and did everything in his power to provide the resources necessary to succeed. He recognized the importance of inspiring his forces and expressing appreciation for their sacrifices. His words neither sugarcoated the dangers ahead nor dwelt on them, and he made himself accountable in the event that his definition of reality or his mobilization of resources fell short.

This delicate balance between maintaining a positive outlook and remaining grounded in reality is familiar territory for leaders of complex projects. There are two traps that must be avoided. The first is the conspiracy of optimism. Optimism that is not grounded in reality results in failure. It leads team members to hold their tongues when they should speak up, for fear of being branded the bearer of bad news. Transparently false optimism will destroy a leader's credibility with the team.

The second trap is the danger of pessimism. A manager who conveys a sense of doom about a project's prospects will create a negative story line for the team. Eventually that story becomes a self-fulfilling prophecy. Team members will believe that their project is slated for cancellation, cuts, or failure. Instead of working hard, they will begin looking for cover or the nearest exit.

The standard tools of the project manager's trade don't offer much guidance about how to define reality and navigate this balance. Experienced leaders know how far they can push their teams to come up with breakthrough solutions for seemingly intractable problems. They invite open discussions grounded in interpretations of hard data, and they give their teams resources and latitude to work creatively. They motivate by defining reality in terms of the mission context, sometimes using external pressures to set up an underdog dynamic. They stretch their teams without breaking them. These skills cannot be taught in a classroom or captured in a professional certificate. The ability to define reality in a way that strikes a proper balance between motivating the team and acknowledging hard truths can only be learned on the job. It is the essence of leadership.

In Their Own Words: Preserving International Space Station Knowledge

BY TIM HOWELL

Photo Credit: NASA

The STS-97 crew delivered and installed the P6 truss, which contains the first U.S. solar arrays, during ISS assembly mission 4A.

As a new International Space Station (ISS) engineering manager in 1986, I quickly learned that having the right mix of people was the key to my team's success and that sustaining success depended on an environment that encouraged people to pass on experiences. I also learned that maintaining performance over time as team members leave an organization is especially challenging. These revelations would serve as a foundation for Design Knowledge Capture initiatives started in late 1997. What follows is a story about gathering stories from ISS engineers who explained, in their own words, how their designs work.

Design of the power management and distribution system, which I had been part of, was nearly complete in 1997, and engineering design activities were shifting to sustaining engineering, assembly, and test. The Rocketdyne ISS sustaining engineering team began discussions with the Johnson Space Center ISS program office to establish methods for capturing design knowledge. The designs themselves were well documented, but we wanted to meet with as many design experts as possible so they could explain how the space station really worked.

"I don't want to call a console operator to ask how long a remote-power control module will last before it fails and get an answer quoted from a spec document on that person's computer," said the NASA ISS program manager at Johnson. "I want that console operator to tell me what the real design margins are based on what he or she has learned from the person who designed it." NASA wanted subcontractors to pass on the experiences of the original designers to maintain strong design knowledge over a projected thirty years of on-orbit operation. In other words, NASA was saying, "Show us how it works."

A Rocketdyne colleague, John Rank, and I developed a proposal to interview ISS subject-matter experts. The plan focused not on collecting documents, but on gathering experts' thoughts, experiences, and explanations of how and why designs worked. We thought that capturing these "nuggets of knowledge" in their own words would provide contextual explanations that might help a console operator or astronaut in 2010 and 2030 understand the ISS design concepts, strengths, and limits. We knew it would be difficult to capture ten years of collective design knowledge and wisdom, but it was important to the future success of ISS to try.

With limited time and resources, we focused on identifying key experts before they left the program. Our mantra was, "Who is the go-to person?" With the help of team managers and coworkers, we were on a mission to find ISS subject-matter experts who were identified by their peers as the most knowledgeable in their engineering disciplines.

The Design Knowledge Capture initiative had three elements:

1. Ask subject experts to help design specific questions they would ask a peer. The questions needed to be specific to the system, hardware component, or software and to the design discipline. We solicited responses from a cross section of engineering and manufacturing program experts in areas including electrical, mechanical, software, and systems. We learned that involving program experts in the design of probing questions yielded richer, more detailed, "how does it work" answers. These same experts were our first interview subjects.
2. Establish interview, presentation, or demonstration recording methods. We respected each individual's willingness to have sometimes very personal one-on-one discussions about his or her design development experiences. Asking permission to record video made most people self-conscious and reluctant to discuss factual details for fear of making a mistake, but we assured them that we would not publish their sessions until they had reviewed and approved them. This put most people at ease and made them feel involved in the process.
3. Publish Web-based, indexed interview content organized by system (such as power management, thermal controls, or communications).

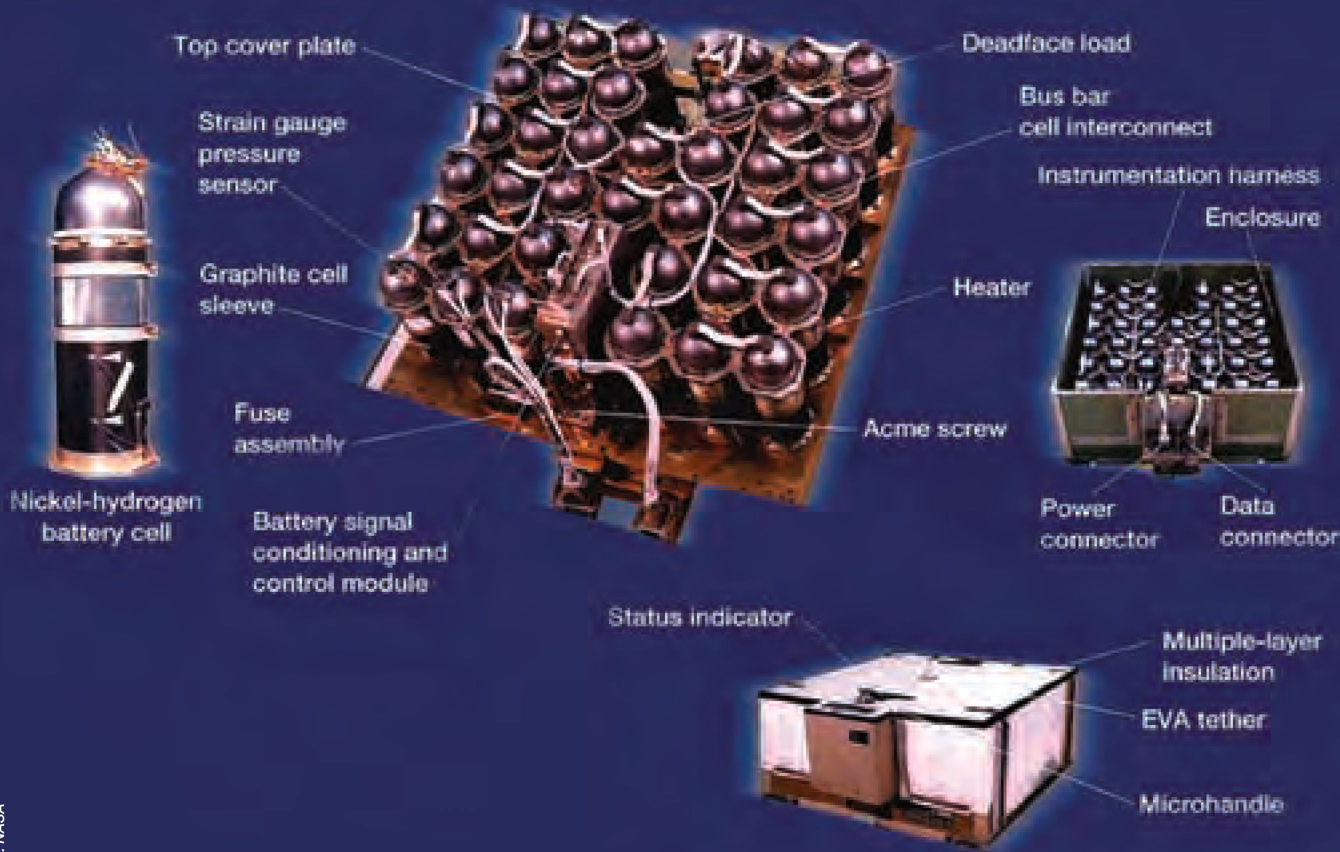


Image Credit: NASA

International Space Station nickel hydrogen batteries.

Planning how to deliver an expert's information was as important as capturing it. "Capture, Index, Share" was a Design Knowledge Capture slogan. If any of those elements are missing, knowledge cannot be transferred. Indexing was particularly important for quick subject searches and learning retention. No one wants to watch a two-hour interview to get to the information they need.

We established a point person, or "site focal," at each company we planned to visit. These people knew their organizations well and guided our search for subject experts, especially those who would soon retire or move on to other programs. We asked team managers to identify the most knowledgeable people and then asked these experts to recommend peers. During this process we would ask, for example, what is the most important thing someone should know about an orbital replacement unit, thermal radiator, or blanket-box release mechanism? These leading questions were intended to start a dialogue to help an expert recall design details. We often facilitated roundtable discussions among teammates; one person would remind another of a performance value, margin-of-safety calculation, or the how and why of a test failure. Using video to capture experts' own words was as close as we could get to placing future students in the room at that moment.

Good learning occurs when one can see, hear, and read at the same time. This is known as the "3–D" effect of learning. What you see may be body language or expression. You hear voice inflections. Reading gives you the details that substantiate the verbal or visual information. Each sensory experience reinforces the others. This rich learning experience improves retention as well as understanding.

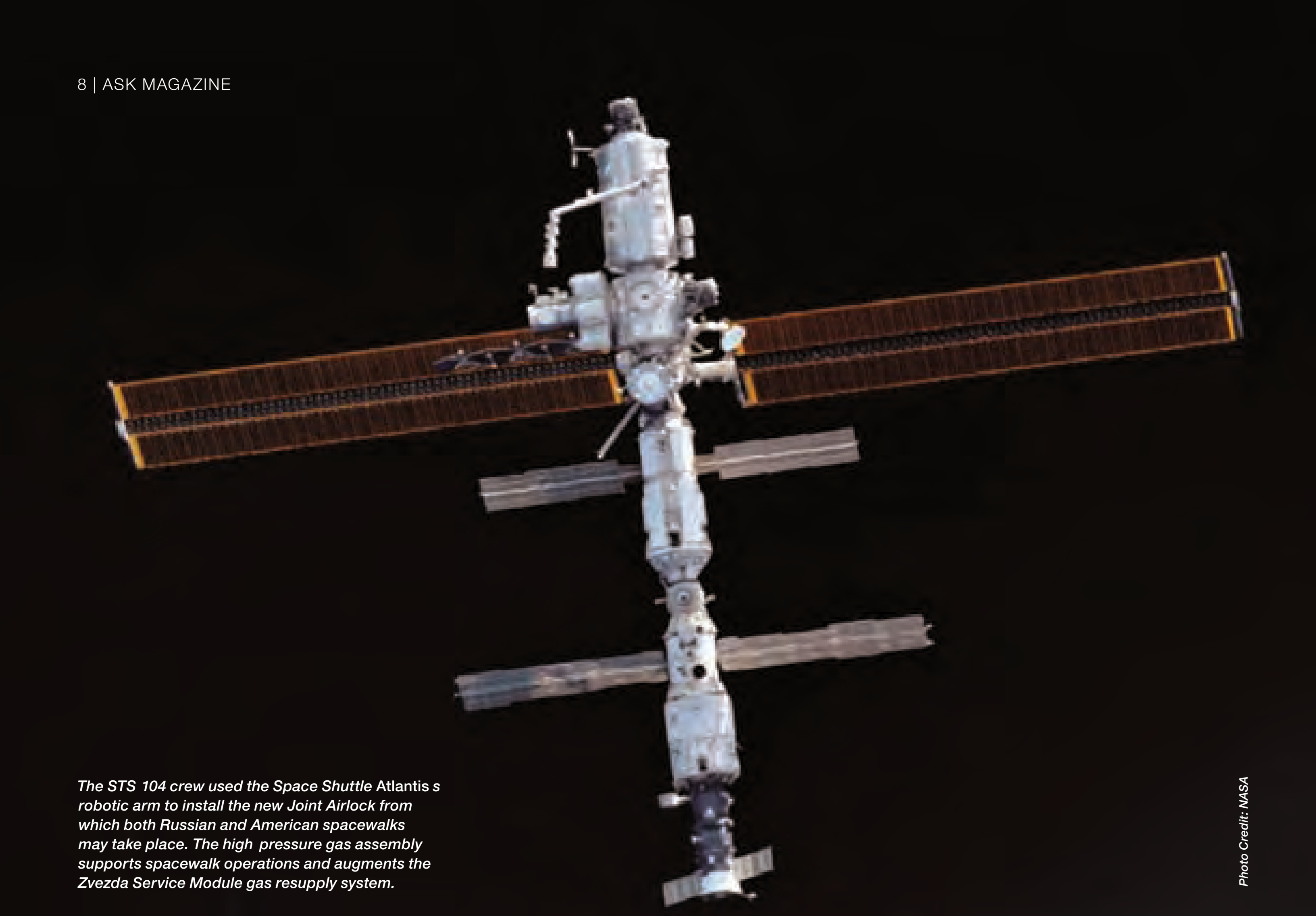
Some Stories from the Field

Here are a few examples of Design Knowledge Capture in action.

The First Solar Array–Deployment Assembly Mission

Several months before deployment, design engineers demonstrated solar-array design elements for Design Knowledge Capture video sessions. Sessions included solar-cell design and fabrication, blanket-box release mechanism tests, and array-tensioning pulley design.

Recorded sessions were published to the ISS knowledge management Web site ahead of the launch and assembly sequence. The site was available to NASA and ISS subcontractors to augment existing procedures and specifications. Between 1999 and 2001, the site received on average 2,000 hits per day.



The STS 104 crew used the Space Shuttle Atlantis s *robotic arm to install the new Joint Airlock from which both Russian and American spacewalks may take place. The high pressure gas assembly supports spacewalk operations and augments the Zvezda Service Module gas resupply system.*

Photo Credit: NASA

Design engineers knew the array panel material had a surface tension that could cause panels to stick together when deployed after a long period of storage in their protective blanket boxes. The longer the arrays were stored, the greater the possibility two panels would not unfold smoothly. Successful deployment tests suggested this was a minor concern, but random panel surface-tension release caused a yo-yo motion of the partially deployed array during the P6 truss solar-array deployment that resulted in tensioning cables jumping off their spring-loaded pulleys.

Armed with a good understanding of solar-array design, members of the astronaut office and solar-array design engineers designed an extravehicular activity (EVA) cable-retraction tool, video recorded how to reinstall the cables, and transmitted the video to ISS astronauts. Astronauts reinstalled the tensioning cables and successfully deployed the P6 arrays during the next EVA. NASA now deploys the arrays more slowly, with periodic pauses to allow time for panels to unfold and minimize sudden tension-cable retraction. ISS astronauts also have the benefit of a "how-to" training video if the problem reoccurs.

EVA Airlock Design

When we first approached the one EVA airlock systems engineer still working on final design revisions and overseeing the assembly and test of the main ISS EVA airlock, he replied that he didn't have much to share. This was a common reaction. We all tend to forget what we know or think what we know is not especially important. After explaining that the Design Knowledge Capture initiatives were attempting to capture undocumented design knowledge, he replied, "OK, if it is OK with my manager." With his manager's blessing, we spent eight hours recording his explanation of airlock systems design principles. We then suited up with cameras in hand for a clean-room guided tour of the airlock in its current state of final assembly. The mix of documentation and visual and verbal explanation of airlock systems provided rich contextual knowledge. We learned three months later the engineer had left the company to build a house in Alaska.

Battery Orbital Replacement Units

One of the companies we worked with worried that sharing detailed ISS battery design concepts might expose information that would damage its competitive edge or even violate U.S. export laws. Many ISS component designs are based on trade secrets and proprietary information. The solution? Design engineers teamed up to record their design rationale through presentations and one-on-one discussions and edited their recordings before

I don't want to call a console operator to ask how long a remote-power control module will last before it fails and get an answer quoted from a spec document on that person's computer," said the NASA ISS program manager at Johnson. "I want that console operator to tell me what the real design margins are based on what he or she has learned from the person who designed it.

delivering the final tapes to ensure that proprietary information would be protected and correct information would be conveyed. The process of revisiting design decisions and trade-offs was as valuable to them as the final video. The engineers were afforded time to reflect and reaffirm that the designs were the best they could be. These recorded sessions were also used to train others within the company.

A Rich Resource

There are nearly three hundred video stories like these archived in the ISS knowledge management Web site at Johnson Space Center. The site's one-on-one or group knowledge-sharing sessions are supplemented by written replies to questionnaires and Orbital Replacement Unit Handbooks. Similar methods have been used on the shuttle program. Senior shuttle design engineers provided video-recorded information that was used to train mission-support personnel. The information contributed to a 100 percent graduation success rate for the first class.

When we started in 1997, SharePoint, AskMe, LinkedIn, and other social-networking tools did not exist. These tools expand our ability to connect and share. I have wondered what it would be like to have a one-on-one conversation with Albert Einstein through Facebook. But these new technologies do not replace other, older methods of teaching and learning. We learn from each other and we learn by doing. Face-to-face mentoring and roundtable discussions still provide the richest form of knowledge exchange; there is no substitute for engaging in direct conversation where one idea triggers another or point–counterpoint debate leads to a solution. But videos that preserve the subtle body language, speech inflections, and contextual references of a face-to-face conversation may be the next best way to preserve and experience an expert's explanation of design concepts long after that expert is gone.

We continue to work to bring people together face to face and virtually to share ideas. We encourage knowledge "stewards" to help others discover the wealth of "live" knowledge available within their organization. Through both practice and technology, we have expanded the casual water-cooler conversation to collaborative communities with few boundaries. The sharing of knowledge by experts "in their own words" will continue to be an important contributor to successful missions. ●

TIM HOWELL was an ISS engineering and manufacturing manager at Rocketdyne in Canoga Park, Calif., for ten years. He went on to lead ISS Design Knowledge Capture and contribute to B-1B, B2, shuttle, and multiple rocket engine tacit knowledge-capture initiatives.

STEPs to Excellence

The Level 1 curriculum of NASA's new Safety and Mission Assurance Technical Excellence Program (STEP) culminates in dramatic studies of times when efforts to ensure crew safety and flight success fell short. Among them are the Apollo 1 capsule fire, the oxygen tank explosion that crippled Apollo 13, and the *Challenger* and *Columbia* disasters. The online studies guide participants in the program through the circumstances and technical sources of the failures toward an analysis of root causes that typically reveals a dangerous convergence of technical, managerial, and cultural weaknesses.

In the Apollo 1 case, for instance, the danger posed by a capsule atmosphere of 100 percent oxygen went unrecognized in part because a string of successful Mercury and Gemini flights using a pure oxygen atmosphere had created complacency. Combined with deficiencies in quality control, safety and test procedures, and communication, that failure to recognize a serious risk cost the lives of three astronauts.

After studying a case, participants take an exam on the System for Administration, Training, and Educational Resources for NASA (SATERN) Web site to show they have mastered the material. The cases come at the end of approximately twenty-five hours of online coursework on subjects including systems engineering, operational safety, software assurance, and quality engineering. Those who successfully complete the entire Level 1 curriculum will receive a certificate signed by Bryan O'Connor, NASA's Chief of Safety and Mission Assurance (SMA), and their center SMA director.

Why STEP?

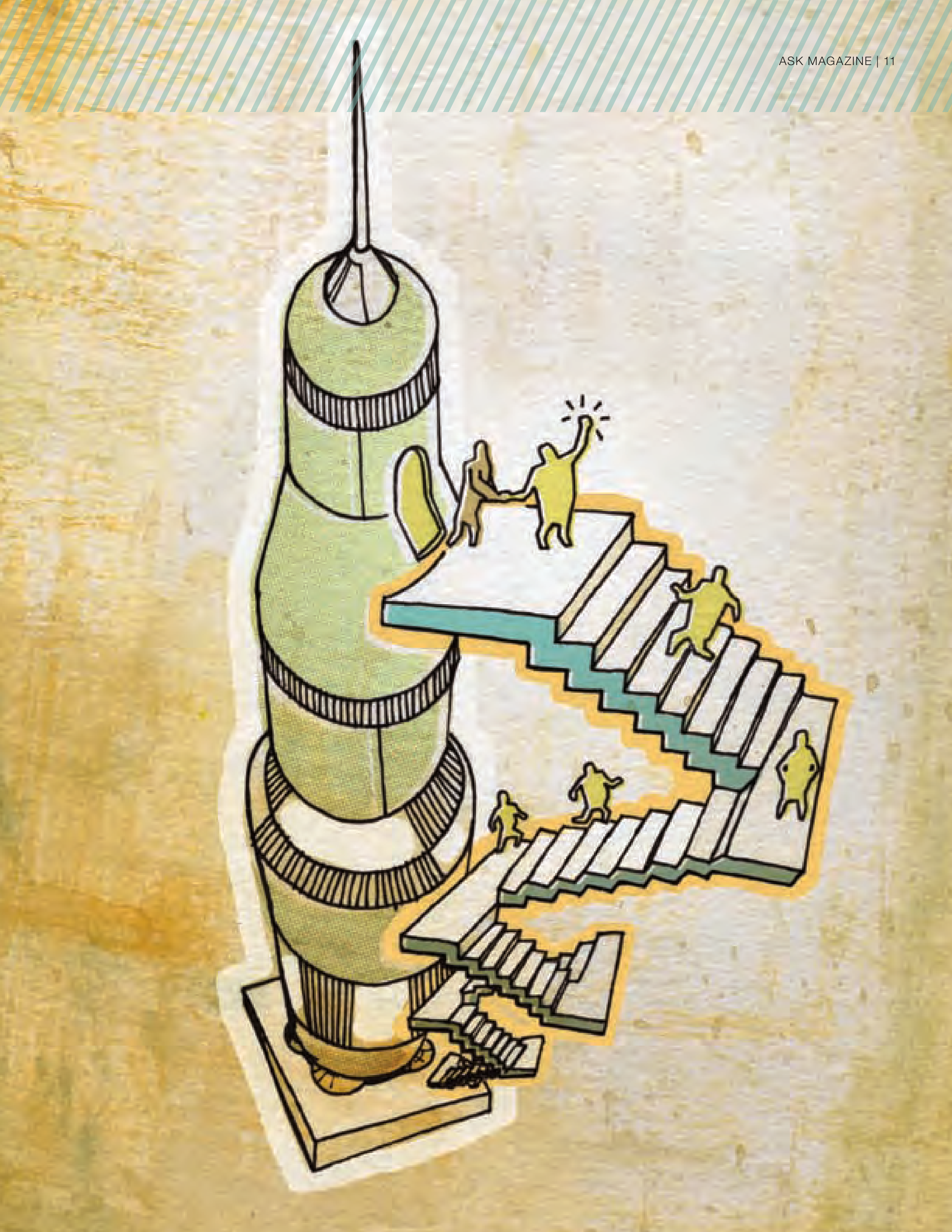
According to O'Connor, STEP is a response to an assessment by professionals in the field that NASA's approach to career advancement and competency-oriented training for safety and mission assurance personnel was "haphazard." O'Connor has noted that reviews after the *Challenger* accident mentioned "the silent safety program" and adds that it was silent because at that time safety people didn't know what to say. The quality of NASA's safety program has improved since then, but the need for consistent and comprehensive professional development remains.

The STEP program, which is being run by the NASA Safety Center in Cleveland under the auspices of the Technical Excellence Office, is designed to develop SMA professionals who can be full, credible participants in NASA programs and projects because they have mastered the tools and practices of their discipline and earned the respect of their engineering and management colleagues. By asking the necessary tough questions early in the design process—questions like, "What if it doesn't work that way?" or "What if it fails?"—and working with the rest of the team to find constructive answers, they will help design safety into the agency's missions from the beginning. Skilled safety and mission assurance professionals who know not only what the rules are but why the rules exist will, says O'Connor, be in a position to say "yes, if" rather than "no, because" when safety-related design issues arise. The goal of the STEP program is to help them reach that level of knowledge and ability.

John Marinaro, director of the Technical Excellence Office and leader of the STEP team, says that STEP will provide a path to that technical excellence, help create a robust safety and mission assurance community of practice, and foster improved collaboration between SMA and engineering at NASA.

Designing STEP Level 1

To develop the Level 1 program, the STEP team assessed twenty NASA and outside learning programs, did six months



of benchmarking, and worked closely with NASA's Chief Engineer and the Academy of Program/Project and Engineering Leadership, or APPEL, to design and develop course material. APPEL has worked closely with the STEP team for two years. The safety training programs at Marshall Space Flight Center and Johnson Space Center were also key contributors to the STEP concept.

APPEL Deputy Director Roger Forsgren says, "The NASA Safety Center explained that they were beginning to build a new training program for safety engineers throughout the agency. They requested design help from APPEL because they were familiar with our program and wanted to model their training program after ours. This is exactly the type of collaboration that Chief Engineer Mike Ryschkewitsch wants APPEL to pursue. I think some of our most significant help went into the STEP Handbook Web site. APPEL is proud of the usability and functionality built into that design. It will help make the training process more intuitive and, therefore, more effective."

In the summer of 2009, 250 SMA professionals at Glenn Research Center and Johnson Space Center participated in a pilot program to test the Level 1 curriculum. The pilot led to some small changes—a few of the lessons were judged to be too long; some participants objected to the proliferation of confusing acronyms—but the general response was overwhelmingly positive. Almost half the pilot participants received credit for completing the full Level 1 curriculum, which consists of twenty-two SATERN modules.

On September 3, Level 1 was officially rolled out to the agency as a whole by way of a Webcast that was viewed by more than one thousand civil servants and contractors at NASA centers and other facilities. Immediately after the Webcast, Kennedy Space Center, Marshall Space Flight Center, Stennis Space Center, and NASA Headquarters offered Level 1 courses that were taken by more than four hundred individuals and facilitated by the SMA directors at those centers. In all, more than 1,200 people have registered for STEP in its first month and more than 250 have graduated from Level 1.

The STEP program is voluntary but strongly recommended for SMA professionals as a means to measure and continually advance the proficiency of the SMA workforce. Level 1 consists entirely of online courses that participants can fit into their individual work schedules. The STEP development team has demonstrated the capability to develop state-of-the-art training modules, but the STEP philosophy is to use as much proven existing learning material as possible, from all available sources. There are, for instance, one-hour video courses on risk management, decision analysis, and systems engineering produced by the APPEL team that introduce and sum up their longer courses on those subjects. "We reviewed the STEP competencies and matched them to our APPEL courses," Forsgren notes. "APPEL also brought several instructors to Cleveland to tape core and domain topic overviews." The videos are linked to accompanying slides; users can listen to the lectures straight through or click on a slide to jump to the related part of the lecture.

A Four-STEP Program

STEP will eventually entail four progressively more sophisticated and demanding levels of coursework, on-the-job training, and continuing education that could include work toward advanced degrees and membership in professional societies. The higher-level curricula will be increasingly discipline-specific. Marinaro points out that supervisors are required to create individual plans for the professional development of each employee in the agency. He believes that this process is seldom fully understood by supervisors or employees; doing it well can be labor intensive.

Marinaro believes that STEP is one of the first comprehensive, career-oriented development programs in the civil-servant sector that will provide safety leaders with a full road map for the six primary safety disciplines at NASA. It provides a training model that can be easily adapted to other career fields. This should provide an instant resource to improve the individual development plan process and solve a major technical competency-development challenge for safety. The aim will be to match the learning process to participants' professional aims and the particular demands of their jobs. SMA professionals who have taken other safety-related courses or who have many years of experience in the field will be able to get credit through an equivalency process and, with the aid of their supervisors, focus on STEP program aspects that meet their individual needs.

The full four-level STEP program will blend and balance the convenience of self-directed online learning with the more time- and resource-intensive instructor-led courses, on-the-job training, and enrichment experiences that contribute to the rich and subtle knowledge that the work requires.

STEP's multiyear approach to continuing education is a major commitment. Completing the entire program will require approximately 550 hours of academic work plus extensive on-the-job training. Marinaro describes STEP as a "career-oriented professional development system" that will make a crucial contribution to developing subject-matter experts in safety disciplines. The ultimate goal of the program is to produce a corps of outstanding safety and mission assurance professionals who will make an important and lasting contribution to the success and safety of future NASA missions. It is a resource that will also be available to civil servants and contractors outside the NASA safety community and in other agencies. It will ultimately provide a repository and set of references to more than 3,000 hours of safety and engineering competency-oriented training. ●

PROTECTING Shuttle and the Environment

BY STEVE GLOVER

Photo Credit: NASA/Ken Thor

Launch Pad 39B and Space Shuttle Atlantis *glow in the dusk.*

NASA's Space Shuttle is one of the most complex systems ever designed, manufactured, and operated. The shuttle program is organizationally complex, too. The program elements that keep it flying are located in many NASA centers, with prime contractors and supporting suppliers spread across the United States. Many of the industries supporting the shuttle, though mainly located in the United States, have parts of their operations in other countries. Coordinating the work of these many organizations requires a major integration effort. The complexity of the shuttle and its support structure adds to the challenge of tracking and responding to environmentally driven reformulation and obsolescence of some of the several thousand products the program uses.

Generally speaking, environmental regulations have evolved from an early 1980s focus on establishing compliance requirements and cleaning up contaminated sites to pollution prevention, risk, source control, green engineering, and sustainability. This change includes an industry trend toward reducing the use and production of many chemicals with the potential to harm humans or the environment. The resulting numerous material and product changes, reformulations, and closeouts raise issues for NASA as well as for the Department of Defense, other federal agencies, and private industry.

The effects of these changes are of special concern to human spaceflight programs, which require highly reliable systems. Environmental regulations and environmentally driven industrial trends can lead to a host of consequences, including risks to safety, schedule, cost, performance, and reliability. One chemical change can potentially involve numerous flight hardware materials. Finding adequate replacements may involve extensive testing and qualification efforts.

The thermal protection system used on the external tank offers one example of continuing environmental challenges. The system contains foam materials that insulate the liquid hydrogen and liquid oxygen propellants inside the tank, maintaining them at their cryogenic temperatures and preventing ice formation on the tank exterior. A chemical blowing agent provides the critical insulation and cell-structure properties of these foams. The foam blowing agent used early in the shuttle program was chlorofluorocarbon (CFC)-11, a class I ozone-depleting chemical. It was phased out of production at the end of 1995 by Environmental Protection Agency regulations.

Considerable research and development were required to qualify a replacement agent: hydrochlorofluorocarbon (HCFC)-141b, a class II blowing agent with lower ozone-depleting potential. When, in 2003, regulations also phased this material out of production, the shuttle program and NASA Environmental Management Division worked with the Environmental Protection Agency to obtain an allowance to continue production of this flight-critical material until the end of the program. The orbiters and solid rocket boosters also used this foam, but the orbiter project team has been able to replace HCFC-141b with an insulating material that is free of ozone-depleting chemicals.

The Environmental Challenge

Identifying and mitigating environmentally driven risk is a large, complex, challenging task. Obsolescence risks stem from both regulatory influences and industrial trends. Regulations for a particular chemical may include detailed requirements affecting production, uses, discharges, and emissions. Some chemicals are placed on watch lists as agencies evaluate their potential health and environmental effects. Some are regulated outside the United States, and chemicals may be regulated at the federal, state, and local level. To further complicate matters, regulations are subject to continual updates and changes.

Industrial changes may occur for a number of reasons. Companies may decide to eliminate or reduce the use of certain chemicals based on their regulatory status, their known or potential toxicity, or the likelihood of future regulation. Our concerns about these changes fall into two categories: unidentified changes and material performance changes. Not knowing when a company changes a formulation is of course a major concern.

Space Shuttle project elements work with their vendors to identify changes before they occur, but suppliers to those vendors

Photo Credit: NASA

Handheld still image taken by Discovery's *crew of the external fuel tank as it was jettisoned after launch of STS-114.*

sometimes change their products without notice. It is important to have controls in place to flag unexpected product changes. Often only limited information is available about the influence of regulatory requirements on industry. When changes occur, understanding how the new material will perform is essential. We must understand specific uses, processes, and controls involving any changing material so we can appropriately assess the risks. Key questions to ask include, what is the use of a particular chemical or material? Is it a critical use? How many places is it used? Once we are aware of a material change, we must coordinate with the supplier to understand the change and review the supplier acceptance testing as well as our in-house testing. If that testing is inadequate to determine performance, we need to develop and carry out new qualification testing and/or technical analysis to verify that the material will perform to the specifications.

The Shuttle Environmental Assurance Team

In the late 1990s, some members of the materials technical community realized they needed to work together to try to solve problems created by the continuing impact of product obsolescence on the shuttle program. This early informal team, called the Shuttle Replacement Technology Team, began identifying potential environmentally driven obsolescence issues and shared data and approaches to mitigating those risks. In 2000, the Space Shuttle program manager directed that a formal Shuttle Environmental Assurance (SEA) initiative be established to put a team and processes in place to proactively identify, communicate, and mitigate environmental assurance risks. The team would communicate with both management and the technical community.

The team is a multidisciplinary, multifunctional group made up of representatives from the shuttle program, project elements (orbiter, Space Shuttle main engine, reusable solid rocket boosters, external tank, flight crew equipment, ground support equipment), associated prime contractors, and members from supporting organizations, including NASA Headquarters, the Space Operations Mission Directorate, the Environmental Management Division, NASA centers, International Space Station program, Constellation program, and the U.S. Air Force.

Our first task in developing the SEA team was to create a group that covered all shuttle project elements, the prime contractors, the centers (mainly environmental offices and materials engineering offices), NASA Headquarters, and other supporting organizations that focus on shuttle operations. We successfully recruited team members who have the information, knowledge, and skills to identify, communicate, and help each other mitigate issues. Once the team was established, we had to answer questions concerning our scope and processes, and how to reach our overall environmental assurance objectives. Also, determining how we would create requirements and hold such a large team responsible without explicit authority (since we depend on some organizations outside the shuttle program) was a major task. Several individuals from earlier groups helped us define requirements that made good sense for all stakeholders. Dealing with environmentally driven issues often requires the expertise and cooperation of many stakeholders.

Establishing effective communication has been a major team accomplishment, but it has not come easily. Obtaining information from stakeholders and understanding their different perspectives, integrating risks across shuttle elements, getting centers to talk to each other, connecting centers and programs

DEALING WITH ENVIRONMENTALLY DRIVEN ISSUES OFTEN REQUIRES THE EXPERTISE AND COOPERATION OF MANY STAKEHOLDERS.

and environmental engineering to materials engineering, and communicating to the program and project community on environmental issues have been major challenges. The sheer volume of regulatory reviews and the amount of information we need to communicate was initially overwhelming.

We have developed good communication channels that include the SEA Web site, technical interchange face-to-face meetings, and regular teleconferences. Our documentation and reporting provide clear, concise information about risks and concerns. In addition, we developed a regulatory matrix to help communicate regulatory changes and identify potential risks. We also use technical notices to communicate industry changes. Facilitated risk analysis has been an important tool, since we often work with multiple risks that have to be integrated into programmatic risk. We also use technical papers to collect the factual information on a potential issue so the risk can be evaluated appropriately. We have established interfaces with other government agencies to share information on risk and mitigations.

Broad Benefits

The work we do has a direct impact on the success of shuttle missions. We have been successful in mitigating environmentally driven risks because we provide sound technical work and risk mitigation, create products the community finds useful, and save cost and time. Our team approach has saved resources by sharing technical information, coordinating mitigation work, and using common risk, technical, and communication tools. Many SEA products and processes benefit programs other than the shuttle. For instance, the experience gained by the Space Shuttle program in understanding regulatory requirements and trying to find a replacement for HCFC-141b is helping the Constellation program in its replacement and allowance efforts.

The SEA team has formalized access to technical experts in materials engineering, logistics, and environmental requirements. The SEA team gives NASA a technical connection to data and reviews on proposed environmental legislation and regulations, executive orders, and Environmental Protection Agency research that could affect NASA missions. Our risk management process and reporting process also help connect working scientists and engineers to the higher-level managers.

Other NASA programs face or will face environmental issues similar to the shuttle's, so it has made sense to include the International Space Station program and the Constellation program in SEA activities. Continuing government and industry efforts to protect the environment will affect virtually all NASA programs. The SEA team will continue to help deal effectively with the issues those actions will create for the duration of the shuttle program. Working as part of this very professional and dedicated SEA team to meet these challenges has been a very gratifying experience. ●

STEVE GLOVER is an engineering lead and technical manager for the shuttle program and is currently the Shuttle Environmental Assurance lead and Shuttle Transition and Retirement Environmental Cross-Cutting manager. His background is in environmental and chemical engineering and engineering management, and he has twenty-eight years' experience in these areas.

Apollo Technology: Back to the Future

BY PIERS BIZONY

In April 2007, a team of awestruck technicians discovered that the apparently lifeless artifacts on display from a long-vanished era of space exploration were not quite so dead after all. They carefully removed access panels on an old spaceship, revealing pristine mechanisms within.

The Apollo command modules on display at Kennedy Space Center s Saturn V Complex. The umbilical housing compartment can be seen between the service and crew modules in the lower right area of the image.

Photo Credit: NASA Kennedy Space Center

AT THE END OF ITS MISSION, AND JUST PRIOR TO REENTRY INTO THE EARTH'S ATMOSPHERE, AN APOLLO CAPSULE HAD TO SEPARATE CLEANLY FROM THE REAR SERVICE MODULE THAT HAD CARRIED MOST OF ITS AIR, WATER, ELECTRICAL SUPPLIES, AND PROPULSION FUELS. DOZENS OF POWER WIRES, FLUID CABLES, AND DATA CONDUITS HAD TO BE DISCONNECTED IN AN INSTANT. HOW WAS THIS RELIABLY ACCOMPLISHED?

The Apollo spacecraft on display at the Kennedy Space Center in Florida is the unflown backup for the 1975 Apollo–Soyuz docking mission that signaled the end of the Cold War space rivalry. All its systems are intact. Dan Catalano and a privileged group of mechanical engineers and pyrotechnics experts from Glenn Research Center in Ohio were granted permission to strip down the one small section of this spacecraft that most interested them. They wanted the answer to a problem that continues to challenge the best minds in modern space engineering.

At the end of its mission, and just prior to reentry into Earth's atmosphere, an Apollo capsule had to separate cleanly from the rear service module that had carried most of its air, water, electrical supplies, and propulsion fuels. Dozens of power wires, fluid cables, and data conduits had to be disconnected in an instant. How was this reliably accomplished?

Artist s concept of the Apollo crew module.

Image Credit: NASA

Behind the umbilical housing sat a tiny set of explosive guillotines, through which all the cables and lines snaked in a neat bundle. When the time came for the capsule to drop away, the guillotines sliced through metal and plastic as though they were butter. A backup set of guillotines, powered by an entirely separate electrical system, insured against failure. And all this was in a box the size of a car battery. Forty years later, Apollo still has lessons to teach as NASA gears up for a return to deep-space astronaut missions using capsules.

Catalano said, "I grew up in the Apollo age and used to watch all the launches. I was a product of that era. To be able to come and actually touch the hardware is a real thrill for me." Convincing the general public, thronging past this and similar museum exhibits, to be equally impressed is a challenge. There is something about the superficial appearance of the old Apollo equipment that needs to be explained to them.

In popular culture, spaceships are supposed to look sleek and futuristic but, even today, the real-life hardware sometimes lacks a certain stylishness. There is a reason for this. Take a look, for instance, at how commercial airliners are built. The production runs are large enough to justify the initial huge costs of purpose-built factory tooling and templates. The cabins have molded interior fittings that tuck neatly into the corners and meet seamlessly with the window frames, the foldaway tables look like they belong on the back of the seats, and so on. There will be some decorative flourish, probably featuring the airline logo. Inside and out, everything fits together into a more or less cohesive whole.

The same cannot be said of a typical spacecraft. These are hand-built machines, with populist styling absolutely not on anyone's priority list. It makes no economic sense for aerospace companies or space agencies to create production lines for machinery that is only going to be assembled a few times. And, given the energy required to lift mass into orbit,


Photo Credit: NASA

The Apollo lunar module DSKY keypad.

spacecraft designers do not have the luxury of adding merely decorative touches. Consequently, there is a spare, nuts-and-bolts feel to most spacecraft that causes inexperienced observers to think of them as disappointingly crude, almost willfully antique.

The cultural reference point for what spaceships are supposed to look like is almost certainly Stanley Kubrick's 1968 science-fiction film *2001: A Space Odyssey*, itself a product of the age of Apollo. Kubrick's prop designers first sat down at their drawing tables in 1964, at the start of what would turn out to be a long and complex production, yet the ships they invented still look futuristic and still tend to dominate everyone's thinking when it comes to the "archetypes" for space machinery.

Kubrick took advice from the corporate world, and they in turn delivered idealized versions of what they expected space vehicles to look like. Crucially, they envisaged a world in which the commercial marketing of space transportation was commonplace. Hence, each cabin and cockpit in *2001* had a sleek look designed to appeal as much to the paying customers in the passenger seats as to the pilots who flew up front.

It is fascinating that the new space tourism companies, such as Virgin Galactic, have thought along similar lines, creating interiors for their suborbital spacecraft that satisfy our expectations of how things *should* be, with digital control panels, soft padding on the cabin walls, and space meals you can suck through a straw, just like in *2001*. This is all an illusion, a marketing ploy. In real life, the interiors of space shuttles or Apollo capsules do not look at all luxurious.

Visitors to space museums expect gleaming science-fiction props, and the real spacecraft that they encounter often leave them slightly shocked. They peer through the hatch of an Apollo capsule and see a dimly lit interior encrusted with ancient clockwork. There are no touch-sensitive screens or plasma displays. The instrument panels are a mechanical maze of switches and dials, and the electrical energies that once powered them no longer lend them some energy.

People are struck by how primitive everything looks. In particular they often observe that the lunar module seems, today, like something lashed together by kids in preschool. The styling of technology changes, and people's expectations have evolved with it. If we want to gain an impression of how futuristic Apollo seemed four decades ago, we need to make a couple of time-travel journeys of the imagination.

First, picture Louis Blériot in 1909 making what seemed at the time an epic journey, a crossing of the English Channel by air, in a monoplane of such fragile design it seems unthinkable, today, that anyone could have trusted their life to it. Look also at Charles Lindbergh's *Spirit of St. Louis*. Would you expect that machine, with its homemade finish, to have carried a man safely across the Atlantic Ocean? Yet these two famous planes were heralded as portents of a new world. They were *futuristic*, because no one had seen anything like them at that time.

To the generation who witnessed Apollo when its hardware was factory fresh, the vehicles conveyed a similarly novel and futuristic impression. Picture the command module brand new, covered in mirror-smooth silver-foil insulation so that it looked like a single piece of polished metal. (The foil burns

With the umbilical housing cover safely detached, the intact cord assembly is in full view.

Photo Credit: NASA Kennedy Space Center

off during reentry, leaving the capsule a drab, brown color.) Now visualize the interior of the spacecraft surgically clean and brightly lit so that the astronauts can see what they are doing. There is not a single scuff, nor the tiniest flaw, in the paintwork. The fans and air-conditioning units are humming, and the control panel is a shimmer of lights and trembling dials. Apollo seems almost alive. By the standards of the 1960s at least, this was the most advanced machine in history—and everyone who saw it at the time sensed that truth.

The same applied to Apollo's electronics. We often hear that the onboard Apollo Guidance Computer (AGC) had less power than a modern digital watch. But it all depends on what we mean by "power." At the time, it was one of the most capable computers ever invented.

In terms of raw processing capability, our modern home PCs may be more "powerful" than an AGC, but they tend to be plugged into just a few interfaces with the outside world: a printer, a backup disc drive, a screen, and a router. By contrast, an AGC was connected to a three-axis inertial navigation system allied to an optical star telescope, while its twin aboard the lunar module also absorbed data from two radar rangefinders: one directed toward the lunar surface, the other keeping tabs on the orbiting command module. The AGC also mediated between the astronauts and the thrusters and rocket engines that drove their ships through space.

Translating the AGC's capacity into modern computing parlance can be misleading, but its magnetic core ROM stored the entire suite of guidance programs in the equivalent of about 36 kilobytes. Here lies another of the extraordinary "powers" that this machine possessed: the power of lines of software reduced to their most disciplined fundamentals, so that a small amount of code could deliver astonishing results.

The AGC's third and most important "power" was a reliability that we can only dream of today. Nothing was "stored" in ROM when the AGC was switched off, but once activated, it booted up in less than a second. It was a

IT'S A CLICHÉ THAT APOLLO KICK-STARTED THE MICROCHIP REVOLUTION, BUT THERE'S SOME TRUTH HERE. NASA BOUGHT UP 60 PERCENT OF AMERICA'S ENTIRE OUTPUT OF INTEGRATED CIRCUITS IN THE EARLY 1960s, DELIBERATELY ALLOWING THE NEW INDUSTRY TO ACCLIMATE ITSELF TO MASS PRODUCTION AND RELIABILITY CHECKING OF NEW CHIPS, AND TEMPORARILY SHORING UP AN INDUSTRY FOR WHICH FEW OTHER MARKETS YET EXISTED.

totally hardwired system, because the software was encoded as patterns of wiring, snaking in and out of the little ring-shaped cores, that could not be overwritten or erased. Even when Apollo 12 was struck by lightning soon after launch in November 1969, and the interior of the capsule blacked out for a moment, its AGC swiftly recovered to fly the rest of the mission. It was a reliable piece of equipment because it had to be. Lives depended on it.

The AGC's fourth "power" was the ability to change the broader world around it. The computer processor itself depended on a relatively untried device: the integrated circuit. The first examples had been invented as recently as 1958 by Jack Kilby of Texas Instruments. A year later, Robert Noyce of Fairchild Semiconductors (and later, the founder of Intel) refined the process by putting all the components on a silicon chip and connecting them with copper lines.

It's a cliché that Apollo kick-started the microchip revolution, but there's some truth here. NASA bought up 60 percent of America's entire output of integrated circuits in the early 1960s, deliberately allowing the new industry to acclimate itself to mass production and reliability checking of new chips, and temporarily shoring up an industry for which few other markets yet existed.

Another revolution was in the means by which people with little desire to become computer experts (the astronauts) could communicate with the AGC via a small display and keyboard, known as DSKY. They inputted short numeric codes, signifying programs that they wished to initiate. The DSKY then "talked" back at them with five lines of numeric displays and a small panel of sixteen labeled lights.

DSKY transformed the relationship between people and computers. With our touch-sensitive screens and graphic interfaces, we take for granted our ability to operate computers without having to understand their internal workings. In the early 1960s, the idea of nonspecialists having anything to do with them was radical.

The AGC was the mediator of another new union, commonplace today but revolutionary at the time: that between computers and airplanes. On May 25, 1972, test pilot Gary Krier flew a modified F-8 Crusader jet fighter, knowing that for the first time in history, his joystick commands did not feed directly to the aircraft's flight control surfaces but were first verified and adjusted by an electronic mind. Sixty percent of the software for the world's first-ever fly-by-wire aircraft consisted purely of Apollo code. This success changed the future course of aviation.

The history of AGC and the many other Apollo innovations also informs our future. As NASA reaches for new horizons in space, it is essential that it pioneer new and inspirational technologies whose influences ripple throughout the culture and economy at large, just as the machines of Apollo did forty years ago. Bold innovation continues to be a key responsibility for NASA. When those involved with the current generation of space architecture next engage with the public, we must hope and expect that they can give as good an account of the technological revolutions they are creating as the designers of Apollo could. ●

PIERS BIZONY has written about science, aerospace, and cosmology for a wide variety of magazines in the United Kingdom and the United States. *2001: Filming the Future*, his award-winning book on the making of Stanley Kubrick's *2001: A Space Odyssey*, has become a standard reference work. It was also the basis for a C4 documentary film. In 1997, *The Rivers of Mars*, his critically acclaimed analysis of the life on Mars debate, was short-listed for the NASA/Eugene M. Emme Award for Astronautical Writing, while *Starman*, produced as an acclaimed book and a BBC film, told the story of Soviet cosmonaut Yuri Gagarin's life for the first time.

Image Credit: NASA

SON OF LEM: Lunar Lander Design Today

BY JOHN F. CONNOLLY

A typical NASA project begins with a set of requirements that describe all the functions and performance a spacecraft must possess. A vehicle is then designed to satisfy those requirements. This process produces a design that initially attempts to meet all requirements equally, after which it is difficult to reduce capability if the vehicle is found to exceed mass or cost limitations. Our risk-informed design approach to Altair, the next lunar lander, is different. Our aim has been first to design a vehicle that meets a minimum set of requirements and then incrementally add functions and performance to that initial design. This approach means that the decision to accept each additional requirement will be informed by its individual impact on cost, performance, and risk. This process was derived in part from NASA Engineering Safety Center Report PR-06-108, "Design, Development, Test, and Evaluation (DDT&E) Considerations for Safe and Reliable Human-Rated Spacecraft Systems."

After defining the "minimum functional" vehicle in the first lander design-analysis cycle, the Altair team identified major risks that would affect the safety of the crew and the success of the mission in subsequent design cycles. The project team was able to identify the specific performance "cost" of each increment of crew safety and mission reliability added to the minimum spacecraft design. Residual spacecraft risks will continue to be evaluated as subsequent design cycles assess the performance, cost, and risk impacts of adding additional vehicle functionality and other factors, such as manufacturability and maintainability.

The Baseline Design

The first step of the process was to establish a "minimum functionality" baseline design by scrubbing the vehicle requirements back to a small number that described the lander's essential functions and constraints. The core requirements for the Altair lander were to carry a crew of four to the lunar surface for seven days with 500 kg of payload, loiter for up to 210 days at a polar outpost, deliver 14,500 kg of dedicated cargo, fit within the Ares V shroud, perform the lunar orbit insertion burn with the Orion spacecraft attached, carry an airlock, and work within the Constellation architecture. Key constraints were

Three crewmembers work in the area of the lunar lander on the lunar surface in this NASA artist s rendering.

mass limits of 45,000 kg for crewed missions and 53,600 kg for cargo missions.

The minimum functional design was the baseline from which to identify vehicle risks in order to mature the design to one that was "safety enhanced." The team first identified risks that contributed most directly to a loss of crew and then studied multiple mitigation options for these risks. We developed decision processes for both selecting the risks to be studied and evaluating the mitigation options that were incorporated into the second design-analysis cycle. In this cycle, the primary measure of risk reduction was the reduction in loss-of-crew risk, and the primary "cost" measure was added mass. The outcome of this risk-reduction design cycle was a reduction in the risk of loss of crew from 1:6 to 1:206 by expending 1,300 kg of mass for more robust components, selective redundancy, and dissimilar system backups. This first cycle of risk-informed design brought the lander design within striking distance of the target risk requirement of 1:250.

The third Altair design cycle focused on loss-of-mission risks in the same way that loss-of-crew risks were addressed in the previous cycle. The team identified lander reliability risk areas and studied options that increased reliability at different levels of mass

The Common Extensible Cryogenic Engine, or CECE, is fueled by a mixture of liquid oxygen and liquid hydrogen chilled to subzero temperatures. The goal of the Altair lunar lander descent engine is to slow the vehicle so astronauts can land safely.

expenditure. We also began to incorporate additional capabilities, such as the ability to land at any site on the lunar globe. This global access capability will be "bought back" in the same way that safety and reliability were reintroduced into the minimum design—with known impact to risk and performance.

Risk-informed design provides early, critical insight into the overall viability of the end-to-end architecture and provides a starting point to make informed cost–risk trades so risks can consciously be bought down. The Altair team has used the education afforded by risk-informed design to look at risk reduction in its many forms rather than blindly applying fault-tolerance rules or preconceived risk-reduction solutions. The process inherently produces risk metrics for each added capability, and cost analysis can easily be added to facilitate evaluation of the true cost and risk changes that accompany each added capability. Perhaps most importantly, risk-informed design creates a "smart buyer" team that understands the balance of risk drivers and mass performance within the design.

Maturing the Design

Risk-informed design is a time-consuming process that may not work for projects with compressed schedules; the first three design-analysis cycles took the Altair team approximately twenty-four months to complete. To optimize the risk-based design effort, the Altair team chose to hold the vehicle design constant so as not to introduce new variables into the design, with a plan to revisit vehicle configuration once the first two buyback cycles were complete. With the completion of those cycles, the next step was to prioritize the configuration and maturation studies that would have the greatest impact on the vehicle design. Altair considered a list of more than two hundred potential configuration–maturation trades, and from that list chose the following studies as the basis for a special trade-analysis cycle that was inserted into the vehicle's development schedule:

- Alternate descent-module configuration
- Alternate ascent-module and airlock configuration
- Alternate ascent- and descent-module separation concepts and analyses
- Structural stiffness design
- Descent-module tank residuals
- Human-piloting capability maturation
- Operations concepts and timeline maturation
- Spacecraft "safe" configuration for critical faults

The trade-analysis cycles will give us a fresh look at the lander design to determine if the current configuration is optimum for the current architecture. Possible changes may include a reduced number of descent tanks, alternative descent-stage structure, alternative placement of the ascent module and airlock, change of the ascent-module pressure-vessel shape, and alternative methods of packaging cargo. It's important for a design to be revisited on occasion. As engineers, we sometimes become so enamored of our designs that we fail to see large innovations or subtle alternatives that may improve the design solution. Scheduling regular revisits to the design configuration offers the team the opportunity to step back and reconsider the design choices they have made.

Design Challenges Abound

As we've worked through the early phases of the Altair design, we have a sense that we are walking the trail the Apollo designers blazed before us. The physics of lunar landing demand that the lander perform velocity changes—about 1,000 m/sec to decelerate into lunar orbit, 2,000 m/sec to decelerate to a soft landing, and another 2,000 m/sec to accelerate back into lunar orbit. Additionally, a lander must include life support for the human crewmembers. So much of the lunar lander "design space" is determined by physics. Large tanks of propellant surrounded by structure, an attenuation system for landing, and a pressurized volume for crew habitation all directly address the physics of lander design. Those physics and engineering realities mean that the Altair lander will bear little resemblance to an X-wing fighter or even a homely *Star Trek* shuttle craft, as much as the designers would have liked it to.

Instead, Altair will look like the big brother of the Apollo lunar module because the physics of lunar landing is unchanged and technology has improved only incrementally since Apollo. Apollo designers not only understood the physics of the problem perfectly, they were very smart, especially given that they were inventing much of the technology. Our challenge is to apply the lessons learned from Apollo and combine them with the incremental improvements in technology from the past four decades.

Still, the design process is full of technical challenges, including the timely development of a variable-thrust descent main engine, control of propellant levels in a multiple-tank system, scavenging of cryogens for fuel-cell use, development of a high-reliability ascent main engine, control of lander center-of-gravity, and lander stack frequency during launch and translunar injection.

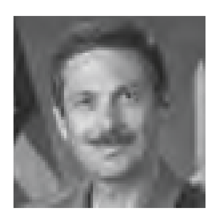
In addition to the technical challenges are management and administrative issues encountered during the early conduct of the lander project. These include acquiring a skilled workforce, competing with other projects for resources, and coordinating projects in different points in their project life cycle.

NASA lacks adequate human spacecraft design and development expertise. As an agency, we simply don't have enough large human spaceflight projects to consistently train human spacecraft developers. New human spacecraft developments occur at NASA approximately once per generation, and those spacecraft are typically developed by industry with NASA providing initial conceptual work, requirements, and then oversight and insight. New projects such as Altair offer an opportunity to take the in-house phase of the design to system design review (or perhaps a bit beyond) to expose a new generation of designers to the early design phases beyond writing requirements. Innovative partnering between NASA and industry can further extend in-house experience into the mature design phases of a project. To supplement its design teams, NASA is reaching into its robotic lander experience, Space Shuttle and International Space Station development expertise, and its Apollo lunar module knowledge to bring experience to the current design challenge.

Another challenge is that of ramping up a new project at the same time other projects are peaking in their development and resource needs. The lander project will be several project milestones behind Constellation's Orion and Ares I and will compete for resources with these more mature projects. These projects, though started at different times, must eventually perform future missions together, which creates challenges in defining the interfaces among these elements. This challenge is reflected in interface requirements documents: the more mature projects will have more fully developed interfaces, and the projects that are closer to the beginning of their life cycles may be left to accept interface requirements established by their more mature siblings.

In other words, designing a new human lunar lander is a multilayer systems challenge. The Altair project must create a lander design that reflects the physics of spaceflight and limitations of human performance while balancing performance, cost, schedule, and risk; works within the integrated architecture performance, cost profile, schedule, and integrated risk and reliability targets of the Constellation program as a whole; and fulfills the policy directives of NASA's strategic plan, Congress's NASA Authorization Acts, and policy and budget guidance from the Administration's Office of Management and Budget, Office of Science and Technology Policy. To pull this off requires a team with a true systems perspective—an understanding of how a change made to one lander parameter affects other factors, and other levels. ●

JOHN F. CONNOLLY leads vehicle design and engineering for NASA's Altair Lunar Lander Project Office at Johnson Space Center. Prior to joining the Constellation program, he served two years at NASA Headquarters as the deputy of the Exploration Systems Architecture Study team, leading the definition of the lunar architecture that is now the basis for NASA's exploration planning.



NASA helicopter bird s eye view of Max Launch Abort System flight.

Photo Credit: NASA/Jim Mason Foley

WHAT WOULD MAX DO?

BY DAWN SCHAIBLE

In 2007, the Exploration Systems Mission Directorate asked the NASA Engineering and Safety Center (NESC) to design, develop, build, and test an alternate launch abort system for the new Orion crew module. Ralph Roe, director of NESC, became project manager for the Max Launch Abort System (MLAS), named after Maxime (Max) Faget, a Mercury-era pioneer who designed the Project Mercury capsule and the Aerial Capsule Emergency Separation Device, commonly known as the escape tower. What we learned on MLAS could help the primary launch abort system team with some of their own technical challenges, and it was an outstanding learning opportunity for engineers who took a project through its entire life cycle in less than two years.

While this was a larger effort than any of its previous assessments, NESC was well suited to meet two of the project's primary constraints: do not impede the inline design of the Orion launch abort system and be ready to conduct an MLAS pad abort demonstration in parallel with the Orion launch abort system test.

Developing the Concept

In order for us to accomplish our pad abort test in time, we needed to keep the design simple and use commercial off-the-shelf hardware and designs whenever we could. We went through a number of iterations to establish objectives for the MLAS test vehicle and adopted very conservative safety and design margins to compensate for our rapid prototype-design process. It was Faget's approach to design and development, and his assertion that Project Mercury "would have never been done in the time it was done if it had not been simple," that led us to adopt the motto, "What would Max do?"

We streamlined our processes and added redundancy only for those items that were essential to mission success, such as collecting flight test data. We prevented requirements creep by asking ourselves how it would affect our overall test objectives, and only those items that were essential for mission success made their way into our requirements.

Our test vehicle would demonstrate our concept but would not physically represent an operational vehicle, so we were not constrained by weight requirements. The operational vehicle would have multiple solid rocket motors inside a bullet-shaped composite fairing, which was different from the single solid launch abort motor positioned above the Orion crew module in the primary launch abort system. For the pad abort demonstration test, we used four solid rocket motors located below the crew module. Later in the design process, we added a landing parachute demonstrator, based on the Space Shuttle solid rocket booster recovery system, to demonstrate an alternative landing system configuration for crew module recovery.

At the time, one of the greatest technical risks for the Orion launch abort system was the attitude control motor, designed to steer the crew module. The MLAS concept was of potential interest because of its relative simplicity, aerodynamic performance, and weight savings. Many of these theoretical gains would be accomplished by eliminating the attitude control motor and the launch abort tower. By developing an alternate, passively stable approach in parallel with the Orion design, we were able to collect data that could assist the current launch abort system designers if they encountered technical challenges.

Forming the Team

To form a core team, Roe looked to members of NESC, including NASA Technical Fellows, for experience in aerodynamics, avionics, propulsion, software, and guidance, navigation, and control. He also used NESC's agencywide infrastructure to gain access to expertise and contacts at NASA field centers. The MLAS team now includes more than 150 engineers, analysts, technicians, and support personnel from almost every NASA center, with team members providing matrix support directly to the MLAS project.

We also sought out mentors—including Apollo-era engineers, project managers, and astronauts—who readily shared their insights and experiences, helped us focus on the most important things, and pointed out areas we might be overlooking. Having been through similar challenges, they served as a terrific sounding board, and their independent perspectives were crucial to the team's success. For example, our mentors convinced us to move from a three-point attachment design to a single-point attachment harness between the four main parachutes and the crew module because of test failures they experienced with a similar three-point design early in the development of Apollo.

Partnering with Wallops Flight Facility allowed us to leverage their sounding-rocket experience and use their range and launch facilities for the pad abort test; the Wallops engineers and analysts became integral members of our team. Faget conducted similar activities at Wallops in 1959 to develop the launch abort system for the Mercury spacecraft.

One of the more enriching aspects of the MLAS team was the interaction between individuals who came from the human spaceflight, robotics, research, and aerospace centers. We relied heavily on expertise from the research and robotic centers during the concept development phase, and as we moved through design and into assembly, the individuals with test and operations experience shared their knowledge with the team. We incorporated best practices from the aeronautics and human spaceflight centers into Wallops processes during integration

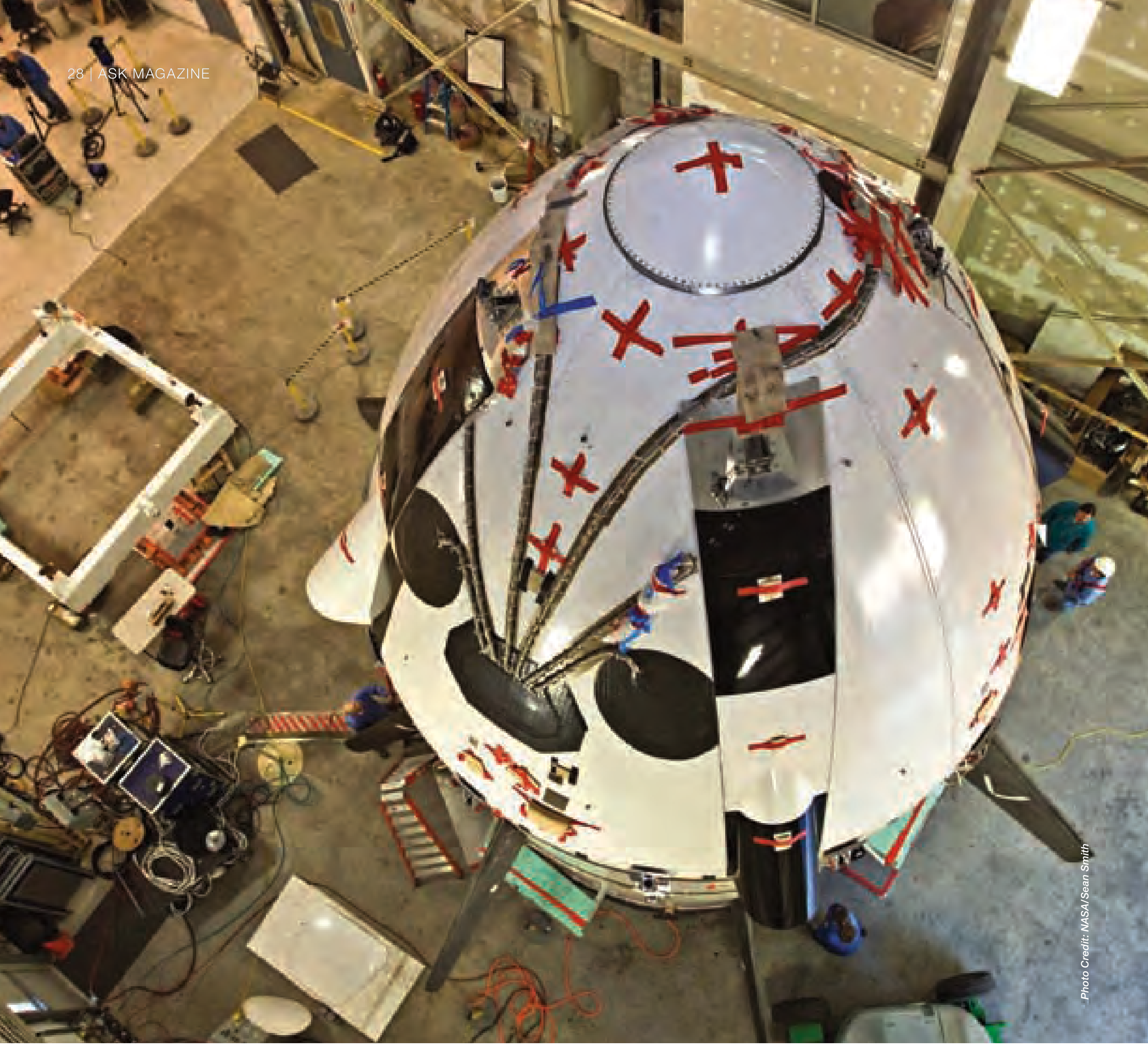


Photo Credit: NASA/Sean Smith

The Max Launch Abort System vehicle features a bullet-shaped forward fairing that covers a simulated crew module, not shown.

and testing. This project also provided a number of engineers with their first experience in a control room, on headsets, for test, checkout, and launch. They learned from others who work in this environment on a regular basis.

Recognizing the unique opportunity MLAS provided to junior engineers to design, develop, and fly a complex system, we asked center directors to nominate high-potential engineers with five to ten years' experience for our project. They became known as our "resident engineers," named after the medical residency concept. They were a true asset to the team, bringing with them energy, expertise, and enthusiasm.

Our resident engineers never sat on the sidelines, observing others; they were integral members of the team. Within two days of joining MLAS, we asked them to define the test vehicle's instrumentation. Gathering data was one of our primary objectives, so this was no fluff task. They took complete ownership of the instrumentation, including its procurement, installation, mounting bracket design, and checkout. In addition, they designed, installed, and tested the entire flight camera system for the test vehicle. Because the MLAS project was completely independent from the Constellation program, team members had the ability to try, fail, and fix—an invaluable learning experience.

"MLAS has given me the unique opportunity to participate in a cradle-to-grave project that includes technical experts from every NASA center," said Samantha Manning, a resident engineer from Kennedy Space Center. "I've gotten hands-on experience during all phases of the project. The people I've worked with and the knowledge I've gained have been and will continue to be valuable assets to my career."

Joseph E. Grady, a resident engineer from Glenn Research Center, agreed: "MLAS gave me the opportunity to contribute to the landing and recovery task and to see firsthand how a systems engineering approach is used to integrate the efforts of all the different disciplines involved."

The resident engineers have built a cohort of their own peers that will last long after the MLAS project is over. In addition to the experience gained by doing critical project work, they have had the rare privilege to closely interact with our mentor team, several NASA Technical Fellows, and other agency experts. "It was a rewarding experience to be part of a team that put together experts from all NASA centers and the aerospace industry to design, build, and test a flight-demonstration vehicle in such a short time," said Grady.

Project Management and Systems Engineering Approach

Because the team was dispersed across the country, we employed several strategies to ensure good communication and integration. To build relationships and understanding among the team, we conducted co-located meetings almost every month, usually at Langley Research Center or Wallops. These weeklong sessions allowed us to work through our tougher technical problems and complicated topics and facilitated a faster-paced decision-making process. In between these meetings, the team relied heavily on teleconferences, WebEx, and instant messaging. These virtual design sessions allowed team members across the agency to review models, designs, and analyses whenever needed.

Because the MLAS project was separate from the Constellation program, we had the ability to tailor an approach that was faithful to the spirit of NASA Procedural Requirements 7123.1A. Given the fast-paced, prototype nature of our project, we accepted the risk involved with concurrent design, development, and testing. In setting up our processes—and in the spirit of our motto, "What would Max do?"—we decided to streamline our documentation by eliminating boilerplate information and relying on checklists if they provided the same information as a formal plan.

We also instituted a forum for project control: the MLAS Configuration Control Board. Project leadership and all subteam leads were voting members on the board, which controlled everything from our flight test timeline, project risks, requirements, and design. We relied heavily on a tiger team approach for tackling integrated technical issues quickly, assigning an integration lead and having all pertinent subteams provide members. This approach allowed us to effectively address such issues as vehicle stability, assembly, and alignment. A "product needs" list helped us capture, track, and prioritize product deliverables, such as data, analyses, detailed designs, trades, or decisions.

… OUR MENTORS CONVINCED US TO MOVE FROM A THREE-POINT ATTACHMENT DESIGN TO A SINGLE-POINT ATTACHMENT HARNESS BETWEEN THE FOUR MAIN PARACHUTES AND THE CREW MODULE BECAUSE OF TEST FAILURES THEY EXPERIENCED WITH A SIMILAR THREE-POINT DESIGN EARLY IN THE DEVELOPMENT OF APOLLO.

Knowing that we were accepting risk because of our pace and concurrent design-and-build approach, we sought independent perspectives and reviews. We included our Safety and Mission Assurance team members as integral members of the Systems Engineering and Integration team, keeping them involved in all decisions and actions. We also tailored the standard milestone reviews to conduct three Independent Technical Reviews, inviting the same reviewers each time.

To reward and encourage engineering innovation, a can-do attitude, and a commitment to the safety and success of the

A prelaunch view, with Dawn Schaible in the foreground, of the control room at NASA's Wallops Flight Facility.

Photo Credit: NASA/Sean Smith

project, our project manager instituted the Max Engineering Excellence Award. These awards have served to publicly recognize the best of our team.

Successful Test Flight

On July 8, 2009, the MLAS team was rewarded with a fully successful flight demonstration test, including sixteen pyrotechnic events and nine parachute deployments. It will take several months for all the data to be reviewed and analyzed, then a final report and briefing will be shared with the Orion project and Constellation program. To see the results of long hours and hard work was tremendously gratifying for the entire team. We hope this successful flight test will serve as a model for future alternative, risk-reduction efforts at NASA.

Learning by Doing

Robert Seamans, NASA's deputy administrator in the Apollo years, said, "You cannot have good technical people on standby doing nothing and suddenly put them on the job when you have a problem. You have to have competent people doing exciting work that is not central to the program so they can be thrown in to fix the problem even if it takes six months." Developing MLAS as an alternate design to the launch abort tower system currently used not only allowed NESC to help gather technical information, but also provided valuable hands-on training for a team of engineers and analysts.

Omar Torres, another resident engineer at Langley, said, "Working with NESC has exposed me to the difficulties and glories of developing an intricate system such as the MLAS capsule. Taking part in the discussions of design and troubleshooting where subsystems of different engineering disciplines come together has been one of the most instructive and engaging developments of my career. Participating in the MLAS resident engineering program and working with the remarkable team of engineers in the project will always be one of my most significant experiences." ●

DAWN SCHAIBLE is the manager of the Systems Engineering Office for the NASA Engineering and Safety Center (NESC). She was also the MLAS systems engineer and integration lead. Prior to joining the NESC, she worked at the Kennedy Space Center, serving in various systems engineering, integration, and ground processing roles for the Space Shuttle and International Space Station programs.

INTERVIEW WITH

George Morrow

BY DON COHEN

George Morrow is the director of the Flight Projects Directorate at Goddard Space Flight Center, a position he has held since 2007. He began his career at Goddard in 1983 as an engineer working on spacecraft battery systems. Don Cohen spoke with him in his office at Goddard.

COHEN: In your position as director of Flight Projects, what do you see as the biggest project pitfalls?

MORROW: A new project, a new area of research that opens up for scientists, gets people excited and enthusiastic and, a lot of times, overly optimistic about what a project might be able to accomplish and what the cost and schedule might be. We raise expectations. Then, as we mature the design and the cost estimates and schedules, we find that, lo and behold, we can't really do as much as we thought for the dollars we have. That tends to be disappointing to the customers and stakeholders supporting the project. So a major pitfall is being overly optimistic early in the project life cycle. We're doing things to independently analyze and estimate cost and schedule much more than we have in the past so we can be accountable for meeting commitments at a much earlier phase in the project.

COHEN: Is that independent analysis done by people outside the project team?

MORROW: Absolutely. Independent analysis is being done by people outside the project team in NASA and, in most cases, by people outside NASA. Goddard has its own Resource Analysis Office that has the advantage of having a database of how Goddard specifically has performed on projects dating back several decades.

COHEN: Can you think of specific cases where outside reviewers said, "You have to pull back?"

MORROW: I don't know of a specific case where that came about as the result of a formal review. But there are cases of us

"WHEN YOU'VE GOT THE PROJECT SCIENTISTS **completely engaged** AS INTEGRAL MEMBERS OF THE MANAGEMENT TEAM EARLY—NOT ONLY IN **identifying what the science objectives** ARE AND **what measurements are essential**, BUT IN UNDERSTANDING THE HARDWARE AND SOFTWARE IMPLICATIONS—THEN YOU GET A MUCH MORE **synergistic and innovative** TRADE SPACE."

moving through the process and realizing along the way that we're not going to be able to deliver what we thought we could for the price. In those cases, we work with our customers and stakeholders to descope, commit additional resources, or both.

COHEN: Am I right in thinking that projects have a better idea of what is technically feasible and scientifically necessary when engineers and scientists work together from the beginning?

MORROW: Absolutely. I'm working with Nick White, the director of Exploration and Science here at Goddard, trying to make sure that the project and program scientists are fully engaged as members of the project and program senior management teams. The situation on each project and program is different and is sometimes personality driven, based on the managers' and scientists' background, experience, and what they're interested in doing, but you're absolutely right: when you've got the project scientists completely engaged as integral members of the management team early—not only in identifying what the science objectives are and what measurements are essential, but in understanding the hardware and software implications—then you get a much more synergistic and innovative trade space. There are ways to gain efficiency and optimize the system that may not be apparent if scientists aren't fully integrated in the project team.

COHEN: Where have you seen that collaboration between scientists and engineers working well?

MORROW: James Webb Space Telescope [JWST]. John Mather, our Nobel prize–

winning scientist, is the senior project scientist on JWST. He is fully engaged in the project team and understands intimately the design of the observatory, the optics, the instruments, and how they play together. When trades are done, Mather and his associates are in there with their sleeves rolled up.

COHEN: Are there other project pitfalls you want to mention?

MORROW: Another pitfall is that project managers and project teams tend not to manage the early phases of a project with the same sense of urgency that they employ in the endgame of system integration and test leading to launch. This is exacerbated by the fact that customers and stakeholders also don't have the same sense of urgency to make hard decisions, finalize requirements, and commit consistent resources early in a project. When we get to the integration and test [I&T] phase, people identify and solve problems fast. In the early phase of a project, issues are identified and there is a lot of conversation, but the sense of urgency isn't the same. If we managed the early phase of projects with the same sense of urgency as system I&T, we'd be a lot more efficient in the overall life cycle. That's something that I'm trying to instill in our project teams.

COHEN: What are you doing to change what seems to be a fairly basic fact of human nature?

MORROW: Our directorate management team is proactively tracking open issues and asking questions such as, "This issue has been here for a month; when are you going to get to the endgame and figure out how to move forward?" It's an uphill battle.

COHEN: Approximately how many projects are you supporting and what is your responsibility for them?

MORROW: At any one time Goddard has fifteen to twenty missions in the implementation phase, another ten or so in early concept and study phase, and in excess of twenty in the operations phase. All those projects report to me here in the Flight Projects Directorate. As you might know, the NASA governance model states that programmatic responsibility flows from the NASA Headquarters Mission Directorate Associate Administrator to a program manager to a project manager. While all Goddard program and project managers report to me, I'm not in that chain. My job is to ensure from a center perspective that projects are provided with the resources they need, that the center supports the planning and in-house development necessary, that we apply consistent management processes, and we facilitate and develop the infrastructure for project management at Goddard. I ensure that the technical, cost, and schedule decisions are consistent with NASA and Goddard processes and technical and programmatic standards. So, while I'm not in the programmatic chain, I work to ensure program and project success. My staff and I engage weekly and usually more often with each of the programs/projects and receive weekly status reports and top-ten issue reports from every project. We review the projects' budgets and their execution. Our job is to facilitate their success while not getting in the way of the programmatic responsibility chain.

COHEN: That sounds like a delicate task. I assume it includes apportioning limited resources.

MORROW: In the past few years Goddard has probably been the busiest we've ever been. We've had six major launches in the past year and have several more to come later this year and next. There's also a lot of formulation work going on for the next generation of Earth science missions. Personnel and facility resources have been stressed, so we reprioritize and mediate conflicts as we have to.

COHEN: How does NASA decide which Earth science missions should get those limited resources?

MORROW: An Earth science decadal survey was completed about two years ago. That serves as the overarching guidance for what an Earth science program should look like at NASA. Mike Freilich, who's the head of Earth science at NASA Headquarters, is using that survey as his road map for what priority should be given to which missions and which should be launched first.

COHEN: I sometimes think the public forgets how much NASA Earth science and planetary science missions have taught us.

MORROW: And continue to teach us. LRO [Lunar Reconnaissance Orbiter] is the first U.S. mission to the moon since Clementine a few years ago, and that was not a NASA mission. There are boot prints and hardware on the moon, but we've never had a high-fidelity digital map of the moon. We have better information about Mars than we do of the moon. And the information we do have is mostly at the equatorial regions of the moon, because that's where Apollo went. Now we want to go to the poles. The objective of the LRO mission is, among other things, to provide that high-fidelity digital information to support future lunar robotic and human missions. From an Earth science perspective, NASA currently has the most capable fleet of Earth science missions in orbit in history. Earth scientists have been able to make great strides in understanding climate change and identifying the measurements that will be imperative to have in the future. That said, the fleet is aging, and in order to ensure continuity of the measurements currently being obtained and incorporation of future research measurements, we are studying and formulating many future mission concepts.

COHEN: Do you see a tension between planning and standards—maybe as embodied in NPR 7120.5D—and the flexibility that unique projects require?

MORROW: There is a tension. We try to keep it a healthy tension. We are always weighing the specificity of the processes people have to follow against the latitude that a project or program manager needs to manage within those processes. In recent times—and 7120.5D is a good example—the standards have been developed completely in the open with the participation of all the centers. Developing that document was a fully open process that experienced practitioners at each of the ten NASA centers participated in. NPR 7120.5D really represents the way we do business. And it isn't so prescriptive that it doesn't allow the latitude program and project managers need.

COHEN: Do you think project management at NASA has changed since you joined the agency?

MORROW: In a lot of ways, a project manager twenty-five years ago was the king of the castle; he had much more latitude to operate than project managers do now, and we were much more dependent on the person than we are now. We go through cycles; the pendulum swings one way and back the other. I think we're at a fairly healthy place today.

COHEN: Tell me a little about your own early experiences.

MORROW: I spent ten years working on Hubble Space Telescope, from just before initial launch through the second servicing mission. I was able to be part of the management team that was able to figure out what was wrong with the telescope, fix it in the first servicing mission, and improve it in the second. Working under folks like Joe Rothenberg, John Campbell, and Frank Cepollina was invaluable because they had so much experience and know-how. The way they went about identifying and solving the problems and communicating to the outside world to get advocacy for what we were doing enabled us to be successful. Joe Rothenberg was a master at communicating inside and outside the program so that everybody remained comfortable and we could actually do what we were planning to do in the first servicing mission. Frank Cepollina had a masterful gut feel for what could be accomplished, what the team was capable of doing, and then he knew how to drive the team to make it happen.

COHEN: What you are describing isn't technical expertise.

MORROW: Often our best technical people don't make the best project managers. Project managers have to have a well-balanced background. They have to be people persons, with the ability to communicate both orally and in writing. They have to have a positive attitude and a vision to lead the team. Project managers have to be technically sound, but they wouldn't necessarily be called technical experts.

COHEN: What was your first project at NASA?

MORROW: As an engineer in the Space Power Applications Branch working on battery systems, I supported a project called ERBS, Earth Radiation Budget Satellite, which was a small satellite launched on the Space Shuttle in 1984. Within the first days of arriving at Goddard, I was in meetings on the project with folks I was working with.

OUR philosophy AND strategy AT GODDARD IS THAT OUR ENGINEERS HAVE TO HAVE direct, hands-on experience IN ORDER TO BE successful BUYERS AND MANAGERS OF SYSTEMS.

I supported ERBS through launch, so after being at NASA only a year, I found myself at the Cape, in the shuttle bay, supporting prelaunch preparations. It doesn't get any better than that!

COHEN: Lots of people who came to NASA years ago talk about being given significant responsibility right away. Is the same true today?

MORROW: Our philosophy and strategy at Goddard is that our engineers have to have direct, hands-on experience in order to be successful buyers and managers of systems. We are committed to engineers and scientists getting that kind of experience in the first few years of their careers. That's why we believe we have to have at least two in-house missions under development at any one time. We just finished up with Solar Dynamics Observatory and Lunar Reconnaissance Orbiter, and we have the Magnetospheric Multiscale and Global Precipitation missions starting up. In addition to those in-house spacecraft missions, we also need instrument and sensor system development going on in house. That's why we're doing things like the Thermal Infrared Sensor for LANDSAT and the Integrated Science Instrument Module for JWST in house. We fight for that in-house work.

COHEN: Did you imagine early in your career that you would have a managerial position?

MORROW: Not at first, but I think one of the advantages I had was having to multiplex across several projects. The person that hired me left within a month or two after I arrived. We were short staffed, so I had to work on many projects. I was able to see different project managers and teams and how they interacted. I came to understand what the jobs of a project manager and deputy and observatory manager and instrument manager were like. Fairly quickly, I determined that I wanted to manage projects some day. Because I had that exposure, I was able to say, "I'm a component engineer now. If I want to be a project manager, I need to be a systems engineer, I need to be an observatory manager, and I need to be a deputy project manager." After about five years in the power branch, I had the opportunity to work on Hubble as a systems engineer. Some in the organization said, "No, you ought not to do that; you ought to manage subsystems first. Take it slow." I went counter to that advice. I was a systems person for a few years on Hubble, and then I became an observatory manager before the first servicing mission and a deputy project manager after that. It worked out well! ●

Eric Gorman:

STARTING AT NASA NOW

After talking to George Morrow about his experience as a new NASA employee in the early 1980s, Don Cohen asked Eric Gorman about the experience of becoming a NASA employee today. When they spoke at the end of May, Gorman was just about to take a civil service position at Goddard.

COHEN: You've been working for NASA as a contractor?

GORMAN: I worked for Orbital in their building for a little over a year on the Hubble Space Telescope mission. They immediately gave me a couple of load analyses and stress analyses on brackets and structures that they were adding for the mission.

COHEN: Did you think, "This is really great," or, "I'm new and I don't know what I'm doing?"

GORMAN: I was very scared at first. I'd done schoolwork—the teacher says it's either right or wrong. Now it was, "You're smart enough to figure it out, and we'll make sure you're not screwing anything up, but you're ultimately responsible for this because your signature is on it." I felt a great deal of responsibility. After I moved here—I'm coming up on a year at Goddard—my responsibility level increased more than 100 percent. I'm now the mechanical lead for an entire subsystem of the Global Precipitation mission satellite. I'm in charge of six avionics boxes with three unique designs. I make sure that the avionics boxes meet mechanical and thermal requirements, maintain schedules, write procedures and reports, and I will be involved with testing and delivery to the spacecraft.

COHEN: Who's watching what you do now?

GORMAN: I've got some senior mechanical guys that I go to for advice. They look over my shoulder once in a while to be sure things are going well, they offer advice and experience, but day in and day out I'm pretty much responsible. Originally a senior engineer had the mechanical lead position, but he was moved to another project and I stepped up and assumed his responsibilities. He still checks in once in a while, asking if everything's going well. I've even gone to the branch head, Chuck Clagett. He's a mechanical guy so I've asked him questions.

COHEN: Have you sometimes gone in the wrong direction?

GORMAN: I'll typically ask a question if I'm unsure. There hasn't been anything where I've made a decision without the proper guidance.

COHEN: How good a job do you think the agency does incorporating new people?

GORMAN: NASA as a whole does a great job of immediately putting co-ops and interns to work. In my experience, everyone who has come here has been given good, meaningful work to do immediately. If a person feels what they're doing is important, they will be a motivated employee. My friends that have gone into jobs that are menial or meaningless usually leave those jobs. All my friends who have careers feel they were given responsibility in their companies and that their position matters.

HOPE FOR THE FUTURE

In November 2006, then–NASA Chief Engineer Chris Scolese brought together an advisory group of aerospace veterans to think about creative ways of giving young NASA employees the skills they will need to lead future projects and programs. Gus Guastaferro, an invited guest of this Management Operations Working Group, suggested developing a hands-on project that would give young engineers and scientists the opportunity to take a small mission from concept to launch to post-flight analysis.

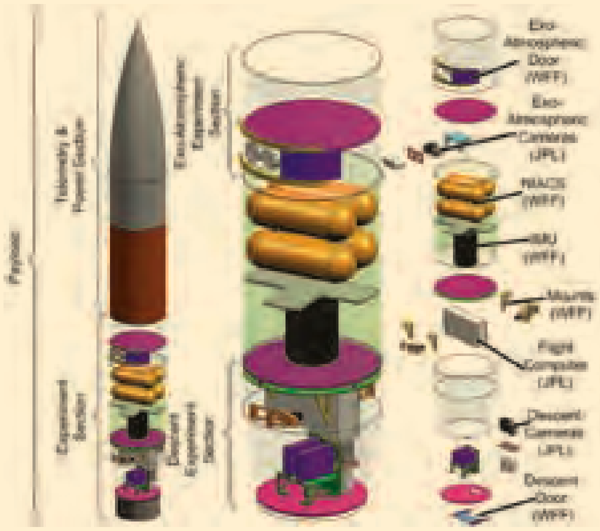
Just over two years later, NASA centers received an invitation to submit proposals for the first Hands-On Project Experience (HOPE) training opportunity. Five centers responded with project ideas. The winning plan, to improve terrain-relative navigation by collecting ground imagery during a sounding-rocket flight, came from the Jet Propulsion Laboratory (JPL). In the spring of 2009, a group of young JPLers led by project manager Don Heyer got to work on what they called the Terrain-Relative Navigation and Employee Development (TRaiNED) project.

Creating HOPE

Guastaferro's conviction that actual work experience provides uniquely valuable learning and his sense of what a hands-on learning project would look like came from his early days at Langley Research Center in the late fifties and early sixties. To develop the skills needed to add space exploration to the center's aeronautical work, Langley had members of its newly formed Space Task Group plan and carry out small rocket launches from Wallops Island. That experience gave Chris Kraft, Robert Gilruth, and other Apollo-era leaders knowledge of the technology and management of space programs that became the foundation of their achievements at the Manned Spacecraft Center in Houston, later renamed Johnson Space Center. Guastaferro notes, "In my own career, I pushed hard to become the launch director of the small Scout launch vehicle at the Western Test Range in 1966 to get my own hands-on experience. My decision to do that was based on the early days in the Space Task Group at Langley and the experience set the stage for my assignment to Viking in 1968."

All NASA employees learn from experience, but when the learning comes from playing relatively small roles in long, complex projects, it can take many years to develop the repertoire of skills needed to lead projects and programs. The projects in the program that grew out of Scolese's request would last approximately one year, allowing participants to experience all phases of a spaceflight project in a concentrated form and much sooner than they normally would in the course of their careers. The brief missions would give them valuable perspective on how project elements and stages meshed into a whole to achieve the aims of the mission.

Early on, the advisory group envisioned the Academy of Program/Project and Engineering Leadership (APPEL) as the sole sponsor of HOPE. It seemed a natural choice, given that organization's responsibility for learning and development. Scolese believed, though, that having the Science Mission Directorate (SMD) become a co-sponsor would increase the value of the initiative. In addition to sharing funding responsibility, SMD would give HOPE added legitimacy by ensuring that the projects would have a genuine scientific goal and not be "merely" training exercises. Brad Perry was designated SMD lead and given responsibility to ensure that HOPE projects would make a scientific or technical contribution to one of SMD's



Schematic of the Terrain-Relative Navigation and Employee Development project payload.

Image Credit: NASA/JPL

four divisions: planetary science, Earth science, astrophysics, or heliophysics. Perry said, "I am excited to be involved with HOPE and the opportunity it affords to develop future NASA leaders through practical 'hands-on' experience."

Wallops was recruited to provide launch services for the projects. A budget of $800,000 per project was established (with the understanding that centers would be free to add funding). By the end of 2008, the team developed a training opportunity announcement soliciting proposals for the first HOPE project. The document specified the two main goals of the program:

- To provide hands-on experience on an Earth or space science flight project to enhance the technical, leadership, and project skills for the selected NASA in-house project team.
- To fly a sounding-rocket science payload, which will have a useful purpose for the SMD by either providing new or complementary science data for one of the four SMD science divisions or by developing capabilities in support of SMD science objectives.

Evaluating the Proposals

The proposals received from five NASA centers offered a wide range of investigative ideas. Three separate groups reviewed the submissions. One, led by Guastaferro, evaluated their training merit. Paul Hertz, SMD's chief scientist, led the panel judging their scientific merit. The group led by Carlos Liceaga assessed the quality of their technical management—the likelihood that the proposed plans and resources would accomplish the project aims on time and on budget.

Results from the three panels were merged to arrive at a final judgment. The JPL terrain-relative navigation proposal was the winner. Because the project built on a previous sounding-rocket mission, it promised to accomplish its scientific goals while limiting its scope by reusing much of the technology from that earlier flight. The JPL submission was also strengthened by the existence of an early-career-hire development program at the center called Phaeton. The two programs were a natural fit. Phaeton (which will be the subject of a future *ASK* article) provided the mentoring resources needed to make HOPE successful.

The First HOPE Project Begins

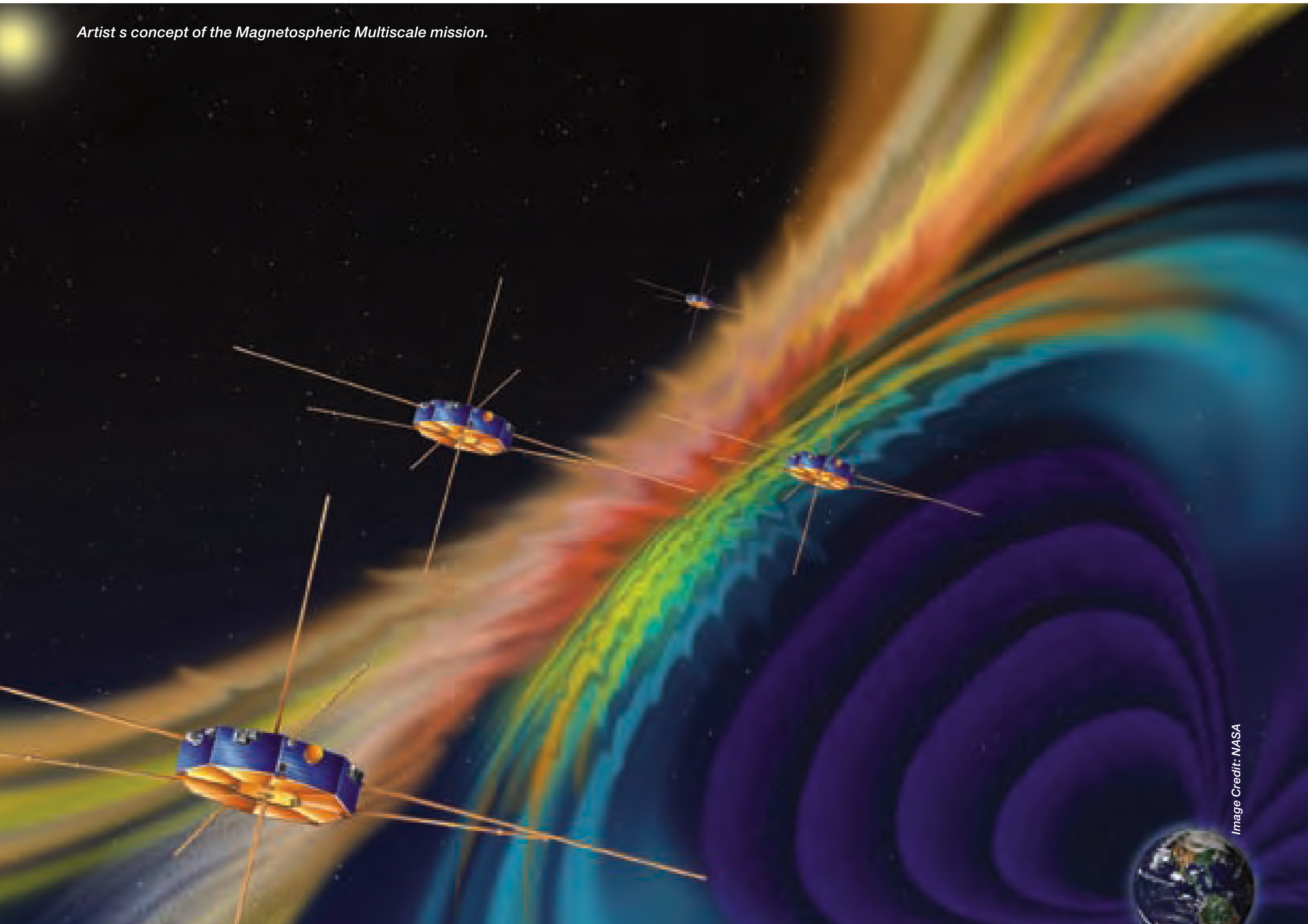
A Mission Initiation Conference at Wallops Island in May 2009 officially launched the project. At that meeting, the Wallops team presented their plan and Wallops personnel described their sounding-rocket services. To give participants the benefit of authentic project experience, the TRaiNED initiative will follow standard NASA procedural requirements. A Standing Review Board assembled for the project will see the team through milestones including a system requirements review (held in early July), preliminary design and critical design reviews, and a mission readiness review. The project launch is scheduled for June 2010. Several months into the work, project manager Heyer said, "The TRaiNED project is giving a group of early-career hires an opportunity to learn firsthand how a flight project is implemented, from formulation through flight."

The main goals of the project are of course accelerated learning from the promising early-career hires at JPL and scientific results that can contribute to other NASA programs. But APPEL and SMD also hope to learn from the experience. They are observing and evaluating the TRaiNED experience with an eye to improving future HOPE projects. Whatever shape NASA's future missions take, they will require the highest possible level of technical and managerial expertise. So Scolese's call for new and better ways to develop the skills and knowledge of young NASA engineers and scientists to carry out future programs will remain important. HOPE is one promising response to that call. ●

Magnetospheric Multiscale: An In-House and Contracted Mission

BY KAREN HALTERMAN

The Magnetospheric Multiscale (MMS) mission, a scientific satellite–development project managed by the Goddard Space Flight Center, is both an in-house project and a contracted one. The four MMS spacecraft are being developed by Goddard; the 100 MMS instruments are being developed under contract to Goddard. MMS offers examples of the advantages and disadvantages of both kinds of work, and the challenge of combining the two.



Artist s concept of the Magnetospheric Multiscale mission.

Image Credit: NASA

MMS is a NASA Science Mission Directorate heliophysics mission intended to gain an understanding of the universal process of magnetic reconnection, in which energy in magnetic fields is converted into particle kinetic energy and heat. The mission consists of four identical satellites, each with a payload of twenty-five instruments, that will circle Earth in highly elliptical orbits to measure magnetic fields, electrical fields, plasmas, and energetic particles. The satellites, flying in a tetrahedron formation as close together as 10 km, will take measurements in three dimensions with unprecedented resolution. Launch of all four satellites on one Atlas V is scheduled for August 2014.

Contracted and In-House Work

Most of NASA's funding is spent on contracts. Large corporations, universities, medium-size companies, small businesses, research institutes, and consultants work under contract to NASA to provide rockets, space hardware and software, aeronautics research, scientific analysis, ground-system development, and resources for the myriad activities that NASA undertakes. Some of NASA's responsibilities are inherently governmental and cannot be contracted, but some development items that could be contracted are carried out by NASA employees.

As explained in the NASA Strategic Plan, the agency needs to maintain the institutional capability and core competency of its workforce by performing some of the hands-on work itself. At Goddard, most satellite projects go to prime contractors, but some are developed in house—the spacecraft is designed, manufactured, and tested by Goddard civil-servant engineers. In-house projects provide the workforce with the personal experience necessary to oversee the development of contracted work. Support-service contractors augment the civil servants' work, providing business and engineering expertise, including configuration management and mechanical engineering.

In 2006, NASA Headquarters assigned the development of the MMS spacecraft as a Goddard in-house development. All MMS instruments will be developed under a single contract by Southwest Research Institute.

In-House Development

Under the management of the MMS project, the Goddard Applied Engineering and Technology Directorate (AETD) will design, manufacture, and test the four MMS spacecraft and integrate them with the four instrument suites. MMS spacecraft development involves configuration-controlled documents and signed work agreements between the MMS project and AETD, but there are no contracts associated with in-house development. From the project management perspective, there are pluses and minuses to in-house spacecraft development.

Advantages

- Being internal to Goddard, the spacecraft team is physically located at the same place as the project and knows the Goddard culture. Communication between the project and the spacecraft team is enhanced by this proximity and common frame of reference. Misinterpretation of technical terminology, which sometimes varies among NASA centers, is minimized. For example, the MMS spacecraft team knows what "protoflight testing" entails, but the members of the MMS instrument team had to learn the Goddard definition of this term. Face-to-face discussions between the project and the spacecraft team happen every day. The project is in daily contact with the instrument team through teleconferences and e-mail, but in-person meetings occur less often, on average once a month.

BOTH IN-HOUSE AND CONTRACTED APPROACHES CAN BE SUCCESSFULLY USED TO DEVELOP FLIGHT PROJECTS. AS SUGGESTED HERE, BOTH APPROACHES HAVE SIGNIFICANT STRENGTHS AND SIGNIFICANT POTENTIAL WEAKNESSES.

- Compared with the lengthy process of formal contract direction, major technical and programmatic changes can be carried out more quickly by an in-house team. Once the project's Configuration Control Board has approved a change that affects cost, schedule, or technical performance, the Goddard spacecraft team can immediately move forward with the new configuration. The instrument team, on the other hand, may need to wait for the contract modification in order to implement the change.
- Regular meetings with Goddard senior management are used to discuss status, address issues, and give the project some influence over the in-house work. Goddard senior management has helped the MMS project resolve facility-usage conflicts with other projects. By contrast, contracts can be bumped by higher-priority contracts. A Goddard project cannot override a DX classification—military programs judged to have the highest national priority—which permits military activities, such as buying electrical and electronic engineering parts needed in satellites, to take precedence over NASA civilian work.
- The Goddard workforce—from senior engineers leading subsystems to journeymen engineers developing designs to fresh-outs tackling hands-on testing—gains the practical experience of spacecraft development from concept through launch. Of course, the contractor's workforce also gains experience, but this knowledge may not be applied to future Goddard missions.

Disadvantages

- As government employees, the Goddard spacecraft team tends to be less focused on cost control and meeting deadlines than industry counterparts who are accustomed to meeting contract requirements. With launch several years in the future, some members of the team need regular reminders about the importance of schedule performance.
- The NASA accounting system and financial reporting requirements are not conducive to large in-house projects. For example, NASA budgeting and monthly financial reporting require civil servant labor costs to be reported separately from other costs, but earned value management requires civil servant labor to be included in the appropriate work breakdown category. Hence, the MMS project must perform financial planning and reporting of the same cost data more than one way—a duplication of effort.
- AETD seeks to advance spaceflight technology, a commendable goal, but MMS is cost constrained like all projects. Occasionally, the project must temper the zeal of spacecraft engineers to experiment with new technology when an existing design meets requirements, costs less, and is less risky to build. MMS engineers have expressed interest in using composite materials, nanotechnology, and newer flight computers, for example. The project rejected these ideas as being more expensive or not mature enough for the mission.
- Components of the spacecraft that meet mission requirements and are commercially available will be competitively procured. It does not make sense to reinvent flight-proven items such as transponders, batteries, and thrusters. This means, though, that in-house development includes contracted items prone to the accompanying disadvantages of contracted work.

Contracted Mission

The MMS instruments are being developed under a Goddard contract with Southwest Research Institute, which leads a team of subcontractors and international partners that collectively will build 100 instruments for the mission. As with all Goddard contracts, NASA provides the requirements, funding, and oversight. The Southwest Research Institute team designs, manufactures, tests, and delivers the instruments to the MMS project. The project reviews the design and contract deliverables, provides technical direction and the interfaces to the spacecraft, works with the instrument team to resolve issues, and monitors technical progress, schedule, and costs. From the project management perspective, there are pluses and minuses to contracted missions.

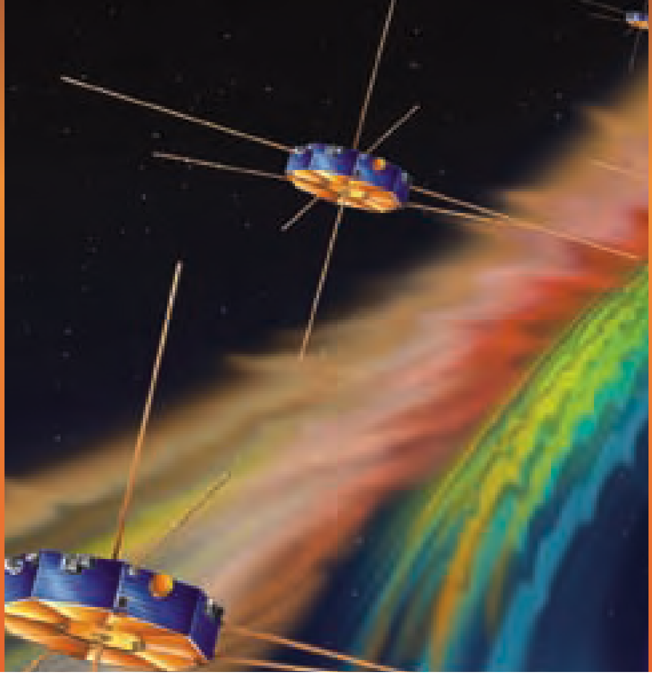
Advantages

- While the project is ultimately accountable for all project activities, the contractor is fully responsible for producing the deliverables of the contract. The contractor directly manages the work; identifies, hires, and assigns the people with the necessary skills for the work; procures the parts and materials; and provides facilities to build and test the flight hardware. Since the MMS instruments are being acquired through a single contract, Southwest Research Institute is responsible for all of them, including those developed by its numerous subcontractors.
- Contractors selected to develop entire satellites or complex instruments generally have the people, experience, and infrastructure needed for such complex engineering efforts. As a result, a small NASA team is sufficient to monitor the contractor's progress. Only a handful of the MMS project staff is dedicated exclusively to the administration of the Southwest Research Institute contract.
- The contractor, usually following a hard-fought competition to win the contract, is motivated to succeed in order to maintain a reputation in the aerospace community, pursue future government work, and earn profit for stockholders. Award fee contracts, which pay costs plus additional payments that depend on how well the contractor met specified performance goals, are particularly effective in providing periodic feedback to contractors and identifying areas for improvement. (In this particular case, award fee evaluations are not an available MMS management tool because Southwest Research Institute is a nonprofit organization with a cost plus fixed-fee contract.) As the home institution of the MMS principal investigator, Southwest Research Institute is committed to the science and the mission.
- When the contract ends, NASA does not have responsibility for placing the contractor's employees into new jobs or keeping the contractor's facilities in use.

UNIVERSITIES ON THE MMS INSTRUMENT TEAM ARE ALSO AFFECTED BY THE ECONOMY, AS LESS STATE MONEY IS AVAILABLE DURING HARD TIMES, WHICH COULD RESULT IN HIRING FREEZES OR LESS FUNDING FOR LABS AND EQUIPMENT.

Disadvantages

- The procurement of NASA flight hardware–development contracts is a lengthy process. Preparing all the documents needed to release the request for proposal, conducting the source selection, and negotiating the contract typically take more than a year. After the contract is in place, it still takes a long time to execute contract modifications because changes must be approved by the project's Configuration Control Board and the center's procurement and legal offices. If a major modification to the MMS Southwest Research



Institute contract were needed, it would take several months to execute, possibly affecting the project schedule.

- Regardless of the best efforts to write complete and accurate specifications and statements of work, these documents inevitably have ambiguities. Disagreements about what is in scope and out of scope can lead to protracted arguments, increased costs, and even legal disputes. The contractual relationship between the MMS project and Southwest Research Institute is a good one, but now and then different interpretations arise, such as the extent of IT security requirements.
- At times, NASA may need to help the contractor; for instance, by providing specialized expertise. Some universities on the MMS instrument team do not have the robust quality assurance programs required to develop flight hardware. The project will provide mission assurance assistance to the MMS instrument contract as needed, which must be covered by the project budget.
- Business cycles and the overall state of the economy can adversely affect contractors. Most NASA contractors also support the Department of Defense; downturns in defense contracting may result in layoffs or closing of plants that affect NASA work, relocating it to other locations or increasing indirect costs stemming from a smaller business base. Takeovers, mergers, and sales of company divisions can also negatively affect NASA through loss of corporate knowledge, low morale, or changes in policies and procedures. The period of performance of the MMS instrument contract is long (it started in 2003 and ends after MMS on-orbit operations have finished in 2018). There have been and probably will continue to be changes in the corporate make-up of the instrument team. Universities on the MMS instrument team are also affected by the economy, as less state money is available during hard times, which could result in hiring freezes or less funding for labs and equipment.

The Best of Both Worlds

Both in-house and contracted approaches can be successfully used to develop flight projects. As suggested here, both approaches have significant strengths and significant potential weaknesses. As the MMS mission proceeds toward its scheduled 2014 launch, management will continue to try to capitalize on the advantages of both the in-house and contracted aspects of the project and minimize the disadvantages. ●

KAREN HALTERMAN is the MMS project manager. Previously, she was the project manager for the Polar Operational Environmental Satellites project, a fully contracted mission.

Ingenuity and Improvisation

BY JIM HODGES

It began with $2,000 and a cable hanging from an I beam in "The Hangar" at NASA's Langley Research Center in Hampton, Virginia. From that simple start almost five decades ago grew the Rendezvous Docking Simulator, first used to demonstrate linking a Gemini spacecraft with an Agena target in space and, later, to gather data and eventually to teach astronauts to link an Apollo lunar excursion module, just back from the moon, with a command module. Without that link, there might have been no Apollo mission. Certainly, the deadline set by President Kennedy's May 25, 1961, commitment to land on the moon before the end of the decade would not have been met.

A surplus hydraulic motor from an aircraft drove one end of the cable along the roof, and a man hung from the other, wearing an air tank and carrying a hose with an air gun that he could fire as though it were a thruster. On the floor of the hangar, engineers watched and took notes.

"The idea was to simulate what a guy would have to do if he was going to navigate in space from one place to another," said Jim Wise, who communicated with astronauts "flying" the Rendezvous Docking Simulator by intercom.

"These guys were smart enough to bootleg some parts and help make it work with that $2,000," Wise said, adding, "To talk about this now seems so juvenile, but you had to start somewhere. Some of the aircraft people said, 'These space guys are just playing.'"

In fact, the space guys were putting in motion a plan that one of their own had charted on a blackboard and sold to NASA hierarchy over the objections of space pioneers, including Wernher von Braun and Max Faget. John Houbolt, assistant chief of the Dynamic Loads Division at Langley, ran the numbers involved in landing on the moon, then taking off again in a 65-foot spacecraft versus one only 14 feet tall, and launched a campaign for a concept called lunar orbit rendezvous. A primary issue, he said, was lifting from Earth the 82,700-lb. moon lander that would be required for Earth-orbit rendezvous versus one weighing 19,320 lbs.

"John Houbolt stuck his damn neck out, is what he did," said Donald Riley, who also worked on the simulator. "Houbolt knew we couldn't take all that weight to the moon."

The catch to Houbolt's idea was literally a catch. If the lunar excursion module couldn't dock with the command module that was orbiting the moon at 17,000 mph, 240,000 miles from Earth, the result would be two astronauts finally walking on the lunar surface but never getting back home to talk about it.

Langley set out to build a simulator. As with all simulators, it began with this premise: "One thing that most people don't grasp right away is that simulators that are tasked to study a specific thing do not have to be authentic in detail," said Wise. "You only have to detail the part you are studying. That means that some of the simulators appear to be extremely crude, but as long as they are faithful to that part you are studying, it's OK."

From the cable, the docking simulator continued to evolve in fitful phases. "We used lots of junk," Wise said, laughing. "I remember I got a catalog of government surplus stuff, and we used a lot of it on simulators at Langley."

Thrusters mounted on a pilot's helmet to foster a sensory aspect to spaceflight bridged the gap between the rope and designing and building a simulator that would effectively mimic a real docking. One primary idea for the simulator evolved from the trial-and-error experimentation: it had to react in many ways like an airplane.

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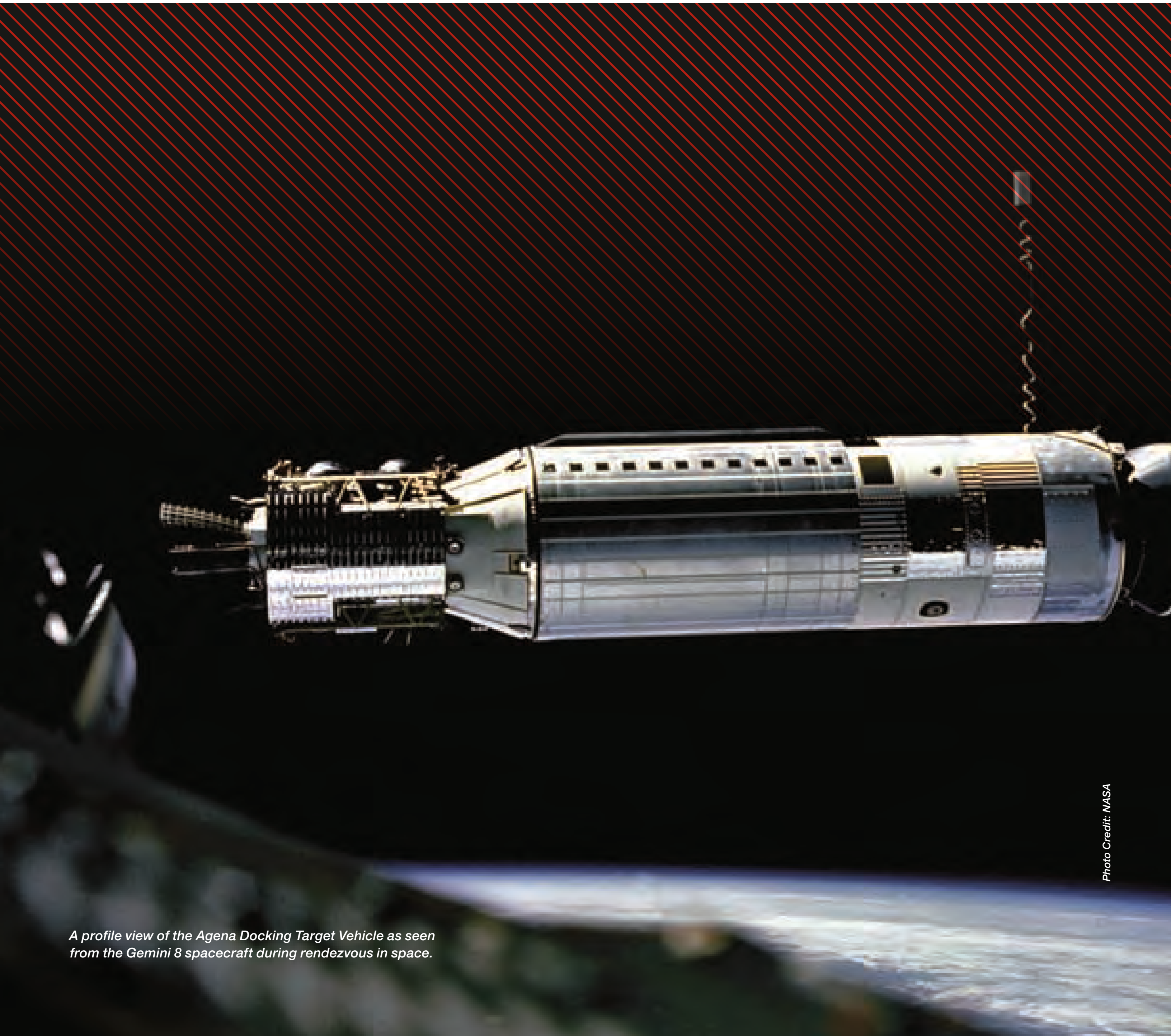


Photo Credit: NASA

A profile view of the Agena Docking Target Vehicle as seen from the Gemini 8 spacecraft during rendezvous in space.

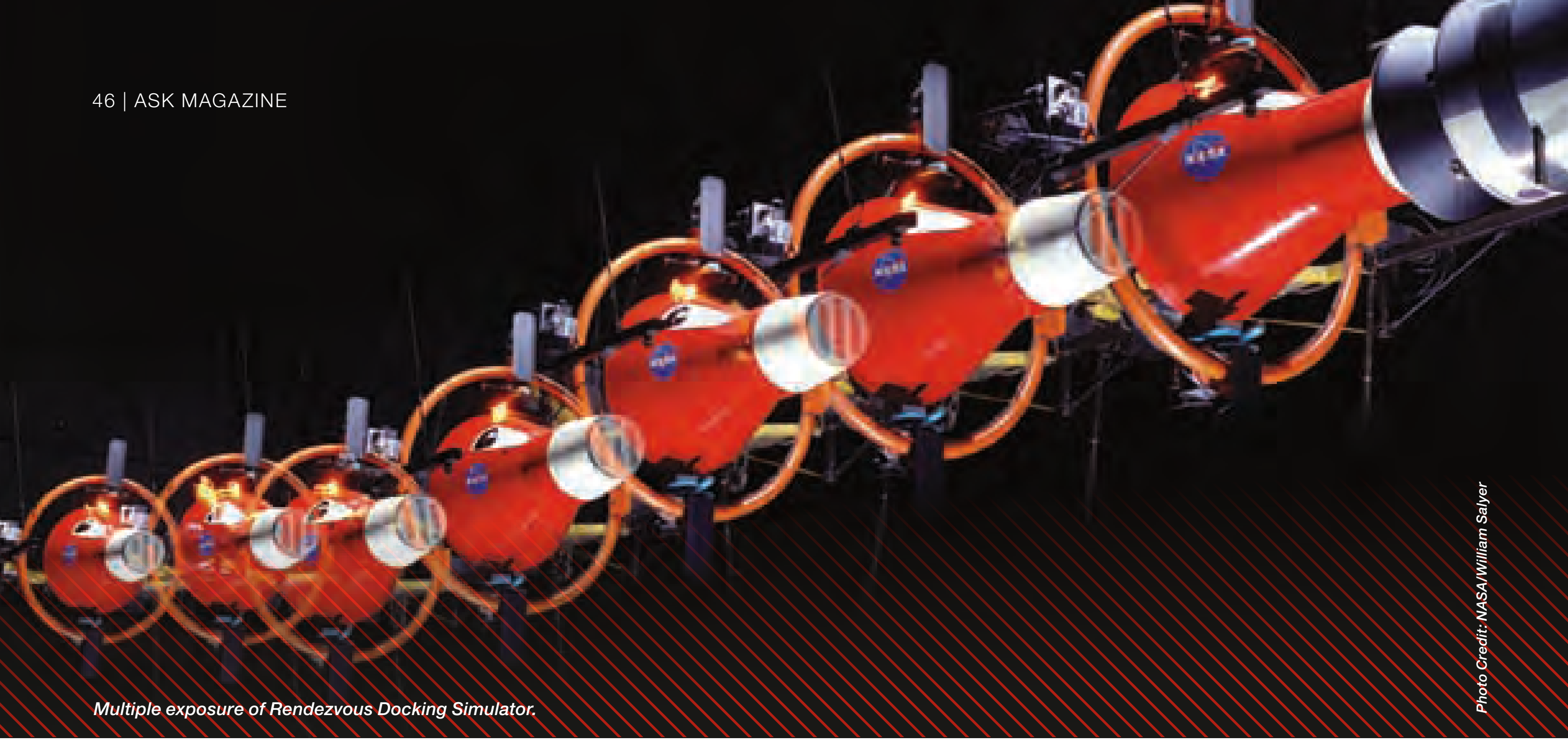


Photo Credit: NASA/William Salyer

Multiple exposure of Rendezvous Docking Simulator.

"I DON'T THINK IT EVER WAS GOING TO BE A TRAINER," YENNI SAID. "WE WANTED THE DATA FOR RESEARCH." BUT TRAINING EVOLVED.

"We needed six degrees of freedom for pitch, roll, and yaw," said Dick Yenni, one of several NASA test pilots who participated in the development of the Rendezvous Docking Simulator by "flying" it and offering feedback to developers before the astronauts became involved.

Another breakthrough came when an analog computer showed up at Langley to monitor and record data from tests on an F-101. "It was a big computer: 5,000 vacuum tubes, 20 feet long, 6 feet high," Wise said. "Then they canceled out the F-101 contract when the space thing got going. So what were they going to do with this computer?"

The computer was taught the characteristics of docking in space. Said Yenni, chuckling, "You could probably do as much with a laptop now."

The design group was headed by Arthur W. Vogeley and Max Kurbjun of the Space Mechanics Division, along with Roy Brissenden, Alfred Meintel, Jack Pennington, and Marvin Waller. Finally, the group believed it had the idea they needed, and on June 3, 1961, $243,020 was requested for a docking simulator.

The cockpit was that of Gemini, with a window in front of the pilot. The cockpit was inside a gimbal that allowed the required six degrees of roll, pitch, and yaw, and it was to run on a 210-foot track, 40 feet in the air in the cavernous Langley hangar.

But once on his back in the simulator, how would an astronaut dock with the capsule?

"When they 'flew' this thing, they couldn't see the capsule out of the windshield," said Sheila Thibeault, then a recent college grad. "They had to use a television camera, a closed-circuit camera. My job was to work on the visual acuity and Vernier acuity, which translates into accuracy." Basically, Thibeault worked on lining up the dim cross-hairs on a black-and-white 1960s television screen.

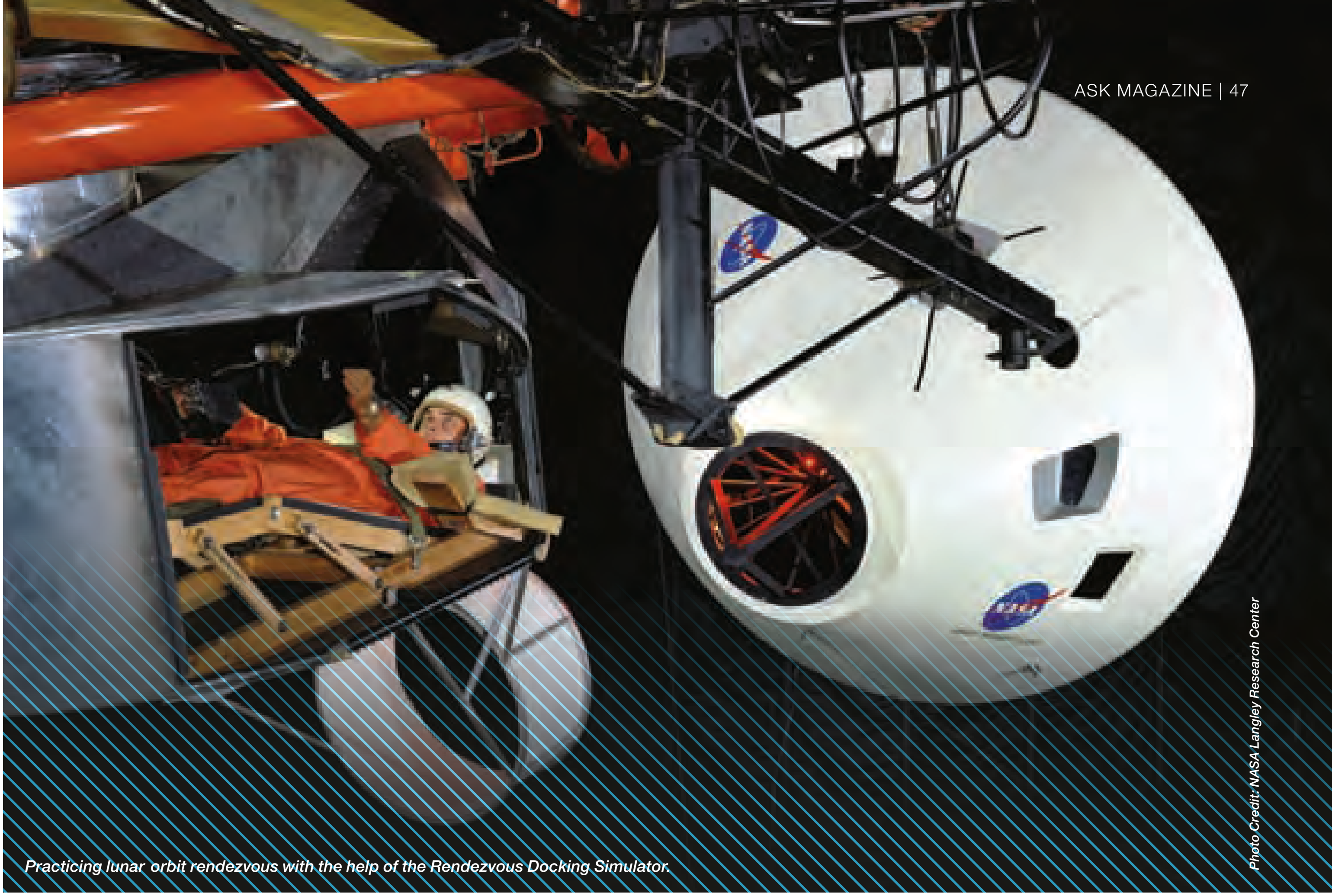
"We would run at night, with all the windows blacked out," said Yenni. "We had an Agena target at the north end of the hangar, and we'd start at the south end."

The Agena target vehicle was developed to launch into space to provide a target for Gemini's rendezvous. Several different lighting patterns were tried to allow the pilots to pick it out from the background of stars.

As Apollo evolved, so did an Apollo cockpit and command module target for the simulator. The cabin was fitted out with airplane instruments, altered for its space mission. The carriage was electrically driven, and so were the pitch and yaw controls. The gimbal was hydraulically driven, and so was the roll control. All that information was fed into the computer in the corner of the hangar.

That information was Langley's primary concern. "I don't think it ever was going to be a trainer," Yenni said. "We wanted the data for research."

But training evolved. The original seven astronauts were stationed at Langley as NASA's space program began and migrated to Houston with the nucleus of the Space Task Group



Practicing lunar orbit rendezvous with the help of the Rendezvous Docking Simulator.

Photo Credit: NASA Langley Research Center

in 1961. They returned to Langley to work on the Rendezvous Docking Simulator and the lunar excursion module simulator, which was built to train the astronauts to handle the final 150 feet before landing on the moon.

"I worked with five of the first seven astronauts," said Riley, who named Alan Shepard, Gus Grissom, Scott Carpenter, Wally Schirra, and Gordon Cooper.

Wise worked on the intercom with the astronauts as they trained on the simulator.

"Buzz Aldrin spent a lot of time in our facility when he wasn't flying the simulator, just observing how things were going, learning things to put into his paper about the rendezvous," Wise said.

Aldrin's doctoral thesis at the Massachusetts Institute of Technology was entitled "Guidance for Manned Orbital Rendezvous."

"I remember working with John Glenn," said Wise. "Alan Shepard spent time with us; Grissom; Neil Armstrong came from a town about twenty miles from where I was from in Ohio."

Training in the simulator that was built to provide data for Langley became a requirement for being launched in Apollo.

"They kept coming back," Wise offered. "I think that's the sign of a satisfied customer."

When they came back, they signed a poster picture of the simulator in Vogeley's office. Only one astronaut who trained on the system did not sign: Ed White, who trained twice but died in a fire on the launchpad at Cape Kennedy before he could add his name to the poster.

Ultimate proof of success came on July 20, 1969, when Aldrin maneuvered the lunar excursion module from Apollo 11 into place and he and Armstrong docked with the command module piloted by Michael Collins.

With the end of the Apollo program, the simulator was adapted to research on open- and closed-loop pilot control issues, aircraft landing approaches, simulator validations, and passenger ride quality.

It no longer is used, and in 1985 it was added to the National Register of Historic Landmarks. The Rendezvous Docking Simulator hangs from the rafters in the hangar, an orange reminder of a time when pioneers were everywhere in NASA.

"It was interesting, following the moon shots on television," Wise said. "You'd work and you'd come home and there it is. Sometimes I still can't believe how lucky I was. I had a very small part of something that was extremely big."

A part that started with a cable hanging from an I beam at the top of the hangar. ●

Former *Los Angeles Times* reporter **JIM HODGES** is managing editor/senior writer of the *Researcher News* at NASA's Langley Research Center.

Managing Conversations for Performance Breakthroughs

BY GERRY DAELEMANS

Reorganizations can have unintended and unexpected outcomes. Sometimes they create new problems in the process of solving old ones. When the Goddard Space Flight Center in Greenbelt, Maryland, disbanded its Special Payloads Division in 1998 during a centerwide reorganization, the Shuttle Small Payloads Project Office (SSPPO) that had been housed there experienced a simultaneous shift in management, projects, and goals. Finding the right footing and regaining a good working environment in this new terrain took a couple years and an uphill climb.

Since its inception in 1984 and until its retirement in 2003, the SSPPO flew more than seventy-five scientific, technological, and student Hitchhiker experiments; 255 Get Away Special (GAS) payloads; and more than 120 Space Experiment Module (SEM) experiments aboard the Space Shuttle. The SSPPO team was well versed in flying payloads on manned spaceflight missions.

After the reorganization in 1998, GAS and SEM became part of the engineering workforce at Wallops Flight Facility, which reported to SSPPO management at Goddard's Greenbelt campus. The SSPPO in turn reported to its new management located back at Wallops.

This new office arrangement, a Wallops workforce inexperienced with manned spaceflight payloads, and the merging of two distinct engineering cultures created new complexity within SSPPO. Also around this time, center management began to question why the office was located at Goddard instead of at one of NASA's manned spaceflight centers. They began pushing for SSPPO to align itself with Goddard's core business; the office would otherwise be moved to a manned spaceflight center.

Listening and Recognition

I became chief of SSPPO in 2000 and quickly realized we had some challenges to overcome. Our vehicle for payload experiments, the Space Shuttle, was slowly being monopolized by International Space Station (ISS) assembly cargo. Our attempts to obtain ISS payload work were unsuccessful. Center management wanted us to move away from manned spaceflight. Wallops and Greenbelt cultures were clashing. Even though people enjoyed the work we did and were very passionate about continuing it on shuttle and ISS, our future looked bleak given the circumstances.

I found myself asking, how could we gain center support for ISS work? How could we align our work with Goddard's core business? How could Wallops and Greenbelt work together more productively and cooperatively? How do we boost morale? How do we avoid going out of business?

As I began thinking about answers, I recalled learning earlier that people's actions are correlated to how they perceive the world around them, and that their perception of the world is formed by the conversations they have—those they speak out loud and those unspoken yet communicated, of which they are unaware. So I began to listen anew to what people were saying.

The foreground conversations were easy to hear, as these conversations had been present in our office culture for years: we love what we do, but we aren't appreciated by management or our colleagues at Greenbelt/Wallops; no one knows the great work we've contributed; they just don't listen; I'm always so busy. There were many positive conversations, too, but the negative ones were of most concern.

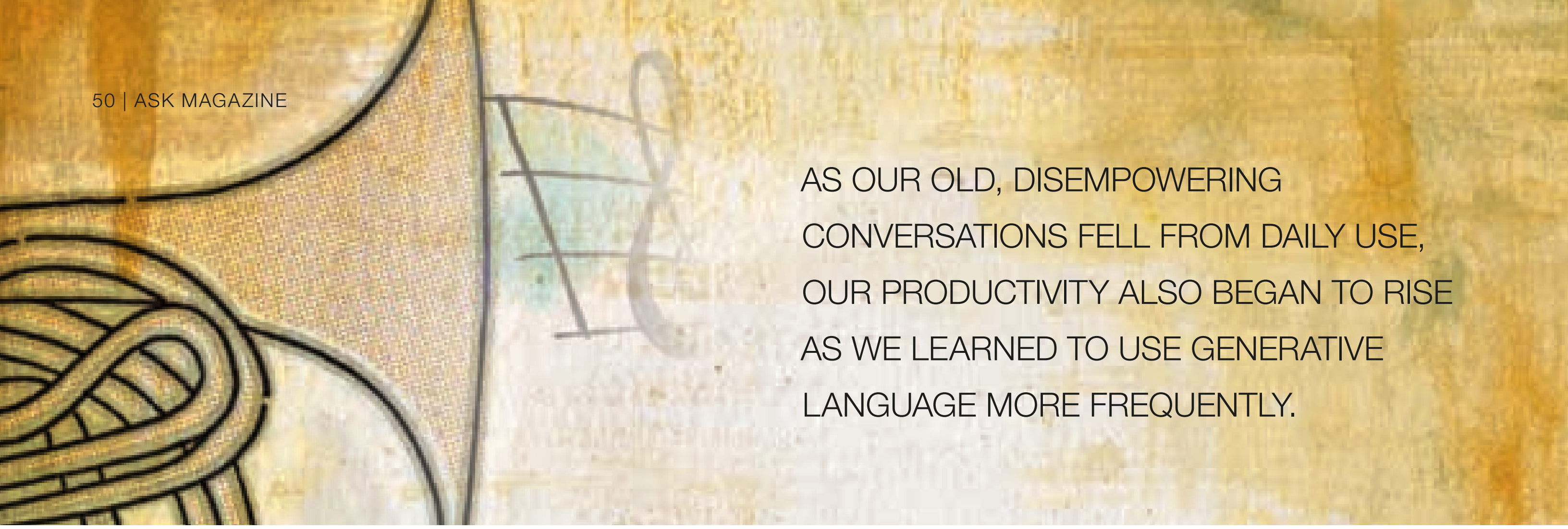
The background conversations took more effort to recognize. To understand how background conversations work, think about driving a car now versus when you were sixteen. When you first began driving, the foreground conversations were likely, "Keep this much distance between my car and the one in front of me, signal 100 feet before turning, and do not pass over a double yellow line." The conversations today might be more like, "How will I get to my destination, who am I meeting, do I need to run chores on my way home?" But the conversations from when you were sixteen haven't gone away. They've been pushed so far into the background you don't hear them anymore, but they still affect your driving.

The same thing was happening on our team. The "we aren't appreciated" conversations and some background conversations we could no longer hear were affecting how we perceived the world, which influenced our actions and results. They were also affecting how the world around SSPPO perceived us. We needed to pull those conversations to the forefront so we could recognize them, let them go, and create new ones.

Communication for Commitment and Results

To help the team hear the background conversations, I arranged a voluntary three-day workshop with an outside expert who supports organizations in distinguishing the background conversations and creating new, powerful conversations designed for maximum performance.

Forty people from the team participated in the workshop, including civil servants and contractors from both Greenbelt and Wallops. The first thing we focused on was the importance



AS OUR OLD, DISEMPOWERING CONVERSATIONS FELL FROM DAILY USE, OUR PRODUCTIVITY ALSO BEGAN TO RISE AS WE LEARNED TO USE GENERATIVE LANGUAGE MORE FREQUENTLY.

of listening, and listening with the mind, not only the ears. For instance, if I were having a conversation and listened only to decide if I agree or disagree with the speaker, I'm going to miss a lot of what is actually said. Because I am unaware of this agree/don't agree filter, I may miss hearing opportunities, requests, or warnings in the conversation. Our team had similar filters; their default listening mode was oriented to hear only evidence that center management didn't support us or Greenbelt didn't respect Wallops. We were missing opportunities to take new actions because our background listening was deafening us.

For three days our team worked on bringing pervasive thoughts and conversations from the background into the foreground. The work we did was analogous to Newton discovering the three laws of physics. He did not invent inertia, acceleration, mass, friction, or resistive forces; he pulled these phenomena from the background to the foreground using math. Similarly, our workshop pulled forward the three laws of human performance: our actions are correlated to how we perceive the world; how we perceive the world arises in the language (conversations) we use; and generative language, which is future-action oriented, transforms how the world occurs for us.

It was clear that just changing our actions and expecting a different outcome in performance was not going to elicit the results we wanted; this is a recipe for history to repeat itself. With the team clear of our background and foreground conversations after the workshop, we were free to create new conversations: ones that used generative language and contained possibilities of an exciting future.

Evidence that we succeeded began to emerge after the workshop ended. Because we had realized we were the authors of our "no support from center management" message, we were able to rewrite it. By making this change, we also altered how others perceived us. The other NASA groups we dealt with started to relate to us differently.

Whereas before we had been denied requests for ISS work, we began receiving inquiries from senior management about how they might support us in getting this work. For instance, our deputy center director established and attended a meeting with me at NASA Headquarters to present our ideas for ISS efforts and to support our funding request for this new work—a request Headquarters granted.

I also received a call from a senior manager who thought our office would be a great place for a project fully aligned with Goddard's core business activities. We took over that project, and now not only were we aligned per center management's earlier requests, we had also found a way to continue our manned spaceflight payload work without moving to a different center.

As our old, disempowering conversations fell from daily use, our productivity also began to rise as we learned to use generative language more frequently. Indeed, one employee who previously had been reluctant to work with the team emerged as a leader, helping improve the relationship between Greenbelt and Wallops. When asked about the change in her behavior, she said that before the workshop, "The air was so thick with negativity and resignation about the future, you could cut it with a knife." After the workshop, those conversations disappeared, "making the air clean again," she said.

Network of Conversations

One of the biggest lessons the SSPPO team learned from this experience was that all we needed to manage was a network of conversations, not the people or the processes. Changing players or plans won't lead to breakthroughs in performance; indeed, it often leads to a future that looks just like the past. By continually listening to conversations, leaders who understand and apply the three laws of human performance can create an environment that brings out the best in people, teams, and organizations. People are much more powerful and passionate than they themselves recognize, and when they understand how they unknowingly inhibit their own performance, they are free to change and fully realize their potential and creativity. ●

GERRY DAELEMANS has been with NASA for twenty years and is currently working in the Advanced Concepts and Formulation Office at Goddard Space Flight Center.

Science from the SKY

BY KERRY ELLIS

Scientists aboard NASA's DC-8 airborne laboratory and a Gulfstream V aircraft captured the breakup and fragmentation of the European Space Agency's Jules Verne Automated Transfer Vehicle as it reentered the atmosphere.

Photo Credit: NASA/ESA/Jessie Carpenter/Bill Moede

The Airborne Science Program within NASA's Science Mission Directorate has helped take Earth science to suborbital heights. With a fleet of customizable aircraft, the program offers scientists unique opportunities to conduct airborne studies all over the globe. Its DC-8 Airborne Science Laboratory can house numerous experiments simultaneously, with many scientists aboard operating their science instruments and assessing data in close to real time. The actual flight plan rarely looks the same as the mission plan at takeoff, requiring project management literally on the fly.

Image Credit: NASA/L. Emmons

Photo Credit: NASA

The DC-8, managed by NASA and operated cooperatively with the University of North Dakota, has been heavily modified with a multitude of viewports along its sides, top, and lower cargo holds. Each viewport allows scientific instruments to peer outside the aircraft through special optical windows or by using probes to collect air, moisture, particulate samples, and other data. To figure out what will go where, the scientists work closely with the DC-8 team to establish the most efficient way to install their proposed instruments and accommodate enough people to operate the equipment. With dozens of different experiments happening concurrently, the installation effort and flight-plan creation require coordination among the scientists, engineers, mission managers, navigator, and pilots.

The science teams determine before each flight where they want to go to gather data, basing projections on weather forecasts, satellite imagery, and other sources of information. Then the scientists and mission managers together create a flight plan; for example, take off from point A, then fly to points B, C, D, and so on. Once airborne, however, the team may realize point B is no longer where they thought it would be because the phenomenon of interest has moved, requiring new navigation points and altitudes.

"We have a link between the airplane and the iridium satellite system that allows us to obtain real-time updates and information on what's most current from ground-based sources," explained Frank Cutler, project manager for the DC-8. "You can communicate with these satellites from anywhere on the globe: North Pole, South Pole, equator, middle of nowhere. Inevitably, we receive new information that changes the entire mission in real time," he said. The navigator on board becomes very busy helping re-plan routes with the scientists, mission managers, and pilots. During the Arctic Research of the Composition of the Troposphere from Aircraft and Satellites field campaign, or ARCTAS, locations for greenhouse gas emissions were based on atmospheric modeling. After takeoff, however, the team received model updates that required moving to new locations for collecting samples.

This flexibility in mission planning and aircraft configurability allows the DC-8 to carry out a variety of missions. ARCTAS was one of the largest missions flown aboard the aircraft in 2008. The atmospheric research, an international collaboration in support of the International Polar Year, collected data to help improve current monitoring and future predictions of Arctic change. Three of NASA's Airborne Science Program aircraft flew the ARCTAS experiments, with the DC-8 carrying twenty-one scientific instruments and flying 184 hours across twenty-two sorties, including flights to Alaska and Greenland. The entire effort involved more than three hundred people from eight NASA centers, twelve universities, three government labs, and several other organizations.

With the airborne laboratory packed with instrumentation to study pollutants for ARCTAS, the team realized they had a unique opportunity for the California Air Resources Board to study the local air as well. Over the course of two weeks, the aircraft made several flights over California, measuring pollutants inland and offshore. Using both the DC-8 and Airborne Science Program's P-3B, the board was able to broadly cover California during a short time and learn more about how pollution forms over the state, where it comes from, and what its sources are.

The DC-8 can do more than help study our atmosphere. Its capabilities have been used for archaeology, ecology, geography, volcanology, soil science, biology, and other Earth sciences. The Arctic Mechanisms of Interaction between Surface and Atmosphere (AMISA) mission, for example, studied the effects of global warming on Arctic ice formation. A collaboration between the University of Colorado, the National Oceanic and Atmospheric Administration, the University of Leeds, the University of Stockholm, Goddard Space Flight Center, and the University of North Dakota, AMISA packed the plane with instruments to detect sea-ice surface characteristics and atmospheric processes.

The flying laboratory has also been used to aid studies above the atmosphere. In November 2008, NASA partnered with the European Space Agency (ESA) to track reentry of a space vehicle. "ESA's ATV-1, a cargo ship on the International Space Station for six months, had completed its mission and was made to be destroyed on reentry, not recovered," Cutler said. "The European engineers

Far Left During the ARCTAS field experiment, scientists flew eighty six research flights to gather data on the Arctic atmosphere. This Google Earth image shows the flight tracks of the three NASA airplanes that collected data on pollutants and atmospheric properties during the spring and summer of 2008.

Left NASA s DC 8 arrives in Thule, Greenland, after its first ARCTAS science flight.

Right Katrine Gorham of the University of California, Irvine, operates the Whole Air Sampler inside NASA s DC 8 research aircraft during a flight on April 12, 2008.

Photo Credit: NASA/Eric James

had made predictions on how it would break up when it hit the atmosphere, and they wanted us to help them document it."

Traveling 1,200 nautical miles south of Tahiti, the DC-8 team communicated in real time with Europe. "ESA let us know where and when ATV-1 was reentering based on its deorbit burn," explained Cutler. As a result, an international team of scientists was able to photograph the ship's breakup upon reentry and confirm ESA's predictions.

Coordination and cooperation for each of these missions is key, not only between scientists, engineers, and pilots, but also between international partners and locations. "People from all over the world support these science endeavors," Cutler said. Each mission usually contains a mix of U.S. citizens and foreign nationals, and campaigns overseas add another level of complexity to the planning. "Inevitably, we're flying into someone else's airspace," explained Cutler. "We have to make arrangements with foreign governments to collect science data over their countries, fly in their airspace, and land at their airfields. It can take three months to prepare for an international deployment," he said.

That coordination usually begins with NASA Headquarters' Office of External Relations, which has contacts with embassies around the world. "We consult with them whenever we want to travel internationally," Cutler said. "They help us contact the embassies, which in turn help us get permission from their governments to operate in their airspace and countries." Obtaining that permission often requires explaining the mission science, the type of instruments that will be flown, and the team that will be aboard the aircraft, including foreign nationals and their countries of origin. "After communicating that information, the various governments are very cooperative," explained Cutler, adding, "It also helps if our science objectives correspond with what their own government agencies and universities are studying."

Research can also be done right at home with the aircraft. Early in 2009, Glenn Research Center and Langley Research Center used the DC-8 as a test bed for manmade fuels created from coal and natural gas. The plane remained on the ground as the collaborating centers tested emissions from the engines and compared them with previously recorded measurements they had from the aircraft.

The Earth-science possibilities seem nearly endless, as do the educational ones. In July 2009, the National Suborbital Education and Research Center orchestrated the Airborne Student Research Program. The first of its kind, the program offered advanced undergraduates and recent graduates an opportunity to conduct airborne science experiments. Students took air samples from various locations and altitudes over California to study chemical content and learn how large dairy operations affect the local atmosphere. They also gathered data about algae in Monterey Bay using spectral imaging. Back on the ground, students will be learning how to analyze the data they obtained and how the information applies to current and future studies.

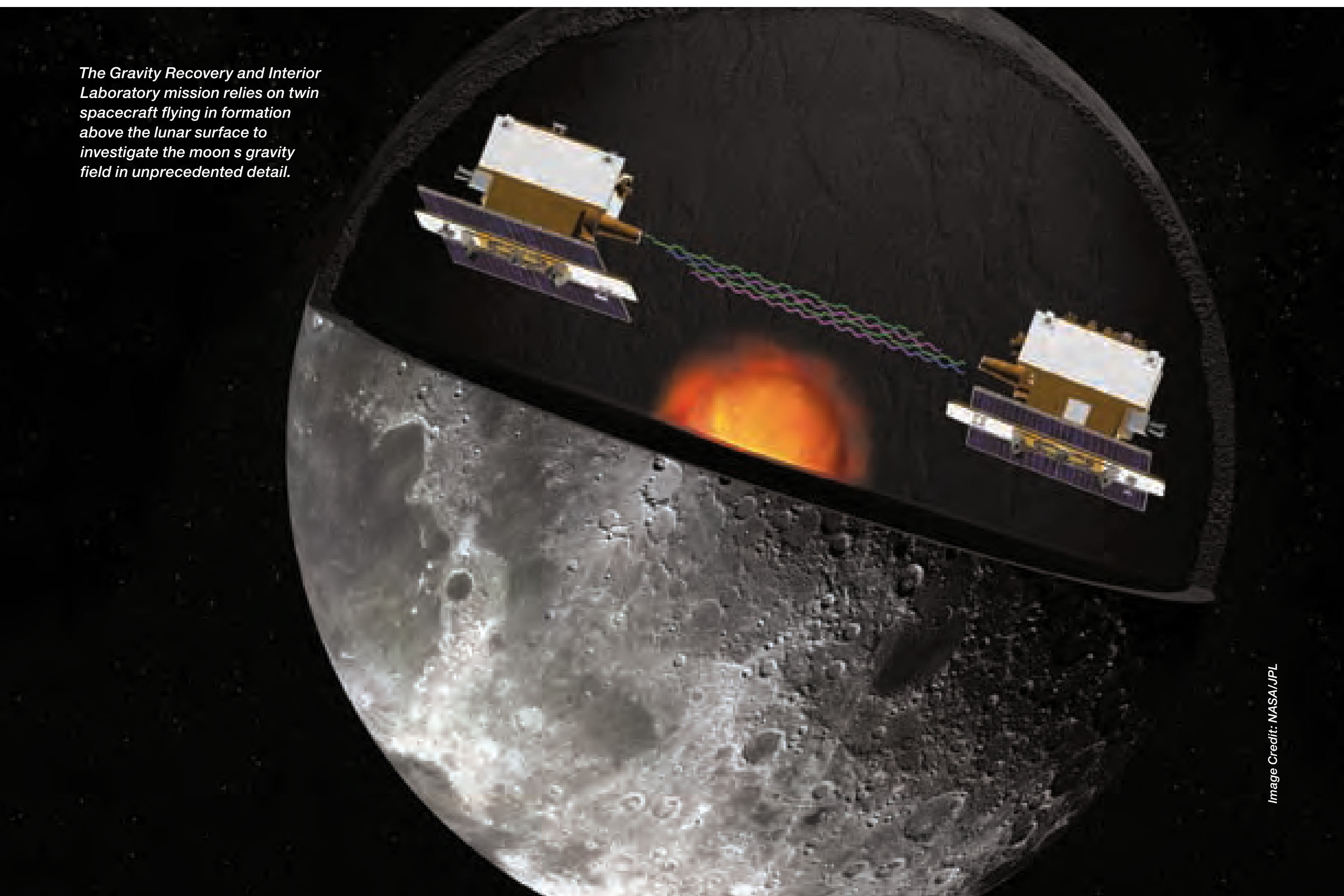
The University of North Dakota helps communicate the educational and scientific opportunities available with the DC-8, and word of mouth from those who have flown helps keep the aircraft busy with experiments. Additionally, the Science Mission Directorate has an annual proposal process outlining various NASA resources, including the DC-8, and reviews the proposals for potential future missions. Scientists can also submit flight requests online through the Airborne Science Program Web site.

Missions can be long and exhausting, lasting eight to ten hours a day for several days, but they are worth it for the science and teamwork obtained. "Imagine flying to Europe every other day," Cutler said when describing the experience, "but the time goes by quickly because you're constantly updating the mission plan and concentrating on getting the job done." After many missions during the past twenty-two years, the DC-8 team has the coordination down to an art. In the next year, they will continue their efforts with operation ICE Bridge, which took off October 12 to initially study the changing conditions of Antarctic glacial and sea ice, and will participate in the Genesis and Rapid Intensification Processes mission to study how Atlantic tropical storms form and develop into major hurricanes. They are also in discussions about helping recover and document reentry of the Japanese Hayabusa spacecraft, slated to return June 2010 with the world's first asteroid sample. ●

Nobody's Perfect: The Benefits of Independent Review

BY MARK SAUNDERS AND JAMES ORTIZ

During a 1995 independent review of the development of Mars Pathfinder, Dr. Mike Griffin, a member of the review team, asked the project team how the spacecraft's radar would determine the distance of the spacecraft from Mars's surface while swinging back and forth below the parachute. Discussion revealed that the team did not have an adequate test to prove that the radar would work as needed. As a result, the project developed a special test program that may have prevented a catastrophic failure.



The Gravity Recovery and Interior Laboratory mission relies on twin spacecraft flying in formation above the lunar surface to investigate the moon s gravity field in unprecedented detail.

Image Credit: NASA/JPL

THE NEW REQUIREMENTS ELIMINATED THE EARLIER MULTIPLE REVIEW BOARDS AND CALLED INSTEAD FOR A SINGLE STANDING REVIEW BOARD (SRB) THAT WOULD EVALUATE PROGRAMS AND PROJECTS AT ALL THEIR LIFE-CYCLE MILESTONES.

In other words, the smartest people can miss things. NASA has sent men to the moon, built and launched telescopes that can see billions of years into the past, discovered water on Mars, and sent spacecraft beyond our solar system. Dedication, technical excellence, and "can-do" optimism have made these dreams come true. We have also unfortunately experienced the agony of spacecraft failures and loss of life.

Dedication and technical excellence can't overcome the fact that we are just not perfect, and sometimes our optimism threatens mission success. Having a fresh set of eyes look at our work can help us see what our own blinders and mental filters may hide. This is the essence of the independent life-cycle reviews specified in NASA's procedural policies. As former NASA Administrator Mike Griffin said, "You cannot grade your own homework." Independent experts review program and project "homework" with team members to find, and help them correct, weaknesses that could turn into problems or disasters later on.

The Evolution of Independent Review

Independent review has existed at NASA for decades, in many different guises. Centers have used it to ensure technical designs and products will perform as expected. After the Mars Polar Lander and Mars Climate Orbiter failures in 1999, the Jet Propulsion Laboratory revamped its internal independent review process to improve the chances of catching the types of flaws that led to those losses. Mission directorates commissioned their own review teams to independently verify what they were hearing from centers working on their projects. In the mid-nineties, the NASA Administrator directed that the Independent Program Assessment Office be established so NASA could confidently promise its stakeholders we could deliver our missions on cost and on time. Sometimes the membership of these multiple review teams outnumbered the project management staff, and the multiplicity and variety of the reviews took up an inordinate amount of the project's attention.

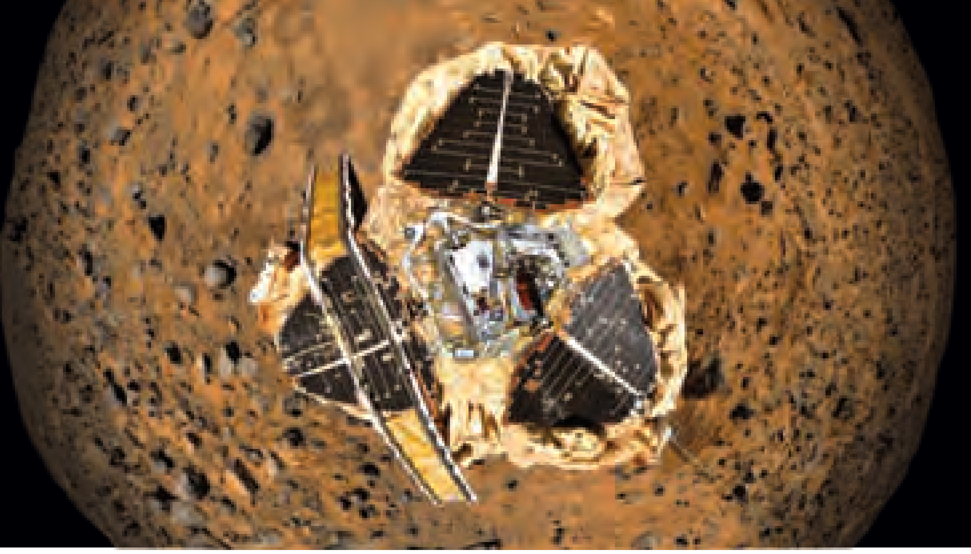
After the 2003 *Columbia* tragedy, NASA revised its governance structure, improving the checks and balances between organizational authorities, and rewrote its program and project management policies in part to ensure that technical and managerial concerns about potential problems would be heard and adequately evaluated. Among the changes incorporated in NASA's new procedural requirement NPR 7120.5D (which we both worked on) was a new and, we hoped, more effective independent review process.

The new requirements eliminated the earlier multiple review boards and called instead for a single standing review board (SRB) that would evaluate programs and projects at all their life-cycle milestones. We also strove to ensure that the reviews would be collaborative and constructive, rather than adversarial. The fact that program and project teams can suggest members whose expertise they respect contributes to the collaborative character of the reviews. (They do not have approval authority, since the SRB is independent.) Also, the core board membership stays the same throughout the mission, fostering trust and good communication. Typically, the program or project participates in the SRB kickoff meetings where the rules of engagement for all life-cycle reviews are set—and the project and review teams have an opportunity to establish a good working rapport.

Another change was that the review process, mainly used for robotic missions previously, would be applied to human spaceflight missions as well. Typically, SRBs for large, category 1 and 2 spaceflight projects have a chairperson, a NASA review manager, and approximately thirteen experts covering the basic disciplines required to execute the project (for instance, propulsion and systems engineering, as well as cost and schedule analysis expertise). Smaller, category 3 projects may not require a formal review manager and may be about half the size.

Once the independence of each member is verified, the SRB chair, with support from the review manager, organizes the board and submits the names of proposed members to the convening authorities, who include NASA's associate administrator, the mission directorate associate administrator, the chief engineer, and the Program Analysis and Evaluation Office associate administrator. Their approval is based in part on a detailed review of the nominees' qualifications.

The overall purpose of these independent reviews is to accomplish the following:



This image is a digital combination of panoramic pictures taken by Pathfinder on Mars and a picture of a lander scale model back on Earth. Sojourner itself is visible inspecting a rock nicknamed Yogi.

Photo Credit: NASA/JPL/IMP Team

- Provide the program/project with a credible, objective assessment
- Supply NASA senior management with an independent view of program/project performance and identify whether externally imposed impediments to the program/project's success are being removed
- Present a credible basis for a decision to proceed to the next phase

Benefits to Programs and Projects

Developing complex systems is iterative and recursive. Teams regularly circle back and revisit earlier work as new information becomes available. This iterative process happens throughout missions, but programs and projects separate design and development activities into logical stages punctuated by major milestone reviews, such as a preliminary design review, that are designed to answer a couple of basic questions:

- Have we done our work sufficiently well and completely in the previous stage to justify continuing on our current path?
- Are our proposed actions, plans, and resources sufficient to complete the next stage as well as the overall development, launch, and operations?

In preparation for these independent reviews, the program or project team conducts its own internal reviews to examine its plans, technical approaches, and programmatic commitments. The team assesses major technical and programmatic requirements along with the system design and other implementation plans and compares technical and programmatic performance with earlier predictions. This preparation for the milestone review gives the team an opportunity to step back from the narrower focus of its daily work and examine its progress holistically. The development team has a chance to examine the assumptions and analyses that support the conclusion that they are, in fact, at the required level of maturity and are ready to proceed.

The SRB's role is assessment; it does not have authority over any program or project. Its review provides expert assessment of the technical and programmatic approach, risk, and progress against the program or project baseline and readiness against criteria in NPR 7120.5D and NPR 7123.1A. The depth of an SRB review is the board's responsibility and must be sufficient to permit the board to understand whether the design holds together adequately and whether the analyses, development work, systems engineering, and programmatic plans support the design and key decisions that were made.

The review objectively assesses the following:

- Adequacy and credibility of the technical approach (requirements, architecture, design)
- Schedule
- Resources
- Cost
- Risk
- Management approach
- Compliance with agency policy (NPR 7120.5D, NPR 7123.1A)
- Readiness to proceed to the next phase

Recently, the agency has begun using more probabilistic techniques for budgeting programs and projects, including budgeting to a target joint confidence level for cost and schedule. Review team programmatic analysts are shifting from performing purely independent estimates of cost and schedule to working in parallel with the program or project control offices, using the same cost- and schedule-estimating methodologies and tools. This approach provides a more efficient, and less adversarial, evaluation of budget risk.

Individual SRB members usually offer recommendations to improve performance or reduce risk. These recommendations and the SRB findings are collected in the board's report. The board chair and the program or project team ensure that all the facts are correct by vetting the report with the program or project manager. Once that process is complete, the team from the program or project under review determines which of the board's findings and recommendations to accept, modify, and implement, and presents its response and action plans to senior management, up to and including the decision authority, at the same time they receive the SRB's reports.

THE FACT THAT PROGRAM AND PROJECT TEAMS CAN SUGGEST MEMBERS WHOSE EXPERTISE THEY RESPECT CONTRIBUTES TO THE COLLABORATIVE CHARACTER OF THE REVIEWS.

Experienced project team members know that identifying risks and problems early makes it easier and less expensive to deal with them. The SRB meetings and reports are key to finding and fixing those issues as early as possible. As in the Mars Pathfinder case, review boards have caught problems that could have turned into major difficulties later. A member of the Gravity Recovery and Interior Laboratory (GRAIL) SRB, for example, identified a range safety launch issue—insufficient "inhibits" between the pressurant and the propellant. Although a waiver would have been granted in the past, he knew that the standards had gotten tougher and the range safety folks would not approve the design.

The project decided to add a valve to the propulsion system to fix the problem. This may have prevented GRAIL from having a launch slip or from spending an enormous amount of money to fix it. Similarly, the independent review team for the Magnetospheric Multiscale science mission at Goddard identified the late selection of the launch vehicle (scheduled after the critical design review) as a major risk to the spacecraft design. As a result, the launch vehicle selection was moved to precede the preliminary design review.

Benefits to Management and Stakeholders

The independent review process is a collaborative effort between agency senior management, center management, technical authorities, and program or project management. Each entity plays a key role in establishing, conducting, and reporting independent life-cycle reviews. The head of each of these organizations approves SRB members and the SRB charter (called Terms of Reference). This collaboration ensures that the needs of each organization will be met.

The independent life-cycle review process culminates at key decision points when the results of the reviews are presented to the decision authority and his or her management council. At these meetings, the program or project manager presents the findings of the SRB and an approach to resolving the issues identified. The SRB chair and the various levels of management all participate in the open dialogue, offering their views and recommendations about the way forward. Success criteria for all life-cycle milestones are considered, and the decision authority determines if the program or project should proceed, proceed with specific actions to resolve outstanding issues, or not proceed until critical actions are resolved. In some cases, they may direct the program or project team to put additional recommendations into practice. This process ensures that all decisions on how the mission is to be carried out reside with the appropriate authority.

A critical part of this process is assuring NASA senior management that we have the cost and schedule resources required to deliver what we've promised. When presenting the results to the decision authority, both the project estimates and the SRB assessment of the estimates help ensure realistic commitments to our stakeholders. Independent estimates now typically fall within 5 percent of the final outcome. In the long run, more realistic commitments will result in increased credibility of the agency with the Office of Management and Budget, Congress, and other stakeholders.

We are using our SRB experiences to continue to improve the review process itself. We periodically meet with the mission directorates, programs, projects, and centers to discuss what we have learned about the process and how to make it better. We have, for instance, developed standard terms of reference for particular classes of reviews to avoid spending time and effort negotiating nearly identical terms for each review. We have also reduced reporting time from several months to thirty days. We expect to continue to learn how to make the standing review board process serve the best interests of NASA missions and all those who benefit from their success. ●

MARK SAUNDERS is the former director of the Independent Program Assessment Office, part of NASA's Office of Program Analysis and Evaluation. He was responsible for evaluating the agency's major programs and projects to ensure they were on paths for mission success and ready to proceed through key decision points. He retired in December 2008 and is now consulting part time with NASA.

JAMES ORTIZ has served as section head for International Space Station systems training and chief of the Advanced Projects Office in the Mission Operations Directorate, as well as manager of the Johnson Space Center Systems Management Office. He is the deputy director (and current acting director) of the Independent Program Assessment Office within the Office of Program Assessment and Evaluation at NASA Headquarters.

Gettysburg Addressed: Common Ground for NASA Engineers and Civil War Generals

BY HALEY STEPHENSON

Three days before the decisive Battle of Gettysburg, General Joseph Hooker, leader of the Union Army, resigned from his post. President Abraham Lincoln asked General John Reynolds to fill the position. Reynolds, who disliked the political strings attached to the job and preferred to lead his soldiers in battle, turned Lincoln down. A few days later at Gettysburg, while positioning his first line of infantry in close proximity to the enemy, Reynolds was shot and killed.

Fast-forward nearly a century and a half. At eight o'clock on a pleasant June morning, the graduates of the inaugural yearlong Systems Engineering Leadership Development Program (SELDP) stood in the shadow of an enormous statue of General Reynolds on horseback and pondered the first of many leadership questions for the day: do you lead from the front or the back, and how close to the front is too close?

The engineers listened attentively to Lieutenant Colonel Gregory D. Hillebrand of the United States Air Force stationed at the U.S. Army War College, their guide for the day. Reynolds's leadership from the front, while noble, explained Hillebrand, didn't work out well. Leaders of the day struggled with this question of leadership location: too far back and they were viewed as cowards and had less control over their men; too far forward and they were seen as brave, but at much greater risk of dying. The loss of a good leader threatened a unit's ability to operate. This problem resonated with Deborah Crane, an SELDP graduate from Marshall Space Flight Center. "Rather than always being up front and directing people and telling people what to do," she said, "you lead from the back and you help people find the direction to lead themselves and others as well."

The inspiration for this learning experience came from SELDP Director Christine Williams, who wanted to give the graduates a unique encounter with leadership challenges they had wrestled with for the past year in forums, technical training, and hands-on developmental assignments at an unfamiliar NASA center. "Seeing the consequences of leaders' decisions and how they affect the outcome when life and death are on the line is a strong lesson they tend to remember for a long time," she said.

Information and Communication

A lesson about the importance of getting good information came from the Confederate side. On the eve of battle, Confederate General Robert E. Lee believed the seven Federal Army corps were scattered far to the south and east, with the closest located in the vicinity of Frederick, Maryland, so he was surprised by news from a spy that Federal forces were assembling in the little town just below them called Gettysburg. Because J.E.B. Stuart, his mischievous but usually reliable cavalry commander, had been out of touch longer than usual, Lee was forced to act on information he did not fully trust. The spy's information was legitimate, but the lack of certainty put Lee's army in an uncomfortable position from the start.

The information deficit continued when Lee sent an engineer to scout the position of the gathering Federal forces near the hill called Little Round Top. The engineer reported that the Federal Army line ended well before the little hill. The next day, based on the engineer's report, Lee sent troops to attack the Federal flank but found that the Federal line stretched all the way down to Little Round Top. Lee's engineer had missed the presence of an entire corps of 10,000 men, Hillebrand said. "He was probably too busy looking at his map," quipped a NASA engineer. A knowing laugh spread through the group; the engineers were familiar with the problem of missing the big

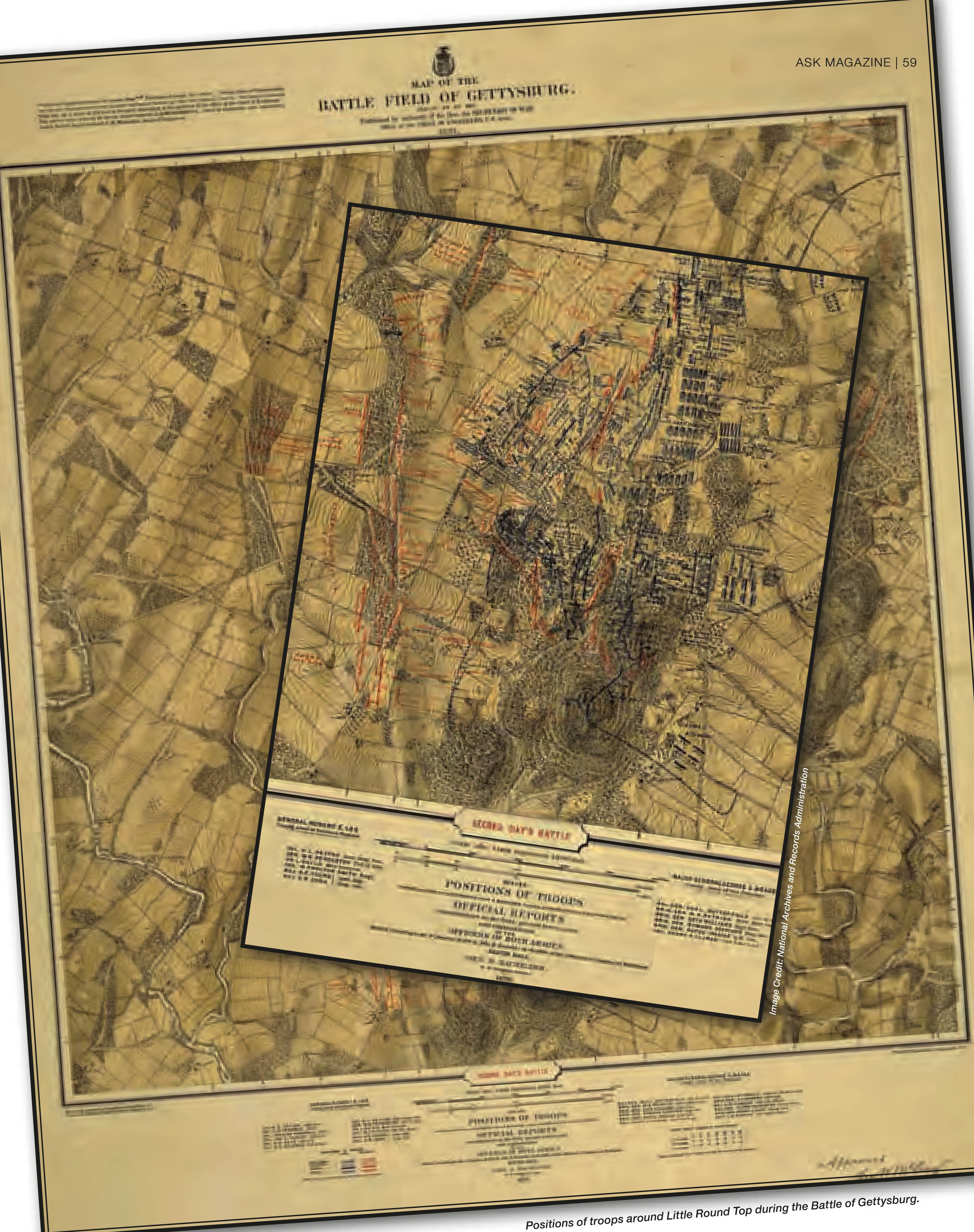


Image Credit: National Archives and Records Administration

Positions of troops around Little Round Top during the Battle of Gettysburg.

"WHY DIDN'T LEE PULL OUT OF THE BATTLE?" SOMEONE ELSE ASKED. … ABANDONING THEIR FIGHT AT GETTYSBURG WOULD HAVE BEEN A BLOW TO THE CONFEDERATE TROOPS' MORALE, SAID HILLEBRAND. IF YOU LEFT A BATTLEFIELD, THAT MEANT YOU LOST.

picture because you were focused on the details. Perhaps, said Hillebrand with a smile, but it's more likely the engineer scouted the wrong location or simply passed by at the wrong time.

Lee had to make a decision based on the information he had. "A lot of what we learned through the program involved methods to develop our ability and confidence to take information—or a lack of information—and make a decision and go with it," said Crane, speaking of her SELDP experience. "Sometimes you don't have all the information you would like to have, but a decision needs to be made."

Successful communication poses two challenges. The first is simply getting a message from one point to another. Commands during the Civil War traveled from higher officials like Lee and George Meade in the back via men on horseback, runners, or a flag-waving system called "wig wag." Orders trickled down to officers at the front who would walk up and down the rows of soldiers standing shoulder to shoulder, not unlike mission controllers in an operations room. The Federal Army had a communications advantage in that their forces were wrapped around the base of the eastern hills, while the Confederates had to deliver messages up and down a five-mile-long line of troops.

Today, we have cell phones, the Internet, and social media such as Twitter, but our messages still don't always get through. "Working on Orion here, information changes so fast," said Jerry Garcia, an SELDP graduate from Kennedy Space Center who had his hands-on assignment at Glenn Research Center. He described constant e-mail blasts conveying updates, information, and requests for the project. "I think the technologies we use to communicate sometimes hinder the intent of the message," said Garcia, "I can get you an e-mail quickly, but did you really understand the intent?" This points to the second challenge of communication: ensuring that the recipient understands the message.

"Know yourself, know your enemy, and you can fight a hundred battles without disaster," said Hillebrand, paraphrasing Sun Tzu. "Lee was very good at knowing who the enemy commanders were from his army days before the Civil War and from reading newspapers," he continued, "but he wasn't as capable at reading his own guys until bad things happened."

Two months before Gettysburg, Lee lost Stonewall Jackson, his right-hand man. Jackson needed little instruction to execute a task, and Lee came to depend on this trait. Jackson's replacement, General Richard Ewell, needed detailed steps and perhaps a few diagrams to accomplish the same task. Lee did not adapt to this new relationship. When he instructed Ewell to attack a Union-occupied hill provided it was practical and he didn't bring on a bigger fight, Ewell decided not to attack because his men were tired. Jackson would have understood that Lee considered the attack essential; Ewell did not.

"This is very analogous to working with different NASA centers," remarked Garcia. "All NASA organizations are required to follow NPRs [NASA Procedural Requirements], but they tailor them to their needs, culture, and center of competency. Each organization views the problem differently. Our challenge is improving cross-discipline communication," he said.

In the afternoon, the SELDP group visited the base of Devil's Den, directly in front of Little Round Top. This is where the Union Army held its line—the site of a teachable moment on the Union's communication breakdowns.

Daniel Sickles, a Union Army officer, was positioned with his corps just north of Little Round Top on slightly lower ground along Cemetery Ridge. He wanted to move his men to higher ground in front of him, so he went about navigating the hierarchy to request permission to move. He may as well have been trying to navigate an automated phone system: he couldn't get the answer he wanted. Not receiving a satisfactory reason not to advance, Sickles went ahead and moved all 10,000 of his men without explicit permission, causing great confusion among the neighboring corps, who worried that they were supposed to be advancing. Sickles' movement onto the high ground caught the attention of General Meade, the leader of the Federal Army, who actually rode out to explain to Sickles why his original position was, in fact, better. Just as Sickles gave the order to turn back, the Confederates attacked.

Sickles' challenge in navigating the hierarchy struck a chord with Dawn Davis of Stennis Space Center. Davis served her SELDP rotational assignment at Marshall, a larger center than Stennis, and noted a difference in the way she had to navigate the hierarchy to find the right person of authority from whom to get permission or approval.

At the end of the day, Hillebrand and the group retraced the steps of the Confederates' final attack—a half-mile journey through thick smoke, a storm of bullets, and cannon fire. The engineers reached the top of a hill, the site of another miscommunication that threatened the success of the North. Here, Union Generals Winfield Hancock and Henry Hunt argued over the best use of limited artillery assets. Their men were firing into clouds of smoke so thick they were unable to see the enemy. Hancock ordered the men to keep firing to boost morale, while Hunt ordered them to stop and save ammunition. Total confusion ensued, as no one knew whom to obey, and the Confederates nearly broke through the Union line.

The three-day Battle of Gettysburg ended on the eve of Independence Day. Of the nearly 200,000 men in battle, more than 26,000 were wounded, and more than 7,000 killed. NASA's day at Gettysburg ended at the top of that hill, just as the battle had.

Further Reflection

The following day, the SELDP class gathered at NASA Headquarters to reflect on the experience, ask more questions, and discuss lessons they had learned from Gettysburg. "Why didn't Lee question or remark on the performance of leaders like Ewell?" one of the engineers asked, noting that Ewell had not followed Lee's orders to take the Union hill.

"All of these guys were gentlemen," Hillebrand explained. "It would have been inappropriate and perhaps disrespectful, dishonorable, to tell someone they were doing a poor job. Lee might have been such a gentleman that he thought he … had to step away. And if he stepped back in to provide more guidance, that would have been embarrassing. That would have been ungentlemanly," he said.

At NASA, he continued, "You don't go up to people and tell them how poor their mathematical skills are, because you're all engineers and you're all expected to have a certain level of expertise. You wouldn't question that level of expertise because that would be impolite, but you might address other areas."

"Why didn't Lee pull out of the battle?" someone else asked.

"Look at your own world," Hillebrand replied. "You work incredibly hard for eight months or a year on a project, and the boss comes in and says, 'We're not going to do that project anymore.' I think many of us would find that demoralizing to some extent."

Photo Credit: National Archives and Records Administration

Portrait of General Daniel Sickles by Mathew Brady.

Abandoning their fight at Gettysburg would have been a blow to the Confederate troops' morale, said Hillebrand. If you left a battlefield, that meant you lost. You feel bad about your performance; you lose faith in your leaders, in your purpose; and the enemy seems tougher than before.

Another reason Lee didn't pull out was overconfidence. Before Gettysburg, explained Hillebrand, Lee had never lost a battle. Why should he stop now, especially so close to Washington? The belief that "what's worked in the past will work now" is a familiar pitfall at NASA. Success creates a false sense of invincibility that must be constantly kept in check. "Even though we're supposed to think about a problem differently," said Garcia, "we still fall back on what's worked best. We're creatures of habit." So how do we break that habit? "Was there any evidence of sharing lessons learned from all the different wars or battles?" he asked.

"People who learned, advanced. People who didn't, didn't," said Hillebrand. There was some evidence of personal reflection and learning, but knowledge sharing and "lessons learned" didn't really exist then the way they do today. Stories of past successes and failures were not treated in an organized way. Formal efforts to learn from successes and failures are a mark of progress. It is one of the things this SELDP group will take with them as they prepare to lead the next generation of NASA programs and projects. ●

The Knowledge Notebook

Slow Learning

BY LAURENCE PRUSAK

If you have traveled in France or Italy recently, you have probably become aware of the "slow food" phenomenon. In contrast to the fast-food outlets we find everywhere in the world—even in France and Italy—the slow-food movement seeks to convince people of the value of food that takes time to prepare and is eaten slowly and thoughtfully. Although I am personally quite sympathetic to the motives of these epicurean evangelists and enjoy the kind of food they promote, I wouldn't want to bet on their success against the incessant marketing for fast food and the potent and addictive combination of salt and fat the industry supplies.

The factor that most likely hampers the slow-food movement is that the ill effects of fast food and fast eating are slow to be felt. You can eat greasy burgers and fries for quite a while and not experience any obvious ill effects—except perhaps being forced to buy bigger clothing.

There is another phenomenon that loves speed for its own sake and that I consider as pernicious as fast food. It is what I can only call "fast learning." It is true that few people get riled up when they hear that the time for their training sessions has been reduced by a day or two. But that probably says more about how the whole training experience is valued than about any belief that they are likely to learn more in less time. What I consider an indisputable fact, yet one almost everywhere ignored in our organizational lives, is that effective learning takes time. Real time. There are no exceptions. There are no techniques or technologies that appreciably reduce the time it takes to learn without reducing the quality of the learning. This has been true for a long time. Well over two thousand years ago, when King Ptolemy of Egypt asked Euclid for a quick and easy way to learn geometry, the creator of that branch of mathematics answered, "There is no royal road to geometry." In other words, everyone, even the king, has to go through the same rigorous and lengthy learning process.

Nevertheless, the e-learning industry in its many forms has tried to promote its various learning tools and methods as not just more accessible or more convenient but more efficient. There is some truth to their claims for convenience and accessibility, but efficiency—fast learning—is a myth advanced by people who are trying to sell you something. To genuinely and thoroughly learn something that is useful in your work takes both study time and participation in the relevant activity. Neither is sufficient without the other and both are intensive, extensive, and largely social activities that can't be packaged on a CD-ROM or a Web site for you to absorb at 11:30 p.m. after work and family time.

Think about a subject you *know*. I don't mean one you just have a lot of information about. You may "know" the capitals of many countries, for instance, or who won the past ten World Series, but that is a kind of knowledge that can be reduced to sentences, lists, or propositions and can probably be taught electronically and learned fairly quickly—as quickly as you can absorb straightforward and unambiguous information. No problem. But this kind of "quiz show" knowledge is very far removed from the type of knowledge that is required for effective project management or cosmology or materials engineering or a thousand other complex and demanding professional activities.

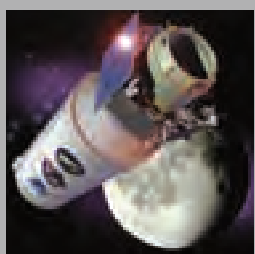
That professional expertise, which goes to the heart of NASA's work and how it gets done, is much more tacit, subtle, and elusive than mere facts about geography or sports. As far as I know, there are only two ways to learn it. The first is through social learning, in real rather than virtual meetings and classes. Discussing theories, methods, cases, and experiences with experts and other practitioners is a very credible way to acquire real knowledge in ways that "stick." The other way to learn how to do challenging work is by actually doing it and reflecting on what you have done. This creates and internalizes lasting learning that includes the real-life expertise that can only be acquired through experience and over time.

These are the learning experiences that create lasting value for the practitioner and the organization. Like good food, cooked and eaten slowly, this kind of learning always takes time and effort. But if you want to increase your skills (rather than your waistline) in a meaningful way, you need to resist the empty promise of fast learning. There is no royal—or virtual—road to engineering or project management excellence either. ●

THERE ARE NO TECHNIQUES OR TECHNOLOGIES THAT APPRECIABLY REDUCE THE TIME IT TAKES TO LEARN WITHOUT REDUCING THE QUALITY OF THE LEARNING.

ASK interactive

NASA in the News



NASA s Lunar Crater Observation and Sensing Satellite, or LCROSS, created twin impacts on the moon s surface in a search for water ice. The satellite launched as a companion mission to the Lunar Reconnaissance Orbiter and traveled 5.6 million miles before reaching the Cabeus crater, a permanently shadowed region near the moon s south pole, where it hit the lunar surface and created an impact that instruments aboard LCROSS observed for approximately four minutes. I am very proud of the success of this LCROSS mission team, said Daniel Andrews, LCROSS project manager at Ames Research Center. Whenever this team would hit a roadblock, it conceived a clever workaround allowing us to push forward with a successful mission. Other observatories captured both impacts, and their data will be shared with the LCROSS science team for analysis. The team expects several weeks of analysis will be needed to make a definitive assessment of the presence or absence of water ice. For more information about the LCROSS mission, including images and video, visit www.nasa.gov/lcross.

Reminder: PM Challenge 2010

The NASA PM Challenge is the agency’s annual forum for NASA stakeholders to learn about and discuss current trends in program/project management and related disciplines by sharing their knowledge, lessons learned, and new ideas that enhance mission success. PM Challenge 2010 will be held February 9–10, 2010, in Galveston, Texas. Registration is open October 26, 2009, through January 8, 2010. For more information, and to register, visit pmchallenge.gsfc.nasa.gov.

Web of Knowledge

NASA has selected 1,732 high school students from 48 states, the District of Columbia, and Puerto Rico to participate in its Interdisciplinary National Science Program Incorporating Research Experience (INSPIRE). The project is part of NASA’s efforts to engage students in disciplines critical to the agency’s missions, such as science, engineering, and mathematics. The selectees will participate in an online community where they can interact with their peers and NASA engineers and scientists. The students will also be able to compete for workshops and internships at NASA facilities and participating universities. To learn more about the program, visit www.nasa.gov/education/INSPIRE.

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