National Aeronautics and Space Administration

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The NASA Source for Project Management and Engineering Excellence | APPEL

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Photo Credit: NASA/ ESA/STScI/J. Hester and P. Scowen (Arizona State University)

ON THE COVER

NASA's Great Observatories—Spitzer, Hubble, and Chandra—teamed up to create this multi-wavelength, false-colored view of the M82 galaxy. The Spitzer Space Telescope contributes to the search for new worlds by studying discs of dust and gas found around nearby stars, which are thought to eventually form "extrasolar" planetary systems. Chandra allows scientists from around the world to obtain X-ray images of exotic environments to help understand the structure and evolution of the universe.

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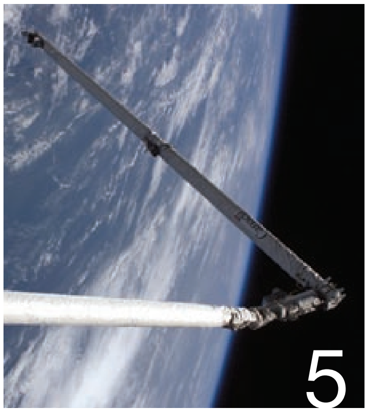

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ask

Issue No. 25

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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 previous academy, Academy of Program/Project Leadership, and its Knowledge Sharing Initiative, designed for program/project managers to share best practices and lessons learned with fellow practitioners across the Agency. Reflecting APPEL's new responsibility for engineering development and the challenges of NASA's new mission, *ASK* includes articles that explore engineering achievements as well as insight into broader issues of organizational knowledge, learning, and collaboration. We at APPEL Knowledge Sharing believe that stories recounting the real-life experiences of practitioners communicate important practical wisdom. By telling their stories, 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.

For inquiries about APPEL Knowledge Sharing programs and products, please contact the Knowledge Sharing Project Manager, Tina Chindgren, ASRC Management Services, 6303 Ivy Lane, Suite 800, Greenbelt, MD 20770; tina.chindgren@asrcms.com; 301-837-9069.

In This Issue

A few years ago, I spent a couple of days driving from meeting to meeting with a woman responsible for coordinating critical activities of a large organization. She spent a lot of the travel time talking on her cell phone and wondered aloud how her predecessors managed the job before that technology was available. But then she added, "The problem with cell phones is they make you think you've had a conversation."

That remark comes to mind now because so many of the articles in this issue of *ASK* make the point that successful communication involves much more than sending messages by phone or e-mail and assuming you've been heard and understood. What needs to be communicated is often more varied, complex, and subtle than the exchange of words those media allow. In "Managing a Critical, Fast-Turnaround Project," Kim Ess discusses the importance of full and honest communication with management and within the team and emphasizes the importance of meeting in person and traveling to the NASA and contractor sites where the work is being done. Given the availability of intranets, e-mail, and videoconferencing, leaders of some organizations think traveling to talk to someone is a waste of time and money, but Ess understands that *being there* is the only way to fully know what's going on (including the things people are afraid to mention) and to create the trust and mutuality that teamwork depends on. All of that supposedly inefficient travel made it possible to build the Orbital Boom Sensor System quickly and well.

Richard Shope ("Communicating Science") says that communication between scientists includes not only words and images but body language and vocal qualities that help express ideas and the emotions connected with them. (Eugene Meieran and Harrison Schmitt's "Imagination, Motivation, and Leadership Make Visions Real" implies that communicating passion and commitment is essential to great accomplishment.) Shope also notes that asking the right questions is key to understanding. That raises an essential point: good communication involves talking *and* listening. In this issue's interview, Eileen Collins emphasizes the importance of genuine listening—that is, really hearing and considering what people say (as opposed to just letting them talk when your mind is already made up). Listening means openness to new ideas from new sources. That kind of openness allowed the Space Infrared Telescope Facility project team to develop a new, dramatically less expensive plan for getting their instrument far enough from the earth ("Finding a Way: The Spitzer Space Telescope Story").

Brian Cooper's description in "Learning to Drive the Mars Rovers" of what trainees go through before they are allowed to direct Spirit and Opportunity, the Mars exploration rovers, shows that communicating complex skills goes far beyond conversation, though conversation with veteran "planners" (as they are called) is part of how they learn. In this case, the communication process includes the experience of analyzing transmissions from the rovers, practicing by way of simulations, and observing and then being observed by people who do the job.

Vincent Bilardo reports in "Seven Key Principles of Program and Project Success" that NASA's Organization Design Team identifies facilitating "wide-open communication" as one requirement for successful projects. This issue of *ASK* makes clear that communication involves observation, attention, and openness as well as talking or writing, and it includes conversation in the way my colleague with the cell phone meant the word: a social act of speaking and listening that, through the sharing of ideas, fosters trust, understanding, and cooperation.

Don Cohen
Managing Editor

From the Director

Passing Forward Centuries of Knowledge

BY ED HOFFMAN

It's amazing how you can examine an object or issue ten, twenty, or hundreds of times and manage to still find nuances or a different view of the whole picture if you step away from it long enough and come back to it later—or even bring in an outside perspective you never had before. So it is with one of my favorite spots on the left bank of Paris, which my daughter, Amanda, was able to experience with me this visit: Notre Dame.

The gothic cathedral stands proud and overwhelming, looking over the city as the ultimate sentry. It assumes its place as the center of a civilization and provides color and warmth to everything around it. We approached it together slowly, looking up and around, getting close and stepping back. There is so much to notice: the truly towering towers, sculptures, rose windows, bells, organ, and reliefs that tell stories. Each of these elements represents a work of art and engineering excellence. As a system, Notre Dame is an inspiring engineering and project achievement that mixes technology, art, science, and religion.

I notice something unique every time I visit. On this occasion I was struck by the duration of the construction. Almost 200 years from concept to completion. This was a project that took close to ten generations to finish. It required an incredible commitment, motivation, and focus as well as a constant supply of talent, resources, and materials to carry the mission forward. Those involved needed a way to provide continuity in learning and sharing knowledge. And it had to span two centuries. How did they do it? More importantly, how can we emulate it?

A large part of our challenge at NASA is the length of our mission for exploration—moon, Mars, and beyond. There are myriad issues—technology, management, finance, collaboration, communication, integration, talent, learning, political support—that will reach across our years of effort, and we need to carry forward what we learn as we address them. It seems hard these days to imagine missions that span decades let alone centuries, but we need to imagine it and prepare for our successors, our future collaborators. We need to communicate, record, and share lessons in the moment to ensure we're all—those of us today and those of us joining us in the future—building with the same vision in mind.

Like Notre Dame, space exploration has the power to inspire and create a sense of world community and commitment toward a bold vision. What we are building today will be expanded upon by others in the future, and it will continue to affect those who look up in awe at these great structures and the space beyond, even 200 years from our beginning. This issue of *ASK* continues the tradition of reexamining what we know and finding the nuances needed for NASA program management and engineering excellence. ●

MANAGING A CRITICAL,

FAST-TURNAROUND PROJECT

BY KIM ESS

As seen from Discovery's *cabin, the STS-114 Remote Manipulator System robot arm for the Orbiter Boom Sensor System flexes above Earth.*

Photo Credit: NASA

Developing the Orbiter Boom Sensor System (OBSS) was a prime example of a highly critical, highly visible, fast-turnaround project. When the work was authorized in September 2003, we were asked to complete it in six months, in time for a projected March 2004 shuttle *Discovery* launch date. After the *Columbia* accident, no shuttle was going to fly until we had the capability to examine it for damage after launch, so any significant delay in building the boom would keep the shuttle program and the work that depended on it—notably the completion of the International Space Station—on hold.

Managing such a project has special challenges and pressures and a few advantages, too. The clearest benefit of such high-profile, critical work is the ability it gave us to recruit top people to what, at one point, was a 500-member team. (And having high-quality team leads was one essential source of success.) We didn't have to convince anyone that the work mattered to the space program and to the safety of our astronauts. And the importance of returning to flight and preventing future catastrophes gave us a defining and unifying goal that inspired hard work and cooperation, although, as with any project, it was important to help team members keep the goal in view as they dealt with the details, complexities, and inevitable frustrations of their parts of the work.

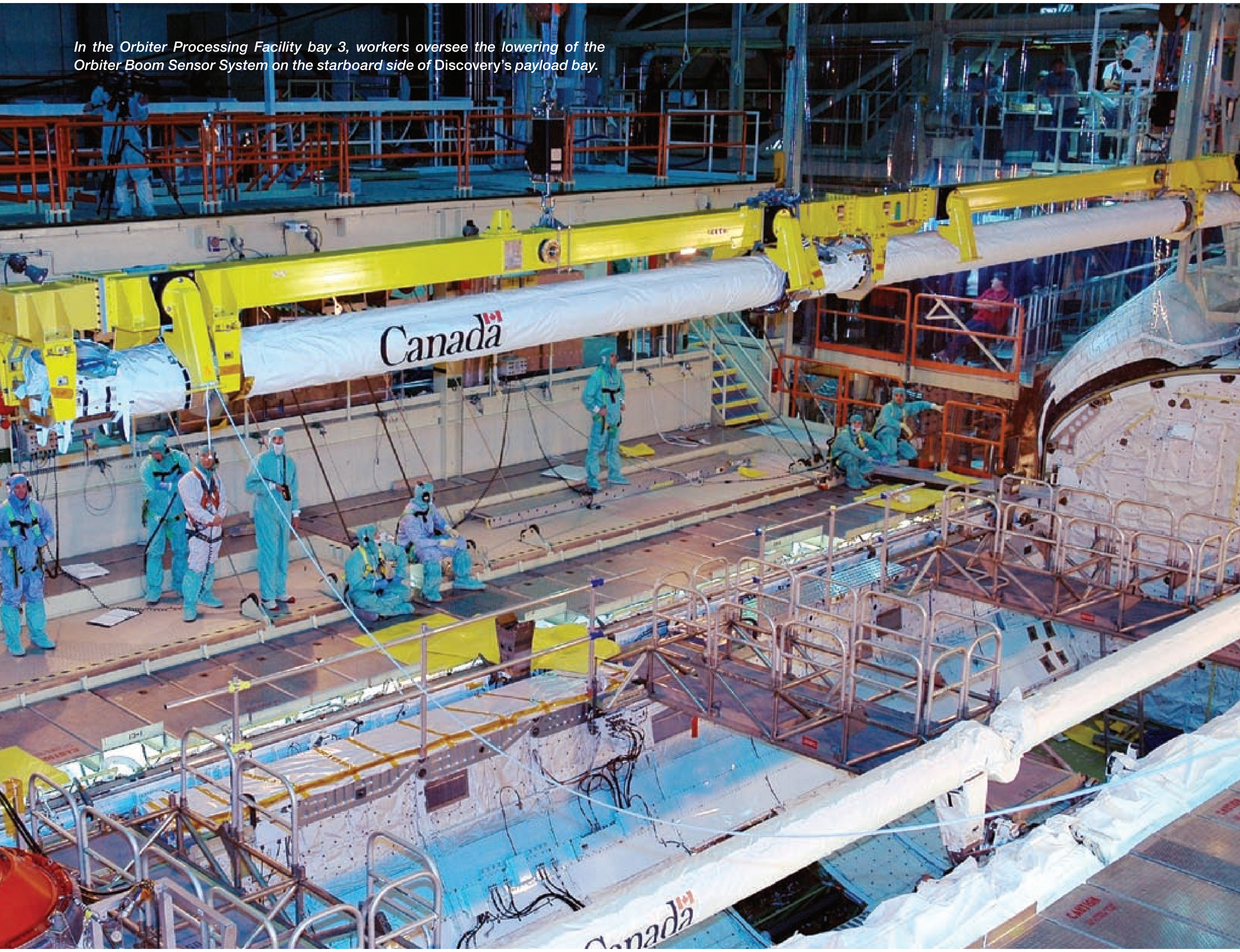
Successfully meeting the technical and organizational challenges of the project required not only team dedication but outstanding communication and openness, constant vigilance to detect and correct problems that could delay development, and clarity about what we needed to accomplish.

Reality Check

The feasibility assessment of inspection options that began weeks after the Columbia accident concluded that a boom sensor system to examine the shuttle's thermal protection system in orbit could be developed using previously flown hardware and existing NASA spares in six months for under $40 million. The system requirements review we held within a month of forming the project management team clearly showed how unrealistic that assessment was. The available hardware was not "criticality-1" rated and therefore not acceptable to use on a system judged essential for astronaut safety. Also, required structural supports and vehicle modifications were not included in the initial assessment. The plans called for two sensor packages to meet the requirement for redundancy, but our initial timetable limited us to one because of the vehicle and boom modifications needed to provide enough power for two sensor packages. Many components—especially electronics—that worked properly in the relatively protected environment of the payload bay would need to be tested for survivability in the harsher conditions they would face at the end of a boom. We would likely have to develop new shielding and heaters to protect them.

One of my first jobs as project manager was to report to the Program Requirements Control Board that we could not meet their proposed cost or schedule. I said that the requirements the program had set for the project would cost $100 million and that we had less than a 10 percent chance of completing the project in the next ten months. Assuming no serious technical problems—a risky assumption—we estimated that the project would take about twice that long. This was not an easy message to deliver, but clarity and honesty were important to our success. I wanted management to support our actual cost and schedule, to recognize the risks, and know the project's real needs. I've sometimes said, jokingly, "We were working so hard we didn't

AS PEOPLE GOT TO KNOW AND TRUST EACH OTHER AND RECOGNIZE THAT WE WERE ALL WORKING TOWARD THE SAME GOAL, INFORMATION ABOUT PROBLEMS BECAME JUST DATA FOR THE TEAM TO WORK WITH, NOT INDICATIONS OF FAILURE.



In the Orbiter Processing Facility bay 3, workers oversee the lowering of the Orbiter Boom Sensor System on the starboard side of Discovery's *payload bay.*

Photo Credit: NASA

ONE OF THE TOUGHEST TASKS OF A PROJECT MANAGER IS TO DECIDE WHEN GOOD IS GOOD ENOUGH AND CALL A HALT TO FURTHER IMPROVEMENTS.

have time to do anything but tell the truth." But the truth in that joke is that telling the Board anything less would have made the project much harder—depleting time, energy, and good will—when we inevitably would have had to go back to management to ask for more time and resources. As it happened, the development cost came within 5 percent of our estimate.

Communication and Being There

Full and honest communication, with management and especially within the team, was a hallmark of the project and a major factor in our success. Weekly project meetings with core team leaders to share information and solve problems were not enough. Frequent teleconferences helped keep information flowing, but they were no substitute for meeting face to face. Travel, travel, travel was the most important part of our communication strategy. Groups in California, Texas, Florida, New Mexico, and Canada worked on the OBSS. Regular travel to those sites was absolutely essential to the work. Only actually being there makes it possible to understand issues fully and provide the necessary support and encouragement. Having the customer on site helps focus the work of even the best contractors. One important lesson we learned was that we should have spent more time earlier in the project with all our contractors. We had assumed it would not be necessary to track or visit experienced contractors that had been reliable in the past, but that turned out not to be true. Most critically, being there is sometimes the only way to identify problems before they threaten project cost and schedule.

In one instance, one of our main partners did not report a manufacturing problem it thought it could handle alone until weeks before a major delivery milestone, leaving no time to adjust the schedule in other parts of the project to compensate for the resulting delay. A lead team member went to their facility and stayed until he was sure they were back on track. Their reluctance to report the problem as soon as it arose is not surprising. NASA engineers and contractors usually try to solve problems before they elevate them to the next level. "Never show up without a potential solution" is part of the culture. But we needed to change that behavior, to encourage people to bring up every concern to the project level as soon as it occurred so the best resources from the whole team could be applied to solve it. Over time, we established a we-have-a-problem attitude rather than a they-have-a-problem attitude. Having people travel from site to site contributed to this change. As people got to know and trust each other and recognize that we were all working toward the same goal, information about problems became just data for the team to work with, not indications of failure.

Having a single repository for all project documents was another valuable contributor to collaboration. The systems engineer assigned to OBSS was our "documents guru." Even though International Traffic and Arms Regulations meant there was some information our Canadian partners could not see and therefore added a management chore, that central repository saved time and effort by organizing documents and making them easily accessible.

Another aspect of our communication strategy dealt with communicating with outside assessment groups. The OBSS project was subject to a lot of scrutiny. Independent assessments were conducted by the Inspector General's Office, by numerous safety and financial organizations, and by the Stafford Covey Task Group. Some assessments were helpful and some were not. We found it essential to have people specifically assigned to handle these outside requests for information, to act as a buffer for a technical team that was already stressed by the demanding work and could not afford to be distracted from their project tasks. The central repository also helped with assessments. As requests for information rolled in, we could send the link and let the requesting organizations pull the data they needed themselves.

Managing Risk

Open communication and our emphasis on identifying and dealing with potential problems as soon as possible were important parts of our efforts to reduce risks that could threaten our schedule or the successful performance of the boom. I initially resisted devoting time and resources to a formal risk-management system, but it proved well worth the investment and our top-level risk matrix became a valuable tool when providing updates on the project's status. Because our schedule was so critical, we used multiple vendors for long-lead components and multiple shops for critical-path manufactured parts to ensure that a serious problem with one item would not delay the project. And we worked serially on three units—two flight units and a "spare" to give us some additional insurance against unforeseen manufacturing problems.

Fully integrated testing of the system on the flight vehicle revealed problems that would otherwise not have been discovered until the boom was in orbit. The risk of technical failure is high in a fast-turnaround project given that requirements development, design, and build phases come in rapid succession, so integrated testing is all the more important.

Moving Deadline, Changing Requirements

The return-to-flight launch date changed several times during our project, for reasons unrelated to progress on the boom. Early in our work, the original six-month target became nine months and then a year. Ultimately, *Discovery* launched in July 2005, sixteen months after we began work. At first glance, this sounds like good news for us—who can object to having more time to complete their project?

But the repeatedly changing date created its own problems; the postponements created an expectation that we would increase the quality, performance, and safety of the product without, of course, adding to the budget. The biggest example of changing requirements increasing cost was the decision to use some of that "extra" time to develop the originally specified two-sensor packages instead of the one that earlier deadlines seemed to require. In effect, we had multiple release dates for the OBSS, having the single-sensor version certified, tested, and ready to fly while we worked on the two-sensor boom. We followed that same pattern with software development, making sure one version was ready to fly while the team worked on enhancements that might or might not be tested, certified, and ready to go by the launch date.

As anyone who has managed a NASA development project knows, even without launch delays, it is hard to get team members to stop improving the product. They will want to fill any additional available time with tweaks and enhancements. One of the toughest tasks of a project manager is to decide when good is good enough and call a halt to further improvements.

Success

The Space Shuttle *Discovery* took off July 26, 2005, approximately two and a half years after the *Columbia* accident. On the 27th, the hard work of the OBSS project team paid off when the Orbiter Boom Sensor System successfully deployed and examined *Discovery*'s thermal protection system. While we were confident the sensor would work and believed the mechanical elements of the system would work well, we breathed a collective sigh of relief when the boom was successfully re-stowed in the shuttle's payload bay. ●

KIM ESS joined NASA in 1987 and has been a project manager in the Orbiter Project Office at Johnson Space Center since July 2001. She has been the project manager for the Space Shuttle Orbiter Boom Sensor System since September 2003.

MITRE: The Collaborative Landscape

BY JULIE GRAVALLESE, REN RESCH, JEAN TATALIAS, AND DON COHEN

The MITRE Corporation's goal is to "bring the corporation to bear" on critical national problems—to apply all its relevant knowledge and experience to each of the complex projects it takes on for the U.S. government. Making valuable knowledge available when and where it is needed has always been a primary aim of knowledge management and the goal of many knowledge-intensive organizations. MITRE has succeeded far better than many organizations at supporting the learning and knowledge sharing that bringing the corporation to bear requires. The practices, technologies, values, and environments behind this success offer a useful model of how knowledge sharing works. MITRE's experience shows that there is no single source of effective collaboration and certainly no technology "solution" that makes it happen. Collaboration and effective knowledge management rest on a foundation of mutually supportive elements—a broad and varied collaborative landscape.

NASA and MITRE were both established in 1958, NASA in response to concerns over Soviet technological dominance represented by the launch of Sputnik and MITRE to support efforts to strengthen our nation's air defense systems, a major cold war concern. MITRE is a private, not-for-profit organization that applies its expertise to U.S. government defense and security issues and other issues of national importance. Its 5,750 employees are divided between principal offices in Bedford, Massachusetts, and McLean, Virginia, and located at more than sixty sites around the world, mainly at facilities of its government clients. It takes on complex projects that demand effective knowledge sharing—no one person or isolated team can know everything required to do the work well, and MITRE's accumulated experience is an expected and essential part of what it offers its clients.

The MITRE Information Infrastructure

MITRE's corporate intranet and portal—the MITRE Information Infrastructure, or MII—is part of the company's response to its knowledge and collaboration needs. It is an unusually sophisticated and successful example of this kind of technology—and one of the earliest, first used in 1995. It is telling, though, that as MITRE developed its collaborative technology, it continued to connect its campus buildings with enclosed walkways. MITRE's leadership understands that meeting in person is an essential element of collaboration and knowledge sharing and that shaping the physical environment to encourage conversation is an important investment. Like other knowledge strategies we describe later, talking face to face is a medium of rich and subtle learning that documents in a repository cannot match, and it is an opportunity to strengthen the social ties and trust that make people more likely to use a system to which they and their colleagues contribute.

At MITRE, successful collaboration, and more specifically expertise location, relies on both the social networks the corporate culture encourages and fosters and the technology, primarily the MII. MII users seeking information on a particular subject—say enterprise systems engineering—can find relevant documents including reports, briefings, discussions, blogs, and community of interest Web sites, ranked by relevance to the topic. Users can also search the expertise locator to identify fellow employees or departments that have posted documents on the subject, ranked according to the likely depth of their expertise. The system bases the rankings on documents submitted to the MII and participation in community discussions. This approach to expertise location works better than self-reporting expertise locators—that is, systems based on profiles employees construct themselves to indicate their areas of competence and interest. Many organizations that try self-reporting expertise locators are disappointed by them. Some serious flaws undermine these systems: profiles quickly become outdated and few employees can be bothered to revise them every time they do new work or change focus; people are not necessarily good judges of their own expertise; and they seldom provide the level of detail that many knowledge seekers require. MITRE has successfully avoided these flaws, and internal experience shows that the results, while not perfect, closely match the names that the human knowledge networks would also point to.

The MII has worked well for more than a decade because the group that designed and manages it has been willing to let it evolve (and help it evolve) over the years in response to the needs and preferences of users. Jean Tatalias, MITRE's director of knowledge services, notes, "The fundamentals remain the same, but we continually add content and applications, with major design upgrades every three to five years, including customization, navigation, and infrastructure enhancements." A major change came early in its deployment. The original system design included "Publish" folders intended for important documents generated during project work and "Transfer" folders as a less formal, temporary document-exchange space. But users avoided the Publish folders, which to many suggested that only polished, "publishable" papers were acceptable. Also, the required HTML conversion was slower and less reliable than storing documents in their native formats. Staff used the Transfer folders as their main repository instead because they helped teams work across computer platforms and gave users the most control. Rather than trying to force users to obey the intended system "rules" (which never works), system designers eliminated the Publish folders and threw their support behind the Transfer folders.

How does the MII work in practice? Here is an example. A MITRE project leader receives a question from his government sponsor: What does MITRE know about UAVs (unmanned aerial vehicles)? He immediately turns to the MII collections and an active Listserv discussion to quickly find pertinent information. Within ten hours, he has accumulated a significant amount of data. He spends the next day working through the material to arrange the data into respective categories appropriate to the questions. Through the contacts made on the MII discussion list, he engages his colleagues in a quick peer-review process. He then creates an interactive CD with his findings, which includes a summary paper and hyperlinks to myriad resources. This neat little package gives his customers just about everything they need to make decisions on procuring and budgeting for UAVs.

The MITRE manager believes that having access to the breadth of information and active discussion groups is extremely valuable to the company and typifies MITRE's ability to leverage its knowledge. The customer is surprised and impressed not only by the amount and quality of data, but by the amazingly quick turnaround time. It takes the customer two weeks to assimilate the data—and they consider the work a wonderful "Cliffs Notes" version of material supporting intelligence surveillance and reconnaissance. The blended use of technological and social infrastructure, including MII and the discussion groups that provide up-to-date input from colleagues, happens every day at MITRE. This particular instance occurred before the Listserv discussions were indexed; now they can be searched on the MII as well.

The Collaborative Landscape

As we have suggested, the MII could not work in a vacuum, no matter how well designed it is. A rich context of behaviors, values, and environments support it and all aspects of knowledge sharing. Physical workspace is one. As buildings are renovated, small kitchens and comfortable seating areas where small groups can sit and talk are included. The campus InfoCenters are adjacent to cafés that serve snacks and coffee—effective magnets for creating a collaboration catalyst and drawing people together.

> SUCCESSFUL COLLABORATION, AND MORE SPECIFICALLY EXPERTISE LOCATION, RELIES ON BOTH THE SOCIAL NETWORKS THE CORPORATE CULTURE ENCOURAGES AND FOSTERS AND THE TECHNOLOGY.

MITRE also uses technology to extend workplace connections. Its extensive, high-quality videoteleconferencing facilities allow multilocation meetings, discussions, and presentations. These "team rooms" go a long way toward making the Bedford and McLean offices, separated by more than 500 miles, feel like part of a single facility. Most other sites also have videoteleconference facilities that link them to both campuses and to each other (i.e., multipoint). While the

NO ONE PERSON OR ISOLATED TEAM CAN KNOW EVERYTHING REQUIRED TO DO THE WORK WELL, AND MITRE'S ACCUMULATED EXPERIENCE IS AN EXPECTED AND ESSENTIAL PART OF WHAT IT OFFERS ITS CLIENTS.

company used to use the term "reach back" for site personnel to take advantage of the expertise of main-campus employees, it now uses "reach across," expanding the meaning to include tapping the extensive knowledge of employees located at customer sites.

Since its beginning, MITRE has had a collegial atmosphere and interest in learning that some employees describe as academic rather than corporate. Employees hold frequent Technical Exchange Meetings, or TEMs—as many as thirty a year on subjects ranging from performance engineering to service-oriented architectures to technology portfolio management. Anyone in the company can organize a TEM to share what they judge to be important ideas with their colleagues. The meetings are advertised through the MII News Center and banners, Listservs, community Web sites, and the MITRE Activities and Information Display (MAID) screens distributed throughout the MITRE campus. The TEMs are a major mechanism of knowledge exchange at the organization, a further opportunity for relationship building, and proof that MITRE takes its claim to "bring the corporation to bear" seriously. Members of MITRE's Corporate Communications and Knowledge Services Division often act as reporters who capture the essential content of these meetings as a resource for both the attending staff and for future readers who could not attend but can access the records in the TEM archives.

Fulfilling the Mission

MITRE's mission is to work in partnership with the government, applying systems engineering and advanced technology to address issues of critical national importance. Commitment to this essential work is an important part of the collaborative landscape. The shared goal of a worthwhile mission helps knit people together and tends to reduce the conflicts, competition, and suspicion that prevent knowledge sharing and other kinds of cooperation. The best NASA project managers know this and describe how keeping a project team's collective eye on the mission goal supports collaboration and excellence. Knowledge management initiatives that emphasize financial savings or other efficiencies rarely win employees' wholehearted participation.

MITRE's work for the government is neither simple nor straightforward. Government sponsors ask MITRE to undertake large, complex, and sometimes unique projects. No single person at MITRE has the skills to meet these challenges; no one element of the organization's collaborative landscape is "the answer" to organizational knowledge and learning. MITRE's work creates an intrinsic need to collaborate, builds teams with multiple skill sets, and provides systems, like the MII, to fulfill MITRE's mission and truly bring the corporation to bear. The strength of what MITRE does lies in the consistency and interconnection of its values, goals, behaviors, practices, and technologies. ●

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INTERVIEW WITH Eileen Collins

BY DON COHEN

In 1999, Eileen Collins became the first woman to command a shuttle mission. She commanded *Discovery's* return-to-flight mission in 2005, after the *Columbia* accident. She retired from NASA this year. Commander Collins talked to Don Cohen about learning to be an astronaut and about what being an astronaut has taught her.

COHEN: Tell me a little about how you learn to be an astronaut.

COLLINS: There are two kinds of learning—formal and informal. The formal side is pretty easy. Astronauts go through a structured training program with a syllabus, classroom work, simulators, T-38 flying. There are clear objectives; you know what you need to know and you learn it. Informal learning is more difficult because you don't always know what you need to know.

COHEN: What's an example of important informal learning?

COLLINS: You need to learn the jobs people are doing. You need to learn people's names so you know who to call to help you if you need something done—who's in charge of what part of the organization and what engineer is working on what part of the project. Those things aren't in the curriculum or in a book. A leader or manager needs to get to know the people themselves: their families, their hobbies, the specific needs they have in their lives. I keep a notebook of who I meet and under what circumstances and jot down one or two things they said to me that I might need to know a year from now.

> **“INFORMAL LEARNING IS more difficult BECAUSE YOU DON’T always know WHAT YOU need to know.”**

COHEN: How did you learn that you needed to learn those things?

COLLINS: Experience. You make mistakes as you go along. I found myself saying, “I wish I had written down the name of the person running that program.” As an astronaut, I meet a huge number of people. After the *Columbia* accident, I asked my crew to travel to the various centers and factories around the country that work on the Space Shuttle program. We went to Michoud in New Orleans, where the external tank is made, to Rocketdyne in Southern California, to Thiokol in Utah. We met people and presented awards, including Snoopy awards [for outstanding performance that contributes to flight safety and mission success]. It’s important to meet people and learn what they do.

COHEN: And it’s important for people working on the program to meet you.

COLLINS: It’s hard for the astronauts to meet everybody because we have responsibilities in the office and families we need to see, so we try to spread out. Not every employee will meet every astronaut, but we hope that every employee will meet some astronauts. Besides, it’s fun. When we meet the employees, we get motivated to strive harder because we can see how hard other people are working.

COHEN: Before you flew, you held several support positions at NASA. Did they help you prepare to fly?

COLLINS: I worked in three big jobs: shuttle engineering, astronaut and testing support at Kennedy Space Center, and CAPCOM [spacecraft communicator] in mission control. I was fortunate to see three very different parts of the organization and meet many people in engineering and operations—a huge benefit when I flew. Having worked in a variety of jobs increases your confidence as an astronaut because you know the people you’re dealing with when you’re up in space. When I was at Kennedy Space Center getting ready to launch on my mission, I felt more comfortable and more prepared because I had worked there. When I was in space, I was more comfortable and prepared because I had worked in mission control and understood what was going on there. And because I had friends and contacts in the engineering directorate at Johnson Space Center, I was able to communicate with them better about how things operated on our mission.

COHEN: It's always easier to communicate with people if you've done the same job.

COLLINS: It allows you to be more frank and a better communicator because you know the things they need to hear and you know the technical language they speak.

COHEN: Are there things you did as a shuttle commander and insights from your astronaut experience that can help the Agency pursue its new mission successfully?

COLLINS: When I was commander of STS-114, the return-to-flight mission, I asked my crew to be creative, to think about everything that could go wrong during the mission that no one has thought about yet and bring it to the attention of the flight control team. We have a plan for what we want to do, but we also need to have a plan or a partial plan in place for what could go wrong. Many people never thought foam could hurt the outside of the shuttle. There are other things out there that we don't realize could hurt us. I asked my crew and the people I worked with to try to be creative and smart about those things.

COHEN: Other insights?

COLLINS: Astronauts have a unique perspective because we have touched so many different areas: crew systems, engineering, operations, working at Kennedy Space Center and Johnson Space Center. And the fact that you have been there gives you unique insight into the kinds of things that can be done—how much work an astronaut can do on a day-to-day basis. You don't want to give the astronauts too much because they'll try to do everything on the schedule and will get overworked and tired. On the other hand, you want to optimize what you can get out of the mission.

COHEN: Those issues will be even more important as missions get longer.

COLLINS: You need to be realistic about how much work to expect from the astronauts who will be on the moon. You're better off underscheduling because things will inevitably break and need fixing and things seem to take longer when you get up there. When you're on Earth you do a lot subconsciously. You don't think about walking from one place to another, you just do it. In space, you have to think about how to get from point A to point B. Thinking about getting from one place to another keeps you from thinking about what you're going to do when you get there, so everything takes longer. That will be true for astronauts on the moon, with its one-sixth gravity.

COHEN: Do you have any particular advice for the first commander of the Crew Exploration Vehicle [CEV]?

COLLINS: That person won't need advice on the technical side of the job. On the people side, I would advise the CEV commander to be prepared for a lot of media attention. We get little training in handling the media and publicity that goes with some of these missions. For example, John Young, the commander on STS-1, had a huge amount of media attention. So did my flight in 1999, when I was the first woman shuttle commander, and the flight last summer, because it was a "return-to-flight" mission. I would say, hire one person to handle the inflow of e-mail, letters, and unusual requests. The crew can't deal with those things; it's too distracting. But I think it's important for the Agency to respond because part of our charter is education. I gave the same advice to Barb Morgan, who was Christa McCauliffe's backup and will fly as the teacher in space next year. You need to focus on your job; you've got to have someone else take care of these other things you don't have time for.

COHEN: Does seeing the earth from space give you a new perspective on the world?

COLLINS: Yes, you do see the earth from a different perspective. It's so beautiful—blue and white, a water planet. My first thought after looking out the window was, "The earth is round!" Of course we all know that, but it was the first time I'd ever seen it with my own eyes. The auroras—the northern lights and southern lights—are beautiful from space. I had never seen them before because I had never been that far north or south. I sometimes think of the earth as a Christmas tree ornament because it's small in the big scheme of things and it's fragile. The surface of the earth has an extremely thin atmosphere on it. We live on a small and fragile planet.

“I ASKED my crew TO BE creative, TO THINK ABOUT everything THAT COULD go wrong DURING THE MISSION THAT NO ONE has thought about yet AND BRING IT to the attention OF THE FLIGHT CONTROL TEAM.”

COHEN: Does that perspective stay with you when you’re back on Earth?

COLLINS: Yes, and I want to learn more about the planet and ways we can preserve it for future generations. I do a lot of reading and studying about the earth. Also, I want to visit places I’ve seen from space: Australia, the Great Barrier Reef, those beautiful little islands in the Pacific. Looking down at Europe and the Middle East, you think of all the history that took place in those areas and you want to visit them.

COHEN: Although I’m sure it’s not the same as being there, I think even seeing photos of the earth from space have changed the way people think about our planet.

COLLINS: Definitely. Most of the change in my perspective came from studying to be an astronaut. Maybe the last few percent of what I know about the earth comes from viewing it from space. The studying made more of a change in me, and that’s something anyone can do if they have books and a computer and the desire to learn.

COHEN: What’s your response to people who argue that we shouldn’t spend our resources on further space exploration?

COLLINS: The space program is an investment. In the short period of time we’ve been sending people into space, life on Earth has benefited tremendously. We have better ways of observing and communicating, with telescopes and communications satellites in orbit. Someone said, and I agree, that when people look back at the twentieth century and early twenty-first century 500 years from now, they will see space exploration as our biggest contribution—the things we did to get off the planet to learn how to live in space stations and on the moon and Mars. We’ve gotten off the planet; we will move on to traveling faster so that some day people can travel outside the solar system.

COHEN: Before we end our conversation, is there anything else you’d like to say to our readers who work in the space program?

COLLINS: Yes. It’s important for people to listen to one another. Listening is hard, especially if you don’t agree with what the person is saying. But you’ve got to listen and let people know that you heard them and have considered what they said. The leader cannot possibly make decisions in everybody’s favor, but he or she needs to let people know that what they said was considered. Decisions have to be made and cannot be delayed unnecessarily because of disagreement. That’s one of the things I did. I said, “I hear you. I listened to you. Now I’ve got to make a decision.” ●

Growing Space Systems Engineers: The Key to Realizing the Vision for Space Exploration

BY ROBERT D. BRAUN

The current ARES wind tunnel model is shown in May 2004.

Photo Credit: NASA Langley Research Center

Now that NASA is headed back in the direction of becoming a space flight development agency, the Agency's need for highly capable space systems engineers is greater than it has been since the end of the Apollo program. Unfortunately, at many NASA field centers the current demand for capable space systems engineers with strong technical leadership skills far exceeds the supply. This issue has been overshadowed by media debates about the destinations and timetables for the vision for space exploration and the challenges of returning the Space Shuttle to flight. As a former NASA space systems engineer and a professor of space technology, I believe that systems engineering technical competency is central to NASA's ability to realize its bold human and robotic space exploration plans.

Today, there are a number of high-caliber space systems engineers in the Agency's field centers who eat, sleep, and breathe technical excellence and possess the development expertise needed to craft our nation's future exploration programs. Complemented by systems-savvy project managers who carefully balance technical risk, cost, and schedule, these personnel are the heart of any successful development effort. But, because NASA has operated for more than a decade without a development initiative on the scale of the new vision for space exploration and was given limited hiring authority during this time, I do not believe the Agency is currently staffed with enough experienced space systems engineers to complete its mission.

While pockets of systems engineering excellence exist at each NASA Center, few of these organizations have sufficient in-house systems engineering and project management expertise to meet the demands of all the development missions presently assigned. For NASA to successfully implement the vision for space exploration, the NASA field centers must be transformed into technically focused organizations distinguished by space flight development rigor. These missions demand a focus on technical excellence across the organization, a systems engineering approach to project implementation, technical insight and crisp decision-making from project managers, clear communication across the organization, and early risk

GOOD SYSTEMS ENGINEERS ARE NOT BORN; THEY ARE CREATED OVER TIME.

identification, prioritization, and mitigation. Some of the necessary expertise can be developed and sharpened through cross-fertilization of systems engineering skills, experiences, and organizational approaches among its field centers. For example, space flight development practices and personnel at the Jet Propulsion Laboratory and Goddard Space Flight Center have been honed by decades of robotic exploration mission and flight system development. Lessons learned at those centers could be directly applied to the Agency's human space flight efforts by way of workshops, collaboration, and the rotation of systems engineering personnel in the next few years—early enough to benefit NASA's major near-term human space flight development tasks.

Good systems engineers are not born; they are created over time. Intellectual curiosity and education are required, but so is substantive experience operating across the boundaries of traditional aerospace disciplines in a hardware or mission development setting. As a university professor, I know that the knowledge needed to become a skilled systems engineer cannot be found in a textbook or classroom. We teach orbital mechanics, aerospace structures, space propulsion, and even systems engineering methodology, but the traditional educational approach is ill equipped to prepare a real space systems engineer. The important skills can only be mastered from years of "doing the work" in a space flight development culture. While a traditional university curriculum can provide the foundation and tools needed to begin a successful space systems engineering career, a complete space systems engineering perspective requires a hands-on development experience that spans the whole life cycle of a project.

Paramount to strong systems engineering expertise is the ability to see the big picture; seamlessly integrate the contributions of disparate disciplines; balance technical, cost, and schedule risk; and learn from failure as well as success. Over the course of my NASA career, I sharpened these systems engineering skills by working as part of small, focused teams, including those responsible for the Mars Pathfinder, Deep Space 2 Mars Microprobes, Mars Sample Return Earth Entry Vehicle, and ARES Mars Airplane hardware development activities. These efforts continuously strove to reduce technical risk while living within stringent cost and schedule constraints. Thinking back on these space flight system development efforts, I am struck by a few common characteristics—the engineering excellence each of these teams exhibited daily, their passionate commitment to achieving the team goal, clear communication and camaraderie, and a singular focus on mission success. Succeed or fail, space flight system development is about enjoying and learning from the ride. Members of these teams did just that, learning from each developmental struggle, becoming stronger and wiser, and eventually applying these lessons to larger space flight projects like the Mars Exploration Rover missions and the Mars Science Laboratory. Such small space flight development projects serve a vital personnel development function, allowing for creativity, learning, and innovation, requisite steps to becoming a true space systems engineer.

To meet NASA's space systems engineering needs of the future, the Agency must create a hands-on development environment in its field centers, relying on strong systems engineers to understand and evaluate mission risk. Landing on Mars will never be a low-risk venture, nor will developing a telescope capable of detecting Earth-size planets around other stars, flying a new generation of human-rated launch systems, or carrying out a lunar surface mission. Our nation needs to dream big, and these are precisely the right missions for NASA to pursue. For ambitious projects like these, when low risk is not an option, good systems engineers who understand from experience how to identify, assess, and reduce risk are vital. A long-term development culture at all NASA field centers will nurture the space systems engineering expertise we need among the Agency's current personnel. A mix of small and large space flight projects is needed to develop this expertise, providing both "sink or swim" and mentor/apprentice experiences, while allowing each of NASA's Centers to develop

Left: *This artist's concept of the proposed Mars Sample Return mission shows a rendezvous of the orbiting sample container with the Earth return vehicle.*

Right: *In Kennedy Space Center's Spacecraft Assembly and Encapsulation Facility-2, Jet Propulsion Laboratory workers mate the Mars Pathfinder small rover to one of the lander's three petals.*

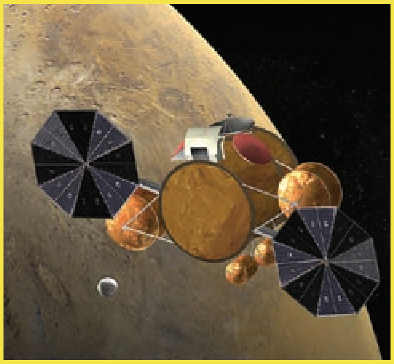

Photo Credit: NASA Jet Propulsion Laboratory

Photo Credit: NASA Kennedy Space Center

appropriate systems engineering practices and gain a stronger understanding of the concept of acceptable risk. This may be the most effective way to grow the Agency's current personnel for the missions of tomorrow.

PARAMOUNT TO STRONG SYSTEMS ENGINEERING EXPERTISE IS THE ABILITY TO SEE THE BIG PICTURE…

We must also start early, improving and expanding on the relatively small number of opportunities students in our nation's universities have to participate in hands-on space systems development and operations activities. These efforts require only modest funding and may be the only way to create the pipeline of space systems engineering talent the Agency will need in the future. Recently, the number of such opportunities has been reduced as NASA focuses its resources on large, near-term human space flight development efforts. This choice may work in the near term, but where will the systems engineers for the 2018 human lunar mission cut their teeth? Without the proper smaller-scale hardware development and mission operations experiences to teach them how to design, test, fail, re-design, test again, and then fly, these systems engineers will simply not be there in NASA's time of need. Such smaller-scale efforts have the potential to dramatically increase the number of young space systems engineers with the interest and experience to help them carry out the Agency's plans for human lunar exploration. Hands-on student activities would offer meaningful learning experiences by spanning the complete project life cycle while providing immediate benefits, enhancing the scientific return of NASA missions or advancing important space systems technologies. Sponsoring student-focused hardware development activities would also encourage a closer working relationship between current NASA engineers and the outstanding generation of young engineers in the nation's universities, improving the pool of new engineering talent that NASA can draw on as the students graduate.

NASA is returning to its roots as a space flight development organization. Success will depend on large numbers of the Agency's current technical staff getting experiential training to make up for more than a decade of neglecting the Agency's technical expertise, particularly in the areas of space systems engineering and space flight project management. Small space flight development efforts must be a vital element in the Agency's personnel development strategy, providing a practical means of building a systems engineering competency and an environment in which well-understood risk can be taken, technical creativity and innovation applied, and space flight development lessons learned. In addition, the best way to develop the expertise NASA's multidecade exploration program requires is to increase the number of hands-on space systems development and operational activities at our nation's universities. NASA has been given a grand set of future human and robotic space system challenges. Agency management must focus on growing the personnel who can successfully make this bold vision a reality. ●

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On August 25, 2003, at 1:36 a.m., I was sitting in the Mission Director Center at Cape Canaveral. That is the exact time the Delta II rocket ignited and carried the Space Infrared Telescope Facility (SIRTF) into an orbit that is the first of its kind with an infrared telescope design that is also the first of its kind. After three months of successful in-orbit checkout, SIRTF was officially commissioned and renamed the Spitzer Space Telescope after Lyman Spitzer, the renowned astrophysicist.

This vibrant image taken by Spitzer Space Telescope shows the Large Magellanic Cloud, a satellite galaxy to our own Milky Way galaxy. Nearly one million objects are revealed for the first time in this Spitzer view.

Photo Credit: NASA/JPL-Caltech/M. Meixner (STScI) and the SAGE Legacy Team

FINDING A WAY:
THE SPITZER SPACE TELESCOPE STORY

BY JOHNNY KWOK

As I write this article, Spitzer has just celebrated its third anniversary, and all indications show its cryogen, which cools the telescope and its instruments to just a few degrees above absolute zero, will last beyond five years. An infrared telescope observes the thermal emission of objects and therefore must be kept very cold to prevent its own emission from drowning those from observed objects. Spitzer uses liquid helium to cool the telescope to 5 kelvin; the detectors are cooled to 1.4 kelvin, or –272°C.

SIRTF was originally conceived as a follow-on mission to the InfraRed Astronomical Satellite (IRAS) that was launched in January 1983. At that time, SIRTF stood for *Shuttle* Infrared Telescope Facility. The shuttle was supposed to be the workhorse for all NASA payloads, human or robotic, and SIRTF was to fly two-week sorties attached to the cargo bay. Almost as soon as this concept was conceived, though, it became clear the shuttle environment was not conducive to the thermal sensitivity and cleanliness required by an infrared telescope. The shuttle-attached concept was replaced by a free-flyer concept: SIRTF would be launched by the shuttle, and the Orbital Maneuvering Vehicle (OMV) would raise its altitude to 900 km. When the cryogen ran out, the OMV would bring SIRTF back to the shuttle, the cryogen tanks would be refilled, and the OMV would raise it back to operating altitude again.

An infrared telescope in a low-Earth orbit has to overcome two disadvantages. First, the earth is a significant heat source. Second, it blocks half the sky. In addition, the telescope cannot point near the sun, so the telescope would routinely have to change its attitude to ensure sensitive optics and thermal surfaces would stay within design constraints. Of course, we know that the OMV never materialized, and after the *Challenger* accident in 1986, the shuttle-based concept was dropped completely.

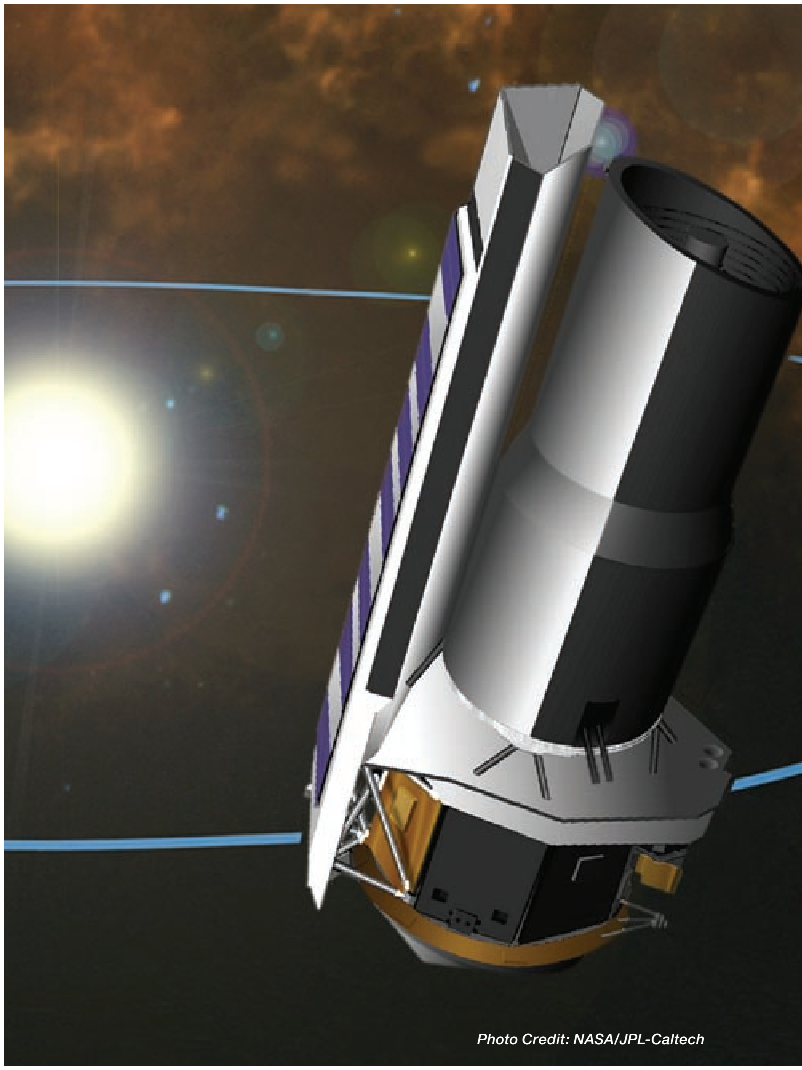


Photo Credit: NASA/JPL-Caltech

Artistic concept of the Spitzer Space Telescope in solar orbit.

In November 1988, the Jet Propulsion Laboratory (JPL) was asked to conduct a SIRTF high-Earth orbit (HEO) study. That was when I became involved with the project. I led the mission analysis portion of the study. We chose an orbit altitude of 70,000 km, which was later raised to 100,000 km. That altitude eliminates the two disadvantages of the low-Earth orbit mission. At that distance, the earth only blocks a seven-degree cone of the sky and the effects of the earth's heat are minimal. Also, that altitude is above the trapped radiation zone, the region surrounding the earth where high-energy charged particles from the sun, and cosmic rays, are trapped by Earth's magnetic field and can interact with infrared detectors to produce undesirable noise.

The high-Earth orbit has a significant disadvantage, however. To achieve it, the launch vehicle would have to carry the telescope into a parking orbit, initiate a burn to transfer the telescope to 100,000 km (a quarter of the distance to the moon), and then perform a second burn to circularize the orbit. The total change in speed of the two burns is about 4 km/sec, more than what is needed to send a spacecraft to Mars. It only takes about 3 km/sec to escape Earth's gravity. To reach a high-Earth orbit, we would have to use a Titan IV launch vehicle. I knew that the orbit was not efficient, but the project was going well using that mission concept and we had no motivation to propose changes. One estimate of the total cost of the mission was close to $2 billion, however. In the budget-constrained climate at NASA, it was inevitable that the Titan SIRTF would be cancelled, as it was in late 1991.

The project had to regroup. Jim Evans became the project manager in January 1992. The scientists and instrument teams scheduled a meeting at JPL to consider ways of reducing cost. A week before the March meeting, Jim came to my office to ask me if I had any ideas. I was a little taken aback by his personal visit. Jim was new to the project, and he and I had not known each other prior to SIRTF. I was supporting the project on a part-time basis but was not part of the project staff and not collocated with the project team. Jim was at least two levels above me in the JPL management hierarchy. Trying to sound as casual as I could, I replied, "I can talk about changing the orbit."

Jim's background is not in astrodynamics, so I did not try to explain the details of my idea. I simply said that sending the telescope into an Earth escape orbit would make it possible to use a smaller launch vehicle, such as one of the Atlas family. He took my word for it and said he would ask to put me on the agenda. A couple of days before the meeting, the agenda was circulated. I was not on it. I thought Jim had not followed through, or the agenda had so many other proposals that mine was dropped. I was not going to push for it. I was surprised again when Jim called me and asked me if I had changed my mind about presenting the orbit option. When I told him I was ready but the agenda did not include me, he said that was a mistake. Shortly afterward, a new agenda was circulated, with my name included.

The day came. When it was my turn to speak, I explained why a high-Earth orbit is an inefficient orbit and used an Atlas performance chart to show that the Atlas can carry only 1,600 kg to HEO but can carry 2,700 kg to an escape orbit. That was still a far cry from the 5,700 kg SIRTF designed for launch on a Titan IV. But I pointed out that a telescope in cold, deep space far from the earth might not need as much cryogen to cool it. In addition, the size of the sun/Earth aperture shield could be reduced since there would be no Earth avoidance zone anymore. Using a foam cup as a prop for the telescope and a 3 x 5 inch index card stapled to the side of the cup for a solar panel, I explained how the telescope would always have the solar panel toward the sun and still be capable of pitching and yawing to allow long-duration observations.

My brief explanation was met by a few seconds of dead silence. Then Frank Low, the facility scientist, jumped up and said, "That is the best idea I've heard today." The project quickly put together a proof-of-concept study and showed that an Atlas SIRTF was possible, but with the mission life reduced from five to two and a half years. One estimate pegged the cost in the mid-$800 million range, a reduction of more than half.

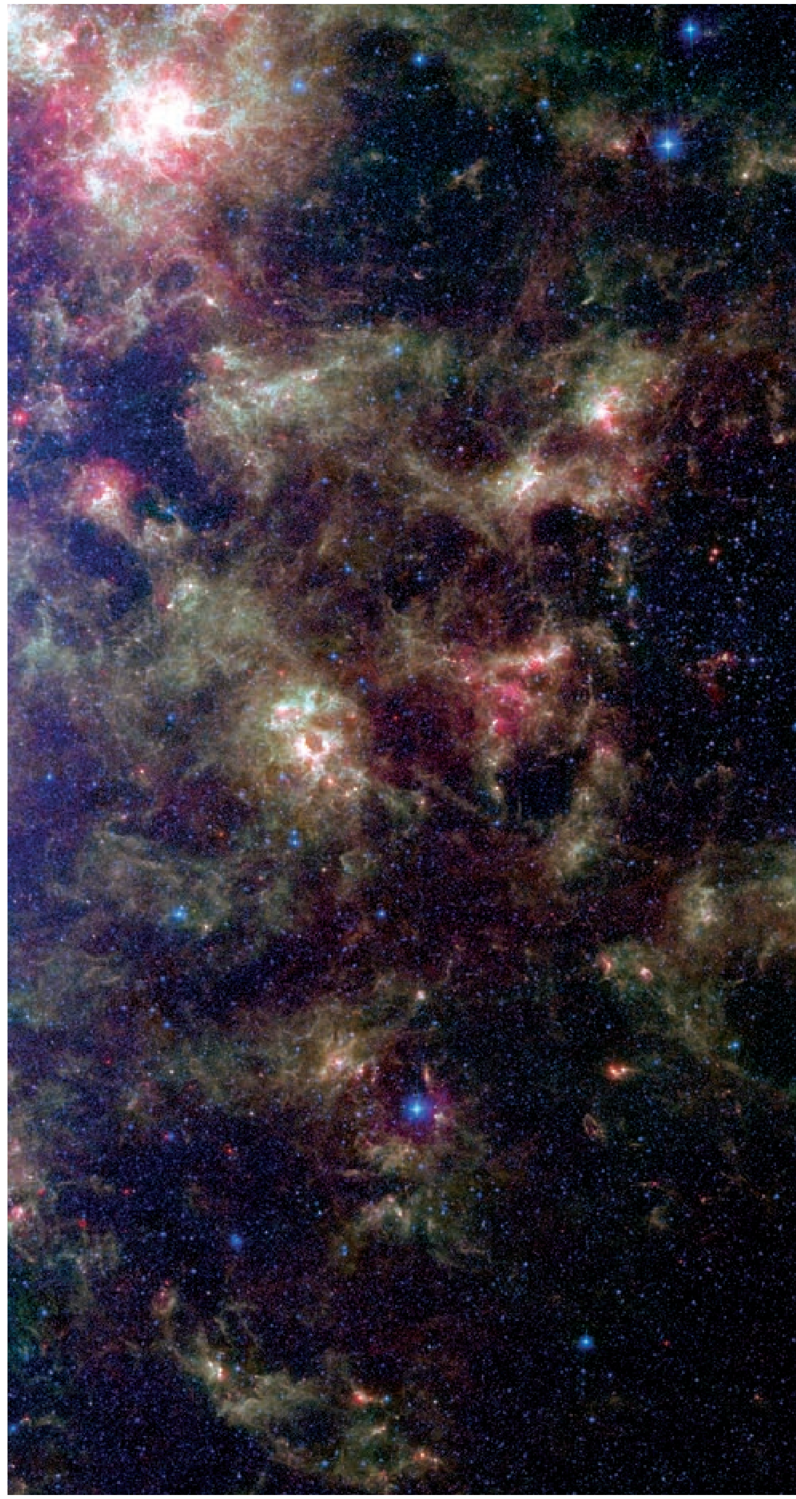
The new SIRTF mission was well received by NASA Headquarters and Dan Goldin, who became the NASA administrator in April 1992. But the cost was still too high for the era of faster, better, cheaper. The project team was told it had

THIS WAS SUCH A RADICAL DESIGN THAT IT TOOK A SIGNIFICANT EFFORT TO ARRIVE AT A PROOF OF CONCEPT… IT TOOK ANOTHER EIGHT YEARS TO GO FROM THAT CONCEPT TO LAUNCH.

The Spitzer Space Telescope, without the solar panel, during integration and testing.

Photo Credit: Russ Underwood, Lockheed Martin Space Systems

DON'T GET LOCKED INTO ANY ONE WAY OF ACHIEVING YOUR GOAL; THERE MAY BE A BETTER WAY TO SOLVE THE PROBLEMS YOU FACE THAN THAT FIRST GOOD IDEA.



to cut the price tag to under $500 million and consider the Delta II class of launch vehicles. It was time to pull another rabbit out of the hat.

The rabbit took the form of a warm launch concept proposed by Frank Low in late 1993. In traditional infrared telescope missions, the telescope and its instruments are housed inside a thermal bottle, the cryostat. Liquid helium fills the insulating walls of the cryostat, and the telescope and instruments are already cooled at launch. Frank proposed to let the coldness of deep space encountered in the solar orbit help cool the telescope and put only the instruments in the cryostat. Not having to build a cryostat to encase the entire telescope would eliminate a significant amount of mass, possibly allowing a Delta II class launch vehicle.

This was such a radical design that it took a significant effort to arrive at a proof of concept. In early 1995, the project finally settled on the Delta II solar orbit warm launch SIRTF. It took another eight years to go from that concept to launch, with many trials and tribulations, but the mission concept essentially remains the same. With better refinement in the cryogen system design and the use of an enhanced version of the Delta II, we managed to build a SIRTF with a cryogen life of at least five years. The launch mass of SIRTF was 852 kg.

The basic lessons of this long, complicated story are fairly simple, but I think they're important. First, don't get locked into any one way of achieving your goal; there may be a better way to solve the problems you face than that first good idea. Second, when you're looking for new ideas, especially radical new ideas, it makes sense to cast a wide net and welcome a broad range of thinking, expertise, and imagination.

As I was sitting at the Mission Director Center at Cape Canaveral watching the Delta II rocket carry SIRTF into its solar orbit, I could not help wondering what would have happened if Jim had not insisted that an idea had to be heard. ●

Note: Jim Evans left SIRTF in October 1993 when he was promoted to assistant lab director. Sadly, he passed away shortly afterward. This story is a tribute to him and many of the unsung heroes on SIRTF who contributed to the success of the mission.

JOHNNY KWOK joined the Jet Propulsion Laboratory in 1979 as a trajectory engineer and mission designer. He worked on the Spitzer (SIRTF) mission from November 1988 to December 2003, first as a member of the concept development and proposal team, later as the mission engineer, and finally as the facility engineer.

Imagination, Motivation, and Leadership Make Visions Real

BY EUGENE S. MEIERAN AND HARRISON H. SCHMITT

In 1968, Gordon Moore and Bob Noyce left Fairchild Semiconductor to form Intel Corporation. Intel soon became one of the most important companies in the world, a crucial driver of the Information Age, while Fairchild declined. In the mid-1970s, Digital Equipment Corporation (DEC) took a huge bite out of IBM's mainframe business by creating the minicomputer; twenty-five years later, DEC has disappeared. In the early 1980s, Apple created a huge following when it introduced the Macintosh computer; Apple largely fell off the radar screen for a number of years, only to be recently resurrected as an innovation powerhouse. In 1967, NASA experienced a disastrous fire on the Apollo 1 spacecraft that killed three astronauts; two years later, Neil Armstrong and Buzz Aldrin stepped onto the lunar surface, the first of six crews to do so. NASA subsequently underwent severe budget cuts leading to the cancellation of at least three lunar landings, but then sent rockets to Venus, Mars, Saturn, Neptune, Pluto, Jupiter, Mercury, many outer planet moons, even outside the Solar System. Today, the Mars Spirit and Opportunity rovers are still churning out valuable information, far exceeding their expected life.

We believe that the difference between success and failure in these varied cases, the difference between succumbing to disaster and learning how to reach greater goals in the future comes down to three ingredients: leadership, imagination, and motivation. If you have none of them, or only one, success is unlikely. If you have all three, it is almost certain.

Intel was founded by Bob Noyce and Gordon Moore, both acknowledged as technical masterminds as well as great visionaries. Andy Grove joined them and lent technical talent as well as an organizational mind-set that changed the world by creating and delivering revolutionary new semiconductor devices. They created a company that motivated people through personal recognition as well as financial rewards; that led to the invention of the microprocessor by Ted Hoff, Intel's first Fellow, and erasable memory or EPROM by Dov Frohman. Imagination, leadership, and motivation made this success possible. Intel's leadership was willing to bet their company's future on the potential value of these new devices. Frohman and Hoff were young men with deep technical knowledge, and Gordon Moore, of Moore's Law fame, and Bob Noyce, co-inventor of the integrated circuit, understood the technology as well as the capability of these people. This combination, along with the motivation to succeed inspired by Grove's leadership, led Intel to shape the information future of the world.

NASA endured the fire on Apollo 1 and chose not to sink into despair but to learn from the experience. On the second manned Apollo flight, less than two years later, astronauts Frank Bormann, Jim Lovell, and Bill Anders flew around the moon and enabled Neil and Buzz to step out on the surface, just seven months and three missions later. They too had wise leaders like George Low and Wernher von Braun, who understood the technology, had a vision of the future of space travel, and had a great motivation to succeed, fueled by the desire to beat the Soviet Union and by an inner drive to be first to the moon, regardless of politics. NASA's workforce, mostly people in their twenties, was motivated to succeed, particularly after the fire. They analyzed the entire Command Module to ferret out all the potential problems and, ultimately, built a safe Command Module. The wise leaders considered and accepted the calculated risks involved and had the imagination to change a mission's schedule to allow for a direct flight to the moon after just one manned Apollo flight, even though the lunar module and the Saturn V booster were still being debugged. And so the flight of Apollo 8 opened outer space to exploration and conquest.

These same qualities came into play after budget cuts eliminated several lunar missions. Imagination showed how to explore the solar system using unmanned vehicles, how to land vehicles on Mars, and how to analyze comets and asteroids. Leadership kept NASA's mission in view in spite of the difficulties. Motivation ensured success regardless of budget cuts and technical challenges.

Leadership means making decisions that often involve significant risk (like going to the moon on Apollo 8 after just one manned flight, or betting the company on our ability to replace core memories). It's the great and therefore risky goals that fuel motivation: the goal of creating the Information Age, putting a man on the moon, or hitting an asteroid moving at 50,000 km/hr with a little space probe. Powerful motivation can empower great leaders (Churchill comes to mind), but great ideas most often need great leaders and high motivation to succeed. Von Braun's vision and capability to go to the moon needed a John Kennedy to make that vision a national goal and George Low to make it achievable.

When imagination is insufficient to discover what's really possible, and huge opportunities are lost or leadership fails to make meaningful but risky decisions that take advantage of emerging opportunities or fails to motivate the workforce, then challenges and setbacks are likely to lead to failure, not success. So our advice is quite simple, though following it may be quite difficult:

- Allow people to be imaginative and innovative. **Imagination** makes the near impossible possible.
- Allow leaders to provide **leadership**, not just management skills.
- Help leaders choose ideas that create **motivation** for the people working on them. These ideas will flourish in spite of the obstacles. ●

EUGENE S. MEIERAN is Senior Intel Fellow and a member of the National Academy of Engineering.

HARRISON H. SCHMITT was the Apollo 17 Lunar Module Pilot and is chairman of the NASA Advisory Council.

Featured Invention: Emulsified Zero-Valent Iron

BY JOHANNA SCHULTZ

When faced with a big problem, it's often the small ideas that are able to create big results. Allowing those ideas to grow is equally important, according to Dr. Jacqueline Quinn, who helped create an innovative groundwater treatment technology that uses nanosize and microscale bits of iron (ZVI particles). "Let the science expand beyond your original plans," says Dr. Quinn, "and it will take you places." The result, Emulsified Zero-Valent Iron (EZVI), worked so well that it is currently in use to treat not only groundwater pollution but above-ground PCB pollutants as well.

Dr. Quinn, an environmental engineer in the Applied Sciences Division of the Kennedy Applied Technology Directorate, joined Kathleen Brooks, an analytical chemist in the center's Materials Science Laboratory of the Center Operations Directorate, along with Drs. Christian Clausen, Cherie Geiger, and Debra Reinhart at the University of Central Florida's Departments of Chemistry and Civil Environmental Engineering to come up with a solution that would provide a safe, effective, and economical way to clean dense nonaqueous phase liquids (DNAPLs) from the environment. DNAPLs are a common cause of environmental contamination at thousands of Department of Energy, Department of Defense, NASA, and private industry facilities around the country. Kennedy Space Center's Launch Complex 34 was polluted with chlorinated solvents that were used to clean Apollo rocket parts during the space program's early years. When left untreated, DNAPLs contaminate fresh water sources and are costly and difficult to remove.

The team's original treatment concept relied on using iron, which has been used to eliminate chlorinated contaminants in groundwater for about a decade. Iron is cheap and is found in most groundwater environments from natural sources such as iron oxides, hydroxides, and sulfates or sulfides. It is also essentially nontoxic. When iron metal is exposed to chlorinated solvents (particularly dissolved solvents) in groundwater, it creates a reaction that replaces chlorine in the molecules with hydrogen, leaving a harmless end product of ethene or ethane.

"Once we came up with this idea, we saw that it could be extrapolated to treat a different compound in a different environment," says Dr. Quinn. The expanded idea included treating polychlorinated biphenyls (PCBs), a compound commonly used in the 1970s for hundreds of applications from carbon paper to paints, adhesives, and dialectic transformers, which has proven exceptionally difficult to safely remove from the environment. "We have altered the metal we use for the degradation and developed different liquid membranes for the emulsion droplet to extend EZVI's capabilities and treat PCBs in addition to DNAPLs," explains Dr. Clausen. According to Dr. Quinn, "We've been able to take our original technology into a completely different application use."

Leadership and vision were essential elements to the team's success with EZVI. Brooks, who initially joined the team as a graduate student in environmental chemistry, found particular inspiration from the guidance and examples of the team's senior researchers. Quinn also attributes EZVI's success to the team's collaborative and flexible approach to research. The research team had worked together on projects in the past and was "a very comfortable working group," explains Dr. Quinn. "We know each other's triggers and how to work with those sensitivities." This familiarity promoted rapport, trust, and experimental freedom that were essential to thinking beyond the usual methods of DNAPL clean-up (slow, inefficient pumps and costly thermal treatments) to create something entirely new. "We discussed many options and in the end weren't tied down to one idea," explains Quinn. "And once we came up with something that worked, we sat down again and asked ourselves, 'How can we expand this product to treat other contaminants as well?'"

While the group allowed themselves plenty of creative licenses, they were also realistic about financial parameters surrounding the project. "At the time, everything that was getting funded was nanotechnology," Quinn explains. "We knew we had a high probability of getting our project funded if it used nanotechnology, so we decided to use nanoscale materials." Dr. Geiger added that the nano iron particles were essential for moving EZVI deep through the soil to the highest concentrations of contamination. In order to do this without expensive trenching, they needed very small particles that could move through a series of wells.

There were also considerable regulatory hurdles surrounding the use of iron to clean up environmental pollutants because it was publicly perceived as harmful to the environment. "Every time you introduce a new technology that's going to be released into the environment, you face a challenge in getting the regulatory community to understand that what you're putting into the ground is going to be beneficial," says Dr. Quinn. "Iron is in the vitamins we take and does not pose a harm to the environment in the scale and scope we were proposing to use it in." The team came up with the idea to use food-grade products such as vegetable oil that would create a surfactant to hold the EZVI system together. "We went with materials that were specifically understood to not have an impact [on the environment]," Dr. Quinn explains. "We didn't even test surfactants that we knew could potentially be toxic, because we knew it wouldn't go anywhere."

The resultant EZVI overcomes the limitations of current DNAPL treatment technologies because it is able to directly treat the contaminant particles by mimicking and therefore exploiting DNAPL's chemical properties. The oil membrane acts as a wick that pulls the DNAPL contaminants out of the water (much as a paper towel pulls water into the towel when placed on top of a spill on your kitchen counter) while the nanoparticles break down the DNAPL into harmless compounds that can be consumed by microbes in the soil. "The EZVI droplets are like mini-reactors that are sent into the most concentrated contaminant areas," explains Dr. Geiger. The result is a quick, effective, and cost-competitive substance that produces less toxic and more easily degradable by-products than conventional methods.

The result of the team's flexibility and willingness to expand upon their initial hypothesis has produced a level of success that even they hadn't initially imagined. Quinn explains that more than 60,000 gallons of EZVI has been put into the ground at four industrial locations and at three locations within the Department of Defense. The technology has won the SE Federal Labs Consortium 2005 Excellence in Technology Transfer award, the national Federal Laboratory Consortium Excellence in Technology Transfer Award for 2006, the NASA 2005 Invention of the Year Award, and the 2005 NASA Commercial Invention of the Year Award. "It was just a great experience to work with a team who knew each other so well, who had such a level of respect for each other and each others' talents, and who weren't afraid to pursue new ideas," Quinn says. ●

Conversation with Kathleen Brooks

Kathleen Brooks joined the EZVI team while she was a graduate student and now works for NASA full time. She talked to Kerry Ellis about what she learned from the experienced team she joined.

WHAT DID YOU LEARN FROM WORKING ON THIS PROJECT?

Even if 90 percent of your experiments fail, you just keep trying until you get one that works in the lab. In order to create something that would be reliable and work in the field, we needed to reproduce the exact same results each time, which was difficult. In this type of work, it's important to remember that one experiment can give you results that are either false or too good to be true. You need to keep testing in order to get a product that works.

HOW DO YOU PERSIST WHEN 90 PERCENT OF YOUR EXPERIMENTS FAIL?

Sometimes proving that something *doesn't* work isn't as exciting as proving that it does, but you can learn a lot from experiments that don't work well. At the very least, you help other chemists know what *not* to do. You can't expect anything to work magically the first time. None of us expected this idea to work as well as it did!

WAS IT DIFFICULT JOINING A TEAM THAT HAD WORKED TOGETHER IN THE PAST AND HAD SUCH A CLOSE-KNIT RELATIONSHIP?

I had worked in environmental analytical chemistry for ten years, but working as a part of this team was a life-changing experience for me. I was accepted as part of the team from the beginning, and I got my job at NASA through my experience with the team. I am still part of the group today, doing research on PCBs. The work complemented my research background, so I immediately thought of ways to make the concept work. I felt comfortable and that I could just jump right in and get going.

HOW DID YOU GET INVOLVED ON THIS PROJECT?

I took an environmental chemistry class with Dr. Geiger and did a presentation on groundwork contamination. When she asked me to join the group as a researcher, I was hesitant at first. I'd focused on environmental research for so long that I felt ready to try something new. But after I spoke to Dr. Quinn and others on the team, I realized that we could really do this.

WHAT DID YOU MOST ENJOY ABOUT WORKING ON THIS TEAM?

Everyone had very specific things to offer that made it easy to work well together. Dr. Quinn is very analytical and good at the business side of things, Dr. Clausen is an amazing think tank, and Dr. Geiger keeps us all organized. These individual contributions matched well together. Vision is also important. Dr. Clausen and the team had drawn out the basic idea, and we were able to reproduce it under the microscope. That was exciting.

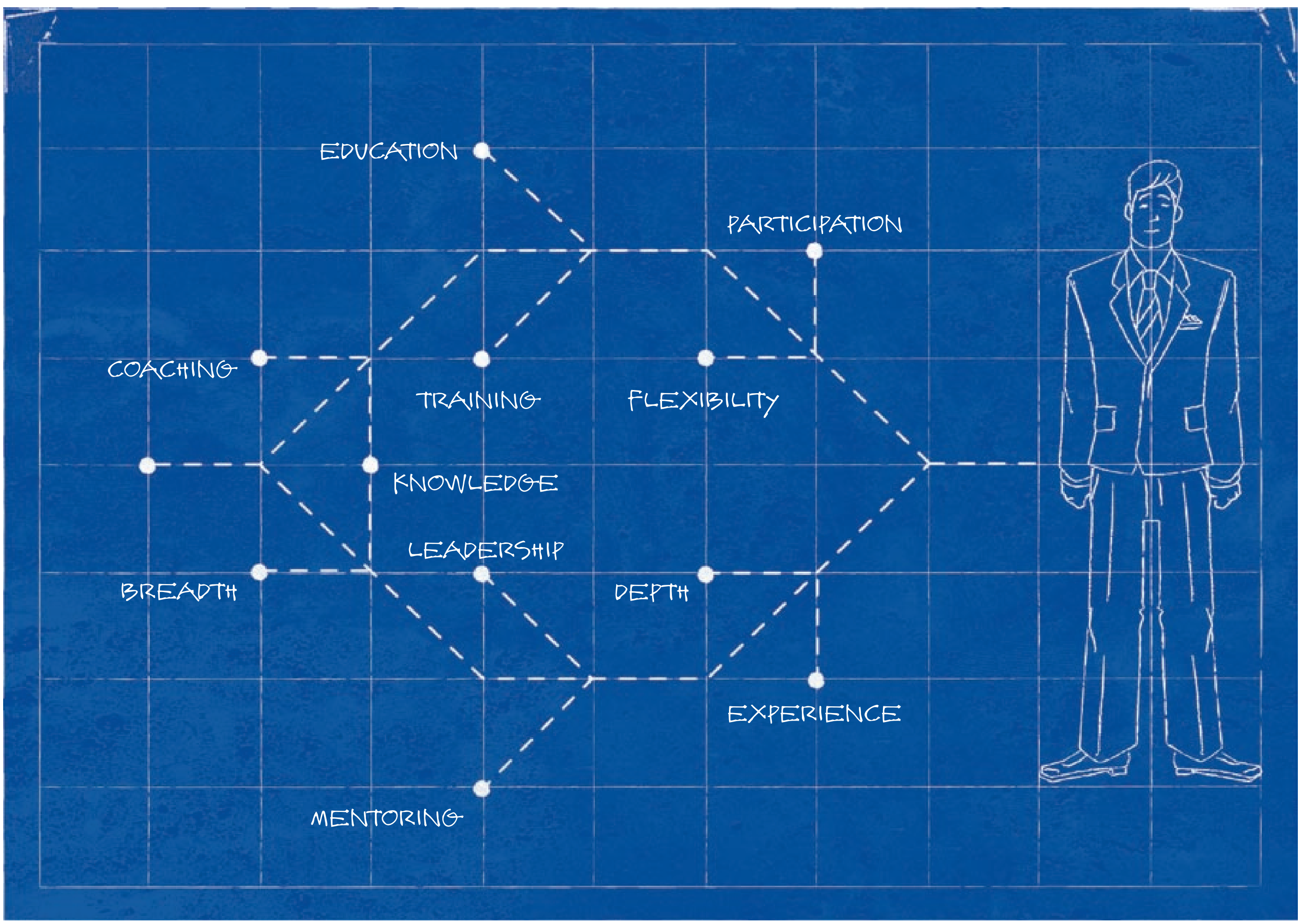
DO YOU AGREE WITH DR. QUINN'S ADVICE OF NOT LOCKING YOURSELF IN TO ONE IDEA?

Yes. It's a huge task to take something from a pure concept, make it work in the laboratory, and then get it into the field. For example, we had several different emulsions that worked. We preferred one version over the other options, but when we tested it in the field, our preferred choice was no longer feasible, so we were forced to go back to our previous research and continue testing.

How Do You Make Good Managers BETTER?

BY MICHAEL A. SPATOLA

In the middle of winter in 2005, Art Pyster, SAIC's director of systems engineering and integration, sponsored a companywide workshop to develop strategies for improving workforce management and collaboration. I was not expecting to do more than *participate* in the workshop, and I looked forward to the sessions, which would address both program management and systems engineering. Little did I know that as a result of this workshop bringing together by chance the director of systems engineering and the director of learning and leadership development, my job would change entirely.



SAIC, which provides scientific, engineering, and other technical services to the U.S. military, has a strong tradition and emphasis on project management. We also have a deep-seated culture of independence and an entrepreneurial spirit ("a thousand companies in one"). That tradition led to strong corporate support, training, and approaches dedicated to "Excellence in Program Management" and excellent but sometimes independent practices and initiatives within line organizations. When Ken Dahlberg took over as SAIC's chief executive officer, he was clear in his first direction for program management: "Get our program managers better training."

Easier said than done. We wanted this to be a collaborative effort across the company and raise our program management (PM) development to the next level. To define "better training," we created a small planning team—which I led as the overall program manager—and a PM Advisory Panel, comprising senior program managers from across the company. The team given this task believed the only way to substantially improve PM training was to go back to first principles to figure out what makes for program management excellence, and we took a leap of faith, hoping management would understand the value of that approach. The guiding principles we created for improving our PMs were as follows:

- Competence in program management is developed through education, training, and experience *with* mentoring and coaching. **You need all three.**
- Program management professionals can be developed and advanced along a flexibly defined career path. **There is more than one way to gain the education, training, and experience needed to be a successful program manager.**
- Program managers need to develop broader expertise through technical, functional, line, and other roles. **PMs need both breadth and depth.**

Once we established our guiding principles, we needed to create a competency model that clearly defined the knowledge, skills, and attributes our PMs needed to be successful. With that model, then, as our foundation, we could (and had to) design a curriculum and career path that helped program managers acquire that knowledge and those skills.

The first version of the SAIC PM Competency Model was ready for review by the end of May 2005; then it went through three months of review, comment, and update. In a company of more than 44,000 employees, we were faced with a "review, comment, and update" process across six organizational groups and twenty-four business units. We also held review sessions with our PM Advisory Panel, keeping in mind the members were from different locations and offering them different times to participate so the PMs on the West Coast could contribute. Sending out material a few days in advance, we used a Web-based DataExchange system, audio teleconference, and projection systems to help our discussions and ensure everyone was looking at the same information. To get the best participation possible, we would schedule several opportunities for them to join the discussion.

We also wanted feedback from our line managers, and we were smart enough to realize they already had many demands on their time. To ensure we got their feedback without taxing their workloads more, we sent our preliminary drafts to line managers' key staff, asked our PM Advisory Panel members to help notify line managers about the materials, and set up several discussion sessions for them. We also offered to meet with any business unit general manager who could not attend a discussion session.

One lesson we learned from the comments we received was that *how* the model was displayed was just as important as *what* the model displayed. Because of that, we reexamined the model from a communications point of view and adjusted it so we had several versions for different audiences. Looking back at our process, our keys to success were

- Recognizing that PMs need to have both leadership and management skills, which resonated across the company
- Considering SAIC's company values and needs, which established a model consistent with our culture
- Evaluating *appropriate* external sources, which added credibility to the final results
- Realizing that the skills a PM needs vary by project size and complexity, which allowed a fuller look at what we really need in a PM

- Identifying competencies by project type aided in developing a curriculum, which focused on the right training for each type of project

Using the PM Competency Model as the foundation, we created a "map" that showed what courses we had and which competencies they helped support. Historically, SAIC had emphasized internal program management courses that were both developed and taught by SAIC experts. But the "state of the practice" for program management as well as our own internal processes had grown and evolved to better meet the needs of practitioners and customers. Unfortunately, not all of our internal courses had kept pace.

To make sure our courses reflected "better training," and recognizing our limited internal resources to both develop and instruct courses, we kept in mind the following:

1. Training within the curriculum, consistent with the competency model, should be **tailored to project type.**
2. Training should include a mix of vendor-provided "state of the practice" training focused on **project management skills**.
3. Training should include complementary **company-specific training** focused on applying those project management skills within the SAIC environment.
4. Leadership training should form an essential part of the curriculum, just as leadership is an essential part of a project or program manager.
5. Training should include both **core** (required) and **recommended** courses.
6. Line organizations will supplement the PM curriculum with additional required courses based on customer, project, and organizational needs.

Because our stakeholders felt the working relations and review processes we used for the PM Competency Model were disciplined, fair to all, and complete, we used it again for developing our curriculum. Our first major review of the curriculum from the line organizations had more than 300 comments, which was a huge response. In addition to responding to this feedback, having representation from senior-level (seasoned) program managers from across the company was critical to our success. And we would not have succeeded without participation across the company throughout our efforts. That participation kept interests high, ensured real needs were identified and met, and aided buy-in to solutions to those needs—all of which were key.

Releasing the new PM curriculum represented a philosophical change in SAIC's approach to project and program management training: external vendors, more training, increased training costs, and more. And as the first classes were held, e-mails hit my inbox and the phone started ringing with an overwhelmingly positive response to what we had done. I could tell our long journey to success had really just begun, and that there is much more to come in the future. ●

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communicating SCIENCE

BY DR. RICHARD E. SHOPE III

The enterprise of scientific inquiry is an adventure of going where curiosity beckons. Scientists generate questions, propose explanations, carry out investigations, and communicate their findings. Communication within a scientific discipline has its own challenges, but cross-discipline communication is especially rich in difficulties and pitfalls.

Each scientific discipline has its own language, history, and methodologies, and tends to view the rest of the science world through its own set of experiences. A field biologist values the surrounding context of an ecological niche where a molecular biologist finds the heart of the matter in the laboratory tracing DNA sequences. When an astrobiology mission brings both those scientists together on the same team, they may find it very difficult to communicate to one another without a deliberate effort to understand and empathize with each other's perspective. A large and diverse space science team working on a major solar system exploration mission compounds the challenge. Several fields come together and must agree on a common set of goals, objectives, and strategies for data gathering. This requires the art of diplomacy, maneuvering through minefields of potential errors, biases, and disagreements based on the diversity of the science cultural views. Each investigator's drive for mission success generally motivates them to work toward common ground where their specializations can meet, but it can be rough going.

As a science research analyst working for the Office of Science Research and Analysis at the Jet Propulsion Laboratory (JPL), my job is to communicate effectively across the gulf separating scientific specialties. I report highlights of recent JPL space science research results to discipline program scientists and managers in decision-making positions at NASA Headquarters. Through this process of what I call space science "upreach," I provide one of many streams of information that help NASA's Science Mission Directorate remain aware of the leading-edge developments in solar system research occurring at JPL under their auspices. My communications must quickly frame the big picture, get to the point, highlight the significance, quietly mention a recommendation or two, and then exit as gracefully as a silent mime, having ignited a spark of interest that flashes through the NASA hallways.

What qualifies me for this job? Two things, really: my lifelong interest in science and my mastery of the art of mime.

I grew up in a family of renowned virologists. As a child, I sloshed through central New Jersey fields and woods with my grandfather (Richard E. Shope) and galumphed through barnyards with my father (R. E. Shope, Jr.) as they went virus hunting. For me, it was a grand time of swatting mosquitoes and filling my quota of laughter and wonder, enjoying the company of my actively curious namesakes. I would ride with my grandfather to his laboratory at the Rockefeller Institute in New York City and look out the window at the East River or marvel at his honorary degrees while he fiddled with his centrifuges. On different occasions I would visit my father's virology lab at the University of Minnesota Veterinary College in St. Paul as he checked the results of his viral cultures in Petri dishes and made the rounds to check on the experimental animals.

So I grew up speaking "science" as a first language. Early on, I learned that science is less about *knowing* than about *questioning*. Question everything, including authority and tradition, but most especially question one's own first impressions and pet ideas. No knowledge is to be considered absolute. Looking at a situation with new information or from a different point of view might change what is actually known. So the scientist must remain open to divergent possibilities and points of view. At interdisciplinary gatherings of science colleagues at JPL, I learn most from listening to the questions scientists ask each other. Often they are the same questions that form in my own mind—fundamental questions that aim at understanding how esoteric details relate to the big picture.

My earliest claim to fame is as a mime artist who studied with Marcel Marceau and other great mimes in Europe and Japan. That experience and expertise also contributes to my effectiveness as a science communicator. I mastered the art as a performer, but I also apply its underlying principles to the field of science education. Those principles are epitomized in the Greek concept of *mimesis*, the representation of reality in art. Participatory mime accompanied by narrative explanation—movement and words together—guides participants to construct vivid conceptual understandings of dynamic processes. What is normally an interior thinking process—analyzing and then synthesizing or constructing a map or model of a dynamic system—occurs out in the open as a mime improvisational event.

For groups of visitors at JPL, I often create a participatory mime of the Mars Exploration Rovers, treating each component as a live character. I invite volunteers in the audience—most often a mix of parents, teachers, and children of all ages—to act out the science story. Using my mime skills and informed by reliable data, I guide them through gestures and explanations toward an understanding of the science concepts. One group acts out the robotic arm, working in synchrony to deploy its science instruments. Each instrument—the Rock Abrasion Tool, the Microscopic Imager, the Alpha Particle X-ray Spectrometer, the

Mössbauer Spectrometer—is played as a separate heroic character. Each "character" creates mime moves that aim to communicate how the instrument works, what it measures, and how it relates to the underlying science concepts. The result is that all those present have a shared experience of *mimesis* in action: either as direct participants (by acting it out) or as participant observers (by actively watching). This *mimediate inquiry* event—that is, this tangible representation of reality (*mimesis*) mediated (as externalized constructions of thought) by meaningful mime and narration—can be referred to, talked about, replicated, and modified by an infusion of new information.

The thinking processes of the artist and the scientist are analogous—both apply their skill and knowledge to complex data to construct a representation of reality that can be tested and validated. For the mime artist, the test is whether the mime performance communicates meaningfully and increases understanding for an audience. For the space scientist, the test is whether the dynamic model continues to correspond to the real-world phenomena it seeks to explain. And scientists, too, often employ a kind of *mimesis* to make their ideas visible—or tangible—to their colleagues, using a combination of written, spoken, and visual presentations at their gatherings. As Glenn Orton describes the spinning bands of atmosphere near the poles of Saturn, there is a hint of a dancer's pirouette in his body language. Kevin Baines speaks so kaleidoscopically fast that in the space of two or three minutes, your mind has visualized quick updates of the deep storms of Saturn and high-flying ammonia clouds in Jupiter's upper atmosphere. This is where the discourse of science gets highly animated, as differing interpretations of results are argued about and worked through toward eventual consensus about the viability of a proposed explanation. This is also where it becomes apparent that science communication is a complex process even among scientists. Speaking across disciplines is an act of intercultural communication. And this is where my own mix of expert studies of science, intercultural communication, and mime come into play.

I GREW UP SPEAKING "SCIENCE" AS A FIRST LANGUAGE. EARLY ON, I LEARNED THAT SCIENCE IS LESS ABOUT *KNOWING* THAN ABOUT *QUESTIONING*.

For example, from 1989 to 1994, Magellan's science instruments beamed radar waves through the thick layers of sulfur dioxide clouds to map nearly every nook and cranny on the surface of Venus. In 2002, as Dr. Sue Smrekar and her team at JPL pored over the Magellan data, they noticed patterns formed by surface features that resembled polygon-shaped formations on Earth. But these Venusian polygons were on a vastly larger scale. She and her team developed a computer algorithm that could scour the surface of Venus for candidate areas where giant polygons exist. As the computer scouted out the terrain, Dr. Smrekar had to shape the data into mental pictures that would help her recognize key patterns. It was as if she and her science team were physically there, on Venus, climbing atop the basalt plateaus, looking closely at the forms to unlock their mysteries and unravel millions of years of Venusian history.

Enter the science research analyst/mime artist. Through the use of *mimediate inquiry* processes I climb into the science story to gain my own understanding. In this case, I incorporate the dynamical model proposed by Smrekar to inform participatory mime performances, figuratively climbing atop the basalt plateaus and re-experiencing the formation of the Venusian polygons. If my *mimediate* picture is accurate, which I check by conversing further with the scientist, then I am confident that I have the understanding I need to create the space science highlight. In this roundabout way, my mime expertise supports my work in the highly specialized world of space science upreach as I communicate significant results to science decision makers.

One of the deepest human yearnings is to feel that one's work is significant. A space scientist's involvement in a massive enterprise like the space program can arouse a feeling of existential *in*significance. The scale of the extragalactic abyss inspires trembling and trepidation. In a different way, so does realizing that you have stepped into an uncharted region of specialized knowledge and your professional reputation hangs on the improbable success of a chunk of aluminum carrying a highly sophisticated science instrument hurtling through interplanetary space for several breath-suspended years to capture miniscule and esoteric measurements, which will be beamed back through space to Earth, streaming into your laptop to be interpreted by your own agile mind. Then you turn that thrill of discovery into a paper that goes through months of peer review in order to be published for the specialist science community, which views the paper as one tiny brush mark on a lavish canvas. And you face the nagging question, have I glimpsed reality or have I been fooled by its shadow? The verdict may dangle unresolved for years in the ensuing discussion among colleagues. Such is the ongoing angst of the space scientist. My work, communicating the import of scientists' results to decision makers and scientists outside their discipline, is one critical piece of this shared enterprise of space exploration and inquiry. ●

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Seven Key Principles of Program and Project Success

BY VINCENT J. BILARDO, JR.

To support the Next Generation Launch Technology Program and the Constellation Systems Program, twenty seasoned program managers and systems engineers from the aerospace industry, academia, and government joined together to create the NASA Organization Design Team (ODT). The team conducted a series of workshops, surveys, interviews, and studies to discover and describe the essential elements of successful programs. As a result of this work, we believe that the following seven key principles are critical to program and project success.

The X-38 Vehicle 131R drops away from its launch pylon on the wing of NASA's NB-52B as it begins its eighth free flight December 13, 2001.

Photo Credit: Carla Thomas, NASA

Principle 1: Establish a Clear and Compelling Vision

Creating a clearly defined vision of the future that inspires and motivates the workforce is an important first step on the path to project success. An effective vision statement should be vivid, concise, motivating, and memorable. Early in NASA's history, President John F. Kennedy provided a clear goal to "land a man on the moon and return him safely to Earth." NASA created the Mercury, Gemini, and Apollo programs to achieve that vision. The Apollo program required billions of dollars, millions of hours, and thousands of men and women, yet that simple goal drove the entire effort. For almost a decade, President Kennedy's words pushed the space program forward.

A lack of vision can be disastrous. In its 2003 report, the Columbia Accident Investigation Board (CAIB) noted the lack of a national mandate for NASA over the past three decades. According to the report, this absence contributed to NASA's failure to receive budgetary support, which resulted in an Agency struggling to do "too much with too little."[1] Without a compelling goal, successive Administrations and Congresses were unwilling to commit the billions of dollars required to develop the next generation of space transportation.

Principle 2: Secure Sustained Support from the Top

Maintaining top-level support for large programs requires developing and sustaining "program protectors" inside and outside an organization. Managers should also establish effective working relationships with key stakeholders. A home division CEO protected Lockheed Martin's stealth fighter prototype by setting up special financing to maintain the secrecy of the special project for which Lockheed's "Skunk Works" became famous.[2] This allowed the project to be autonomous and prevented other interests at the company from interfering with the work in progress.

A lack of "protectors" has caused many programs to fail or be cancelled. The X-38 project could not survive changes to project requirements because it lacked a top-level protector.[3] The Advanced Launch System and National Launch System programs also suffered from poor support. These programs began during President Reagan's Space Defense Initiative (SDI). When President Bill Clinton took office, he de-emphasized the SDI and eliminated the heavy lift requirement that had founded the initiative. The program was later cancelled despite five years of intense effort by major aerospace companies.[4]

Principle 3: Exercise Strong Leadership and Management

Strong leadership requires managers to identify and develop other leaders and technical staff, define clear lines of authority, demand accountability, implement sound project management practices, and demonstrate uncompromising ethical standards. As Dr. Wernher von Braun—a key leader of the Apollo program—often emphasized, you should hire people smarter than you and give them the responsibility and resources needed to accomplish the task.[5] This allows managers to focus on the program as a whole, a crucial perspective for leadership to maintain.

John Muratore, X-38 project manager, emphasized that strong project leaders should also resist the rush to flight until all technical and safety issues have been resolved.[6] The X-38 management team delayed their flight test program to allow for more aerodynamic analysis. They would not proceed to the next flight test until they had completed the analysis and run it by an independent review team. As a result of Muratore's "test before you fly" approach, the project had two perfect flights.

This uncompromising integrity for project performance also requires ethical behavior from managers. Team members will not follow a leader they know is capable of unethical behavior and decision making. Lack of integrity fosters cynicism among the team and can compromise the mission.

Photo Credit: U.S. Navy

A Virginia *class attack submarine surfaces.*

Principle 4: Facilitate Wide-Open Communication

Fostering open communication has always been a cornerstone of good project management, but it can be—and has been—stifled by leaders who do not want to hear bad news. As a result, the bearers of bad news learn to stop communicating problems upward. Not listening is bad; criticizing anyone who brings to light unpleasant, but necessary, information is worse. Few individuals will dare come forward with critical information if they know they are likely to suffer public criticism.

Dr. William Starbuck of New York University identified several other reasons why organizations suppress communication and have trouble learning from both success and failure.[7] Organizations tend to overlearn and repeat behaviors that result in success, which can cause inflexibility when new problems require different approaches. But organizations also have trouble learning from failure, often writing off failures as idiosyncratic and overlooking possible systemic causes. This tendency, known as the "normalization of deviance," was evident in the Space Shuttle *Challenger* accident.[8] According to the CAIB report, faulty communication also contributed to the loss of Space Shuttle *Columbia*.

Principle 5: Develop a Strong Organization

Dr. Starbuck emphasized that organizations can remain effective over long periods if three interdependent pillars—culture, rewards, and structure—are carefully designed and aligned.[9] The National Polar-orbiting Operational Environmental Satellite System was an outstanding example of careful organization design and culture management.[10] The program intentionally sought to create a new culture by collocating personnel from the program's three contributing agencies: Department of Defense, National Oceanic and Atmospheric Administration, and NASA. They carefully negotiated respective roles and responsibilities before staffing and initiating program office operations. In this way, they carefully removed as many potential organizational conflicts and barriers as possible before executing the program.

The *Virginia* Class Submarine program, according to deputy program manager George Drakeley, is a good example of a strong organizational architecture that aligned well with the product being produced. This program structured itself around the Integrated Product and Process Development acquisition methodology, which the Department of Defense developed in the 1990s to streamline major weapons systems acquisition. The payoffs of this approach included a shortened overall design schedule, a reduced number of change orders because they encountered fewer problems during construction, reduced cost in vehicle production, and an operational weapon system that effectively balanced capability and flexibility with cost.

Principle 6: Manage Risk

NASA has always taken risk into account when pursuing a mission. In the early days of Apollo, management required quantitative estimates for these risks. However, during the later Apollo era and the shuttle era, NASA relied primarily on qualitative—or "gut check"—measures to estimate and control mission success and safety risk.[11] As a result, NASA began to address other risks qualitatively, including cost and schedule. The Agency used bottom-up, judgmentally based approaches, which

ORGANIZATIONS TEND TO OVERLEARN AND REPEAT BEHAVIORS THAT RESULT IN SUCCESS, WHICH CAN CAUSE INFLEXIBILITY WHEN NEW PROBLEMS REQUIRE DIFFERENT APPROACHES.

were not tied directly to technical risks that were often the causes of mission loss. Using quantitative models of potential accident scenarios as well as developed operational data and physical models of relevant phenomena is necessary for managing safety and mission risk on a continual basis.[12]

Professor Elisabeth Paté-Cornell indicated that one of the most valuable lessons learned from her work on the Space Shuttle and elsewhere was the importance of continuously collecting operational data and embedding it into a risk-based structure. Doing this provides an ongoing or "living" measure of the residual risk in continuing operations. The Concorde's crash on July 25, 2000, provides an example of how this data might have been used to forestall failure. During 75,000 hours of previous Concorde operation, fifty-seven tires had burst and debris had come close to penetrating the fuel tank several times. Using a "living accident precursor" system had proven valuable in hospital anesthesia, the Ford/Firestone Explorer tire failure, and the Boeing 737's leading edge.

Principle 7: Implement Effective Systems Engineering and Integration

The final key principle comprises several subprinciples:

- Develop clear, stable objectives and requirements from the outset.
- Establish clear and clean system interfaces.
- Maintain effective configuration control.

- Use modern information technology and analytical tools to model and simulate system performance, including organizational performance, well in advance of hardware development.

The very nature of developmental programs implies the outcome is, at least to some degree, uncertain. Shifts in objectives result in increased requirements. These shifts and resulting requirement changes lead to program delays, cost increases, and even program failure or cancellation. In successful programs, systems engineering and integration (SE&I) establishes a clear and stable set of objectives at the outset and develops a minimal set of requirements to achieve those objectives. Several programs limited top-level program requirements to one page. The F-117A program[13] had only five requirements. Muratore advised against writing documents just to fill in the squares and recommended carefully controlling and tracking interfaces.[14]

In addition to clean product and system interfaces, many presentations given in the ODT's workshops emphasized the importance of establishing clear and clean *organizational* interfaces. Specifically, they stressed designing an organization's structure to mirror the architecture of the system being developed.

Once the program objectives, requirements, and interfaces are solidified, they must then be controlled by establishing an early program baseline around them. The SE&I effort must keep the design team on track and be continually vigilant against "requirements creep." Shifting requirements ultimately led to the demise of the National Aerospace Plane program, which started in 1984 as a single stage–to-orbit technology demonstrator but ended in 1993 as a collection of various hypersonic technology development activities.[15]

Monitoring requirements and risk with modern information technology and analytical tools can help reduce what was once a very labor-intensive process. The *Virginia* Class Submarine program used a single electronic database to integrate all aspects of design, planning, and construction. The team used the database to link design with production and business operations, providing a fully integrated data set throughout the program's life cycle.[16] This database also enhanced the effectiveness of early developmental hardware/software-in-the-loop testing.


Photo Credit: U.S. Air Force

An F-117A Nighthawk in flight.

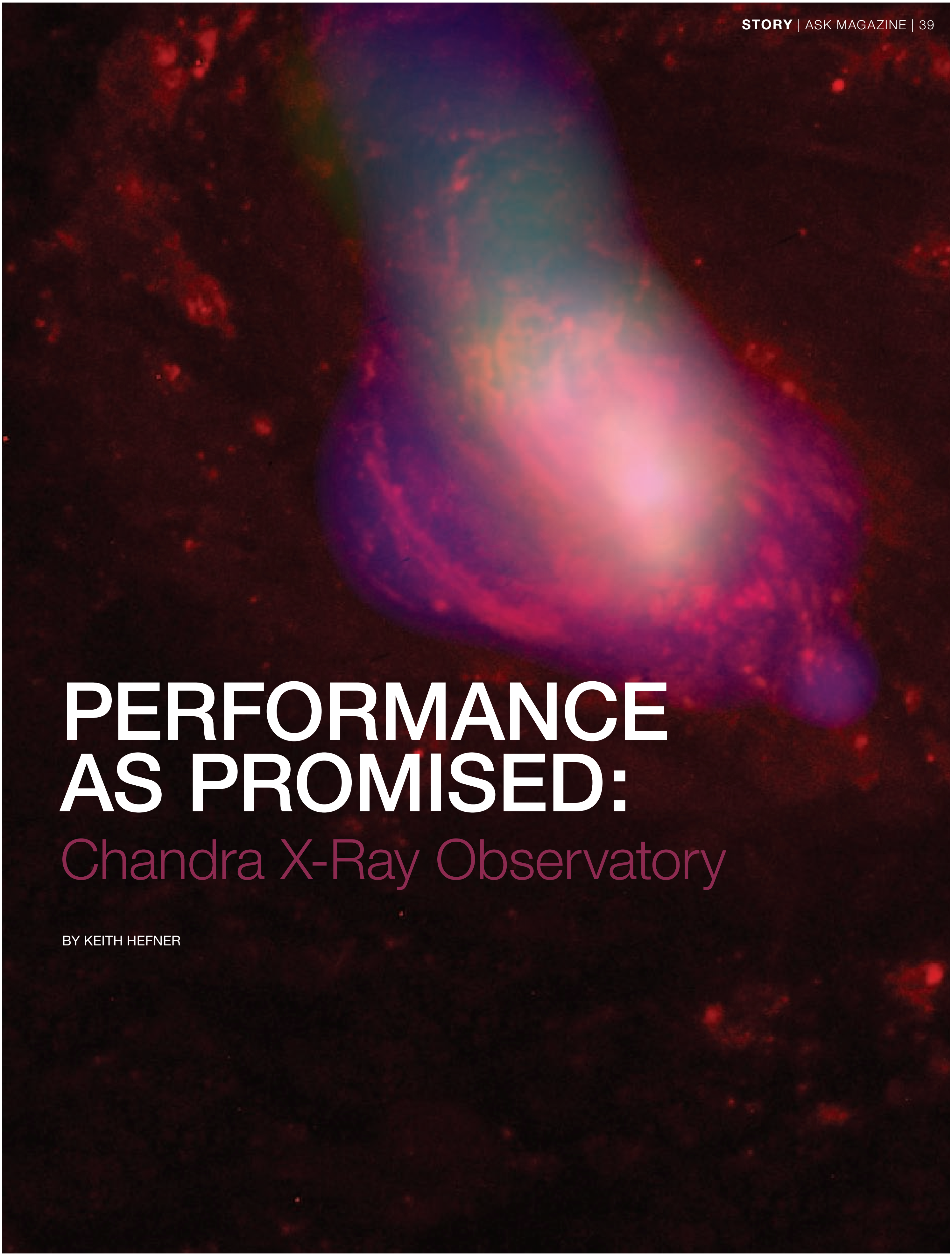
Creating Your Own Success

While there is no set formula to guarantee program and project success, the ODT's efforts have defined a firm foundation on which leaders can build. Learned from the unfailing teachers of experience and error, these principles are a starting point on the road to success. But more important than discovering what aids success and what cripples it is capturing those discoveries, sharing them with other leaders, and ensuring they are understood by everyone on the project team. The ODT's robust efforts have done just that, and the results will benefit more than the next generation of space exploration for which it was formed. ●

The above article is a summary of a much larger study. A link to the full report can be found on our "ASK Interactive" page in this issue.

VINCENT J. BILARDO, JR., currently manages the Ares I-1 Upper Stage Simulator project at Glenn Research Center and founded the Organization Design Team in 2003 while serving as a program/project manager at Langley Research Center. He has twenty-four years of broad federal government experience.

1. Richard H. Buenneke, "On Not Confusing Ourselves: Insights on Organization, Policy, and Culture from the *Columbia* Accident Investigation," presented at ODT Workshop III: Organization Design and Best Practices, Williamsburg, VA, December 2003.
2. Sherman Mullin, "Lockheed Skunk Works Program Management with Focus on the F-117 Stealth Fighter Program," presented at ODT Workshop VI: Building a Historical Program Database, NASA Johnson Space Center, May 2004.
3. John Muratore, "X-38 Program System Engineering Lessons," presented at ODT Workshop VI: Building a Historical Program Database, NASA Johnson Space Center, May 2004.
4. Darrell Branscome, "Advanced Launch System," presented at ODT Workshop III: Organization Design and Best Practices, Williamsburg, VA, December 2003.
5. Dave Christensen, "Space Program Lessons Learned/Best Practices," presented at ODT Workshop III: Organization Design and Best Practices, Williamsburg, VA, December 2003.
6. See note 3 above.
7. William Starbuck, "Keeping Organizations Effective Over the Long Run," presented at ODT Workshop I: Tools and Methods for Organization Design and Analysis, NASA Langley Research Center, August 2003.
8. Diane Vaughn, *Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA* (University of Chicago Press: 1996).
9. See note 7 above.
10. Stanley Schneider, "National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office," presented at ODT Workshop III: Organization Design and Best Practices, Williamsburg, VA, December 2003.
11. K.P. Sperber, "Apollo Experience Report—Reliability and Quality Assurance," NASA TN-D-7438, September 1973.
12. Elisabeth Paté-Cornell, "On Signals, Response, and Risk Mitigation: A Probabilistic Approach to Precursors Detection and Analysis," presented at ODT Workshop I: Tools and Methods for Organization Design and Analysis, NASA Langley Research Center, August 2003.
13. See note 2 above.
14. See note 3 above.
15. Ming Tang, "National Aerospace Plane Organization and Management," presented at ODT Workshop III: Organization Design and Best Practices, Williamsburg, VA, December 2003.
16. George Drakeley, "*Virginia* (SSN 774) Class Submarine Program," presented at ODT Workshop VI: Building a Historical Program Database, NASA Johnson Space Center, May 2004.

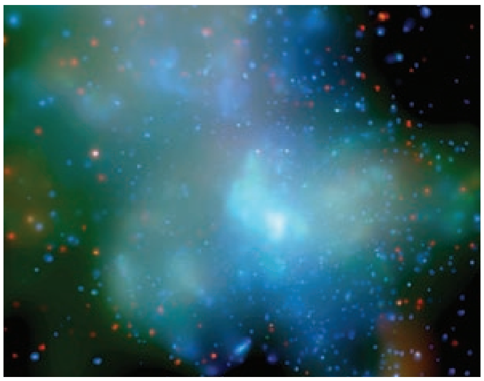


PERFORMANCE AS PROMISED:

Chandra X-Ray Observatory

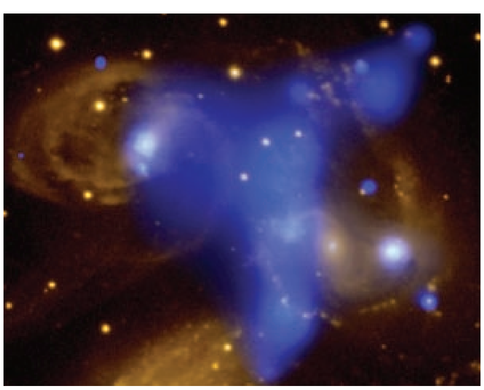
BY KEITH HEFNER

Photo Credit: NASA/CXC/MIT/UCSB/P. Ogle et al. (X-ray); NASA/STScI/A. Capetti et al. (optical)



This image was produced by combining a dozen NASA Chandra X-ray Observatory observations made of a 130 light-year region in the center of the Milky Way.

An artist's illustration of the Chandra spacecraft in orbit.



The hurly-burly interactions in the compact group of galaxies known as Stephan's Quintet are shown in this composition of a Chandra X-ray Observatory image, in blue, superimposed on a Digitized Sky Survey optical image, in yellow.

The Chandra X-ray Observatory inherited a legacy of good lessons from the Hubble Space Telescope, and nearly the entire team as well. Since we'd all worked together for years on Hubble, Chandra began with a great team environment and incredible communication, so we were prepared to handle upcoming challenges.

NASA Headquarters decided to restructure Chandra in January 1992 despite the highly successful mirror technology demonstration in September 1991 that won us Congressional approval to begin the observatory's full design and development. NASA senior management had determined that Congress would not fund the originally planned Chandra program, and they challenged the entire team to develop dramatically less expensive options to conduct the mission. While such exercises are unfortunately all too common, identifying significant savings (and later realizing those savings) is much rarer. We accomplished it in less than four months.

Restructuring the program was not easy. Headquarters was pushing for deep budget cuts, the science community was vociferously resisting, and Marshall Space Flight Center was working hard to recover a viable and sustainable program. A broad team came together to achieve what seemed impossible: Marshall's Observatory Projects Office, in-house Marshall staff at the X-Ray Calibration Facility, Marshall's Project Science Office, a science team from the Smithsonian Astrophysical Observatory (including Chandra Science Center, which operates the observatory), and four principal investigator teams. Northrop Grumman Space Technology led the industry team and worked with Marshall to build teamwork—not by holding team-building off-sites, but by fairly and rigorously analyzing the technology and our new goals. By considering a wide range of alternatives and making decisions based on data and analysis, what could have been a contentious decision evolved to consensus and served to bring the entire team together.

We evaluated cost, schedule, performance, and risks for each new option. Balancing science utility and cost led us to select a highly elliptical orbit with uncrewed robotic delivery, deployment, and maintenance. The proposed 100,000 km apogee orbit would provide much greater science observing time, since Earth would block the telescope's line of sight for a much smaller fraction of each orbit, but two alternate technologies were necessary to reach this flight path. We used composite materials extensively to reduce observatory mass from more than 32,000 lbs to 10,110 lbs. We had to eliminate other features entirely: four of twelve mirrors were removed from the plans along with two focal plane instruments—one was primarily a low-risk backup; the other did not require mirrors of Chandra's quality and was assigned to fly on another spacecraft. We also changed Chandra from being a low-Earth orbit telescope like Hubble to a higher-orbit observatory to allow us the same amount of observation time with lower operations and servicing costs, which meant eliminating shuttle servicing from our plans. Because we knew we wouldn't be able to reach the observatory again, its design had to be extremely robust.

The team achieved some significant performance improvements through the restructuring as well, including better photon collection due to iridium mirror coating, higher-efficiency detectors, and better-than-expected mirror coating reflectivity. Mirror smoothness provided focus three times sharper than our requirements. Chandra achieved significantly more observing time than we anticipated because restructuring lowered our anticipated time in slewing, safe modes, scheduling inefficiency, etc. and enabled the observatory to spend less time in radiation belts by raising its orbit from 100,000 km to 140,000 km. Chandra provided substantially more performance than promised for the budget.

The restructuring saved American taxpayers $3.6 billion, but it also left the program with a very lean budget. NASA was entering an era of "faster, better, cheaper," and while Chandra was still a large program, it was given very limited flexibility. Our team was able to execute the lean program because of a program management approach that allowed us to focus on mitigating key risks and a culture that emphasized high-value investments or savings, which influenced individual, organizational, and team behavior to focus efforts on what was best for the program.

Proactive Risk Management

Chandra demonstrated the value of reducing technology risk. The team proactively conceived and created a prototype pathfinder for the spacecraft that ended up preventing a two- to three-month delay. We had allocated reserve funds to produce a model of a key portion of the Structural Test Article (STA)—a model of the spacecraft structure. Creating the pathfinder uncovered a problem with the resin, which only partially cured at room temperature during the forty-six-day lay-up. If we had not created the pathfinder, this problem would have emerged while developing the equipment compartment for the STA and caused the delay. These lost months would have led to a late start in the mechanical integration of our flight spacecraft, and ultimately may have threatened the overall program schedule.

Lessons learned from the central cylinder pathfinder were folded into the STA's development. We shared knowledge not only with regard to materials and designs, but also with respect to assembly and testing processes. Later, the team used the STA's static loads test to develop ways to reduce the flight structure's static test by four months. We also simplified the approach for applying loads to minimize time-consuming configuration changes. These measures reduced required testing from more than thirty weeks to seven weeks.

Our team also encouraged efforts to push back against some risk-reduction expenditures. Examples include working closely with Johnson Space Center to get a test exemption for the elements that bore Chandra's 500-lb. mirrors. We also developed a gravity off-load approach for the High Resolution Mirror Assembly (HRMA), which allowed it to be checked during a series of other tests already occurring at the X-Ray Calibration Facility instead of being shipped later to ITT in Rochester, NY, for separate tests that would have extended its build time.

High-Performance Culture

Cynics assume project team members will play "project manager's poker" and exploit problems elsewhere in the program. Some take it as given that industry can be counted on to take advantage of government changes, and there will be waste and inefficiency because project organizations can't work as a team and would rather "throw problems over the transom." If these behaviors had occurred among the Chandra team, the program might have slipped many years and suffered high overruns.

At a monthly meeting with the telescope subcontractor ITT, an engineer announced his team had discovered a problem in meeting a Level 3 specification for the obscuration caused by the HRMA's thermal baffling. ITT had developed an effective fix

IF CULTURE IS A KEY DRIVER OF OUTSTANDING PROGRAM PERFORMANCE, THEN THE CRITICAL QUESTION IS HOW TO CULTIVATE A HIGH-PERFORMANCE CULTURE.

for $282,000 to meet the science requirements with no schedule impact, and the team was ready to move forward with the plan. A science center representative, who had the engineering insight to understand the validity of the violation and the proposed fix, was in the audience. He also had the science insight to understand the violation was trivial and was willing to stand up in a room of fifty people and say, “That is the stupidest thing I’ve ever heard.” He instead recommended taking no action and saving the money. The team listened to him, quickly verified the facts, and eliminated any further efforts on the issue. This is a significant contrast with other programs where no scientist would yield on a requirement affecting performance, no matter how trivial. It also demonstrates a culture that welcomed broad technical and scientific participation and encouraged dissenting opinions.

If culture is a key driver of outstanding program performance, then the critical question is how to cultivate a high-performance culture. On Chandra, the ingredients included an experienced science team that was fully integrated into the project—their culture of skeptical inquiry with a focus on mission utility was a core part of the overall program culture. Including our operations and ground contractors early in our design and development also served us well. They were all intimately involved in the requirements and design reviews and worked with us hand in hand to ensure flight and hardware systems were compatible. A lot of our operations success today is built upon these early steps we took during development. A prime contractor led the industry team and was responsible for aligning corporate incentives and behavior with program goals. The NASA Project Office selected team members and assigned roles based on the best value to the program and led by example in managing the team in a collaborative and constructive fashion. And, after the restructuring, NASA Headquarters and Congress were able to provide stable funding and top-level requirements, which enabled us to focus on project execution.

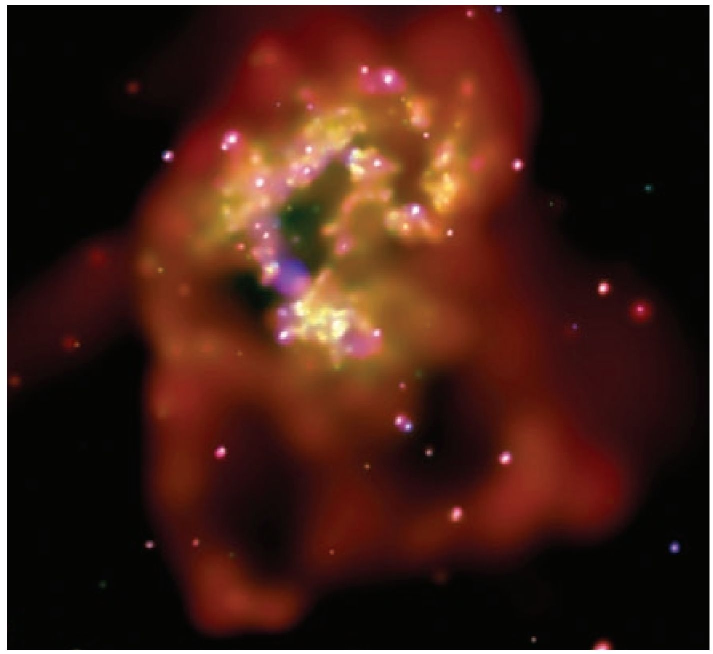


Photo Credit: NASA/CXC/SAO/G. Fabbiano et al.

This montage of NASA Chandra X-ray Observatory images shows a pair of interacting galaxies known as the Antennae. Rich deposits of neon, magnesium, and silicon were discovered in the interstellar gas of this system.

Still Performing

As the nation looks toward bold new ventures in space, the Chandra X-ray Observatory offers an example of how billion-dollar missions can successfully develop with tightening fiscal constraints. Chandra experienced many of the challenges facing space programs—state-of-the-art technical requirements and budget-induced slips and restructurings—and still achieved the originally envisioned performance for dramatically lower cost. This was accomplished through teamwork, systems engineering, advanced technology, and effective approaches for program implementation as well as a high-performance culture that aligned goals and focused on mission success. As Chandra now surpasses its original five-year mission, the observatory continues to provide superb scientific performance. ●

KEITH HEFNER joined Marshall Space Flight Center in 1985 and was assigned to the Observatory Projects Office in 1986, where he specialized in project and resource management with the Chandra and Hubble Space Telescope programs before becoming Chandra’s program manager in 2002. He has received the NASA Exceptional Service Medal, recognizing significant, sustained performance characterized by unusual initiative or creativity, and the Silver Snoopy Award for contributions to the Space Shuttle program.

Everything I Needed to Know About Project Management I Learned in a Cockpit

BY RAY W. STRATTON

In a national survey, nearly 2,000 project managers reported that only 47 percent of their projects met their goals and only one-third said their projects are often completed on time and on budget. If pilots flew aircraft like we run projects, no one would ever fly. Yet every day millions of people fly for work or pleasure and flights arrive on time almost 80 percent of the time, delayed mainly by weather. Airline travel is also the safest form of long-distance travel with a fatal accident rate of .022 per 100,000 hours flown. (If you flew every day of your life, you have less than a 1 percent chance of being in a fatal accident.) We have been flying for just over 100 years, but project management has been around since the building of the pyramids and the Great Wall. As both a pilot and former project manager, I believe some hard-won lessons from thousands of pilots can be applied to project management as well.

Lesson #1: Before spending an hour or more planning a flight, smart pilots make a rough estimate of the trip's distance, fuel requirements, the aircraft's range, and passenger and baggage load to determine its feasibility. If a pilot jumps into detail planning first, he or she can become emotionally committed to a flight that might not be easily completed. **Project Managers:** Do a project feasibility study. Once you begin detail planning, you might be emotionally committed to try to do the impossible.

Lesson #2: Good pilots ask their passengers (their stakeholders) what they want most: the shortest flight, the smoothest flight, or the most scenic flight. It is almost impossible to do all three in the same trip. **Project Managers:** You must know the stakeholders' key expectation. Only one expectation—cost, schedule, or performance (quality)—can be key.

Lesson #3: Pilots know that operating an aircraft beyond its designed gross weight is unwise. You may be able to fill all the seats, fill the tanks, and fill the cargo area, but the plane might be too heavy to leave the ground. Trade-offs are usually needed. **Project Managers:** Manage your constraints consistent with the key expectation. Adjust the other expectations and keep the key constraint fixed.

Lesson #4: Pilots learn that there are many ways to get from A to B. The safest route may not be the most direct route. They evaluate multiple routes for wind, turbulence, safety factors, aircraft capability, and passenger interests and select the best one. Picking the best route requires compromise. **Project Managers:** During planning, evaluate different sequences of project activities and select the best. Consider the stakeholders' expectation and likelihood of success. The first activity sequence is not likely the best.

Lesson #5: Detailed flight planning might prove a flight is impossible, and pilots know the results of a flight feasibility estimate might be wrong. They should prepare their passengers to hear, "The flight can't be done safely, and we are not leaving." Passengers do not have the knowledge to make go/no-go decisions. (The next time your airline cancels your flight, remember it's better to be on the ground wishing you were in the air than in the air wishing you were on the ground.) **Project Managers:** If you can't get a project plan to work out, it won't work itself out later. Let your scheduling and resource tools tell you what you can and can't do. Prepare your stakeholders to hear, "No, it can't be done." They are counting on you to make decisions in their best interest.

Lesson #6: Takeoff is one of the most critical phases of flight. Good pilots monitor all gauges and the aircraft performance early and frequently during takeoff. If the acceleration or anything else is not normal, the takeoff is aborted. The source of the problem is determined and fixed, or the flight is canceled. **Project Managers:** Frequently monitor the beginning phase of your project. Once a week is not too often. Check staffing levels, communication, cooperation, progress, and productivity. If your project does not start off well, stop, fix the problem, and start over. You are unlikely to recover from a bad start.

Photo Credit: U.S. Air Force

Lesson #7: Throughout the flight, pilots check their progress over the ground against their flight plan. Is their path over the ground correct? Is the flight at its checkpoint on time? How long have they been flying and how much fuel has been used? Pilots continuously evaluate the fuel and time required to complete the flight. **Project Managers:** Know your real accomplishments to date. Just knowing the funds and time spent is of little value. Use earned value management to know if the work completed is appropriate for the expenditures. Update your planned completion date and budget if needed.

Lesson #8: Flight planning uses weather forecasts, which are just assumptions from weather forecasters. Assumptions can be wrong, and they create risk. During a long flight, pilots obtain updates to the forecast and current weather conditions. If the current conditions are not as they were originally forecast, it's likely other assumptions about the weather are wrong, too. **Project Managers:** Continue to review the assumptions that were made during planning. If these assumptions prove to be wrong, update the assumptions based upon the current project environment.

Lesson #9: Regardless of weather forecasts, the weather outside the cockpit window is fact. It is what it is and must be dealt with regardless of what was forecast. There is no value in telling the forecasters they were wrong. **Project Managers:** What you see is what you get. Past assumptions and promises about resources, vendor delivery dates, and subsystem performance are history; deal with the present situation.

Lesson #10: Pilots have had accidents when they got distracted during key phases of a flight. In one case the cockpit crew was so focused on a burnt-out lamp that the plane descended into the ground. Airlines have a "sterile cockpit rule" during critical phases of flight: no casual discussions among the crew. Flying the plane is always job number one. "Aviate, Navigate, Communicate" is the pilot's rule to keep things in priority order. **Project Managers:** Running your project is always job number one. If, for example, annual workplace safety training is scheduled during a key project problem-solving meeting, the project meeting gets priority. Getting work done is always most important.

Lesson #11: Planes with two pilots on board have had accidents when each thought the other was doing the flying. In one case, a tandem seat plane descended slowly into the ocean after circling a sailboat. Each pilot thought the other was flying. Pilots are now taught to confirm who is doing the flying. Typically one pilot states, "You have the plane," and the second pilot responds, "I have the plane." **Project Managers:** When you delegate project responsibilities and tasks, release control and confirm new ownership.

Lesson #12: In 1982 Air Florida 90 crashed into the Potomac River and killed seventy-eight people. During takeoff, the first officer said, "That's not right." The pilot replied, "Yes, it is." The first officer cautioned the pilot again, but the pilot ignored his comment and proceeded with the takeoff. Once airborne, the first officer exclaimed, "We're going down," and the pilot said, "I know it." It wasn't until this last dialogue that the pilot took the first officer seriously. Today cockpit crews use a tool called

IF PILOTS FLEW AIRCRAFT LIKE WE RUN PROJECTS, NO ONE WOULD EVER FLY.

Cockpit Resource Management (CRM) to ensure everyone is comfortable with the decisions and actions being taken. The pilot in command listens to alternative opinions and ideas before taking any critical action. Other crewmembers are charged to mention anything that concerns them. **Project Managers:** Charge everyone on your project team with keeping the *whole* project out of trouble. Respect and respond to all concerns.

Lesson #13: Excellent pilots think ten to thirty minutes—or more—ahead of the aircraft's position. Today's training teaches pilots to know what should happen next, how to know when it does, what to do when it happens, and what should happen after that. A pilot who is just keeping up with the aircraft's position is acting more like a passenger than a pilot. **Project Managers:** Know what is supposed to happen next on your project, how you will know it occurred, what you should do when it does, and what should happen after that. While it's important to know what was done last week, it's also important to think at least two to four weeks ahead.

Lesson #14: Good pilots always have an alternate plan and ask themselves, "Where could I land within ten minutes of takeoff, along the route, right now, or if the destination airport has poor weather?" Pilots constantly monitor a flight's progress. If trends show the flight might not be meeting its planned progress, or destination weather is becoming questionable, pilots begin thinking about executing their Plan B. **Project Managers:** Start to re-plan the project before the re-plan is needed. Always be operating to a plan.

Lesson #15: Pilots are required to follow the instructions issued to them by air traffic control, yet U.S. air regulations also state, "The pilot in command of an aircraft is…the final authority as to the operation of the aircraft" and "may deviate from any rule to the extent required to meet (any) emergency." If a pilot needs to climb or dive to avoid an approaching aircraft she can, no questions asked, and just report what she did. **Project Managers:** Assume all the authority you need to be successful. Surveys of senior management have shown their frustration that project managers do not assume more authority. If necessary, do what you need to do and be prepared to explain later.

Lesson #16: The airport at Catalina Island, California, has drop offs on three sides and a hump in the middle because it was built by leveling two mountaintops. While landing, the pilot of a small jet mistook the hump for the end of the runway and accelerated to abort the landing. Once he saw the remaining runway, he applied the breaks to complete the landing. He then realized there wasn't enough room to stop, so he again applied power to abort the landing. There wasn't enough room to accelerate to flying speed, and he crashed off the end of the runway. His first decision to abort the landing was correct in light of his doubts and would have resulted in becoming airborne for a second, more knowledgeable, landing attempt. **Project Managers:** When you make a decision, make it timely and stick with it, unless overwhelming evidence proves it to be wrong. Flip-flopping on decisions wastes resources, frustrates the team, and usually results in poor outcomes.

Lesson #17: Today's aircraft can literally fly themselves thanks to sophisticated autopilot systems, but there have been accidents when these systems did not perform as expected. The pilot typically sees the problem but is out of the loop because he or she let the autopilot control the plane up to that point in time. **Project Managers:** To paraphrase a recent NASA recommendation to pilots, "The more [project management] automation there is…the more the [project manager] should work to remain an active and integral part of the [project]." Project management software cannot run a project.

This wealth of piloting experience is a result of the NTSB investigating each accident and changing habits or systems as a result of these investigations. Unfortunately, there is no "NTSB" for projects, but both pilots and project managers address risk, communication, uncertainty, and a host of common challenges. If you run your project like pilots fly airplanes, you might find it ends as successfully as virtually every airline flight. ●

Note: A version of this article originally ran in Projects@Work *(www.projectsatwork.com). A one-page list of these lessons may be found at www.mgmt-technologies.com/pm_pilots.html.*

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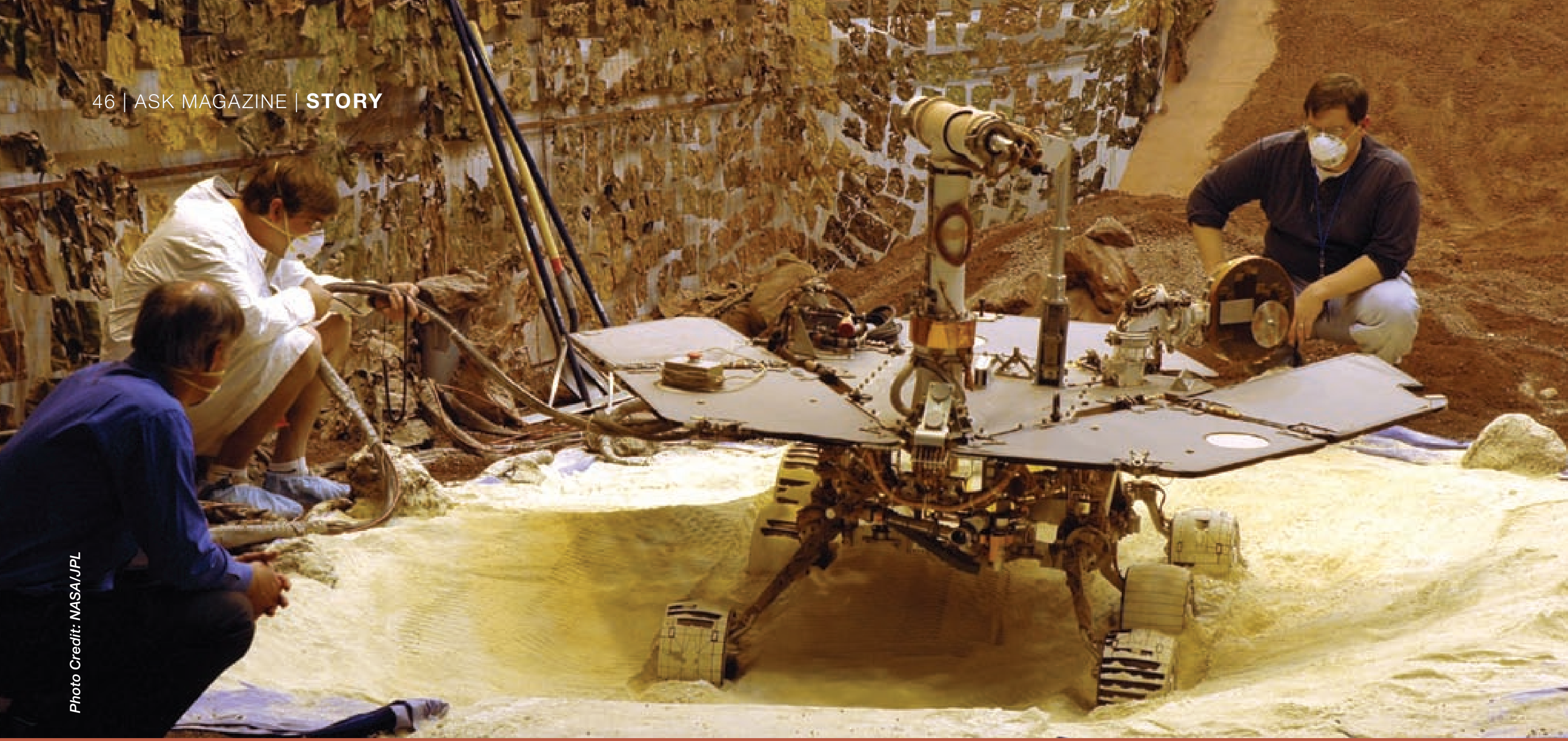

Photo Credit: NASA/JPL

LEARNING TO DRIVE

Learning to drive a Mars rover is no easy task. It's not a process you can just read up on and do right the first time. For one thing, there is the time lag to contend with. It takes ten minutes or more for a radio signal to travel between Earth and Mars, so you get no rapid feedback to show the result of a command or allow for quick corrections of mistakes. The surface of Mars, rock-strewn and with many different types of soil, poses constant challenges. And you have to become intimately acquainted with the peculiarities and limitations of each rover. Spirit (MER A) has been challenged with mountainous territory and now has power constraint issues that have to be taken into account. Opportunity (MER B) has been used to explore a relatively flat, crater-strewn area; it has developed different problems over time that affect what you can ask it to do.

Left: *Rover engineers check how a test rover moves in material chosen to simulate some difficult Mars driving conditions.*

Right: *Men and women of the Mars Exploration Rover mission admire some of Spirit's first images in 3-D.*

Photo Credit: NASA

BY BRIAN COOPER

THE MARS ROVERS

On-the-Job Training

As one of the original group of ten drivers (or "rover planners," as we are called), I came to the task with eighteen years of experience driving planetary rover prototypes and had been a rover driver for the Mars Pathfinder Sojourner rover. I had also led the team that created the software tool called RSVP (Rover Sequencing and Visualization Program) that rover planners use to create the command sequences for the rovers each day, so I knew how the system was supposed to work. Even so, my fellow planners and I had to do a lot of on-the-job training. Getting Opportunity out of the first crater was a challenge. It got stuck in soft soil material, and we had to learn to drive it up the sloping crater wall at an angle and figure out how to seek out more coherent soil. Later the rover's wheels got buried in a sand dune, which we named "Purgatory" in recognition of the long, slow process of extracting it.

Over time, we developed new techniques and sequences to deal with the conditions we found on Mars. We do "slipchecks" to verify that the rover is not stuck—sequences that have the rovers use their onboard visual systems to track features in images and tell if the rover is slipping on soil. Since the rover's flight system assumes perfect traction when they look at the progress of the six wheels, we compensate for slippage in the Martian soil by programming a slightly longer distance than we actually want the rover to travel.

Because of the complexity of the task and the potential damage of a serious mistake, planners always work in pairs. Rover Planner One gets requests from the science team and writes command sequences to carry them out. Rover Planner Two checks the sequences, negotiating changes when necessary, until he or she is confident that the program will work and is willing to take ownership of it. Only then are the sequences sent to a rover.

Selecting and Training New Planners

To develop new teams of planners, we first try to identify promising candidates, using several important basic criteria. Early in the mission we wanted people who could live on Mars time, who have both the commitment and the family support needed to make that possible. Since the Martian day is about forty minutes longer than a day on Earth and most rover operations are only possible when the rovers' solar panels are generating power, planners need to work during the Martian day. In the first three months of rover operation, this meant shifts at all hours of the day and night, seven days a week. Now that we have gotten more from the rovers than we ever expected and the cost per day of exploration has decreased, planners operate in a more Earth-normal mode and take most weekends off. But a planner's eight-hour shift can still start anywhere from 6:00 a.m. to noon.

Good hand–eye coordination is essential, and the ability to visualize and work in a three-dimensional space is important.

During the interviewing process, we sometimes ask people what video games they like to play. A flight simulator fan is a more likely candidate than someone who prefers solitaire. We also favor people who have already worked in some capacity on the Mars Exploration Rover mission and are likely to have some familiarity with the subsystems. Many of the candidates recommended to us are from Jet Propulsion Laboratory's mobility and robotic systems section, where they have gotten relevant experience. Finally, and not surprisingly, we look for people who have the enthusiasm needed to devote the time, energy, and attention that learning and applying rover-driving skills require.

Those chosen for training usually start by spending several months as downlink analyzers. Interpreting the information sent by the rovers helps them learn the subsystems. The job also teaches them how to analyze the "health" of the rovers and familiarizes them with the kind of scientific data their future work as planners will help acquire. At the same time, they begin practicing with the RSVP tool—the software used to command Spirit and Opportunity—which lets them visualize what the rovers do in response to instructions. This virtual training includes using 3-D goggles that allow them to see a stereoscopic image on the Martian landscape that the rovers traverse. Although a few veteran planners who do not have stereoscopic vision have found ways to compensate, the depth perception that 3-D provides makes it much easier to evaluate this unfamiliar terrain—for instance, judging the height and depth of rocks to determine whether they are small enough to roll over or will impede a rover's progress.

DURING THE INTERVIEWING PROCESS, WE SOMETIMES ASK PEOPLE WHAT VIDEO GAMES THEY LIKE TO PLAY. A FLIGHT SIMULATOR FAN IS A MORE LIKELY CANDIDATE THAN SOMEONE WHO PREFERS SOLITAIRE.

Some of the trainees continue to do part-time downlink work when they move on to the next learning phase: five to eight months spent "shadowing" the rover Planner Two role. They work with different teams on different shifts, so their mentors change from day to day and they get the benefit of observing the techniques of a variety of planners. They watch the planners at work; they study documented processes and read the rover planner Web site and wiki to keep abreast of the latest thinking on guiding the rovers. Over time, through this combination of observation and reading, they learn the "flight rules" for rover operations. Their planner mentors give them small tasks and then gradually ask them to do more and more until they're essentially performing the rover Planner Two role under supervision. The veteran teams that work with the trainees meet to share impressions of their progress and decide when an individual is ready to fly solo and become a planner. In fact, the process is akin to learning to fly an airplane, doing more and more under the supervision of an expert until you become expert enough to handle the controls without supervision.

Photo Credit: NASA/JPL

It required more than five weeks of planning, testing, and carefully monitored driving to free Opportunity from the soft, sandy material of a wind-shaped ripple, later dubbed "Purgatory Dune," on Mars.

After gaining experience as rover Planner Two, the candidates begin shadowing rover Planner One. They go from being a checker and explainer of rover sequences to being the sequence creator. This transition can last several months, after which, if they pass the scrutiny of the veteran driving team, they graduate as full-fledged rover planners.

The process is a kind of apprenticeship, where observation, study, and supervised practice combine to pass on knowledge and skills that book learning or theoretical discussion alone could never teach. We think this is the only effective way to teach the complex and subtle skills a rover driver needs. As of fall 2006, we have had seventeen rover planners responsible for moving Spirit and Opportunity over the Martian surface. So far, the two rovers have safely and successfully carried out their mission, functioning for more than 950 sols (Martian days) and traveling a combined distance of almost 16 km. ●

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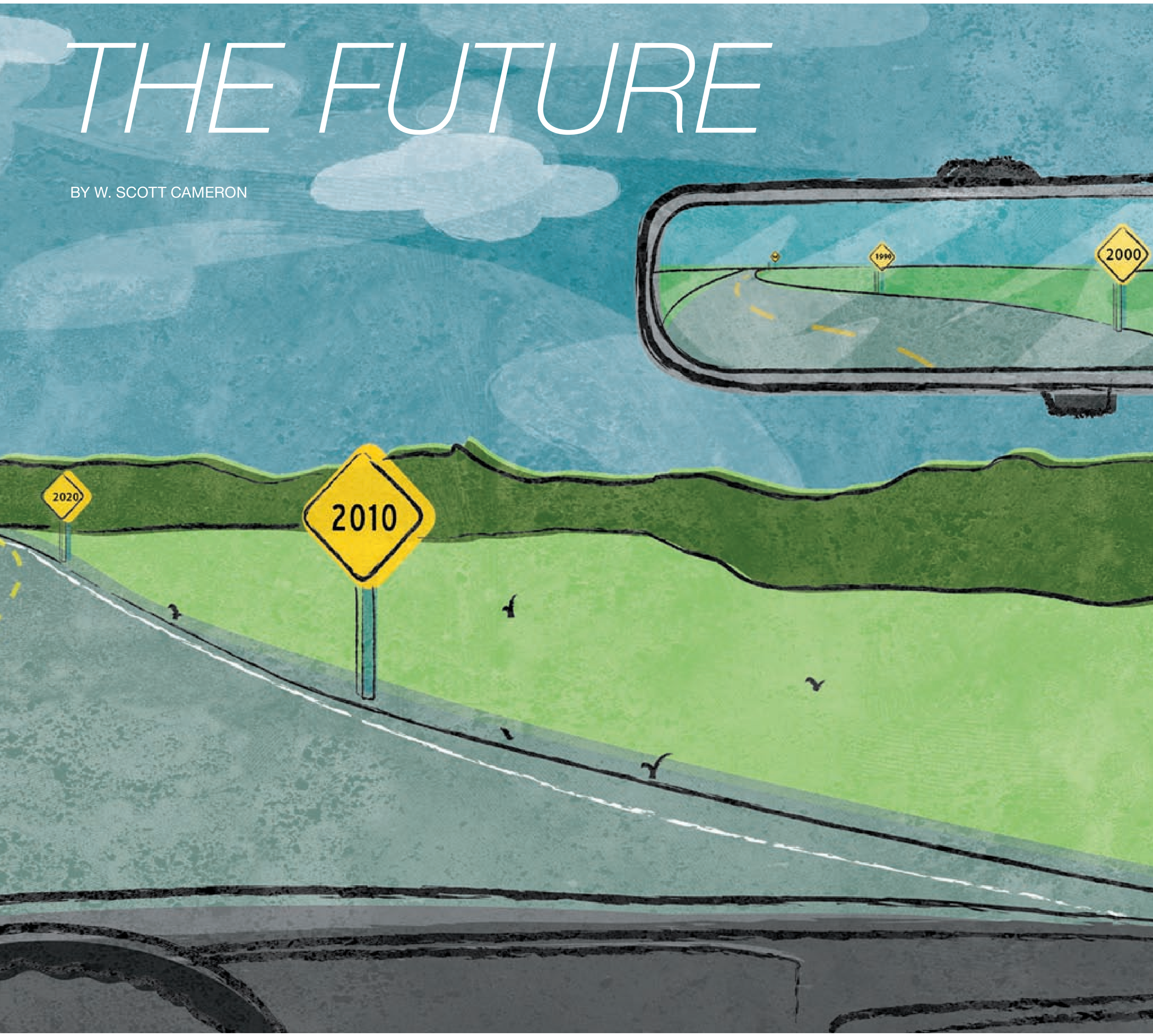
IMAGINING THE FUTURE

BY W. SCOTT CAMERON



In 2004, I was part of a team developing the agenda and session topics for a Procter & Gamble engineering community of practice meeting. This major, two-day, biannual event brings all project managers and related disciplines (construction, cost engineering, capital finance, capital purchasing, and scheduling and planning) in the company together to share experiences and lessons learned.

During the initial agenda-setting meetings, I suggested we address the future, specifically what project management capabilities and skills would be required in 2010. My suggestion was added to a list of potential topics and eventually made the cut. Then our group had to assign speakers. After much discussion, I was chosen to present the topic I'd proposed. Be careful what you ask for!

I tried to wrap my mind around the topic, but I found defining the future to be a daunting task. I didn't know where to start. To make matters worse, initial enrollment figures indicated this presentation was becoming the most requested topic of the conference. In fact, so many people enrolled that I was asked to give the presentation twice to accommodate the requests.

I talked to others about their views of the future to get ideas on what I should cover in my talk. These discussions gave me more things to think about when I needed to focus my ideas, because time was running out to complete my talk. But the responses I'd received helped me realize the basic truth that most people spend little time thinking about the future of their work. Everyone knew where they were today and what they were working on; most were somewhat foggy about what they did yesterday; and only a few took the time to think about where they would be in five years, what they wanted to be working on, and the skills they would need to continue to be successful.

I decided that the underlying theme of my talk would be "Change is a given, not an option." I would try to analyze a ten-year span of the past (1999), the present (2004), and the future (2010) from three different perspectives: corporate, project management, and individual.

It was easy to research past and present corporate strategies, because they were described in the company's annual reports. When a strategy didn't achieve the desired results, it was modified to react to the dynamic marketplace and meet the established company goals.

Past and present project management strategies were also documented and available for review. Driven by organizational strategies, they consistently delivered desired outcomes and were flexible enough to support changing corporate strategies. I found the following to be true of project management:

- The basic characteristics of successful project management had not changed appreciably in the past five years nor were they expected to change significantly in the foreseeable

future. The basic success criteria for a project manager has been—and continues to be—delivering the project on schedule for the stated cost and making sure it meets the defined technical, business, and quality requirements.
- The key to project managers' success is how they apply the tools at their disposal. Right tool + Right application = Successful project. The development of IT tools (cell phones, portable computers, voice mail, BlackBerry, 3D CAD, etc.) and software programs during the past five years has been staggering, with no sign of technology slowing down in years to come.

My final task was to review what the past, present, and future looked like for each individual striving to achieve success in an ever-changing environment. During the August 2004 NASA APPL Masters Forum, author Tom Davenport presented a talk on "The Knowledge Worker Attention Deficit." His presentation reminded me that, along with meeting organizational goals, most change motivators focus on an individual's basic question of "Why change if there is nothing in it for me?"

During my presentation, I reminded the audience that the elements driving and shaping change included organizational need and individual need. Sometimes they were or seemed to be in opposition, but lasting, successful change depended on those needs complementing each other—and on individuals as well as organizations thinking about change and the future. I asked audience members what was driving change in their lives. I had them reflect on the difference between where they had been five years ago and where they were today. I asked them, "What is your assignment, and what does your personal life look like? What tools did you use to be successful over this time period? What do you think you need to be successful over the next five years at work and at home?" I then asked them if they thought they were leading change or chasing it in their organizations and at home.

The presentation was well received. But it was the reflection, discussions, and research during its planning and preparation that taught me an important lesson: If the people leading change five years ago had not had a vision of the future, we would not be where we are today; strategies formulated in the past are often the basis for today's successes. But if I hadn't made this presentation, I would not have taken time to look at where the organization and I were, the progress we had both made, or how exciting the future could be.

Organizations often document projections for the future, but individuals seldom take the time to think about where they have been and where they are going. One of the requirements of my annual performance review is to develop an action/training plan for the upcoming year. In the past, I have not made this

IF THE PEOPLE LEADING CHANGE FIVE YEARS AGO HAD NOT HAD A VISION OF THE FUTURE, WE WOULD NOT BE WHERE WE ARE TODAY; STRATEGIES FORMULATED IN THE PAST ARE OFTEN THE BASIS FOR TODAY'S SUCCESSES.

a high priority. Based on my experiences with my presentation, this activity will become more robust for me.

The question "Are you leading or chasing change?" was my closing slide. I am only now beginning to understand the importance of this point myself. I realized it is essential to look back on the vision and leadership of those who preceded me, to assess the impact they've had on the successes of today, and to use that perspective to plan for the future.

In answering this last question myself, I am investigating ways I can continue to lead change to successfully influence people and organizations in the future. In five years, I want them to look back at what I am doing now and recognize the forces and foresight that drove the successes they will achieve in 2010. Aside from working toward leading change in my professional life, I am assessing ways to lead change on the home front as my wife and I raise our triplet teenage daughters. Try as I might, my future assessment is I will be chasing change in my home life, not leading it for the foreseeable future! ●

W. SCOTT CAMERON has held various positions at The Procter & Gamble Company since 1970 and is currently the global process owner of project management in corporate engineering. He has a BS in civil engineering and an MS in sanitary engineering from Iowa State University.

Knowledge in Brief

Learning from Projects

Project work often generates new knowledge—both technical knowledge and knowledge about how to carry out projects successfully. Members of a project team carry what the experience teaches them to subsequent assignments, but they seldom share what they learn in a systematic way with one another or with others in the organization. When a project ends, participants typically move on to the next task without taking time to evaluate or document their learning from the work just completed. Some organizations have developed interesting processes for eliciting and sharing project knowledge. Here are three examples.

The After Action Review

The U.S. Army developed the after action review (or AAR) to improve learning from experience. At the end of every "action"—a project, a training exercise, a military engagement, or even a single meeting—participants meet to answer three questions: What did we expect to happen? What actually happened? What did we learn? The ground rules for discussion keep the focus on learning rather than assigning blame. The main aim of the process is to help the participants learn from their shared experience, and the army's AAR process includes mechanisms for documenting and aggregating generally applicable lessons in a shared database. Some corporations have instituted their own AARs, with mixed success. It is most effective when it is a firmly established feature of every project or action, not an optional activity carried out when and if people find time for it.

"Harvesting" Project Knowledge at Intel

Recognizing that essential knowledge was often not shared across projects at the company, knowledge managers at Intel have assigned "knowledge consultants" to key projects to help identify valuable knowledge and make it available to others in the company. Spending thirty hours or more on each project, the consultants meet with project members to define their knowledge needs, document important learning at various project stages (which they describe as "harvesting" knowledge), and facilitate knowledge-sharing conversations between people who have knowledge and people who need it. Their involvement with a range of projects gives them information about knowledge needs and resources that those focused on specific projects seldom have, so they can serve as knowledge "brokers," connecting knowledge seekers and providers. The Intel knowledge consultants are also gathering harvested knowledge in a publication they call "Knowledge Nuggets."

Projects as Mentoring Opportunities

Most projects provide opportunities for informal mentoring. Experienced team members often take newcomers under their wing, offering advice and constructive criticism. This kind of on-the-job training and support powerfully teaches the kind of hands-on knowledge that book learning cannot provide.

Some organizations more deliberately combine mentoring and project work. One of them is MWH, which carries out water distribution, wastewater treatment, hydroelectric power, and other water projects. Project planners naturally assign people who have the skill and experience needed to do the work successfully to project teams, but they also intentionally put less experienced people on the teams and match them with team members who can mentor them and help them develop those essential skills. These mentoring relationships, developed through shared work, transfer knowledge from veterans to a younger generation of employees. At NASA, Goddard's SEED program does something similar, training systems engineers by giving them a range of project experience under the supervision of mentors. ●

ASK Bookshelf

Here are descriptions of two books, very different from one another, that we believe will interest ASK *readers.*

Nothing Like It in the World: The Men Who Built the Transcontinental Railroad 1863–1869, by Stephen E. Ambrose (New York: Simon & Schuster, 2000)

Long before Apollo 11 flew to the moon, ambitious engineering projects tested the technical and managerial skills of the organizations that undertook them. Stephen Ambrose tells the story of one of them: the building of the transcontinental railroad nearly 150 years ago. His book describes how the massive project was tackled at a time when nearly everything was done by muscle power. He captures the difficulty of laying nearly two thousand miles of track across land that includes great stretches of desert, three mountain ranges, and vast areas without trees for ties or bridges.

He describes in detail the interactions between engineers and their bosses at the two companies competing to build as much of the railroad as possible. The Central Pacific and the Union Pacific companies had to contend with different problems and circumstances. Central Pacific built the railroad from Sacramento over the Sierra Nevada to the east. The mountains presented particular problems to the engineers and workers; they had to find solutions for tunneling through rock, dealing with deep mountain snow, and choosing the most efficient route. The Union Pacific's starting point was Omaha, Nebraska. Building west from there, they were challenged by barren lands, hostile American Indians, and the extreme weather changes of the Great Plains. The logistics of providing building materials, water, and food caused problems for both companies, as did obtaining enough laborers. Building in unsettled lands required the use of local resources to keep the construction going at a quick rate. Sometimes quality was sacrificed for speed, as when Union Pacific decided to use less durable cotton wood trees to make ties.

Ambrose gives readers a vivid peek into a day in the life of a railroad worker. He describes the backbreaking work and details the rations workers ate and how long they were allowed to rest. The railroad companies pushed their workers hard to win the race. They even built great bonfires out of brush so the work could continue at night. These descriptions reveal the incredible achievement—and human cost—of building the transcontinental railroad.

Building the transcontinental railroad involved challenges and uncertainties that characterize any large-scale project. Managers had to keep their laborers content and the company owners satisfied with the rate of progress. Like NASA project managers, they had to deal creatively with unforeseen problems, while remaining in good communication with superiors and subordinates.

Challenger Park, by Stephen Harrigan (New York: Knopf, 2006)

This book takes up some familiar novelistic themes: a rocky marriage, adultery, forgiveness, and the stresses of caring for children when both parents have demanding jobs. In *Challenger Park*, though, the parents are astronauts. The novel deals mainly with Lucy Kincheloe's training at Johnson Space Center and her troubled shuttle mission, as well as with her troubled personal life.

The marital drama is reasonably well crafted, but *Challenger Park* is no *Anna Karenina*. What makes the book worth reading is Harrigan's evocation of the experience of space flight. Basing his descriptions on interviews and accounts given by real astronauts, he creates a vivid sense of what weightlessness feels like, of the subtle smell of space that clings to a space suit after extravehicular activity, and of the crew members' exhilaration and tension. For readers who work in the space program but will never leave the earth themselves, the novel offers a vicarious ride on the shuttle and visit to the International Space Station. ●

The Knowledge Notebook

The Other Frontiers of Space

BY LAURENCE PRUSAK

While we at NASA are very aware of research and activities related to every aspect of outer space, there are other kinds of space that have been gaining the attention of organizational researchers and practitioners. These include social space and cognitive space, which are increasingly seen as important factors in how successfully organizations can pursue the ever more important goals of collaboration and innovation.

What do we mean by "social space"? I have an old friend who has done quite well for himself and lives on Central Park West, near 95th Street in New York City. His immediate neighborhood, across from Central Park and full of stately apartment buildings, looks and is quite prosperous. But just a few yards further north on the same street, the population shifts dramatically. Residents here are working class people; the buildings they live in are functional but far from prosperous-looking. Despite the close proximity of their dwellings, the social distance between my friend and his neighbors is huge in terms of income, education, employment, and almost every other social category. They occupy different social spaces. Although they live literally a minute's walk from one another, contact between them is minimal.

This is not just a phenomenon of New York City life or city life in general. Similar social distance exists in many if not most organizations. Some commentators point to the positive relationship between physical proximity and collaboration, and they are right to suggest that—all else being equal—a workspace that encourages meetings between people can make sharing expertise easier. But, as my New York City example suggests, physical collocation is no guarantee of mutual understanding, shared goals, cooperation, or even much contact. Rigid hierarchies, which are still the norm for many organizations, create vast social distances between employees. Knowledge sharing across these distances is rare and, when it does occur, rather ineffectual. It is true that sometimes organizations create physical barriers that reflect and increase the distance between "classes" at work—mahogany rows where access to leaders is guarded by zealous executive assistants. But removing those barriers without significantly reducing the social distance will not improve communication. What you know and whom you speak to depends on where you are socially as well as physically. Among other things, this is why many executives only have a vague idea of what goes on in their organizations.

Social distance is one of many sources of differences in cognitive space—the ideas, assumptions, values, and perspectives through which one understands and acts in the world. People who inhabit very different cognitive spaces will naturally find it difficult to understand and work with one another. So this subject has also attracted the interests of researchers who want to increase collaboration and reduce "knowledge friction" in organizations. Sometimes this research takes a cultural turn, looking at cultural institutions and values to understand how and why cross-cultural teams and projects succeed or fail. At the Babson College Working Knowledge Research Program, we have looked at how cultural differences influence some cross-cultural collaborations. People in different parts of organizations—engineering, marketing, manufacturing, and others—tend to live in different cognitive spaces even when their general cultural backgrounds are similar.

Successful collaboration depends on bridging those cognitive gaps. For example, the Honda Corporation used to develop new car models in a linear fashion, with the research and development group handing off prototype models to operations, which in turn passed them on to marketing. Each group tried their best to modify the prototype according to their own perspective on what is feasible and what will sell. Not surprisingly, Honda found this method inefficient and ineffective. They began to insist that the groups work together to produce one prototype they all agreed on. They called this way of working "Knowledge Fusion." It has proved to be a successful way of bridging knowledge and cognitive spaces in a productive way.

Intraorganizational collaboration is a life or death issue in our knowledge age. Not using the full knowledge of the organization when and where it is needed is a major handicap. Lessening social and cognitive distance increases the likelihood of influence, familiarity, trust, and empathy. It is difficult to help a person in their knowledge search if one "lives" far from him or her in terms of social space.

Getting out of your own social and mental space and genuinely interacting with others not in your social group is a good way to start. (The fact that this rarely happens in many organizations is one reason for the increasing social and cognitive distances we see everywhere.) Another road may be to ensure projects and teams are staffed with people from differing social and organizational groups. Most people get to know and like others with whom they work on a continual basis, and this, too, can help overcome social barriers.

We don't expect these walls to fall with a mighty crash any time soon, any more than we think that New York's social divisions will dissolve. But the issue has been neglected for too long, and the hope that merely calling for collaboration or designing a more open and accessible office plan will overcome the problem is bound to be dashed. Social and cognitive space matter. ●

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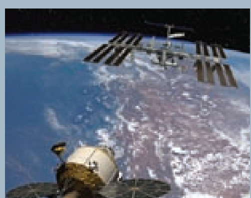
ASK interactive



ASK Magazine Special Issue on Constellation

Lessons from the past are guiding NASA's next step into the future as the space agency prepares to replace the Space Shuttle with an Apollo-style vehicle for human explorers. *ASK Magazine* plans to release a special issue in 2007 about NASA's new Constellation program to capture these lessons and new ones that are discovered as hundreds of people pave the way for the next generation of space exploration. From stories about crew exploration vehicle Orion's design and build to the challenges of organizing cross-center efforts, you can help *ASK* provide the stories you need and want by letting our editors know what you think and by sharing your own stories. To submit stories or ask questions, contact Managing Editor Don Cohen at doncohen@rcn.com or Technical Editor Kerry Ellis at kerry.ellis@asrcms.com.

Read more about the Agency-wide effort to return us to the moon and journey on to Mars online: http://www.nasa.gov/mission_pages/constellation/main/index.html.

Reminder: PM Challenge 2007

Don't forget to register for NASA's PM Challenge 2007, the Agency's fourth annual project management conference. It will be held February 6 and 7, 2007, in Galveston, Texas, near the Johnson Space Center. The conference will feature twelve tracks, including Spotlight on Systems Engineering, Mission Success Stories, Risky Business, Knowledge Works, and much more! Registration opens November 1. For more information, and to register, visit http://pmchallenge.gsfc.nasa.gov.

Web of Knowledge

NASA has created a knowledge network to promote learning and sharing among NASA's engineers. Through NASA Lessons Learned, an Agency-wide search, an expertise locator, and discipline-specific communities of practice portals, the NASA Engineering Network connects engineers to NASA's vast engineering resources to help them solve problems and design solutions more effectively and efficiently. Find out more about the Network online: http://nen.nasa.gov (NASA only)

For More on Our Stories

Additional information pertaining to articles featured in this issue can be found by visiting the following Web sites:

Seven Key Principles for Project Success
http://pmtoolkit.saic.com/PDF/Seven Key Principles of Program and Project Success.21Mar06.pdf

Spitzer Space Telescope
http://www.spitzer.caltech.edu/spitzer/index.shtml

Chandra X-Ray Observatory
http://chandra.harvard.edu/index.html

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