National Aeronautics and Space Administration

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The NASA Source for Project Management and Engineering Excellence | APPEL

WINTER | 2006

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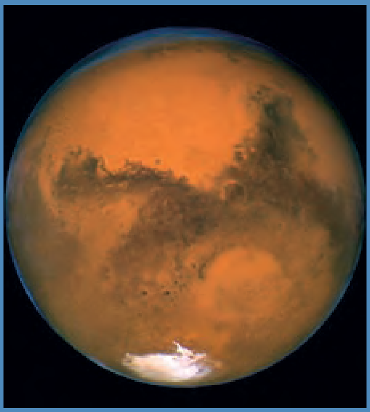

ON THE COVER

NASA's Hubble Space Telescope snapped this picture of Mars on October 28, 2005, within a day of its closest approach to Earth on the night of October 29. Hubble astronomers were excited to have captured a regional dust storm on Mars that had been growing and evolving over the past few weeks. The dust storm, which is nearly in the middle of the planet in this Hubble view, is about 930 miles long measured diagonally, which is about the size of Texas, Oklahoma, and New Mexico combined.

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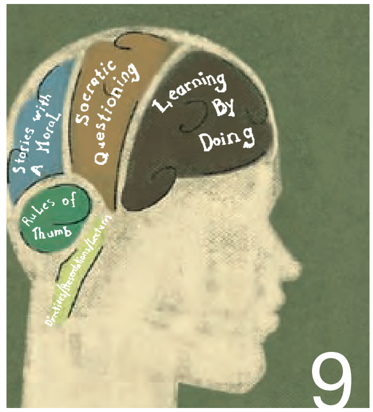
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The Academy of Program and Project Engineering and Leadership (APPEL) and *ASK Magazine* help NASA managers and project teams accomplish today's missions and meet tomorrow's challenges by providing performance enhancement services and tools, supporting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

ASK Magazine grew out of APPEL's Knowledge Sharing Initiative. 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 and industries. These stories contain knowledge and wisdom that are transferable across projects. 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*.

Please direct all inquiries about *ASK Magazine* editorial policy to Don Cohen, Managing Editor, doncohen@rcn.com, 781-860-5270.

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

In This Issue

WELCOME TO THE NEW *ASK*. Readers of the earlier version of the magazine will find some familiar features here—most notably, stories of project management challenges and the lessons they teach. We continue to believe that stories recounting the real-life experiences of practitioners provide important practical wisdom—a kind of conversation on paper that is the next best thing to talking face to face.

Reflecting NASA APPEL's new responsibility for engineering career development (which Ed Hoffman mentions in his column), we are adding stories of engineering achievement to the magazine. In this issue, we describe a new thermal barrier used to protect the O-rings in solid rocket motors and an unmanned aerial vehicle that detects and soars on updrafts. Those articles illustrate not only the technical skill of NASA engineers but their ability to get outstanding results with modest resources.

ASK will also now publish articles that explore broader issues of organizational knowledge, learning, and collaboration. As Chris Scolese notes in this issue's interview, NASA needs to excel as a learning organization and to develop and retain critical knowledge to meet the challenges posed by its ambitious new mission. To launch our consideration of those subjects, we include here an article on learning strategies at Goddard Space Flight Center and a piece on retaining the rich, experiential knowledge that Dorothy Leonard and Walter Swap call "deep smarts." Laurence Prusak's "Knowledge Notebook" reflects on the importance of understanding different kinds of knowledge that contribute to effective work. And the NASA Knowledge Map included in this issue we hope will serve as both a useful guide to basic information about the work of NASA centers and a picture of the impressive skills and accomplishments of the organization as a whole.

The stories you will read here tell about careful planning, realism, commitment, trust, and collaboration as sources to success. A theme running through many of them—from the development of the Compton Gamma-Ray Observatory to Orlando Figueroa's many projects—is the importance of communication. Most of the other success factors—certainly trust and collaboration—depend on good communication. Without it, teamwork is impossible and success unlikely.

Communication is what *ASK* is all about, and we believe the highest form of communication is conversation—the back-and-forth of shared ideas, questions, arguments, agreements, and explanations. Our new "*ASK* Interactive" page invites you into conversation with us. Your insights, questions, complaints, and stories will help make *ASK* a better magazine and a part of the larger conversation that is an essential part of NASA's pursuit of excellence.

Don Cohen
Managing Editor

From the Director

Change and Continuity

The Wikipedia (a comprehensive, free, online, editable encyclopedia that would have been unthinkable even a few years ago but for me demonstrates the power of change) defines change as the quality of impermanence and flux. Like most human activities, even highly successful ones, *ASK Magazine* and the Academy that supports it have changed. I guess this was inevitable given the changes in leadership, mission, and technology that NASA as a whole has undergone in the past several years. We are now focused on missions to the Moon, Mars, and beyond, challenging goals that will require the highest level of technical and organizational excellence.

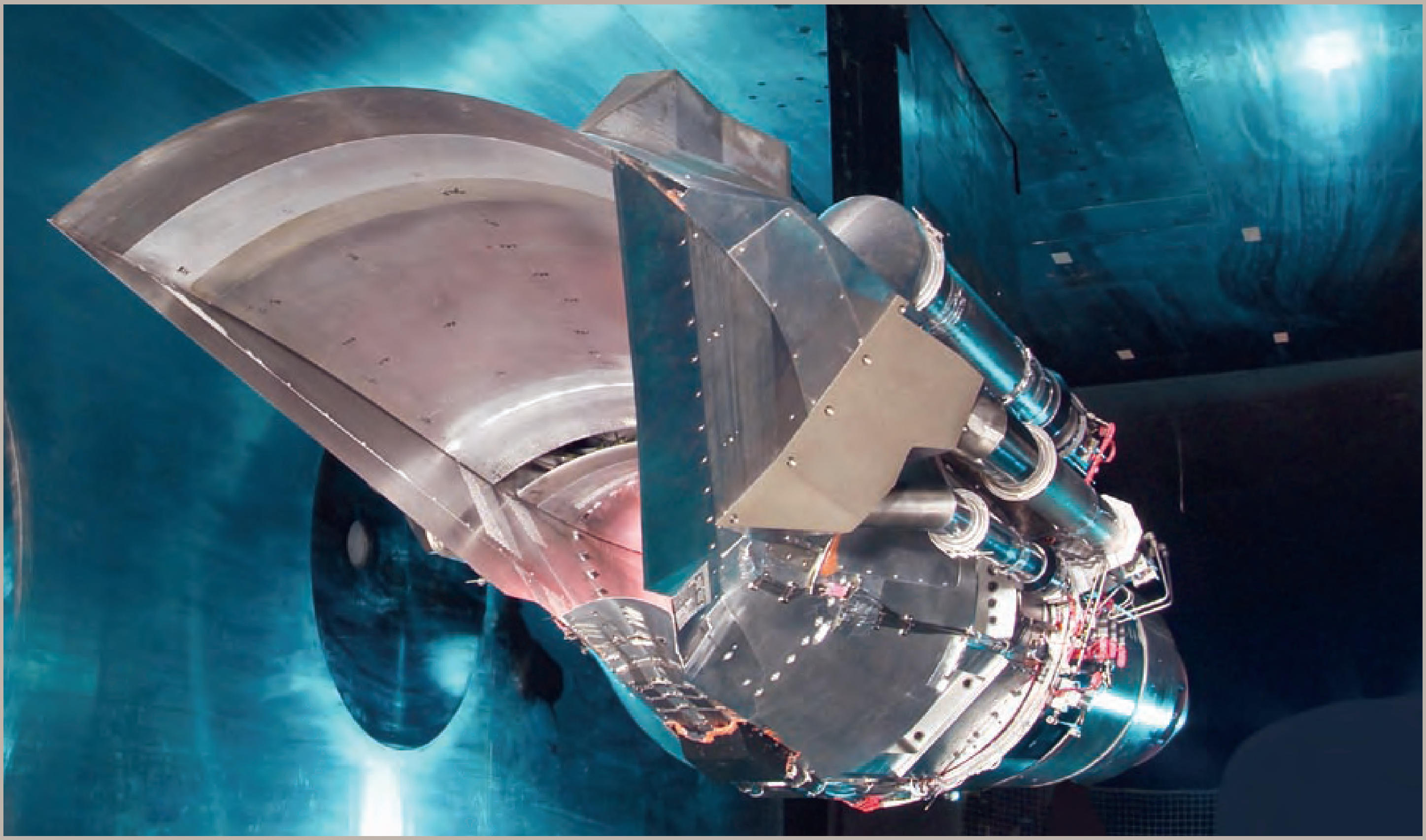
The former NASA APPL is now the NASA Academy of Program/Project and Engineering Leadership (NASA APPEL). The addition of the letter "E" reflects significant, additional responsibility for the Academy—for engineering career development as well as project management. In keeping with this new responsibility, NASA APPEL is now housed and managed in the Office of the Chief Engineer (OCE). I remain the Director of the Academy and the *ASK Magazine* publisher, and Mr. Anthony Maturo serves as the APPEL Deputy Director. The Academy team now includes Dr. Jon Boyle, a long-time Academy leader and contributor, serving as Program Manager; Ms. Tina Chindgren, a recognized expert in the fields of Organizational Learning and Knowledge Management, serving as the APPEL Knowledge Sharing Project Manager; and Mr. Benjamin Bruneau serving as the APPEL Knowledge Sharing Analyst. We also have a new world-class editorial team with Editor-in-Chief Lawrence Prusak, Managing Editor Don Cohen, and Technical Editor Kerry Ellis.

One thing has remained constant. It is our belief in the power and purpose of storytelling, that most ancient of knowledge creation and transfer tools. Good stories engage and motivate us; they illuminate subtle and contrasting points of view that otherwise would be lost to both novice and experienced practitioners of professions. In the world of work, they provide a practical framework to deal with extraordinary change, allowing us to imagine the possibilities of a new environment before that new environment arrives, better preparing us for the supposedly unimaginable and unheard of. We can also communicate our expectations through storytelling, expanding the boundaries of the possible. Stories broaden our perspective by allowing us to see with the tellers' eyes. Through stories, we can communicate knowledge that helps us innovate and find new solutions to problems and adds valuable tools to the toolboxes of project management and engineering professionals.

That being said, I guarantee you that this new team will work to make *ASK Magazine the* source for good stories that will help you in your job as project manager and now as engineer. Change gives us new opportunities to present good stories that will enlighten, inform, stimulate, and, perhaps, serve as the "eureka" moment that will open a door to further research or supply a new idea that moves your project to a higher level of performance. If we can accomplish that with a fraction of the federal managers that read this magazine on a regular basis, I will be happy and humbled. Remember that *ASK Magazine* consists of your stories. I encourage and challenge you to help us make this publication better serve your interests as project managers and engineers by letting our editors know what you think of the stories you read here and especially by sharing your own stories with them.

The NASA Fabrication Alliance: Cooperation, Not Competition

BY JERRY MULENBURG



The Parametric Inlet model is shown in a wind tunnel at NASA Glenn Research Center on October 24, 2003.

Usually when an organization announces an efficiency drive that could mean budget cuts and workforce reductions, people scramble to circle the wagons and protect their jobs—to convince the higher-ups that their work is essential and no one else can do it. But NASA's Fabrication Alliance met the efficiency requirements of the Agency's 1994 Zero Based Review (ZBR) by building a cooperative relationship among NASA research centers. In the process of eliminating duplicated efforts and reducing costs, the Alliance created a mechanism for sharing skills and work.

When the Agency instituted the ZBR with a goal of consolidating efforts and creating more efficiency among its centers, no organization faced a greater threat to survival than the Office of Aeronautics & Space Transportation Technology (OASTT, Code R), which included Ames Research Center, Dryden Flight Research Center, Langley Research Center, and Lewis Research Center (now Glenn Research Center). "We all knew that we were kind of in trouble, especially in the area of manufacturing," said Peter Murray, former Chairman of the Fabrication Alliance and retired Deputy Chief, Manufacturing Engineering Division, from Glenn. Manufacturing at NASA centers often means producing complex, one-off prototypes and components—not a process that lends itself to efficiency.

In an attempt to meet ZBR goals and identify possible inefficiencies, Code R created an intercenter team called Project Reliance. Nearly 80 key people—two to three individuals from each function within the aeronautics centers—gathered for one intense week at Ames. The participants created subteams according to their functional specialty, including acquisition, engineering, Automated Data Processing, experimental facility operations, manufacturing, plant management, technical information production, and technical library. Guided by a Steering Committee of senior managers from each center, Project Reliance aimed to identify future opportunities for making the most of our resources. The manufacturing subteam saw itself as an investment to ensure that Code R fabrication/manufacturing capabilities would be managed effectively and efficiently across the Agency.

Foundation of Trust

Dubbed the Fabrication/Manufacturing Co-Op, the manufacturing subteam's initial mission was simply to continue the collaboration that Project Reliance had started among Ames, Dryden, Langley, and Lewis in order to improve manufacturing capabilities through cost-effective methods. "Folks…went in with a lot of apprehension about what the outcome was going to be…even to the extent that all the civil servants could possibly go away following this exercise and we would need to find another means by which to get fabrication manufacturing work done in the Agency," said Stewart Harris, Associate Director for Fabrication at Langley and current Chairman for the Fabrication Alliance.

To overcome the initial apprehension, the co-op focused first on getting the right people involved, which included at least two individuals from each center. The co-op wanted one of those people to be at the division level, "someone that could…make decisions for the organization, make decisions for the center, and work issues [in] real time," Harris said. Once the right people were in place, the group focused on building trust among the centers. One of the first steps to building trust among this new team, however, was to throw titles out the window during meetings. "When we got together, we sort of dropped those titles that we all covet so much. … Everyone felt like they had an equal say and what they had to say was important," Harris added.

Communication and participation were strongly encouraged and occurred through weekly teleconferences and face-to-face meetings held two to three times each year—practices that continue today. The co-op meeting location rotated among the four centers and allowed members not only to meet their colleagues in person but also to tour each center's manufacturing facilities and better understand their capabilities. "We started out trying to really benefit from areas that one center had that we didn't. In other words, we weren't trying to take anything away from a center, we were trying to use their expertise," Murray said.

Through a combination of fostering personal relationships across the centers and building a catalog of expertise that listed points of contact within each center, a firm foundation of trust grew among the co-op members. Soon, each co-op participant felt comfortable calling any other member for help at any time.

A New Objective

When Pete Haro, the first Chairman of the Fabrication/Manufacturing Co-Op and Chief of the Manufacturing Division at Ames, retired in 1996, I became involved with the co-op as the Ames hardware development representative. It was immediately clear to me that these folks were on to something big. Not only was the co-op model important to Code R's effectiveness, but it also had high potential value for the entire Agency.

A cross-center user group had already successfully solved the problem of incompatible Computer Aided Manufacturing (CAM) software by agreeing to use common software. Part of this effort included a joint-center training class instead of multiple training sessions at each center—an efficiency that also forged new bonds among those who attended.

The co-op also gained access to the Surplus Utilization Expert, a computer tracking system created by Glenn for

THESE NEW COLLABORATIONS AND EXCHANGES BOLSTERED OUR MEMBERSHIP, RESULTED IN SHARING MORE SOPHISTICATED WORK, AND NURTURED THE DYNAMIC THAT MADE MUCH LARGER PROJECTS POSSIBLE.

obtaining excess government equipment and materials, which saved hundreds of thousands of dollars. Co-op members acquired excess metals and new, or near new, equipment for only the cost of transportation from its current location to the requesting center.

Another major early accomplishment was the acquisition of a single, joint-center contract to obtain outside fabrication services—the first of its kind. The Reliance Consolidated Models Contract allowed all co-op centers to obtain estimates from any one contractor, or all three, and then choose the best offer. Instead of contractors competing and administering separate contracts at each center, outside fabrication work now only required a simple task order. An unexpected benefit from this contract was lower cost estimates from the three contractors—as much as 20 percent less than our earlier experiences with them.

Having achieved these successes, the co-op met in Houston in January 1997 to reinvent and rejuvenate itself with a new set of goals, objectives, and operating policies. Among these were actions each center would undertake that were tied to expected returns from increased efficiency and effectiveness.

We agreed to limit specialized fabrication capabilities to centers that currently had them or to one center that would obtain a capability and share it. Langley, for example, procured a new rapid-prototyping stereolithography system, and the other three centers sent their stereolithography work to Langley instead of purchasing their own machines. By using the common software now in place at all centers, Langley could manufacture and ship products back to another center within a day or two, eliminating both duplication of expensive equipment and significant time and cost to contract the work out. This decision alone represented a savings of more than $1.2 million and cut required labor for this work by two-thirds.

Careful documentation of our efforts revealed returns in excess of $16.5 million in savings and cost avoidance over the next five years. These new goals, actions, and expected savings led to NASA Administrator Dan Goldin awarding the Reliance Fabrication/Manufacturing Co-Op Team the 1997 Administrator's Award for Continuous Improvement. With new confidence from several successful collaborations under our belt, we were certain the co-op would become a long-lasting success at NASA.

Within a year or two after the Houston meeting, we'd accomplished many of our goals. It was time to take another look at our future. To help our centers and the Agency, we began consolidating our centers' capabilities into fewer buildings, eliminating satellite shops, sharing resources such as excess equipment or knowledge of specialized fabrication techniques, and sharing work when any center had available capacity instead of contracting it out. We also created subteams to address current issues, including common business practices, advanced manufacturing and technology exchanges, and a common manufacturing approach for implementing ISO 9000 across the Agency.

A unique problem the co-op faced, and still struggles with today, was paying centers for work they did for one another. The NASA financial system took months to process a funds transfer, but work for critical projects often had to be done in days or hours. Once again, our members' ingenuity went to work. Although Ames could not quickly transfer funds to Langley for critical stereolithography work, Ames could order replacement materials and have them delivered to Langley—which we did, in quantities that covered Langley's cost of materials and labor. We also used a barter system to exchange excess materials and equipment, and we created a system to allocate hours at the beginning of each year for potential work from other centers.

Spreading Our Wings

With some acknowledged uneasiness at the possible effects on the close working relationships we had developed over nearly five years, we recognized that it was time to expand beyond the aeronautics centers and invite other centers to the table. In April 1999, Goddard Space Flight Center joined our team. The advantage the co-op gained was easy access to Goddard's unique metal-plating capability, which we had never had within aeronautics. In September 2000, Marshall Space Flight Center followed Goddard, and soon the Jet Propulsion Laboratory, Johnson Space Center, Kennedy Space Center, and Stennis Space Center fabrication organizations all joined. Now that we were a true Agency-wide team, the Fabrication/Manufacturing Co-Op was renamed the NASA Fabrication Alliance.

During this expansion, we realized that many of the aeronautics centers' fabrication issues and needs were identical to those of other NASA centers. These new collaborations and exchanges bolstered our membership, resulted in sharing more sophisticated work, and nurtured the dynamic that made much larger projects possible.

One of those projects was a high-precision parametric engine inlet that needed to be fabricated for a wind tunnel test. Glenn developed a design for it then used the Alliance to divide the work among four centers. The initial drawing review began in early 2000; the work itself took 22,000 hours and was completed in April 2003. We could not have met the project milestones if we hadn't tried something new and risky. Our creative scheduling included dividing up the complex inlet so its parts could be machined independently at five separate NASA centers. Building the many components simultaneously, instead of serially, was possible because of digital modeling, which our now standardized software allowed us to share across centers.

"WHEN WE GOT TOGETHER, WE SORT OF DROPPED THOSE TITLES THAT WE ALL COVET SO MUCH. … EVERYONE FELT LIKE THEY HAD AN EQUAL SAY AND WHAT THEY HAD TO SAY WAS IMPORTANT."

Weekly telephone conferences kept the project team in close contact, and we exchanged digital photos to show progress and to share problems, which also made final assembly easier. When completed, the precision-machined, mating flow surfaces matched flawlessly, and the project schedule was reduced by at least twenty-four months.

Another critical test of the Alliance collaboration capability came after the shuttle Columbia accident. Johnson was tasked to provide an exact shuttle wing section mock-up, and quickly, to test a theory that the wing's leading edge failed due to foam striking it during launch. Building this precise mock-up of the critical wing section was more work than Johnson could do in the short time available. "Just by bringing that issue up at the [Fabrication Alliance] telecon, they were able to get the job done," said Carl Voglewede, Branch Head for Fabrication Business & Contract Management Branch at Langley.

The mock-up wing consisted of more than 500 manufactured parts and 2,000 fasteners. To meet the extremely tight schedule, Johnson relied on the NASA Fabrication Alliance to fabricate many parts. The Alliance successfully coordinated the distribution of needed parts to the various centers in less than three days. We procured all materials, manufactured every part, and assembled the entire wing in just five weeks. We also provided all the direct personnel contacts needed at each center for immediate support and manufacturing implementation. Ames, Dryden, Jet Propulsion Laboratory, Marshall, and Stennis all provided essential support in the manufacturing of parts. The success of this project was exhibited in a video showing a test foam sample penetrating the mock-up wing's leading edge. The "possible" cause of the accident suddenly became the "probable" cause.

These projects increased our technical knowledge and, more importantly, deepened trust among Alliance members. The strength of the Alliance partnership encouraged us to share hard-earned aerospace trade secrets obtained through past experience to an unprecedented degree.

Future of the Alliance

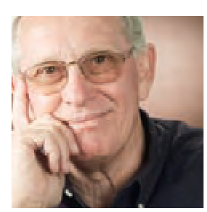
Nurtured and sustained for more than a decade by a handful of NASA fabrication experts' grassroots activities, the Fabrication Alliance retains the spirit and energy of its original members. The Alliance formula—cooperation, not competition—resulted from having a joint goal, building relationships and trust among colleagues, identifying common goals and objectives with a real commitment to implementing them, and maintaining both face-to-face and frequent other communications.

Our members continually strive for innovation and still set new challenges for growth and knowledge sharing. "One of the things I've been working on is regional workforce development. How can we partner with academia, with industry, with government to develop the workforce for the future?" Harris said. After ten years of sharing and building knowledge across the centers, the Alliance faces the challenge of retaining it.

"As we lose personnel either through retirement or people moving to other jobs, the resource situation is getting more critical," said Voglewede. "That's something we've talked about in the Alliance, and we need to put some energies into that," Harris added.

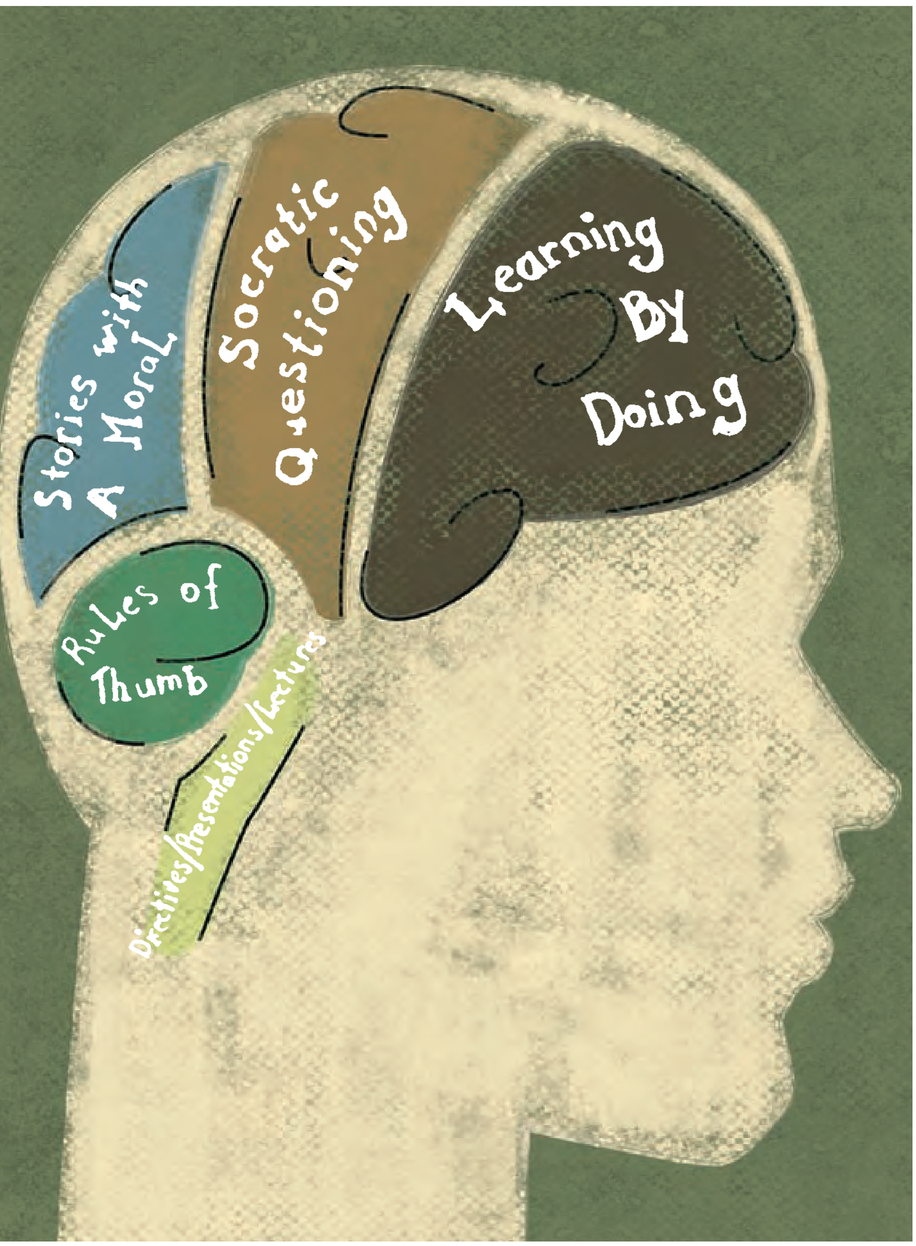
We continue to talk openly about the challenges we face, whether they are technical, resource driven, or Agency issues and initiatives, and we know that accurate, reliable information is only a keystroke or phone call away. Membership turnover has not hampered the respect or enthusiasm generated among the members, and lifelong friendships have resulted from the Alliance interactions. We truly know the meaning of One NASA. ●

While Manager of the Ames Aeronautics and Spaceflight Hardware Development Division (for 8 years), **DR. GERALD (JERRY) MULENBURG** was the Ames representative and an active member of the Fabrication Alliance. He is currently Senior Analyst for project management and systems engineering in the Systems Management Office at Ames. Jerry also represents Ames on the Academy of Program/Project and Engineering Leadership (APPEL) working group and is a member of the *ASK Magazine* Review Board.



Preserving DEEP SMARTS at NASA

BY DOROTHY LEONARD AND WALTER SWAP



By 2006, almost half of NASA's workers will be eligible for retirement, many of them in science and engineering.[1] Some of the knowledge likely to walk out the door is obsolete, irrelevant, or otherwise useless. But some of it is irreplaceable. Moreover, much is tacit, that is, not articulated in any form easily retrieved by others. And the most valuable of that expertise fits our definition of "deep smarts":

Deep smarts are a potent form of expertise based on first-hand life experiences, providing insight drawn from tacit knowledge, and shaped by beliefs and social forces. Deep smarts are as close as we get to wisdom. They are based on know-how more than know-what—the ability to comprehend complex, interactive relationships and make swift, expert decisions based on that system-level comprehension and also the ability, when necessary, to dive into component parts of that system and understand the details.[2]

Deep smarts may be technical or managerial. Intelligent people can develop competence within a couple years, but truly deep smarts are gained only through ten or more years of diverse, active learning experiences. As a senior manager at the Jet Propulsion Laboratory interviewed in 2002 noted about one aspect of management, "You have to balance risk management and cost. And that balance is very difficult to learn without firsthand experience on several projects." In that same set of interviews, senior staff discussed a few highly publicized NASA failures and noted that engineers and managers on one of those projects "didn't have the experience to know when they were doing something wrong. Sometimes you don't know enough to even know that there *is* a problem."

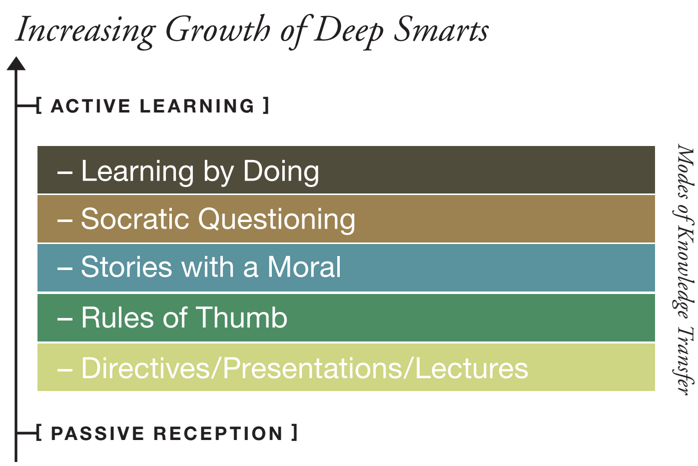
What Deep Smarts Look Like

Consider the following brief example of deep smarts. A scientist realizes that his company is about to lose a profitable Defense Department contract because of basic flaws in software and hardware design that have led a missile prototype to fail. Drawing on twenty years of experience and speaking without notes, he spends several hours presenting to the project team, laying out in detail all the needed changes. It takes several hundred people eighteen months to implement the design changes, but the company wins a contract that still delivers profits decades later.

Experts with deep smarts like these differ from novices, or even relatively competent performers, in a number of ways. They are the "go-to" people in an organization because they seem to be able to make swift, wise decisions without engaging in much obvious analysis. Colleagues seeing such a capability sometimes attribute it to "intuition" or "gut feel." In actuality, when deeply smart people confront a problem, they draw on hard-won experience. Their brain accesses a broad repertoire of relevant work and life experiences and sorts through a menu of possible responses at warp speed, seeking a possible match to the pattern before them. This is not to say that experts are always right nor to disparage the value of the intellectual challenge someone with a "beginner's mind" can add to innovation.[3] But when an expert changes jobs or physical locations, or retires, managers need to consider how to capture that individual's priceless wisdom.

Difficulties in Transferring Deep Smarts

The problems with transferring deep smarts are many. Because such expertise is experience based, it is context dependent and usually heavily tacit. Think of something that you are very good at—it could be as scientific as understanding the behavior of certain kinds of molecules under stress or as homely as baking bread, as cognitively complex as chess or as physical as golf. Now how much of your expertise could you port over to someone else's head? Much would depend upon what mental receptors that individual already had, but the more your knowledge is derived from experience, the harder it is to transfer it to someone else. In fact, you often don't know what you know or bring it into conscious consideration until you are forced to explain or demonstrate it in response to some specific situation. And even then you will often be at a loss for words that would convey exactly what you know, because you cannot structure all your knowledge into words. You have learned through practice and feedback, just as skilled surgeons or masons or teachers do.



Reprinted from *Deep Smarts: How to Cultivate and Transfer Enduring Business Wisdom* (Boston: Harvard Business School Press, 2005).

Actual Transfer Is Impossible

One of the greatest fallacies in management today is the belief that deeply smart people can transfer most of their knowledge through checklists, PowerPoint presentations, or data repositories. Such experts can transfer lots of information; they can help individuals create mental armatures on which to build their own knowledge—but the only path to "transferring" deep smarts lies through re-creation of experience, since that is how the experts acquired pattern-recognition capability to begin with, and since they will never be able to remember and structure all that they know. Moreover, of course, the more actively our brain is engaged, the more we retain. Therefore, we suggest a hierarchy of knowledge transfer modes, ranging from passive to highly active ones. See the figure above.

As this figure suggests, people learn more experience-based knowledge from stories than either rules of thumb or lectures. Vicarious experience transfers more smarts than abstractions. Stories provide context and usually vivid, rich details that lodge in the mind longer than straight lecture or generalities. Socratic questioning ("Why? What then? How do you explain…?") further engages the brains of the people being quizzed and causes them to retain even more of the knowledge an expert offers.

Knowledge Coaches and Guided Experience

But the best way for experts to help others recreate their deep smarts is through guided experience—helping their less experienced colleagues learn by doing. Such experts are functioning as knowledge coaches, and, by taking on this role, they can shorten the time their protégés would otherwise require to achieve deep smarts.

In our international, multiyear research study on deep smarts, we observed four types of guided experience: practice, observation, joint problem-solving, and experimentation. The first of these, *guided practice,* is obvious: most of us have benefited from music or athletic coaching. Such attention to structuring practice and performance feedback is much rarer in organizations, however. Instead, we waste employee time and our resources by forcing people to learn through trial and error, with little well-timed feedback. Yearly performance reviews are usually too little and often too late to help a new manager learn how to conduct meetings, work with client organizations, or manage projects.

There are two kinds of *guided observation,* shadowing and mind-stretching. Few managers think of inviting junior employees as spectators to critical meetings or negotiations, for example, even if such attendance would lay the foundation for those employees' future decision-making processes. A junior staff member we know talked her supervisor into letting her sit in on strategy sessions. Her supervisor was subsequently pleasantly surprised by her increased ability to link her project work to larger organizational issues and anticipate both potential opportunities and difficulties. *Mind-stretching* enables people to experience situations that will challenge their current assumptions and provide new sets of potential responses to problems—that is, expand their experience repertoires. No one at Whirlpool thought of targeting men as customers until a group of product developers toured suburban garages, where they discovered old refrigerators containing beer and extremely messy workbenches. Out of these observations was born the innovative Gladiator line of "beer-ators" ("ruggedized" refrigerators that can withstand temperature extremes) and modular workbench/storage units.

Guided (joint) problem-solving by the knowledge coach and apprentices is a potent technique for re-creating deep smarts. The coach shares diagnostic approaches and provides feedback but allows the protégés to grow their experience repertoires by tackling a variety of problems. The protégé thus absorbs context and, in the best of situations, develops tacit knowledge. In many of the situations we observed, the coach also learned from the protégé through this practice.

Finally, when the situation is so uncertain or novel that even the expert has no sure answers, *guided experimentation* allows for the growth of deep smarts. In such cases, the expert, or knowledge coach, guides the process of experimentation—but does not necessarily prejudge the outcome. For example, when a new technology emerges, no one is immediately certain of its highest-value application. That knowledge is discovered only through experimentation in the market. But there are better and worse ways of experimenting, and a deeply smart person knows where the bleeding edge of knowledge is and how to structure experiments to elicit the most useful information. The protégé learns how to experiment when knowledge is incomplete or otherwise inadequate.

Dual Purpose Projects

"All very well," you say, "but how realistic is it for us to re-create deep smarts through guided experience? Who has time?" It's a legitimate question. But not everyone in an organization has critical deep smarts. Not all knowledge is created equal. For those relatively few who do possess extremely important knowledge, a better question is "how can we afford to lose it?" Yes, we can hire some deeply smart people back as consultants, but that is a very temporary measure. A better program is to plan on the cultivation and transfer of deep smarts by embedding in our systems and culture the practice of setting up projects with a dual purpose: to deliver the business, technical, or scientific output *and* to develop "bench depth" in critical areas through guided experience. We need our deeply smart people to serve as knowledge coaches on such projects. Some experts are already superb teachers, but others may need some instruction on how people learn and how tacit knowledge can be re-created. One organization we know of offers each expert a facilitator to help him or her guide the experience of protégés. Since dual-purpose projects deliver on organizational performance objectives, the investment in learning is less expensive than training programs that separate knowledge acquisition from its application.

Deep Smarts for Mission Success

Retention of critical managerial and technical knowledge is essential for NASA to successfully accomplish its ambitious and far-reaching mission, and some of those vital deep smarts are departing at alarming rates. Even the most sophisticated IT tools for documenting best practices cannot capture and communicate this rich know-how. To ensure its future success, NASA will need to identify experience-based expertise and then design the human development programs to re-create those deep smarts. ●

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WALTER SWAP is Professor of Psychology, emeritus, and former Dean of the Colleges at Tufts University. Leonard and Swap are the co-authors of *When Sparks Fly: Igniting Creativity in Groups and Deep Smarts: How to Cultivate and Transfer Enduring Business Wisdom.*

1. Except when otherwise noted, quotes throughout are from Dorothy Leonard and David Kiron, "Managing Knowledge and Learning at NASA and the Jet Propulsion Laboratory (JPL)," Harvard Business School case # 9-603-062 (2002).
2. Dorothy Leonard and Walter Swap, *Deep Smarts: How to Cultivate and Transfer Enduring Business Wisdom* (Boston: Harvard Business School Press, 2005).
3. See the discussion of creative abrasion in Dorothy Leonard and Walter Swap, *When Sparks Fly: Igniting Creativity in Groups* (Boston: Harvard Business School Press, 1999, 2005).

Cultivating a Community

BY BEN BRUNEAU AND KERRY ELLIS

When beginning a project, most project managers look first for budget approval and a team that will make the project succeed. To garner NASA's continued support after a project has begun, many rely on progress reports and updates to senior leaders that will convince them the project is worth continued investment. But two project managers took a different approach: they convinced their local communities that they could personally benefit from the research. By looking outside NASA and gaining local support, the managers did not need to spend all their time convincing higher-ups that the project should continue. The community helped do it for them.

Dougal Maclise and Jenny Baer-Riedhart worked together in NASA's Environmental Research Aircraft and Sensor Technology (ERAST) program and teamed up on a project called Pathfinder, an unmanned, solar-powered airplane. The Pathfinder project was based in Kauai, Hawaii's northernmost island, and its goal was to develop a solar-powered unmanned aerial vehicle that could remain aloft for many hours to capture research data.

Pathfinder's payload was a small camera attached to the fuselage. Maclise immediately began thinking of ways to use the technology to benefit others. "My objective was to look for new ideas, new ways to use our information. For example, we planned to take pictures of the forests to collect data on agriculture. Then we met somebody who was talking about mapping roads. Suddenly we were aiming our camera at the roads, too," he says.

Maclise focused first on sharing the technology and its potential with the local scientific community. "To help scientists understand the potential value of our data to them, I went on marketing trips around the islands. I met scientists who had no idea about aerial photography and what it could do for them. I tried to explain to them how chlorophyll reflects infrared—what the camera was capturing—more than it reflects green, and how it showed the stress of the plants," he explains.

Recognizing this potential for photo-mapping plant strain, Maclise expanded his audience and went to the local agriculture industry. He began visiting sugarcane producers and tried to explain how the Pathfinder project could help them grow their crops, but it wasn't until he demonstrated aerial photography's benefits that interest grew. "I went for a ride with a sugarcane producer in his helicopter and took pictures of crops to demonstrate the value of the project and to whet his appetite for wider-scale images available from Pathfinder," Maclise explains. "Later, when I showed him the pictures, he pored over them. Within a day he was using the information we'd collected to fix broken irrigation lines. Word of that got around to other parts of the community, like the coffee growers, and they began to see how useful aerial photography could be to them."

Baer-Riedhart recognized that a broader approach to sharing information about the Pathfinder could be useful, and she approached a Kauai resident the team had gotten to know very well, Dave Nekomoto. Nekomoto helped open many doors in the Kauai community for the NASA project. "We involved the Kauai Community College by hiring students to work for us at the Pacific Missile Range Facility (PMRF) and introducing them to advanced solar technology. This was done on Dave

Nekomoto's advice, and he put us in direct touch with the right people at the college," Baer-Riedhart recalls.

The Pathfinder team also learned from Nekomoto the high regard Kauaians have for those who educate their children, so Baer-Riedhart broadened their information-sharing approach even more. "Working with the base commander and the PMRF public affairs office, the NASA and AV team orchestrated an open house that brought in approximately 1,000 local schoolchildren to see the Pathfinder, its payloads, and key parts of the PMRF support equipment. We jokingly called this event the '1,000-Kid March,' and the name stuck," Baer-Riedhart shares. "It was tremendously successful, and students and teachers from across the state participated."

Nekomoto was also quick to let Hawaii's political machine know what was going on with the Pathfinder project. Garnering this political support resulted in Hawaii's entire congressional delegation sending a letter to NASA commending the team on the project's success. "Suddenly money that hadn't been available before appeared [from NASA], and this gave the project some extra lift, so to speak, making our attempts at another world-record-altitude flight an even more viable goal," Baer-Riedhart explains.

People in the community who could benefit from the Pathfinder technology became valuable to Pathfinder's success. These technology users became customers of the project. "Normally, the customer gives you money in exchange for something you give him," Maclise explains. "Those people weren't giving us money, but they're the users of the information we could provide to them, so we collected their needs." By meeting their needs, the team gained increased support and recognition from the community.

Embedding the project into the surrounding community kept Pathfinder alive. "The reality is that every year you have to defend your program," Maclise says. "The best way to keep a program alive is to get the user communities to say they need the data your program provides them. Thus it behooves you to spread your base of support far and wide."

"Many times in our projects we think that just being smarter than someone else or having the best idea is all we need," Baer-Riedhart shares. "That helps, no doubt, but you've got to understand the human side of things. We came to Kauai not knowing how the human dimension would figure into our activities, but we understood that however it worked itself out was going to be critical to our success. That's why we set aside money in our budget specifically for the kinds of activities described here. Call it marketing or public relations, but whatever you call it, by the time we left Kauai, we had probably spent 20 percent of our project time on it."

That effort resulted in project success, as the Pathfinder took flight on September 11, 1995, and set the first altitude record for solar-powered aircraft at 50,000 feet during a twelve-hour flight. In 1998, the plane was modified and renamed the Pathfinder-Plus project. It continues to be adapted and modified for scientific exploration as new possibilities for its use are investigated. These possibilities include monitoring forest nutrient status, detecting crop damage or fires, establishing commercial communications, and creating emergency communication links for recovery and relief workers. ●

Article adapted from Dr. Alexander Laufer, Todd Post, Dr. Edward J. Hoffmann, *Shared Voyage: Learning and Unlearning from Remarkable Projects* (Washington, D.C.: NASA History Division, 2005), 156–58.

Old Lessons for a New Generation

BY MARTY DAVIS

The seventeen-ton Compton Gamma-Ray Observatory (or CGRO), launched aboard the space shuttle Atlantis on April 5, 1991, was, at the time, the heaviest astrophysical payload ever flown. It returned data to astronomers for nine years, detecting gamma rays from sources including black holes and our own sun and providing content for literally thousands of scientific papers. In June 2000 it was safely de-orbited and re-entered Earth's atmosphere.

So the project to build the observatory was a success. But that does not mean it did not have problems, including some serious ones. As Instrument Systems Manager and then Observatory Manager for the project, I got to see both what we did well and what we could and should have done better. Although work on the CGRO began some two decades ago, I believe that our experience offers important lessons to managers of large projects today.

The success of the variety of subsystem and instruments we developed was determined, in large part, by the quality of management. Having the right technical expertise is essential, of course, but large, complex projects like this one stand or fall on how well the work of the many parties involved is coordinated, on sensibly allocating resources of money and time, on identifying and solving small problems before they become big ones—in other words, on project management skills.

A Slow Start

The Gamma-Ray Observatory project got off to a slow start. A study phase began in 1978. Three years later, CGRO was confirmed as a project, but sufficient money to begin the work in earnest was not allocated until two years after that, in 1983. This leisurely pace gave the team the false impression that they had plenty of time to get organized and do the work. The unprecedented size of the project made it difficult to predict how much effort it would entail. Many members of the project team had worked on small, rocket-launched satellites, building instruments in what was almost a hobby shop atmosphere. Even though we knew that designing and building a device so much larger than anything done before would be more challenging, we underestimated just how much additional work that difference in size would generate. Scaling up doesn't mean the same only larger. It creates new technical problems that are difficult or impossible to foresee (and therefore difficult to schedule and budget). In this particular case, it meant moving from the "hobby shop" to more formal design and manufacturing environments. It dramatically increased the number of tasks, organizations, and groups that project leaders had to coordinate, evaluate, and support.

Not recognizing the true extent of the work resulted partly from never having experienced a project this big and reflected a dangerous optimism that we often bring to our projects. A can-do attitude is important, but underestimating the effort needed because you assume *this* project will be free of the problems and inefficiencies that plagued past projects is dangerous. Listen to the wisdom of experience, including rules of thumb (spend 50 percent of your costs by Critical Design Review), past experience (it took 150 people in the past to put a large observatory through integration and test), and common sense (is it really practical to have one group of people analyze and design hardware and software, another group build it, and a third group test it?). We did not always do that, assuming, for instance, that 100 people could do the integration and testing and asking three separate groups to design, build, and test hardware and software components.

On the positive side, we took time early on to document expectations in detail and develop schedules, budgets,

The Gamma Ray Observatory (GRO) with its solar array panels deployed is grappled by the remote manipulator system April 11, 1991. This view taken by the STS 37 crew shows the GRO against a backdrop of clouds over water on the Earth's surface.

descriptions of responsibilities, and fiscal monitoring tools. This preparatory work helped avoid countless future disagreements about tasks and resources. It put us in a position to measure our progress against clearly defined goals and schedules. And it mitigated, to some degree, the unforeseen problems that inevitably arise in long projects. Ours took thirteen years from study phase to launch. During that time, one design engineer died and others retired or turned their attention to other work. Even good, detailed documentation could not entirely make up for the expertise lost in those cases, but it allowed those who took over their roles to get their bearings quickly.

So one important lesson learned is this: Invest time and effort in thorough planning and documentation up front. Doing so will save you time, money, and headaches later on.

Of course, you should be sure to use the management tools you put in place. We often ignored them, explaining away variances, schedule slips, interrelationship disconnects, and technical problems. When our earned-value measurement system told us that the cost of work accomplished so far indicated that we were overspending and underperforming, our gut feeling was that we had workarounds to solve the problem, but the system was right.

Four Instruments, Four Management Stories

Four different instruments included in the observatory were developed by different groups at a variety of locations. Each of these elements of the project was managed somewhat differently from the others. Their circumstances suggest that there is no one, right model for managing large projects, plenty of ways to go wrong, and some key ingredients of success.

Instrument One

One of the instruments had three co-Principal Investigators located at three separate institutions. NASA Headquarters tried to alleviate the tension among them by making one scientist responsible for the entire instrument. Though the participants agreed to this arrangement, it did not eliminate the problems. In reality, the assigned Instrument Manager was in charge of only half the relevant work at his center and none at the other institutions. Assisted only by a coordinator, he shared secretarial, procurement, and financial support with others in his section. So a $40 million instrument was being managed by a two-man team that only actually controlled a third of the work.

One institution sharing the workload was a university that had no experience building flight hardware, but the Instrument Manager had no experienced manpower to assign to the university. Basically, the plan was to have the funds to clean up the eventual mess that all the managers knew would happen.

Center management also had a skewed perception of the complexity of the instrument, which was prevented from flying on its original mission due to budget cuts. They had repeatedly been shown a sketch of it created for that cancelled mission. When the Instrument Manager's center sold the instrument to this new project, they gave the impression—which proved to be false—that extensive engineering backed up the drawing. So management failed to realize how much work needed to be done to build this complex instrument until the project was under way.

In this case, divided responsibility, insufficient manpower, and lack of clarity about the complexity of the task led inevitably to problems.

Instrument Two

The second instrument had only one manager with total responsibility. That avoided issues of divided accountability, but "total responsibility" ended up being the problem. The manager was a very capable section head who also worked on other tasks. He did his own financial, scheduling, and procurement work. He worked hard and convinced himself that he knew everything happening with his contractors. He didn't, but he was so overloaded with work and working so hard to stay on top of it that he was unaware he had lost control.

The project office took up the issue of lack of management support with one of the instrument organization's senior managers. A detailed analysis was put together and discussed with him, but the senior manager pushed for a management consultant to study the situation. After three months of observation, the consultant agreed with the project office's assessment. The report was filed and ignored, however. Eventually, continuing problems spurred a meeting of NASA headquarters, center management, and the instrument organization's senior management, but it came too late to avoid the problems poor management had caused.

Here, an overcommitted manager and the failure of senior management to respond to a problem quickly and decisively were the source of the difficulties.

Instrument Three

A third, simpler instrument also suffered from some management problems, but it had what turned out to be the advantage of being delivered from one NASA center to another. Centers feel a certain (usually friendly) rivalry and need to maintain their reputations in the eyes of the other centers and NASA headquarters. Our project office once brought problems at another center working on the project to the attention of headquarters. The center responsible for the instrument responded by working hard to strengthen its management. If Instrument One had not come from the same center that also housed the project office, reputational pressure might have resulted in a faster resolution of problems.

Instrument Four

The development of the fourth instrument should not have worked, but it did. Hardware responsibility was divided among four different groups with five funding sources from four different countries. But the team took major steps to promote teamwork and a shared understanding of their task early on. They agreed to put their egos aside, support each other's efforts, and follow the lead of the principal investigator. The instrument was managed by a committee, but the committee acted as a single unit.

Even this effective team experienced two setbacks. First, a shortage of funding caused them to choose hardware over system engineering support early in the design phase. This contributed to later technical performance issues. These problems exposed a second issue. No clear lines of responsibility for hardware integration had been laid out with the contractor responsible. In comparison with the issues of poor management that plagued the project's other instruments, these two problems, spread over eight years of collaboration, were relatively minor.

Some Lessons Learned

Despite the many problems suggested, the project was highly successful and yielded outstanding science for almost a decade. As is often the case at NASA, people found ways to do the work and do it well. But recovering from our mistakes was costly and took a toll on participants. Our excellent Project Manager came very close to burning out two of his highest performers. (There is a lot of literature on how to motivate poor performers but not much on how to tell when you are driving your "workaholics" too far.)

Some of the most important lessons of the CGRO project are these:

- Spend ample time up front for detailed, clear, realistic planning. The effort will pay benefits throughout the life of the project.
- Work hard to provide resources appropriate to the complexity of the project. It's expensive to try to do work on the cheap.
- When problems arrive, deal with them quickly and decisively. Trying to explain them away or ignore them makes them worse.
- Communicate, communicate, communicate. The success of the work on Instrument Four came from continual, extensive communication; many of our problems were due to poor communication. ●

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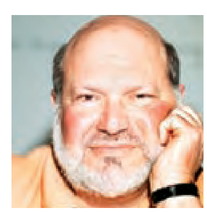
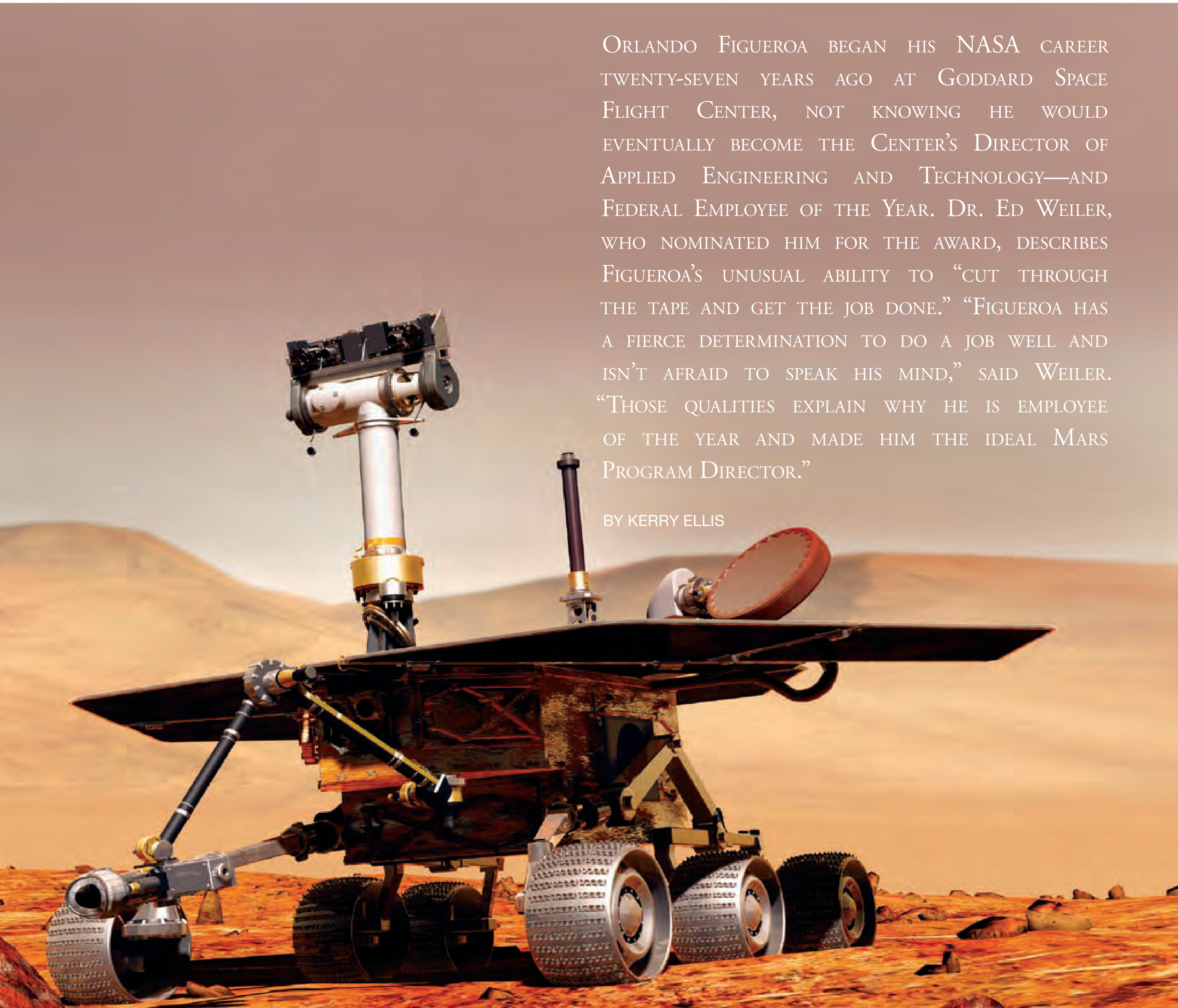


Profile of a Leader

Orlando Figueroa: Federal Employee of the Year

Orlando Figueroa began his NASA career twenty-seven years ago at Goddard Space Flight Center, not knowing he would eventually become the Center's Director of Applied Engineering and Technology—and Federal Employee of the Year. Dr. Ed Weiler, who nominated him for the award, describes Figueroa's unusual ability to "cut through the tape and get the job done." "Figueroa has a fierce determination to do a job well and isn't afraid to speak his mind," said Weiler. "Those qualities explain why he is employee of the year and made him the ideal Mars Program Director."

BY KERRY ELLIS



Technicians maneuver the aeroshell for Mars Exploration Rover 2 onto a workstand in the Payload Hazardous Servicing Facility at Kennedy Space Center.

Figueroa was born in San Juan, Puerto Rico, and obtained a Bachelor of Science Degree in Mechanical Engineering from the University of Puerto Rico in 1978. He moved to Maryland and took his first steps with NASA at Goddard, where he joined the Heat Capacity Mapping mission, which mapped the land over the United States, during its integration and test phase.

"Imagine coming out of school as an engineer all gung-ho about applying whatever I learned and being part of the team that took this mission to the launch pad and launched it successfully," Figueroa said. His first mission became one of his most memorable, not just for witnessing his first launch but for the lessons he learned from the team.

"This group of people embraced me as part of the team," said Figueroa, "and two of my supervisors took very seriously the role of mentorship. John Webb and Joe Dezio met with me often to talk about the job, my progress, and to provide guidance." It was during this mission that Figueroa also learned to keep his eyes on the goal, and he took that lesson to heart during future missions that posed difficult challenges.

Those missions were not long in coming. After applying his determination and skill to missions that included free fliers and the shuttle and to line management positions, Figueroa was approached by Tom Huber and Alan Sherman—Director and Deputy Director of the Goddard Engineering Directorate—to manage the Small Explorers program in 1990. This program represented a move from huge "Battlestar Galactica" vehicles, which might launch once per decade, to vehicles that provided more frequent flight opportunities to the science community. But engineering these smaller vehicles was not the only measure of success. "We knew we had a responsibility not only to build extremely capable scientific spacecraft with relatively small resources but also to help build a capability in the commercial sector so they could also do this on their own," Figueroa recalled.

To put this program on the path to success, he first set about establishing an environment of teamwork and mentorship like the one he had encountered when he first joined NASA. First he had to get to know the team. That required a lot of walking around and face-to-face interactions. This also allowed him to get a sense of what was going on and what was getting in the way. "One of the things that I learned as I was growing up in the system was to be able to very quickly identify areas that needed attention, that were not working as they should to fulfill the end goal of mission success," Figueroa said.

"IN THE LATE '90s VERSION OF THE MARS PROGRAM, WE WERE MOVING VERY AGGRESSIVELY NOT ONLY TO DO ORBITER AND ROVER MISSIONS BUT ALSO TO BRING SAMPLES BACK TO EARTH AS QUICKLY AS WE POSSIBLY COULD. WE WERE TRYING TO DO THIS WITH AN EXTREMELY FRUGAL BUDGET, SO WE WERE ALWAYS OPERATING VERY CLOSE TO AND, UNKNOWINGLY, BEYOND THE EDGE."

He identified key areas that needed attention before the goal could be achieved and went after them with zeal. This quickly led to several small wins, which helped people feel successful early and remain motivated. "I am very open and honest in communicating what I see. It was very direct, not behind anyone's back. It was observing what we need to do and making corrections along

the way," Figueroa said. "We engaged the contractors and other organizations in frequent meetings to discuss progress and deal with issues promptly. We dealt with whatever was getting in the way of completing the deliverables swiftly."

After three successful missions in the Small Explorers program and getting two more on their way, Figueroa moved on to the Large Explorers program, where the X-Ray Timing Explorer and the Advanced Composition Explorer were in development, and a new mission demanding a new approach was looming on the horizon. Headquarters posed the challenge of completing the Far Ultraviolet Spectrometer Explorer mission for half the cost of what was initially envisioned.

Johns Hopkins University put together a strong proposal for the mission. A strong proposal, however, was not enough to ensure mission success. "I knew many of the players at Johns Hopkins," Figueroa said, "so I started to build a relationship with these individuals." This allowed NASA and Johns Hopkins to quickly create a collaborative team. "The way you build that [collaboration] is setting up the channels for frequent communication—daily, if needed, or weekly. This gives them the sense that not only am I soliciting for them to open the door, but that I am willing to open the door as well," he said.

Foreign contributions, batteries, guidance and navigation sensors, and detectors represented challenges that threatened the cost and schedule commitments and required careful and frequent coordination. After the mission launched successfully, Figueroa attributed a large part of that success to good teamwork and the communication his team and the Johns Hopkins team established. "We could talk frankly about anything that was going on at any time, and we dealt with issues promptly before they could grow or, worse, be forgotten," he said.

The skills and knowledge developed through these experiences were critical when Figueroa eventually moved to the Mars program. Prior to becoming the Mars Program Director, Figueroa was the Deputy Chief for Systems Engineering for NASA when the Agency was dealing with the Mars Climate Orbiter and Mars Polar Lander mission failures. In that position, he focused on how to strengthen systems engineering and software capabilities throughout the Agency. When he was approached to take over as director for the Mars program, he knew what to avoid.

"In the late '90s version of the Mars program, we were moving very aggressively not only to do orbiter and rover missions but also to bring samples back to Earth as quickly as we possibly could. We were trying to do this with an extremely frugal budget, so we were always operating very close to and, unknowingly, beyond the edge. The failures demonstrated that we were violating some of the most fundamental principles of engineering and management. We were trying to focus our attention on the bigger, more visible issues, while the system of checks and balances diminished to the point that many small, yet important, things were being overlooked—the accumulation of which was building undue risk in the system," Figueroa said.

Following the restructuring of the Mars program and upon taking over its leadership, Figueroa focused on these issues and others that the individual review teams had uncovered. He again applied his earlier lesson of quickly identifying what prevents success then communicating these observations in an open and honest forum and dealing with them swiftly. He also focused on building a relationship with the Jet Propulsion Laboratory (JPL) to support their success, "because ultimately their success would mean our success," he said. As Dr. Weiler noted, "Orlando would go around [JPL] and just talk to the engineers on the floor."

Keeping the program geared toward success required paying attention to the details, which can be hard to do at the director level. "Orlando worked Mars twenty-four hours a day," said Dr. Weiler. Figueroa relied on building trust and open communication to keep him abreast of the details and any problems that might arise. "Jim Garvin [program scientist], Ed Weiler [Associate Administrator for Science], and I worked hard on opening that communication channel," he said. They constantly spoke about progress and issues and agreed on ways to address issues. Eventually, the program manager felt comfortable enough to call Figueroa at home if a critical issue came up. "I would commit myself to not overreacting to anything and allow the team to do their work, recognizing that they would do well in their promise to come back and give me the details," Figueroa said.

"THERE ARE CERTAIN PRINCIPLES THAT I HAVE FOUND IN COMMON [ON MY MISSIONS] THAT MAKE THINGS SUCCESSFUL … THERE IS A SENSE OF RESPECT AND INTEGRITY THAT OPENS THE DOOR FOR OPEN AND HONEST COMMUNICATION. PEOPLE FEEL FREE TO SAY WHATEVER THEY FEEL MAY BE GETTING IN THE WAY OF THE END GOAL."

His thorough involvement demonstrated an in-depth interest in the technical integrity of the mission and supported an ability to anticipate and act upon programmatic issues as they arose. The Mars Program Manager at JPL and the rest of the JPL team appreciated his genuine interest in their work and the support he provided during the inevitable challenges of the mission.

The Mars Explorer Rover mission launched Spirit and Opportunity in 2004. "At any given time in the last year before launch, if you would have told us we would have two successful launches, two successful cruise modes, two successful landings, and two successful missions in total, Orlando and I would not have bet one-tenth of a penny on that. We would have been very, very pleased landing one of them—that was mission success. We couldn't have hoped for two," said Dr. Weiler. Launching two rovers within days of each other had never been done before, and it was accomplished in three years, from conception to launch, in the wake of mission failures from Mars '98.

"He excited a nation. He excited a world. How many federal employees get that opportunity?" said Dr. Weiler.

Now Figueroa has come full circle, returning to the center where he began his education in leadership. As Director of Applied Engineering and Technology at Goddard, he continues to apply what he learned throughout his career to his current job. He is now responsible for 1,300 employees and provides guidance on engineering and system technology. "It is a large organization with exceptional people, and it has a record of success that is hard to match. I want to build from that success to better serve the center and the Agency," Figueroa said.

"There are certain principles that I have found in common [on my missions] that make things successful," he said. "There is a sense of respect and integrity that opens the door for open and honest communication. People feel free to say whatever they feel may be getting in the way of the end goal.

"I talked about maintaining focus on the end game and recognizing that there are going to be very difficult challenges along the way. … To pretend that this is going to be an easy task along the way is foolish and unreal.

"Acknowledging the people who are actually doing the work is another very important part of leadership. I know the individuals I mentioned [as mentors] always took that very seriously, and I'm grateful for them taking the time. I hope I can do as good a job at being the mentor, the example, the leader, the focus that the people who embraced me when I started were. I am certainly committed to it." ●

Innovation Report

The ICB: Recognizing and Rewarding Innovation

BY ROGER FORSGREN

When Congress established NASA under the Space Act of 1958, it realized that the new Agency created to answer the Cold War challenge of Sputnik needed to be a fertile ground for scientific and engineering ingenuity. In order to encourage that creativity, they authorized the Inventions and Contributions Board (ICB) and included it in the legislation that created NASA.

The ICB recognizes and rewards the technological inventiveness of NASA employees and NASA contractors. By doing so, it helps to energize the creative spirit that has made NASA the premier engineering organization in the world. The Board reviews and makes recommendations about the significance of each application for award. In 2005, we received 771 applications from individuals and groups and gave monetary awards totaling nearly $1.8 million to 2,628 individuals.

To become a member of the Board, one has to be recognized as an expert in his or her field and be nominated by a center director. To maintain our objectivity in evaluating applications, we seek to have each center represented. The NASA Chief Engineer, Chris Scolese, chairs the Board.

To reward NASA's engineering excellence and stimulate creativity, the ICB provides four separate Space Act Awards: Board Awards for innovative projects, Patent Awards for inventions, Software Awards, and Tech Brief Awards for ideas accepted for publication in *Tech Briefs Magazine*.

Since our inception in 1958, we have granted more than 89,000 monetary awards to NASA employees and contractors. The Board Awards can be as high as $100,000, depending on the potential significance of the contribution. Currently, Patent and Software Awards are $1,000 for sole inventors or authors and $500 each for multiple contributors. If an idea is published in *Tech Briefs*, we award $350 to each author.

One recent project that received a Board Award was a rotary blood pump, also known as a ventricular assist device (VAD), which won the NASA Commercial Invention of the Year in 2001. The small, turbine pump works with the heart to pump blood instead of replacing it completely. The idea for this pump came from a NASA employee who was also a heart patient. He spoke with Dr. Michael DeBakey about the problems with existing VADs and suggested that Dr. DeBakey speak with NASA engineers about improving them. The result of that collaboration is now regularly used to help heart transplant patients.

An earlier Board Award project developed on-board flight software for Apollo. Margaret Hamilton designed all components and subsystems to eliminate interface errors at the systems level and make all hardware components subservient to the software. Three minutes before Eagle's touchdown on the Moon on July 20, 1969, the software overrode a command to switch the flight computer's priority processing to a radar system that had accidentally been turned on. If the software override had not been active and successfully preprogrammed, the Apollo Eagle might have aborted the mission or crashed that day.

In addition to our Space Act Awards, we present a Software of the Year Award and hold a ceremony each year at NASA headquarters for the winners. The ICB also works with the NASA General Counsel to provide the Invention of the Year Award. To highlight NASA's technical achievements for upper management, we also print an annual report detailing the most significant contributions made throughout the previous year.

In upcoming issues of *ASK Magazine,* I plan to describe some of the outstanding technical work that is being done throughout the Agency so readers can learn about the contributions our colleagues are making. This issue of *ASK* features an article on one of this year's two Inventions of the Year, the braided carbon-fiber thermal barrier developed by Dr. Bruce Steinetz and Patrick Dunlap at Glenn Research Center. ●

If you have questions about the ICB, please feel free to contact me at Roger.Forsgren@nasa.gov. If you want to learn more about the awards process, please visit our Web page at http://icb.nasa.gov.

ROGER FORSGREN earned a bachelor's degree from Georgetown University and a bachelor's and master's degree in engineering from Cleveland State University. He started his career at Glenn Research Center as a technician and worked as a manufacturing engineer in the Manufacturing Engineering Division and as a program manager in the Microgravity Science Division. In 2005 he was appointed the Director of the Inventions and Contributions Board and transferred to NASA headquarters.

2004 Invention of the Year

BY LAURIE STAUBER

A phone call from a concerned Thiokol engineer in 1997 led Dr. Bruce Steinetz and Mr. Patrick Dunlap of the Glenn Research Center to work on developing a flexible barrier that could withstand the extreme temperatures generated by solid rocket motors. The braided carbon-fiber thermal barrier they invented has won the NASA Government Inventions and Contributions Board Invention of the Year Award for 2004, which was presented at a special NASA Headquarters ceremony in September 2005.

Engineers at Thiokol (now ATK Thiokol) worried about heat effects they were finding on the O-rings that sealed the joints between nozzle sections of their reusable solid rocket motors, or RSRMs. In its worst form and combined with brittleness caused by cold weather at launch, a similar problem in the motor's field joint led to the Challenger disaster in 1986; lesser nozzle O-ring heat effects have been observed on flights since then. One of the ATK Thiokol engineers remembered reading about an award Steinetz and Sirocky (a former colleague) had received for high-temperature seal work. He called Steinetz and asked if the seal team could apply their expertise to the solid rocket motor's seal problem.

The carbon thermal barrier seal passes a torch test with flying colors.

Steinetz and Sirocky's 1997 Invention of the Year award was for a ceramic, braided rope seal used in the engines of the F-22 and other applications that require an effective insulator that is also flexible and resilient. But the RSRM presented a much greater challenge. The original ceramic seal was exposed to temperatures of around 1500°F. In ATK Thiokol's rocket motor, the thermal barrier would face temperatures of around 5500°F. When the engine fired, pressure in the RSRM nozzle joints would go from ambient atmospheric pressure of 14 lb./square inch to 1,000 lb./square inch in less than a second. The thermal barriers would have to protect the booster's O-rings from high temperatures while allowing enough gas through to provide the pressure needed to seat the O-rings firmly in their sealing positions. And the thermal barriers would have to survive for close to two-and-a-half minutes, the length of time that the rocket fired.

The challenge was all the greater because Steinetz and Dunlap had no money earmarked for the research. They could borrow a little funding from other projects that would benefit from what they learned, but they would have to find an inexpensive way to develop and test possible solutions.

Luckily, a standard oxy-acetylene torch generates about 5500°F of heat, so they had a ready-made, low-cost tool for screening potential thermal barrier materials. They first tested their ceramic braid seal. The torch burned through the material in just over six seconds. Next they tried a thermal barrier made of braided phenolic, a heat-resistant plastic. It lasted approximately 40 seconds. Their third test material was an eighth-inch diameter rope braided out of an aerospace grade carbon fiber, a close cousin to the material used in some golf club shafts, fishing rods, and other sports equipment. The carbon braid was promising, lasting about two minutes before it burned through. A quarter-inch braid lasted more than six minutes. They had taken a major step forward in solving the problem and communicated the results to ATK Thiokol.

ATK Thiokol ran tests on the carbon-fiber thermal barriers, first in rockets with 70 lb. of thrust (as compared with the millions of pounds of thrust of their full-scale rockets) and then on larger, though still scaled-down versions of the RSRM. The thermal barriers passed with (literally) flying colors. Tests that recorded temperatures more than 2500°F on the upstream side of the dual thermal barriers registered less than 200°F on the other. The braided structure was key to solving the problem of letting sufficient pressure through to seat the downstream O-rings while

THE CHALLENGE WAS ALL THE GREATER BECAUSE STEINETZ AND DUNLAP HAD NO MONEY EARMARKED FOR THE RESEARCH. THEY COULD BORROW A LITTLE FUNDING FROM OTHER PROJECTS THAT WOULD BENEFIT FROM WHAT THEY LEARNED, BUT THEY WOULD HAVE TO FIND AN INEXPENSIVE WAY TO DEVELOP AND TEST POSSIBLE SOLUTIONS.

protecting them from heat. The new thermal barriers will be used on ATK Thiokol RSRMs for shuttle mission STS-122.

Steinetz says that how the barrier produces so great a temperature drop is "a little bit of a mystery." Looking back on the discovery process, he remarks on how "uneven" technical development is. "A lot of things lined up perfectly, and we were able to come to a solution in short order," he says. "Many research projects don't go like that."

The thermal barriers have also solved a problem in the solid rocket motors Aerojet manufactures for the Lockheed-Martin Atlas V. The 67-foot-long Aerojet rockets are a single piece, with no joints except where the rocket body connects with the nozzle.

Steinetz and Dunlap are pictured with their thermal barrier and patent.

In the summer of 2002, only months before the scheduled launch of an Atlas V to put a commercial satellite in orbit, an Aerojet rocket suffered a dramatic failure on the test stand due to hot gases compromising the nozzle seals and joint. Aerojet engineers asked Steinetz and Dunlap for help and quickly redesigned the joint using three of the braided carbon-fiber thermal barriers. The rocket was certified in June 2003, and the commercial launch took place the following month. Since then, Atlas Vs with pairs of Aerojet rockets have successfully launched the AMC-16 satellite that provides DISH network services and Inmarsat 4-F1, which delivers broadband communications to 86 percent of the world.

NASA will use the Atlas V to launch the Pluto Horizons Spacecraft in 2006 and is considering its use to launch payloads for the International Space Station and future Exploration Initiative missions. Steinetz and Dunlap have turned their attention to other challenges, including developing docking and berthing pressure seals for the Crew Exploration Vehicle and seals designed to mate a new Apollo-like heat shield to the vehicle structure. ●

LAURIE STAUBER currently works as Marketing Liaison Specialist in the Technology Transfer & Partnership Office at Glenn Research Center. She is also the Awards Liaison Officer, manages the Glenn Success Stories Team, and covers *Spinoff Magazine* for the center.

NASA Knowledge Map

www.nasa.gov/about/sites/index.html

ASK Magazine would like to extend special thanks to Stephen Chesley in the Office of Human Capital Management for his assistance.

AMES RESEARCH CENTER
Moffett Field, CA

1,224 civil servants | 1,521 contractors

Focuses on information technology

Engages in wind tunnel development and operation

Uses supercomputing and advanced computer-based modeling

Explores artificial intelligence

DRYDEN FLIGHT RESEARCH CENTER
Edwards, CA

424 civil servants | 520 contractors

Focuses on atmospheric flight operations

Supports development and operations for the Shuttle

Enhances competitiveness in the U.S. aerospace industry

JET PROPULSION LABORATORY
Pasadena, CA

5,225 employees

Focuses on deep space systems

Designs and operates spacecraft to explore the Solar System

Supports research in automated spacecraft operations and related computer science

JOHNSON SPACE CENTER
Houston, TX

2,748 civil servants | 12,282 contractors

Focuses on human operations in space

Serves as shuttle mission control and operations planning

Conducts studies of lunar samples returned by the Apollo program

GLENN RESEARCH CENTER
Cleveland, OH

1,628 civil servants | 1,744 contractors

Focuses on turbomachinery

Conducts combustion research

Prepares chemical and electric rocket propulsion

GODDARD SPACE FLIGHT CENTER
Greenbelt, MD

2,846 civil servants | 4,400 contractors

Focuses on scientific research

Manages and operates the Hubble Space Telescope

Directs development of the Earth Observing System

NASA HEADQUARTERS
Washington, DC

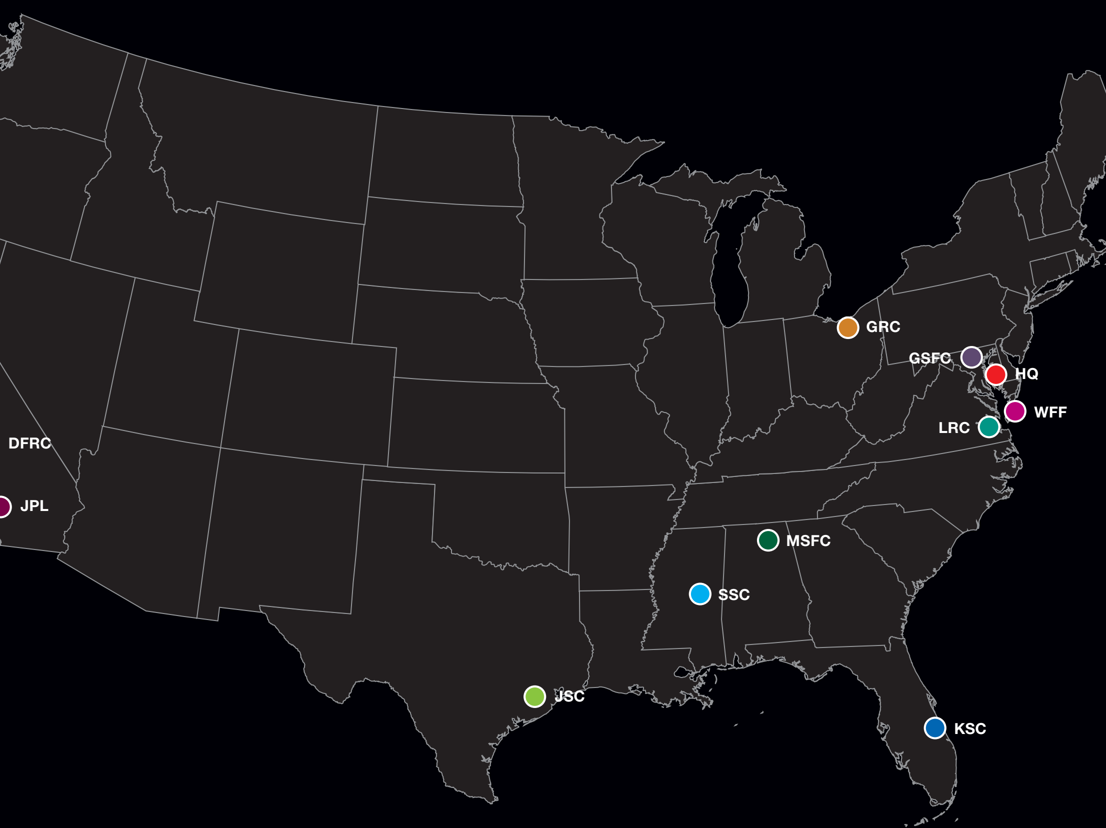
1,500 civil servants | 752 contractors

Headquarters has authority for all NASA-related entities/projects

Interacts with Administration and Congress

Serves as focal point for accountability, communication, and liaison for external entities

Provides agency leadership through budget integration, policies and procedures



WALLOPS FLIGHT FACILITY
Wallops Island, VA

255 civil servants | 529 contractors

Focuses on suborbital research programs

Serves as rocket launch site

Sends scientific research balloons into the Earth's upper atmosphere

LANGLEY RESEARCH CENTER
Hampton, VA

1,906 civil servants | 1,557 contractors

Focuses on aeronautical flight research

Explores hypersonic flight

Examines advanced composite materials and their nondestructive testing

STENNIS SPACE CENTER
SSC, MS

254 civil servants | 1,258 contractors

Focuses on rocket propulsion testing

Maintains and operates a range of test-firing stands

Issues grants for land-use planning and other Earth remote-sensing data

MARSHALL SPACE FLIGHT CENTER
Huntsville, AL

2,391 civil servants | 3,554 contractors

Focuses on space propulsion

Develops pressurized living and working modules for the International Space Station

Preparing to lead development of new generation of reusable launch vehicles

KENNEDY SPACE CENTER
KSC, FL

1,793 civil servants | 10,708 contractors

Focuses on launch and cargo processing systems

Develops and maintains the Shuttle launch pads and control center

Provides primary landing site for the Shuttle

NASA Knowledge Map

In a meeting at Babson College in Wellesley, Massachusetts, *ASK Magazine's* new editorial team met with the Academy of Program/Project and Engineering Leadership's (APPEL) Knowledge Sharing Project Manager, Tina Chindgren, and Director, Dr. Ed Hoffman. During discussion and planning, we confessed that it was challenging for newcomers to take in the **breadth** and **depth** of NASA's research. It occurred to us that even many NASA veterans might benefit from a clear, concise overview of what happens where in the organization. We decided to create an explanatory picture of NASA centers that offers an easy way to grasp the **range** and **location** of NASA activities. APPEL partnered with Hirshorn Zuckerman Design Group to produce this NASA Knowledge Map, which we present here for your use. ● Mapping knowledge is a relatively new concept, gaining currency along with growing recognition of the importance of developing and coordinating organizational knowledge. A knowledge map is meant to present complex details in a visual format that helps people more easily see what an organization "knows." It can be especially useful at showing **geographic location, relationships, and relative size**—information that is hard to communicate economically and effectively in words alone. Visualizing knowledge can aid understanding of an organization's many practices and how they fit into the larger network of knowledge. ● We consider this map to be a work in progress, and we welcome your suggestions for changes and additions that might make it more useful (keeping in mind that simplicity is one of the hallmarks of a good knowledge map). You may find our contact information at the end of this magazine on the "*ASK* Interactive" page.

NASA Core Values

SAFETY

NASA's constant attention to safety is the cornerstone upon which we build mission success. We are committed, individually and as a team, to protecting the safety and health of the public, our team members, and those assets that the nation entrusts to us.

TEAMWORK

NASA's most powerful tool for achieving mission success is a multidisciplinary team of competent people. The Agency will build high-performing teams that are committed to continuous learning, trust, and openness to innovation and new ideas.

INTEGRITY

NASA is committed to an environment of trust, built upon honesty, ethical behavior, respect, and candor. Building trust through ethical conduct as individuals and as an organization is a necessary component of mission success.

MISSION SUCCESS

NASA's reason for being is to conduct successful space missions on behalf of this nation. We undertake missions to explore, discover, and learn. And we believe that mission success is the natural consequence of an uncompromising commitment to safety, teamwork, and integrity.

Source: Strategic Management and Governance Handbook, NPD 1000.0 (Washington, D.C.: Office of the Chief Engineer, August 2005).

INTERVIEW WITH

Chris Scolese

BY DON COHEN

Shortly after he took on the job of Chief Engineer, Chris Scolese talked with Don Cohen about leadership, learning, and NASA's new mission.

COHEN: How do you see the role of the chief engineer at this moment in NASA's history?

SCOLESE: The job that Mike Griffin asked me to do is to bring excellence in engineering to this Agency. I believe we have great engineers, scientists, and practitioners here. One part of my job will be channeling the talent we've got to deliver the new products that we need: a CEV (Crew Exploration Vehicle); a launch vehicle to get us to the Moon and ultimately to Mars; and robotic missions to scout areas where we want to put humans down and to find resources so they can live as much off the land as possible.

COHEN: Do you think it's important to retain the knowledge of older engineers soon retiring from NASA to accomplish this mission?

SCOLESE: Absolutely. In some ways, our human space flight goals are a case of back to the future. We need to learn from the experience of the people that helped us with the shuttle and Apollo so that we have the best possible chance of delivering the vehicles we need. That's going to mean not only looking at people we have currently working in the Agency but talking to people who worked at NASA or in industry and are now retired. A lot of people have been writing books about the Apollo era lately, but there's no

"ONCE WE CAN leave Earth's orbit AND START LIVING OUT THERE, THE BEYOND BECOMES VERY BIG. THE whole solar system and universe ARE OPEN TO US. WE'RE GOING TO BE LOOKING FOR Earth-like planets. WE'RE GOING TO BE LOOKING AT THE fundamental physics OF THE UNIVERSE."

substitute for talking to the practitioners and finding out what the reality was when they were building the lunar module or the capsule.

COHEN: It's hard to capture that knowledge.

SCOLESE: It is, and as you get further from the experience, you tend to remember the good things and overlook the bad. NASA has to become a learning organization. One of the things I want to see us do is get lessons learned out as quickly as possible. We need to do this for our successes as well as our failures. We need to sit down for an after-action review after a mission is launched, catalogue the lessons of that experience, and make them immediately available.

COHEN: After-action reviews seem to work well when they're a standard part of every project. If they're voluntary, people will always be too busy to do them.

SCOLESE: When I went to Goddard, they were required after a mission was launched and checked out. And after every mishap or significant close call, we had an after-action review.

COHEN: So you think learning from mistakes is important?

SCOLESE: We lost some of our luster because of Columbia and the Mars '98 failures. But, as we learned from Mars '98, we can come back stronger when we apply the lessons learned from failure. My job is to take those lessons and produce the successes we need in the future. It's not going to mean we won't have failures, but we want to make sure they are few and far between, and we don't ever want to have a Columbia again. We want to develop a test program that tells us what the limits are so we don't put a crew at risk, so we don't lose a mission. Part of what we learned from Mars '98 is that engineering rigor, discipline, and rigorous review processes give you the highest probability of mission success. We have to apply the same lessons on the human space flight side. We haven't designed a human spacecraft in thirty years. We haven't flown a new human spacecraft in ten or twenty years, depending on whether you include the replacement orbiter for Challenger. We've got to reenergize our talent and go back and get the talent that helped us design and test the shuttle and Apollo. We also need new capabilities.

COHEN: For instance?

SCOLESE: Having a long-term program means we've got to bring in talents that are not traditional to the Agency. We know that many of these new systems are going to last ten, twenty, or thirty years. We have to look at maintainability, supportability, and logistics so they will still be viable thirty years from now. We're going to have to maintain the knowledge that it took to design those systems so we know how to operate and adapt them. The shuttle was designed thirty years ago by a lot of smart people, most of them now gone from the Agency. Many decisions they made that may not seem to make sense today made sense then, but if you don't have the knowledge that allows you to say, "Oh, that's why," you run into issues. The same is true of the expendable launch vehicles. The Delta II is a wonderful vehicle. Had we known it was going to be around for fifty years, we probably would have thought about it differently. Today, we know that what we design will be around for twenty or thirty years, so we can start thinking differently now. That's a new capability for NASA.

COHEN: Does the new mission focus mean hard choices for NASA? For instance, backing away from programs it has supported in the past?

SCOLESE: We certainly have to make hard choices, but I'm not sure the new vision has as much impact on that as other factors. Instead of eliminating capabilities, we will be focusing capabilities. You'll see that all the letters of "NASA" apply. Landing on the Moon is one thing, and we've done it with robotic spacecraft and human spacecraft. So we have some experience there. Mars is different. It has an atmosphere—thinner than Earth's, a different composition, but an atmosphere. That means landing will be a different process. NASA successfully landed on Mars five times, in some cases with powered descent and in some cases using parachutes and balloons. Now we're talking about larger spacecraft to send humans there, so we're going to have to understand the Martian atmosphere a lot better. If our folks working on hypersonic aircraft and aerodynamic shapes can come up with the capabilities that allow us to have a wider range of entry conditions, that makes the job of landing there that much easier. We can use the atmosphere to slow down. For instance, we can use parachutes. Again, most of our knowledge of parachutes comes from the aeronautics folks. If we understand Earth's atmosphere, to a certain extent we can extrapolate that knowledge to Mars. The better we understand the chemistry and physics of the atmosphere, the more likely we're going to be able to land on Mars safely. Understanding the constituent parts of the atmosphere may provide capabilities for robotic air-breathing engines. Also, robotic spacecraft that go in long before humans get there can find not only good landing sites but also resources. Where might there be water? Where might there be heavy concentrations of oxygen-bearing minerals? Where might there be potentials for getting fuel? If we find an area that has water or ice, we can convert that to hydrogen and oxygen, and we've got fuel. If we find carbon dioxide and bring some hydrogen with us, we can make methane. Now we have methane and oxygen: fuel. We can breathe oxygen that we find.

Our vision calls on us to provide economic opportunities and expand our knowledge of science. We're going to be looking at the earth to understand it better. We've just been through powerful hurricanes. If we can support our sister agencies—NOAA [National Oceanic and Atmospheric Administration] and USGS [U.S. Geological Service] and FEMA [Federal Emergency Management Agency]—we'll do that. But our prime focus will be on getting people on the Moon and Mars. Once we can leave Earth's orbit and start living out there, the beyond becomes very big. The whole solar system and universe are open to us. We're going to be looking for Earth-like planets. We're going to be looking at the fundamental physics of the universe.

COHEN: Are there problems of communication and maybe tensions or disconnections among groups—engineers, scientists, astronauts, bureaucrats—that need to be resolved to achieve these goals?

SCOLESE: A lot of what came out of the CAIB [Columbia Accident Investigation Board] report and the return-to-flight task group addressed exactly those issues. We didn't have the communications we needed to make the right decisions. Those barriers are being brought down. The NASA Engineering and Safety Center (NESC) is one example of doing that by bringing together the best engineering talent from around the Agency—not just from Ames or Glenn or Langley or Goddard or JPL or Johnson or Marshall or Kennedy. They are available as a resource to bring exactly the cross-fertilization and different views you're talking about. The Independent Technical Authority is addressing the question of who is responsible for the success of an element or of a system. That's part of what engineering excellence is about.

There's always some tension, frankly, and it's healthy. Do scientists talk to engineers? Of course. If they don't, they're not going to get what they want. Do engineers talk to scientists? Of course. If the scientists don't have good ideas, there are fewer missions to do. Scientists want to accomplish significant things. So does the bureaucracy. They set the goals and then the engineers and astronauts and resource people say, "We can go this far, but not that far." We don't want to lose that tension, but we do want to bring down the barriers of communication. That's part of my job. Engineering excellence always comes down to communication and the ability to work together.

COHEN: So maybe organizational skills are as important a part of achieving NASA's goals as technical skills.

SCOLESE: We definitely have to adjust our management and organizational philosophies to meet those challenges. And we should evaluate those techniques just as we evaluate technologies. When you have a new technology, you're skeptical, you worry about it, you check it, you modify it as you go along until it delivers what you expected. Or you adjust your expectations to what you can deliver. We need to do the same thing with our management systems. We haven't done that. We never look down the road and ask, "Is it giving us the value we expected in the beginning?" When we need a new engine, we develop a test program and look at every step along the way: Are the materials working? Are the temperatures what we predicted? Do our analytical models make sense? If not, what do we have to change? We should do the same thing for our management systems.

COHEN: What is it in your background that gave you the values and insights you're applying now?

SCOLESE: I was in the nuclear navy for about eight years, part of that time working for Admiral Rickover. That instilled a value in me that's absolutely important: being personally responsible for the success and safety of the mission. In the nuclear navy, when a new ship went to sea or you put new hardware on a ship, you went out with the crew. So you *really* want to make sure it works. Of course, you do anyway, but this dramatized the point. You never want to be in a situation where you'd say, "I wouldn't go out on it because it's unsafe." When I was a junior officer, I didn't have much responsibility, but I knew that what I did would have an impact. If we're going to have engineering excellence, technical excellence, and mission success, every single person has to realize that they are part of the team and their work is important to the success of the mission. Whether your work is sweeping the floor; washing windows; typing reports; or designing, testing, or flying the system, you're part of it. You're responsible for your job but also for problems you see. There was the case of a janitor who was sweeping up and noticed bolts lying on the floor. He reported it. I don't think those bolts had a direct impact on the mission, but they showed that people controlling the hardware weren't doing a good job.

COHEN: Is there a part of your experience that helped you recognize the importance of the human or social side of an organization?

SCOLESE: I think sports did it, to be honest with you. I wasn't a very good baseball player in Little League, but we had a coach who was just great. We were a bunch of misfits, but we all got along. The coach taught us what he could, and we probably won more games than we should have. I ended up being pretty good in track, but my first two years on the team were really frustrating. The coach didn't provide any organization. My last two years, with largely the same people and a different coach, were fantastic. We won various championships at the appropriate level. We went as high as we could possible go. I saw that building a team depended not only on the people on the team but also on the

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leadership, and that a well-functioning team can accomplish a lot more than the individuals themselves. Sometimes that involved personal sacrifice. The coach would say, "I know you can win this race, but I really need you to take at least a second or third place in another one." So you thought, "All right, I'm not going to get a gold medal this time." Sometimes you surprised yourself. The team ended up doing well as a result, and we all ended up doing well. Throughout my career, most of my supervisors have recognized the importance of good leadership and helped me to recognize it. In the navy and NASA, I was fortunate to have people who appreciated and understood that and served as mentors. And I had one really terrible person and saw how dysfunctional you could be when you don't recognize and utilize talents.

COHEN: I've been struck at how talented and enthusiastic most people at NASA are.

SCOLESE: In an organization like NASA, you find very few people who are poor performers, but you often find people who are in the wrong job. What we have to do as supervisors, leaders, and managers is find the right job for the person. When you do that, they usually excel. I've yet to find anybody in NASA who just comes in to sit at a desk. Everybody is motivated. They could make more money and have a more relaxed personal life in just about any other place. We build one-of-a-kind items so you never know what's going to happen tomorrow because you're pushing an envelope here. You don't have a blueprint to go back to and say, "We built the last car like this, so this car goes the same way." People here are motivated to do things that are hard. One of the great things about NASA is we're always doing something different and trying to do something better. We're not building the hundred-thousandth car. We work at the frontiers of technology and science and humankind. ●

Straight to the Source

BY JON BOYLE

"It doesn't look good in terms of the schedule. I don't see any way we are going to make the delivery deadline," our project manager said. He settled back into his chair, a look of resignation on his face. I was looking at the same data and coming to the same conclusion. There was no way we were going to meet schedule requirements, much less cost or technical performance requirements, based on the projections we had just reviewed with the management team. The schedule had steadily slipped from project kick-off onward, until now we faced a significant adjustment.

I had just been assigned as the Deputy Project Manager for a critical Department of Defense (DOD) project that was based on cutting-edge technology that had the potential to change the way U.S. forces engage the enemy on the battlefield. The project faced critical challenges of balancing research and development concerns in untested technology with prototype production issues concerning numerous components fabricated by hand for the very first time.

There was no arguing the data. We used a project management software package that captured every detail of the project and provided us with a clear status on every angle of project progression at the subtask level. The project manager, Mark White, was recognized as a technically savvy businessman who possessed encyclopedic knowledge of every detail, and he could quickly tell you the status of any task in his comprehensive project plan. In every senior management briefing, this guy absolutely shone through as an authority on how production projects are controlled, and he always had the right answer at the right time. Mark had never managed a research and development project, however, only production projects with proven technologies. Now we had hit a deep pothole. It looked like the schedule would slip at least a month because of undefined technical production difficulties and slower-than-anticipated assembly processes.

I looked at the management team. Their body language clearly communicated the deep funk the project review had thrown them into and reflected the mood of the project manager. I began to get angry, wondering what, specifically, was putting us behind schedule. I decided I needed much more data than the spreadsheets, projections, and reports could tell me. The fabrication plant was within an hour's drive of headquarters. "Mark," I called across the room, "I'm headed out on a visit to the fabrication facility. Just gonna go and see what's going on." The project manager was back at the computer screen, analyzing the data … one more time as he waved an acknowledgment in my direction.

The traffic could have been much worse, and I pulled up to the gate within the hour. I drove to the assembly building, processed through security, and entered the main production floor. Impressed by the product sitting under bright flood lamps, I noticed a curious feeling surrounding the work area. There was little actual assembly activity going on, but I saw assemblers in little groups talking, drinking coffee, and working on paperwork—doing everything but work on the vehicle. I approached one of the workers and asked, "Where's the foreman?" After I explained that I was the Deputy Project Manager, he directed me to a small room off to the side of the main area.

THERE WAS LITTLE ACTUAL ASSEMBLY ACTIVITY GOING ON, BUT I SAW ASSEMBLERS IN LITTLE GROUPS TALKING, DRINKING COFFEE, AND WORKING ON PAPERWORK—DOING EVERYTHING BUT WORK ON THE VEHICLE.

"I understand you're the foreman here. I'm the new Deputy, Jon," I said as I sat down in Hank Glaser's office. As I talked with the foreman, I slowly realized that he didn't know how important the schedule was and how our activities affected DOD testing requirements that would occur after we delivered the product. I explained the big picture to Hank, covering all the details and how our project fit into program requirements, as well as going over what impact our inability to deliver to schedule would have on other program elements. Hank now understood the situation and anxiously shared with me the technical and production issues that had slowed the project down.

It turns out that there was great concern about wiring together different systems that were being fabricated. The complex product gave off so much heat during operation that the handmade circuit modules required metal heat sink covers. But tight tolerances meant that wiring cables were getting stuck on heat sink covers throughout the product as the workers attempted to run cables. I walked around the production floor with Hank, talking to the workers as we thought about the issue.

I noticed a small piece of wide-mesh nylon screen sitting on a worktable. I picked it up, and it felt slippery between my fingers, stiff and yet flexible. "Hank, would this stuff work if you attached it over the top of the heat sinks?" I asked. "It seems pretty flexible and slippery, but I don't know if it could take the heat, and I'm not sure how you would be able to attach it to the heat sinks." Hank's eyes grew wider as he thought. "You know," he said, "this is pretty unconventional, but it might work."

That afternoon, Hank sent the nylon screen over to engineering to be tested, to design an approach using such a concept, and to see if there were any better materials that could be used to overcome the heat sink problem. As it turns out, engineering conducted heat-dissipation tests and validated the concept of the nylon screen, recommending ordering rolls of the very same material to be attached by heat-resistant glue to the heat sink covers on all modules situated under cable run areas.

I returned to the management team and asked Mark for permission to relocate my duty area to the fabrication plant. Mark readily agreed, since he had already been informed of the technical solution to the heat sink problem. I began delivering the project management report directly to the assembly team, giving them access to the same data that the management team received on a regular basis. I also helped with the assembly process, tucking my tie into my shirt and assembling pieces of the product, even drilling and counter-sinking different parts. I got to know the team pretty well, and we laughed and worried and sweated through the ramp-up to delivery day.

As it turns out, we beat the schedule by two days, and we came in under budget, even after I had ruined some parts of the product by counter-sinking them too deeply with the drill. Leading by example and opening the lines of communication had done the trick. In the assembly worker's view, management had taken the time to come down and work at their level, keeping them informed every step of the way, giving them the big picture about where they fit into the overall scheme of things, and adding outside perspective on a problem they were too close to to solve. I also received the "Counter-Sinker of the Year" Award at the company awards luncheon, gently being chided that we would have come in even more under budget if I had only known how to counter-sink better. ●

DR. JON BOYLE is the Program Manager for the NASA Academy of Program/Project and Engineering Leadership (NASA APPEL) at Arctic Slope Regional Corporation Management Services, responsible for all products and services produced by the Academy and strategic relationships for the program. Dr. Boyle teaches Knowledge Management at Virginia Tech, where he earned his Doctorate. He also holds a M.A. from George Mason University and a M.Ed. from Boston University.

LEARNING TO SOAR

BY MICHAEL ALLEN

On a spring day at Edwards Air Force Base, someone pointed overhead to a flock of migrating white pelicans soaring gracefully in formation. I wondered if the Autonomous Soaring project I had just started would produce an unmanned aerial vehicle (UAV) that could soar as gracefully. Not likely, I thought, as the pelicans soared in perfect unison, optimizing their climb rate in an invisible column of rising air called a thermal or updraft.

Michael Allen stands with the SBXC glider.

The Autonomous Soaring project was initially funded in 2003 with director's discretionary funding. The result of the work done in 2003 was a simulation study using National Oceanic and Atmospheric Administration weather measurements to estimate updraft properties at Desert Rock, Nevada. The study showed that a small UAV could extend its two-hour nominal endurance to fourteen hours during the summer and up to eight hours in the winter. In 2005, with funding from the NASA Flight and System Demonstrations Project, I put together a small team to demonstrate that a small UAV could actually detect and stay within an updraft without human intervention.

While others had written papers and hypothesized about extending UAV flight time by using updrafts to reserve engine power, no one had tested the theory. If our experiment succeeded, we could influence the way UAVs are used for earth science, weather monitoring, and military surveillance. Our success could also increase the effectiveness of a Mars airplane, allowing for observation at levels between the rovers and the orbiters. Since the detection of dust devils on Mars indicates a movement of heat through the atmosphere, a small UAV could ride the same updrafts that form the dust devils and survey the planet from a new altitude.

The fact that hobbyists are able to soar with radio-controlled model gliders in updrafts for long periods of time using only visual cues indicated that our task was possible. The difficulty lay in trying to put soaring skill and good judgment into an algorithm that could run on a miniature autopilot aboard a UAV. The actual vehicle was unimportant. Soaring on updrafts didn't require a different fuselage shape or longer wing span, it required the correct algorithm for detecting thermals in the air and shutting off the engine. We knew immediately that our focus was not going to be on the hardware for our UAV; we had to get the programming right.

A great way to put human language rules into computer code is to use fuzzy logic, which uses a set of nonlinear functions and rules to capture the meaning of less-than-mathematically precise words in algorithms. Our rules for soaring came from the book *Cross-Country Soaring* by Helmut Reichmann, a well-known competition glider pilot. Those rules helped us create the controller that would switch the UAV to soaring mode when a thermal was detected. The new soaring controller worked the first time we tried it in our development simulation, but as soon as we included calculations to smooth the "noise" we expected from the flight sensors, the aircraft wandered along a path that looked like the petals of a daisy. A comparison of the smoothed value used by the controller to the original measured value showed that the problem was caused by a delay the smoothing calculations introduced. Finding better sensors to install on the aircraft would solve the problem, but purchasing and installing the new sensors was beyond the scope of our 1.5 full-time equivalent, one-year project. The solution had to come from a software change instead.

Our team included six engineers and two summer students. None of the engineers worked on the project full time, and the students did not stay for the entire project. This was a side experiment for all of us, and we worked on it because we were interested in the results. We had to be self-motivated for the project to continue and succeed. As a result of our part-time status, only two or three of us could get together at a time, so a rotating cast of people worked on our UAV at any moment. Because of this, software changes had to be easy to make and to test, and they had to be self-explanatory or easily shared through e-mail, since most of our communication was written.

We selected the Cloudcap Piccolo Plus autopilot for flight testing because it used Matlab Simulink software to describe the autopilot guidance and control algorithms. This meant that we could make changes in the software that could be tested using a Matlab-based simulation, or we could test the software using a hardware-in-the-loop (HIL) simulation. The HIL simulation fed aircraft parameters to the Piccolo hardware—the place where the calculations for flight control and soaring were made—and the Piccolo would send back new commands for the rudder, elevator, and aileron, for example, to better maneuver the airplane.

IF OUR EXPERIMENT SUCCEEDED, WE COULD INFLUENCE THE WAY UAVs ARE USED FOR EARTH SCIENCE, WEATHER MONITORING, AND MILITARY SURVEILLANCE.

Once we had the software that would allow us to make quick and easy changes, we had to fix the problem caused by sensor delay. We included an updraft position estimator in the algorithm to give the aircraft a quicker indication of when it was off course. Our subsequent controller worked very well in the Matlab simulation, but it caused erratic behavior in the HIL simulator. We quickly realized we had overtaxed the Piccolo by adding the fuzzy logic controller and updraft estimator in addition to its own autopilot calculations. The fuzzy logic controller was a major cause of the problem; it was taking more time to compute than the updraft estimator or the standard autopilot. Again the problem was quickly fixed in software by re-casting the fuzzy logic controller in a simpler form.

With the software and controller working to our satisfaction, we needed to select a plane. We chose a model glider called the SBXC, made by RnR Products, for flight testing because it had a large fuselage and a wide speed range (18–100 mph). An electric motor with gear reduction was added to allow the airplane to climb to test altitudes and cruise while searching for updrafts. A folding propeller reduced drag when the aircraft shut off its motor during soaring flight. Guidance and control were accomplished using the Piccolo autopilot, which is a self-contained flight computer and sensor package about the size of a brick that weighs only 7.5 oz. It includes GPS, aircraft accelerations and rotational rates, static and total pressure, and a radio modem.

Before flights could begin, we had to solve the problem of flight termination. If the flight had to be terminated, cutting power to the motor would not work because the excellent gliding performance of the motor-glider meant it could still fly long distances. We solved the problem by adding a mechanism to deflect the elevator to 60° and put the aircraft into a “deep stall” if we needed to bring it down. Fortunately, we never had to use this feature during flight tests.

Research flight testing began on August 5, 2005. The first time we turned on the soaring algorithms, the aircraft flew through several updrafts but never switched into soaring mode. One week later, after another software change, we saw our first autonomous detection and engagement of an updraft; the aircraft shut off its motor and climbed 300 feet. The aircraft switched into soaring mode many times during that flight, but it kept finding updrafts that were too weak for soaring. At the end of the flight, we let our pilot, Tony Frackowiak, soar the aircraft remotely so we could gather data to compare with the autonomous system.

We didn’t immediately prepare for the next flight. Instead, the ground station operator, Victor Lin, and I did a quick replay of the flight data in Simulink to determine what was happening. We found that the software fix was simple and increased the updraft vertical velocity threshold used in the mode switching logic to determine if an updraft was strong enough to soar in. We demonstrated the flexibility of our process that day by making a flight software change in the field between flights. The total time needed to analyze the problem, fix the software, compile and load the software on the aircraft, and prepare the aircraft for flight was less than two hours. The change proved successful, and the aircraft found five more updrafts and successfully climbed in one of them to gain 1,000 feet of altitude.

I believe that the success of the project was due in a large part to the flexibility allowed by our unique flight-software change process. The development of analytical tools that could be used to look at both simulation results and flight data allowed flight tests to be another step in the development of the algorithms. The tools made possible a “fly-fix-fly” approach that sped the development of the soaring algorithms. Our UAV never did soar as gracefully as a white pelican, but it was amazing to see our design take flight and soar. ●

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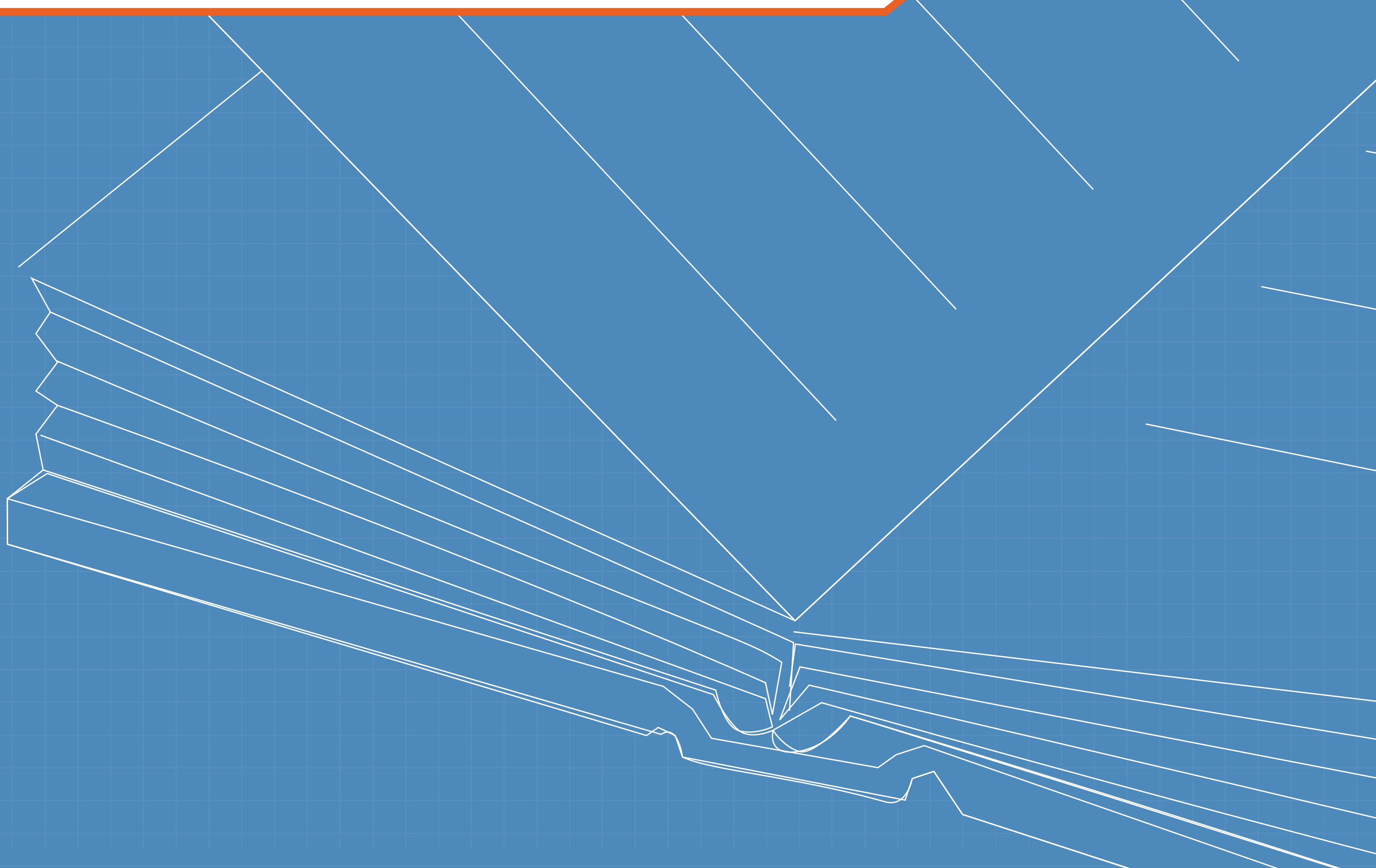
Enhancing NASA's Performance as a Learning Organization

BY RICHARD DAY AND ED ROGERS

> The Board concludes that NASA's current organization does not provide effective checks and balances, does not have an independent safety program, and has not demonstrated the characteristics of a learning organization.
>
> —Columbia Accident Investigation Board Report (2003)[1]



In May 2003, Goddard Space Flight Center recruited a Knowledge Management Architect to apply additional focus to the integrated management of the center's knowledge assets—in particular, its forty-seven years of experience-based wisdom in managing space flight projects. In August of that year, the Columbia Accident Investigation Board (CAIB) released its final report calling for NASA to act more like a learning organization. As Knowledge Architect and Director of the Office of Mission Success at Goddard, we believed that the two challenges of integrating knowledge management and creating a learning organization were intertwined and must be addressed together. This is the story of how we are addressing these twin challenges at Goddard.

Academic literature suggests that a learning organization knows how to retain knowledge, appreciates the value of sharing collective knowledge, and grows more knowledgeable with each activity it performs. Knowledge management literature tells us that the core of an organization's knowledge resides in the work units and projects where it is being generated, not in a centralized repository. The key to managing knowledge is not to extract it from its origins but to facilitate its use both at its source and within communities of practice across the organization.[2] With these ideas as starting points, we set out to design an approach to improve Goddard's performance as a learning organization while improving the way we managed our knowledge.

We started by looking at what was already happening in the Agency. There are many activities called "knowledge management" and dozens of tools and databases in use. Many of these tools seemed to offer some useful efficiency gains by automating activities, keeping records, controlling, and, in a limited way, searching documents. As we looked deeper, we concluded that, to be effective, knowledge management must go beyond simply getting the right information to the right people at the right time. Focusing solely on knowledge efficiency concerns would not necessarily create a healthy organizational learning environment and might, in fact, hinder some types of collaborative learning behavior.

NASA's knowledge management efforts prior to Columbia tended to focus on providing information technology tools with an emphasis on capturing knowledge from workers for the organization as opposed to facilitating knowledge sharing among workers. In line with other organizations (Army, World Bank, and aerospace industry), we emphasized that the core of Goddard knowledge resides in the engineering work units and projects where it is being generated. Therefore, knowledge management should help Goddard project teams, work units, and other groups behave and function as parts of a learning organization, generating, sharing, using, and preserving their own knowledge. The divisions and other work units at Goddard are the primary owners and holders of their knowledge. Goddard's plan is designed to help put practices in place that will facilitate the flow of knowledge and help build the local learning loops that characterize a learning organization.[3] We tried to apply these lessons learned about knowledge management at Goddard to achieve meaningful change toward the goal of becoming a better learning organization.

The Goddard System of Learning Practices

Lessons from the field of strategic human resource management told us that we would need a coordinated system of organizational practices, not a single process or application.[4] We also needed a representation of a learning architecture to support communication and understanding of the concept among project teams. The learning architecture is evolving into a complex, integrated map of Goddard mission success processes, but we nevertheless wanted a concept that would fit on one page, could be represented in a picture, and would make sense to any project manager in less than five minutes. After months of iterations and discussions with project participants, we settled on six practices that we incorporated into a learning-loop diagram (see figure on page 39). The architecture is designed to avoid short-term, suboptimal solutions based on efficiency models, address the three characteristics of a learning organization, and build a more reliable and sustainable organizational system. The next step was to get these six practices embedded in the Goddard project life cycle.

Practice 1: Pause and Learn (PAL)

The Pause and Learn (PAL) process is the critical foundation for learning from projects. PALs are participant discussions of what went right and wrong and what lessons the experience taught. Experience from the Army tells us PALs should occur after major events and milestones.[5] They are valuable because data collected close to the event eliminates the bias of hindsight. The material generated belongs first and foremost to the team, but generally applicable lessons and insights should flow to other projects. The first PAL sessions we did were with the Geostationary Operational Environmental Satellite/Polar Operational Environmental Satellite Program. With multiple instruments on each spacecraft, a number of Source Evaluation Boards (SEB) were needed to evaluate each instrument proposal.

A PAL we conducted helped one SEB team learn from their own challenging experience and provided practical wisdom to other SEB teams.

Practice 2: Knowledge Sharing Workshops

Many science, technical, and engineering seminars and lectures are given at Goddard as a matter of course. These are essential elements of a continuous learning culture. The Knowledge Sharing Workshops are intended to augment those activities with discussions of project management lessons rather than technical challenges and trades. Using a panel construct helps diffuse the individual focus without losing the personal story aspect of the workshop. At each workshop, senior project leaders share their personal insights, what they learned, and what they might do differently based on their recent project experience. These workshops are attended by emerging project leaders at Goddard who want to acquire the practical wisdom necessary to succeed as project managers. To encourage open sharing, these sessions are not recorded. The emphasis on conversation instead of slides and reports frees panelists to bring up even sensitive or unresolved issues.

Practice 3: Case Studies

To build organizational learning capacity for project management, the context provided by project stories must be brought into the knowledge management and learning system. A case study is the primary vehicle to do this. Case studies allow key players to present material, reflect on project management insights, and share contextual knowledge in a meaningful way. In a sense, they are constructed opportunities for fostering conversations. Participants often learn details of other projects or events that they did not know of beyond headlines. They also get to meet the people who were intimately involved with those events and to think through the decisions those people had to make at the time. In other words, they get the benefit of learning from the decision-making process itself, rather than just hearing filtered, after-the-fact explanations. Finally, hearing the story from those who experienced it builds trust, opens relationships, and fosters a sharing environment.

One of our first case studies was on the Vegetation Canopy Lidar project at Goddard that was terminated in June 2002. The case has been used internally at Goddard and twice at the Project Management Challenge conferences in 2004 and 2005. It is also being used by contractors for training outside NASA.

Practice 4: Common Lessons Learned

A diverse panel of experts is periodically convened to review all cases from the past year, looking for similarities and trends. Patterns of behavior that increase risk or the likelihood of failure are identified. Strengths and competencies that could be emulated are also called out. Their assessment is integrated with many other performance and risk indicators for appropriate corrective and preventative actions, including incorporation into processes, rules, and training.

Practice 5: GOLD Rules

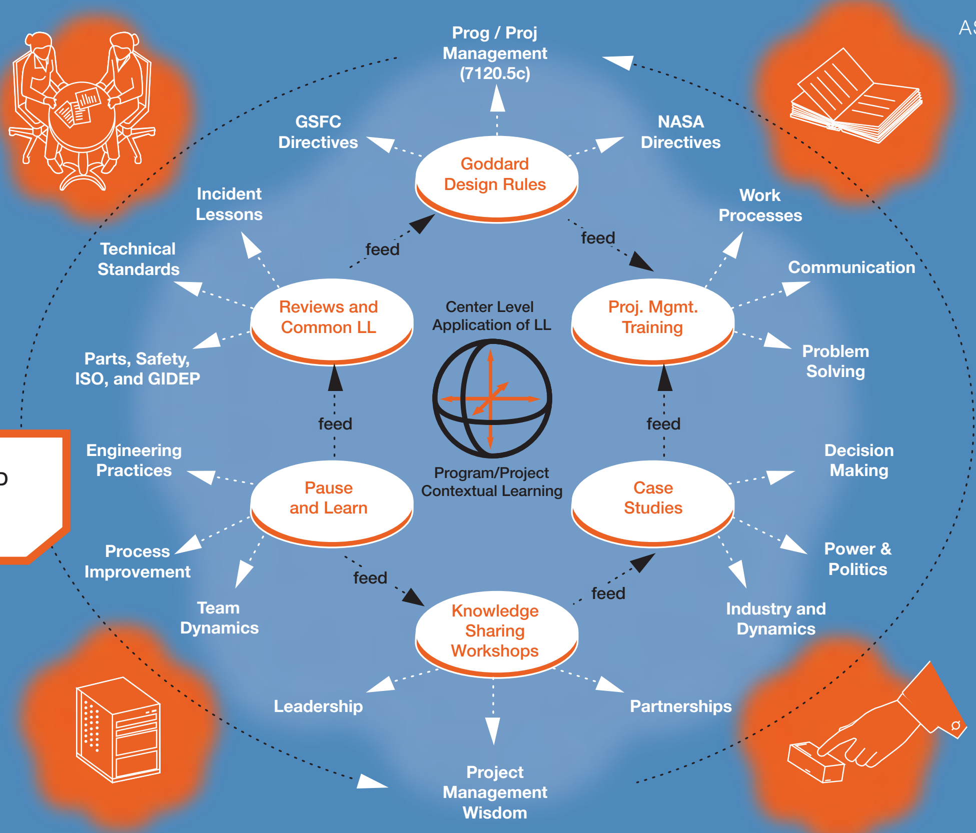
The GOLD Rules are meant to reflect Goddard's wisdom in the design, development, verification, and operation of flight systems. Collected primarily from engineering organizations, they are in essence the best design practices written down. Links are being built from the rules to standards, lessons learned, and case studies so users of the rules can access their context—their origin, intent, and sphere of effect. This allows project personnel to more accurately assess the appropriateness and applicability of the rule to their project and helps convey the embedded wisdom of the rule, not just the sterile technical specification captured in the rule set itself. It is essential that users of the rule do not stop thinking about the practice to which the rule applies. The learning context surrounding the rule enables users to continue to think creatively instead of blindly following rules and inviting possible unintended consequences. Where waivers are sought, the provided context supports a healthy risk discussion to evaluate the implications of granting a waiver or allowing for a deviation.

Practice 6: The Road to Mission Success

The training of all members of extended project teams is crucial to the future success of Goddard. Goddard is taking an aggressive approach to ensure its project leaders, line managers, scientists, engineers, resource analysts, and other professionals have the fundamental skills and the collective wisdom of experienced leaders available to them. We also need to ensure that all employees appreciate the NASA/Goddard legacy and fully understand the way we do business at Goddard and our expectations for safety and mission success. The center has developed a comprehensive series of two-day workshops called the "Road to Mission Success" that will instill the requisite NASA core values and wisdom embedded in cases, PALs, common lessons, and workshops into future Goddard leaders. Senior managers are involved in delivering course cases. The series will become an integral component, and perhaps the capstone, of many leadership training programs across the center and will provide a common, consistent exposure to how the center functions and achieves mission success.

Progress So Far

Goddard has made tremendous progress in building an effective learning organization and responding to the challenges facing NASA in a post-Columbia environment. To succeed in the long term, we must continue to support and reinforce learning behavior that enhances mission success across projects while investing in human capital strategies that assure sustainability



THE GODDARD LEARNING AND KNOWLEDGE MANAGEMENT ARCHITECTURE.

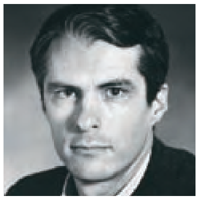
in the future. Accomplishing these goals requires monitoring the health of teams, continuously integrating work processes, and facilitating knowledge sharing within the organization.

The knowledge management reliability problem is how to ensure that engineers bring the line organization's full knowledge, not just their own individual knowledge, to bear on each project. Project outcome should depend less on which engineer is assigned to the project than on the accessibility of the organization's collective expertise. A lack of sharing at the branch level could result in an inability to deliver reliable expertise to projects. Anecdotal evidence indicates this is not an insignificant issue. Experienced project managers relate stories of how important it is to fight to get the right people on the team, tacitly acknowledging that the knowledge and expertise they need for the project are "owned" by particular individuals.

Clearly NASA is concerned about losing expertise as people retire, but we need to build a system that does not depend on the "expert guru" model and instead relies on a shared knowledge community that does not retire but evolves with time. The knowledge management challenge regarding human talent is not how to capture knowledge from people as they leave the organization but how to build learning into all that they do while they are here, so when they are ready to leave, most of their knowledge is embedded in the organization, people, processes, and policies that remain. Such a system will both sustain knowledge and produce more reliable results. This is the goal of Goddard's learning practices system.

Knowledge sharing behavior attracts bright people to organizations. Intellectually curious people know that they have the best chance of being stimulated, creating new knowledge, and participating in exciting discoveries where a team or community of like-minded thinkers are engaged in open and honest sharing of their ideas, insights, and experiments.[6] Goddard wants to continue to attract these people to build on the competencies that have characterized the center for forty-seven years. Though much remains to be done, we have embarked on an ambitious plan to help us function more like a learning organization and in so doing achieve mission success. ●

RICHARD DAY is Director of Mission Success at the Goddard Space Flight Center.



EDWARD ROGERS is the Knowledge Management Architect at the Goddard Space Flight Center.

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Getting to "Go"

BY DARREN BEDELL

As the final "go for launch" was given for the Mars Reconnaissance Orbiter (MRO) mission on the Atlas V 401 launch vehicle, the hair on my arms stood up. The pride of what we were about to accomplish, and the nervous tension of really knowing the risks of space flight, had come to a head.

The MRO mission was the first NASA mission to use the new Atlas V launch vehicle. In fact, it was the first U.S. government launch on the Atlas V. While each NASA mission is important, going to Mars is a very big part of the Agency's goals, and public interest has always been high for missions to the red planet. A few years back, the Headquarters Program Administrator was trying to get the Kennedy Space Center Launch Services Program's (LSP) attention for a seemingly less important mission on a small rocket. "Treat it like a Mars mission," she said, "the most important thing that we have; we have to make it work." For a Mars mission, everyone's sensitivity to mission success is higher than it is for a typical mission.

There have been great successes in going to Mars, but there have also been failures. My career has afforded me the opportunity to work on every Mars mission NASA has launched since the Viking missions, and I've seen both. While none of the failures were due to the launch vehicle, it really hurts when something goes wrong because everybody involved puts so much effort into these missions. Everyone works hard for mission success, which amplifies the anticipation and emotion at every launch.

I'll never forget the day the Mars Climate Orbiter arrived at Mars in 1999. I was in a small room in a contractor's plant in California, listening to the real-time operations going on at the Jet Propulsion Laboratory. I had just learned the mission had failed. I walked into a conference room filled with people who had worked on the launch phase for three years—my face was surely pale—and announced to everyone that "they just lost the Mars Orbiter." Facing these people was very difficult, a scar that I carry with me to motivate myself and our technical team when faced with tough choices on resource deployment, prioritization of issues, and final readiness for launch.

Making a New Checklist

At the beginning of a mission's life cycle, the planetary launch period is in your mind with each decision you make. As you get closer to launch, it really starts to stare you in the face. Taking more time to get it right isn't an option because a Mars planetary mission can only be launched once about every twenty-six months. However, completing the work on time only to experience a launch failure due to our error is what we all feared the most. Facing another launch, this time on a vehicle with very limited flight history, we were determined to get everything right.

The Atlas V was developed commercially by Lockheed Martin, with some of the funds provided by the United States Air Force (USAF) under the Evolved Expendable Launch Vehicle contract. Because new rockets have a history of failure during their first few flights, the Agency established a policy in the 1990s to govern NASA's requirements for using new launch vehicles. The policy was meant to ensure the quality of commercially developed launch vehicles because NASA buys launch services from the industry, which means NASA does not own or control the development of a new launch vehicle.

The Launch Services Program Technical Staff was responsible for refining and implementing the Agency policy in preparation for the MRO launch. In addition to certifying the Atlas V according to policy requirements, the LSP also performed technical oversight of the hardware and unique analyses required to successfully place MRO on its way to Mars.

I'LL NEVER FORGET THE DAY THE MARS CLIMATE ORBITER ARRIVED AT MARS IN 1999. I WAS IN A SMALL ROOM IN A CONTRACTOR'S PLANT IN CALIFORNIA, LISTENING TO THE REAL-TIME OPERATIONS GOING ON AT THE JET PROPULSION LABORATORY. I HAD JUST LEARNED THE MISSION HAD FAILED.

NASA certification only happens for new launch vehicles, and it is meant to ensure the highest practicable probability of mission success for all future missions to be flown on the vehicle.

We had to figure out how to assess the Atlas V for NASA certification because no checklist or definitions existed for new rockets with less than fourteen consecutive, successful flights. To solve the problem, I called my Chief Engineer, James Wood, and my Branch Chiefs, Pat Hanan, Mike Carney, and Jim Robinson, into my office. We knew that most of us would be there giving a "go" for the first launch on the Atlas V, so we needed to come up with something that we could live with that day, something we could accomplish in time, and something we could stand behind when we were asked for our "go."

Creating a Cornerstone for Success

We based our decisions on the risk we would eventually face on launch day, and we referred to a list of previous NASA assessments. The previous assessments gave us a starting place, but the certification items on the list did not apply to this new category of launch vehicle. We really had to think about what would work for certifying the Atlas V. We emphasized the importance of hardware qualification because of our experience with previous launch vehicles failing due to hardware malfunctions, and we added an assessment that used a cause-and-effect "fishbone" technique that identifies potential failure modes and their mitigations. The combination of flight data review for three flights, hardware testing, analysis of the new Atlas V, and failure mode mitigation became the cornerstone of our NASA certification effort.

As we created and refined our certification process for Atlas V, we realized getting to "go" before we could launch MRO would take about four times the effort of a typical NASA mission because we were using a new rocket and we had to certify it. My first thought was to ask for additional personnel. However, the same Program Administrator who

once told me to treat another mission like a Mars mission, the most important thing we have, also told me I was not getting any more people.

To help solve the problem, I had to look outside Kennedy. We partnered with the USAF, National Reconnaissance Organization (NRO), and other NASA centers to perform some of the technical work required for certification. For all information obtained from a partner, the LSP retained technical cognizance of the work performed by the other organization and held all technical and risk decision authority for that effort.

Through a series of government launch vehicle collaboration meetings, the similarities and differences in the LSP, NRO, and USAF approaches to technical evaluation were discussed. Each organization knew that resources were limited, so finding a way to work together would be important. But we reached no definitive agreements during the first two years of the collaboration. We were all on unfamiliar territory and therefore lacked the trust necessary to reach an agreement. We also didn't understand the language of the other organizations, so this new collaboration started very slowly and carefully. To address these issues, we agreed to gather everyone together for one big meeting each year and supplement it with smaller meetings when necessary. As a result of these meetings, the most notable element of the partnership emerged. It involved using Lockheed Martin's Design Equivalency Review, which the NRO funded. NASA engineers worked with Lockheed Martin, USAF, and NRO engineers, and we partnered with Marshall Space Flight Center and Glenn Research Center to increase our technical staff.

We used the equivalency review to document most of the information we needed for the LSP hardware qualification assessment. James Wood and I knew the Lockheed Engineering Review Board process in detail, and we knew the NRO/USAF participation in the review board would be significant, which allowed us to relax our requirement for conducting a separate NASA Engineering Review Board. We required our engineers to participate in the Lockheed engineering review and to conduct a unique NASA evaluation of each component. We also shared our systems engineering evaluation of the components with the NRO and alerted them to any NASA findings they might want to consider in their own evaluation.

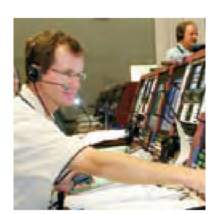
Changing Course

At the beginning of the Design Equivalency Review, we were understaffed and the information was coming in too quickly for us to handle. Our approach to managing the LSP effort had to be changed in the middle because we had too many elements and not enough dedicated leadership. Pat Hanan, who had become the Engineering Division Chief at the time, brought in Dave Sollberger to organize the effort and provide detailed tracking plans to account for all the work being performed by the multiple organizations. For undefined problems or new approaches, establishing the management system is as important as defining the technical work. We learned the hard way that it was better to find a way to avoid falling behind schedule early in the process instead of having to play catch-up just before a deadline that can't be moved. Dedicating someone to manage the relationship with the partner is imperative.

By the end of the equivalency review, the partnerships with other NASA centers were in place, and the information wasn't coming in as fast as we needed to support the planetary launch window. We knew this because of the project management system Dave Sollberger had developed. Problems included delays in USAF launch dates, changes in personnel, and priorities of the Columbia failure investigation at our partner centers. The talented engineers throughout the government have a lot to offer; however, partnering is no panacea. We had to consider the efficiency of the support we received based on the particular agreement and situation, and we were not always in control of our destiny. That is what makes the completion of this effort even more remarkable.

When I think back on hearing the final "go for launch" during the MRO countdown last August, I hope you understand why the hair on my arms stands up in excitement. I know how much thought and hard work it took to reach that moment, and how important a moment it was for the American Space Program. ●

DARREN BEDELL is one of two chief engineers who retain technical decision authority for NASA's Launch Services Program. After receiving a B.S. in Engineering from the University of California–San Diego, he was a McDonnell Douglas structural design engineer for the Delta launch vehicle. He has been a significant part of more than 60 launches during his 20-year career in launch vehicles.



The Knowledge Notebook

What Do We Mean When We Say "Knowledge"?

BY LAURENCE PRUSAK

We are clearly living in a "Knowledge Age." Wherever you look, you find books, articles, programs, courses, advertisements, and degree programs using the word "knowledge" in some way to distinguish itself or its contents. This growing emphasis on knowledge derives from the more complex views of economists, sociologists, and other thinkers who have long (at least since the early 1970s) realized that the economy in the more developed world was devoted more to the production and delivery of knowledge-based products and services than to manufacturing, agriculture, mining, and other material goods. As one leading economic thinker, Paul Romer, succinctly put it, in our new economy "land, labor, and capital are being replaced by people, things, and ideas."

Knowledge has become the main engine of our productivity (and, of course, has always been the source of NASA's achievements), but we still do not have a clear, shared understanding of what the word "knowledge" means. This may seem like a minor point to some of you—just semantics—but in fact that lack of clarity has important implications. I have personally seen tens of billions of dollars spent and largely wasted by industry and governments to develop "knowledge systems" of one sort or another, systems that were touted (and still are, I assure you) as helping organizations be more efficient or effective in working with their knowledge. When queried, the consultants, vendors, and other cheerleaders for these technical knowledge "solutions" would almost always conflate knowledge and information, implying that the two words are identical or close enough to make efforts to distinguish them look like hair-splitting—not the kind of intellectual exercise a busy, time-pressured executive has time for. But the result is that those executives end up spending millions on huge "knowledge" systems that are really information or even data management structures and have little or nothing to do with knowledge.

To make sure that our knowledge investments and efforts really do support knowledge creation and use, we often have to modify our use of the word with some explanatory word or phrase: "I'm talking about tacit knowledge," or "This is about intellectual capital," or "I mean the know-how that you can't capture in a system." Part of the problem is that we English speakers have only one word—knowledge—to describe a variety of ways of knowing.

These things were actually easier to sort out in classical Greece. Aristotle had four different words to choose from to describe different aspects of our one word, knowledge. He could use the word *Episteme* when he wanted to refer to approximately what we mean by scientific knowledge (abstract, explicit, repeatable rules). *Techne* implied the skills and crafts needed to accomplish something. *Phronesis* meant practical skills like sales and management and emotional intelligence. *Metis,* more difficult to translate, was used to mean cunning and savvy—something like what we mean by "street smarts" or "knowing the ropes." It's the kind of knowledge Odysseus had thousands of years ago and a skilled politician has today.

My intention is not so much to give you a lesson in classical Greek as to point out how deficient our language is in trying to encapsulate humanity's mental capabilities in one paltry word. Those of us who try to work with knowledge and help organizations improve their knowledge sharing and use often have to make do with dichotomies that help explain what we mean. We talk, for instance, about "explicit" versus "tacit" knowledge—that is, knowledge that can be stated in words or set down in a document versus knowledge that eludes capture and can only be learned by example, practice, and mentoring. Even this dichotomy is too simple and therefore misleading. All knowledge is somewhat tacit in that even the most explicit, documented manual depends on the huge amount of tacit knowledge the reader already has. And much know-how (mainly tacit) is built of know-what (mainly explicit).

Such conceptual distinctions are still very useful, however, as long as we keep them in perspective. After all, when a person is immersed in a complex task or project, she doesn't usually think, "Let's see, should I use tacit or explicit knowledge now?" or "Do I need a document, a discussion, or data at this point?" The act of doing even a simple thing calls for a huge range of tools, techniques, and understanding that are, in truth, all jumbled together in what William James called the "blooming and buzzing" of life itself.

It is only when we want to do something about knowledge on an organizational scale that we begin to run into these semantic traps and language games. Trying to "manage" knowledge is a difficult task made more difficult by the many definitions and even greater number of assumptions as to what "knowledge" actually is. This is why it is always a good idea to sit down together and do that most rare of management activities—think about what exactly are the types of knowledge you wish to work with when you start designing any project involving the development, retention, and transfer of knowledge. Once you've done that, it becomes easier to answer the less arduous questions of what form the knowledge takes, where it is located, how much value it has, and whether it can be documented or needs to be taught person-to-person or group-to-group.

For instance, some of the knowledge needed to maintain a complex piece of machinery is explicit and can be successfully documented. Performance specifications, standard tests, schedules for maintenance, the expected useful life of parts, and symptoms and solutions for many problems can be captured and shared with technicians by way of a database or manual. Many organizations do exactly that; it is a valid and valuable kind of knowledge transfer. But there is no manual that can teach someone to be a master mechanic, and attempting to write one would be a wasted effort. Such mastery involves a lot of subtle, tacit knowledge (for instance, identifying a problem by a slight change in the sound a machine makes or understanding how to approach a problem you have never exactly seen before). Organizations that recognize the kind of knowledge required for this kind of skill will understand that they need to invest in the kinds of activities that can develop it, activities including apprenticeship, mentoring, and storytelling.

So while we won't all be forced to learn classical Greek (or even classical Chinese, which I'm told has even more terms for what we lump together as "knowledge"), we do need to be clear and careful about what we mean by "knowledge" if we want to be able to support it effectively in our organizations. Developing "meta-knowledge" (knowledge about knowledge) is important. After all, William James also said, "How do I know what I think until I see what I said?"

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The Partnership for Public Service, a nonpartisan nonprofit group that monitors the federal workforce, released a new survey that ranks government agencies according to employee satisfaction. NASA ranked sixth out of 30 overall.

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- **Performance Based Rewards and Advancement**
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NASA's Project Management Challenge 2006
March 21–22,
Galveston, Texas

NASA's PM Challenge 2006, the agency's third annual project management conference, will be held in Galveston, Texas, near the Johnson Space Center. This year's theme is "Putting Ideas into Action." As a mission-driven organization, NASA must continuously strive for improvement in program and project management. By sharing ideas, practitioners increase their knowledge and enhance mission success with more effective, efficient, and innovative ways to manage programs and projects. Registration is now open. Check the conference Web site for additional details: http://pmchallenge.gsfc.nasa.gov

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NP-2006-01-422-HQ