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The NASA Source for Project Management and Engineering Excellence | APPEL

SUMMER | 2010

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Photo Credit: NASA

ON THE COVER

Low-level winds rushing over the Cape Verde Islands off the coast of northwestern Africa created these cloud vortex streets. The top of the Hubble Space Telescope is visible during its lockdown in the cargo bay of Space Shuttle *Atlantis*.

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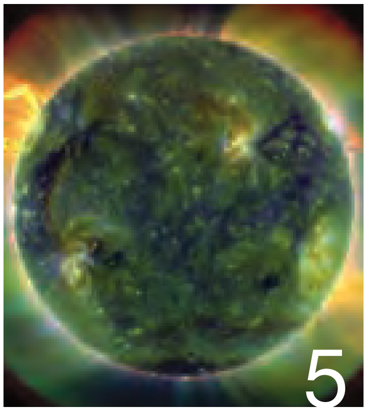

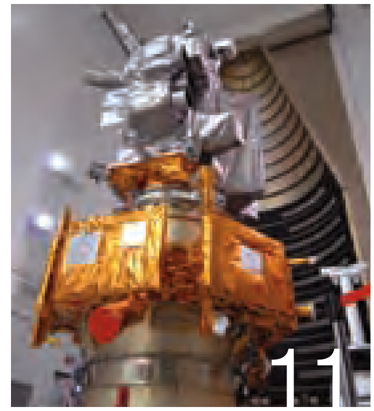

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The Academy of Program/Project and Engineering Leadership (APPEL) and *ASK Magazine* help NASA managers and project teams accomplish today's missions and meet tomorrow's challenges by sponsoring knowledge-sharing events and publications, providing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

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

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In This Issue

This issue of *ASK* features two apparently divergent themes. One is the importance of far-reaching innovation. In the interview, NASA Chief Technologist Robert Braun talks about supporting extensive new-technology development at NASA. That support will include money to refine and test new ideas and, even more importantly, accepting the fact that many ambitious new ideas fail. Failure is the price we must be willing to pay to achieve real technological breakthroughs. ("A man's reach should exceed his grasp," poet Robert Browning wrote—a woman's, too, but Browning was writing in the nineteenth century in the voice of Andrea del Sarto, a sixteenth-century painter.)

The other theme, the focus of several articles, is nuts-and-bolts practicality. As Warren Moos, Dennis McCarthy, and Jeffrey Kruk report in "Redesigning the FUSE Mission," the team that designed and built the Far Ultraviolet Spectroscopic Explorer avoided cancellation by finding a way to achieve the mission's science objective at a little more than half the original projected cost. The Lunar Crater Observation and Sensing Satellite (LCROSS) mission, which sent a spacecraft hurtling into a lunar crater to measure water on the moon, met a tight budget and schedule by reusing and repurposing existing technology ("Moon Mission on a Shoestring"). And "Engineers Without Borders" tells how NASA engineers who volunteer to develop water-treatment systems in Rwanda bring what they learn about using limited resources to develop simple, reliable technology back to their work on spaceflight technology at Johnson Space Center.

What connects these themes? For one thing, the innovation Braun talks about will eventually turn into technical resources that make future missions possible and, in some cases, more economical and dependable. As he says, new-technology development is not an end in itself; it will provide the capabilities that new NASA flight systems will need.

Their other connection has to do with what John Ruffa calls the "non-technical" issues that are as important to mission success as technical expertise ("Ten Systems Engineering Lessons Learned"). How people work together and relate to the organization is critical, whether the goal is radical innovation or the economical reuse of existing technologies. That is why Braun identifies culture change as essential to innovation and why the authors of "Moon Mission on a Shoestring" say that teamwork and effective communication are responsible for the low-cost success of LCROSS.

There are many such human factors. Probably the most important (in part because they influence the others) are trust, communication, and shared commitment to a mutual goal. Ron Taylor ("Nurturing Trust") sees trust as the foundation of outstanding accomplishment in any organization. Ed Hoffman, in his "From the APPEL Director" column, describes the role of relationships, communication, and commitment in three leading Italian enterprises. Cathy Peddie's "Reflections of a Deputy" shows how valuable a trusting, open relationship between a project leader and deputy can be. And T.J. Elliott's "Islands and Labyrinths" is essentially about communication—how to forge the connections that allow people to share what they know.

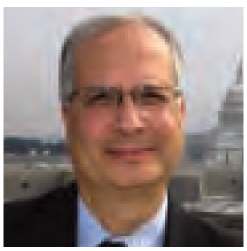
Maybe these are obvious truths, but sometimes organizations focused on technology need to be reminded of the obvious: that project teams succeed when they share what they know, understand what their goal is, and trust that they're working together to achieve it.

Don Cohen
Managing Editor

From the APPEL Director

Lessons from Torino

BY ED HOFFMAN



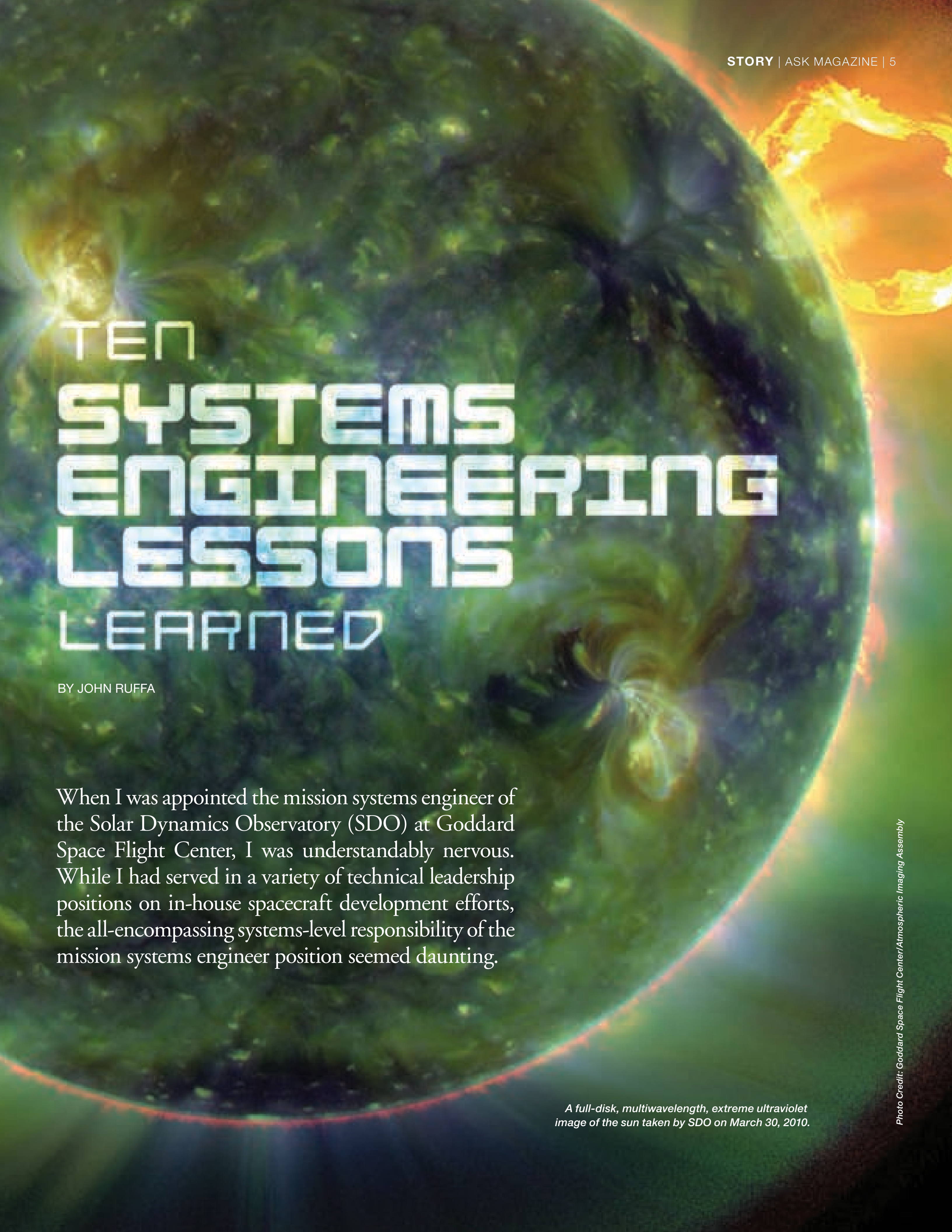
Last spring I had the opportunity to visit three project-based organizations in the Piedmont region of Italy. What I saw was a commitment to three elements that might seem an unlikely combination: standards and processes, cutting-edge technology, and craftsmanship.

My first visit was with Comau, a subsidiary of the Fiat Group that specializes in robotics and automation systems. My conversations with Valerio Crovasce, who leads Comau's project academy, reminded me that in an extremely competitive sector like the automotive industry, having a workforce that's highly skilled in project management is a competitive advantage. Comau strives to develop standards and processes that optimize efficiency for repeatable tasks. On the shop floor, you see robots doing highly routine, standardized, precise, and sometimes dangerous work. At the same time, as a supplier producing components and subsystems for others, Comau's leaders understand that the customer is at the center of any project; stakeholder management is a top concern. Even in an organization focused on robotics, relationships are paramount.

I also visited Thales Alenia, a major European aerospace manufacturer. Thales has a strong program to develop top young engineers from universities and emphasizes learning how to think from a systems perspective. I had a tour of an immersive learning and working environment the company has developed: a three-dimensional representation of everything we know about the solar system. This simulation, which is based on data from the European Space Agency, NASA, and other space agencies, is a powerful learning tool. It gives individuals the opportunity to communicate in real time and form relationships based on learning.

My final visit was to the Ferrari plant. The company was founded as a local entrepreneurial venture and still has a strong sense of connection to the community. The importance of stories is immediately clear. As you enter the facility, you see historical cars on display with small placards that tell their stories. An executive told me that those cars are intended to remind employees of the big picture as they walk by them every day on the way to their workstations. I was also struck by the strength of the craftsman culture, which coexists with precision robotics. The men and women working in specific production areas are experts empowered with a great deal of autonomy, and they exude a sense of pride. When you look out on the factory floor, you see something utterly unexpected: plants and trees that refresh the air. The cars coming off the assembly line bear a closer resemblance to works of art than to mass-produced automobiles.

The bottom line is that it takes all three elements—high technology, standards and processes, and people—working in concert to achieve world-class excellence. Technology is critical for innovation. Standards and processes are means of using knowledge, lessons learned, and best practices in pursuit of quality and continuous improvement. But neither technology nor standards and processes are useful in the absence of highly skilled, educated, and motivated people who have a sense of dignity and purpose about their work. When all three come together, the results are *senza paragone*—without equal. ●



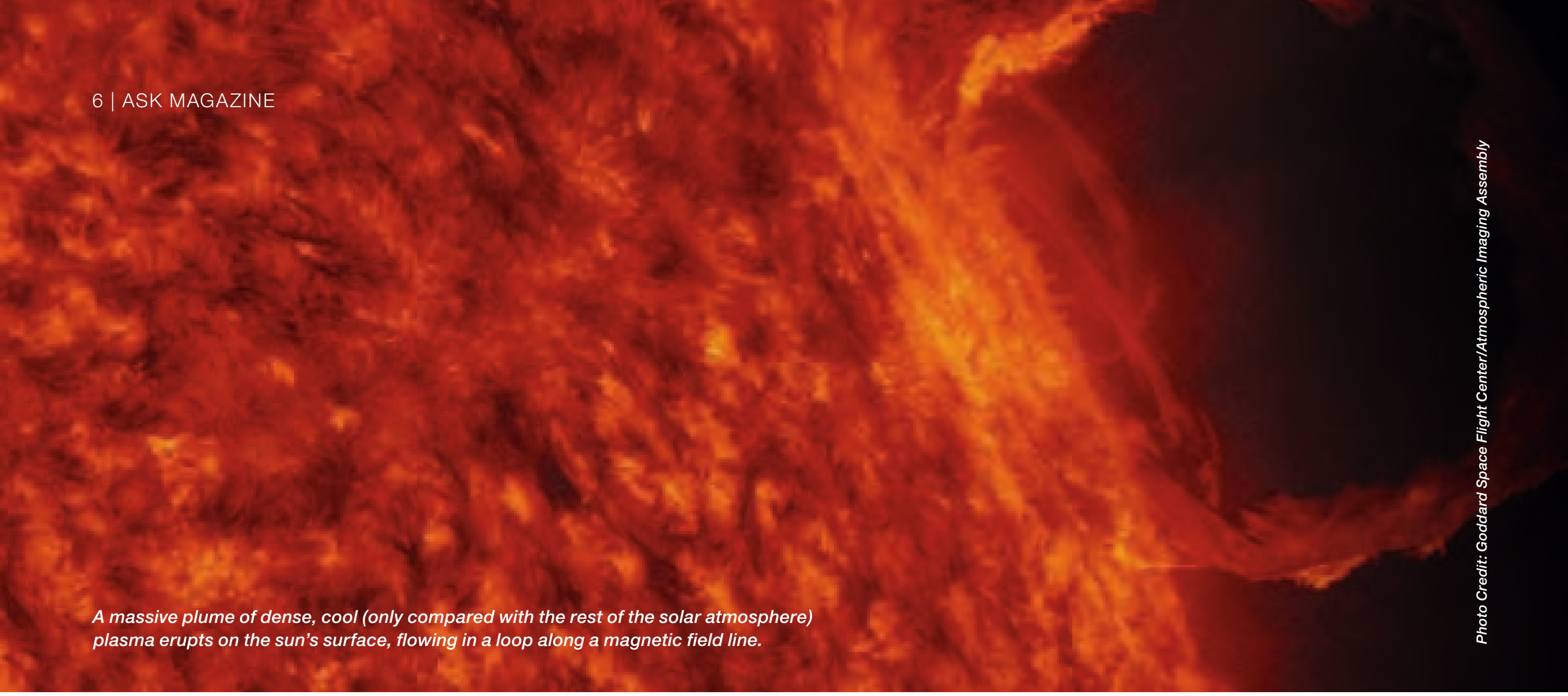
TEN SYSTEMS ENGINEERING LESSONS LEARNED

BY JOHN RUFFA

When I was appointed the mission systems engineer of the Solar Dynamics Observatory (SDO) at Goddard Space Flight Center, I was understandably nervous. While I had served in a variety of technical leadership positions on in-house spacecraft development efforts, the all-encompassing systems-level responsibility of the mission systems engineer position seemed daunting.

A full-disk, multiwavelength, extreme ultraviolet image of the sun taken by SDO on March 30, 2010.

Photo Credit: Goddard Space Flight Center/Atmospheric Imaging Assembly



A massive plume of dense, cool (only compared with the rest of the solar atmosphere) plasma erupts on the sun's surface, flowing in a loop along a magnetic field line.

Fortunately, I had the privilege of working with a number of experienced systems engineers prior to SDO and had a strong technical team to help me navigate the many technical challenges we would face. What surprised me was how many *non-technical* issues I would ultimately face on this mission.

Most systems engineering training focuses on the technical issues, often with very little focus on helping the systems engineer understand and learn to deal with the non-technical minefields that are part of every project. Like technical issues, non-technical issues also have the potential to slow or derail progress.

Realize Most Problems Are Non-Technical

This was one of the biggest surprises that I have found as an engineer and the one for which I received the least amount of training and instruction. At the start of SDO, one of the first things we did was identify driving issues—the problems and challenges we considered the greatest threats to mission success. Little did we know that these technical issues were only a subset of our problems.

Early in the SDO development effort, our systems team started formulating the concept for a reliable, high-performance spacecraft-avionics architecture that would serve as the backbone of our solar-science observatory. Many on our team had just completed a successful in-house spacecraft, the Wilkinson Microwave Anisotropy Probe (WMAP). It seemed to make sense to build upon the foundation of this previous effort and pursue a similar approach.

Nailing down the design and getting buy-in from key players was prolonged and painful, however, often resulting in conflict. Throughout the process, I was puzzled why an approach that was so successful only a few years earlier had turned into a nightmare on SDO. It turned out the influence of non-technical issues was greater than I'd known. Just because an approach was once successful with one team did not guarantee success with a completely different team, one with its own mind-set and biases.

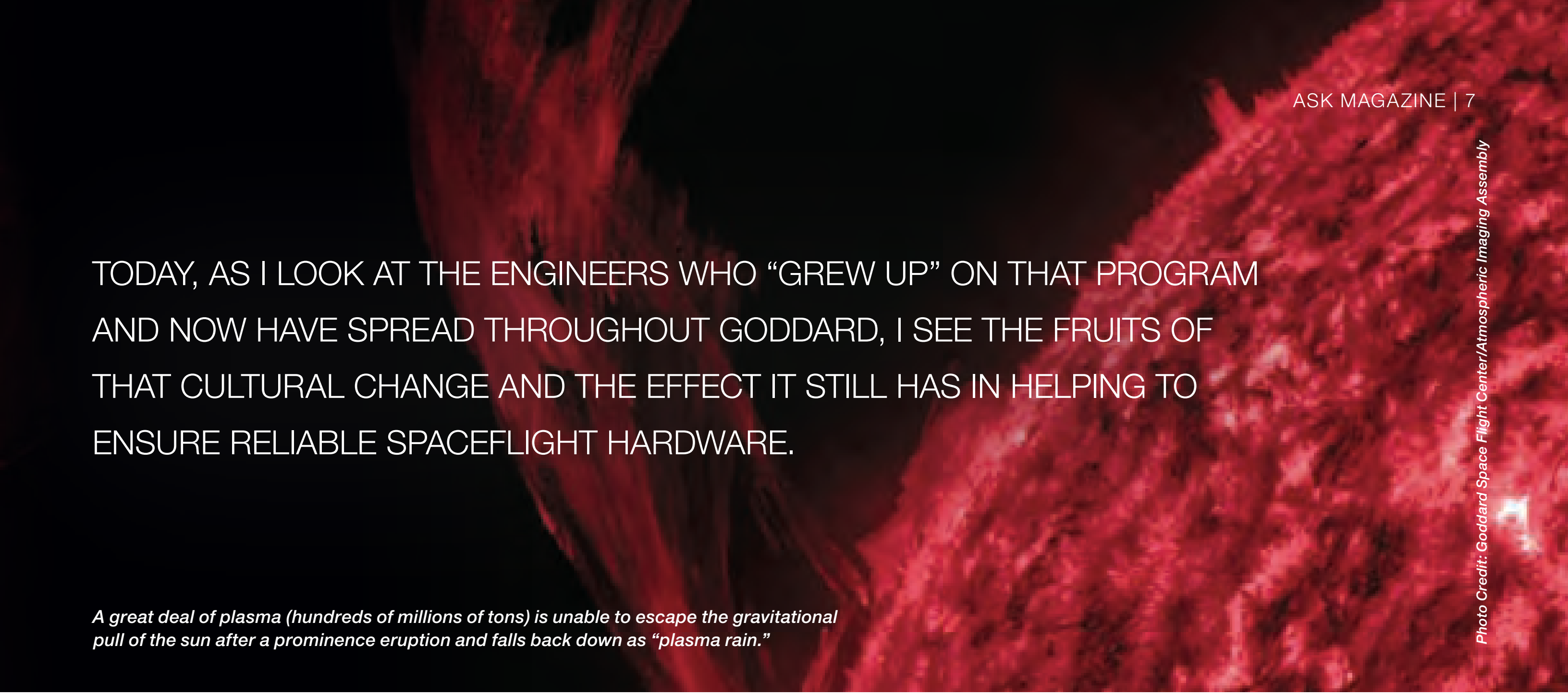
These issues can manifest themselves through poor communication, turf battles, conflicting agendas, technical disconnects, conflicting cultures, and conflicting personalities. Anyone who has worked in a team environment is familiar with these problems. Non-technical issues that complicate communication and the open exchange of information make the technical challenges even more difficult.

Understand and Define Your Team Culture

Every team has a culture—an unwritten philosophy of how a team works, communicates, and interacts internally and to the outside. A team's culture helps define its work ethic, its attention to detail (or lack thereof), how well (or poorly) people are treated, whether questions are openly asked or discouraged, whether it is detail (or "big picture") oriented, and how it approaches troubleshooting and problem solving. Some teams are meticulous, some more casual, some very process-oriented, others less rigid, some open to give-and-take discussions, others more regimented in their communication. Many teams are unaware that their culture can influence mission success.

Early in my career at NASA, I worked with a senior systems engineer who was meticulous in spacecraft testing and troubleshooting, and whose strength in this area contributed to the success of numerous satellites. He strongly espoused the regular use of the formal problem-reporting system to document, track, and close out issues discovered during testing. The engineering team was reluctant to formally document issues in the system. Some of it was laziness, some of it stemmed from the cumbersome nature of the system, and a large part of it was the perception that entering a large number of issues into the system would somehow tag our development effort as being more troubled or problematic than others.

Fortunately, our senior engineer constantly emphasized that the problem-reporting system was simply a valued tool to make sure that issues were properly identified, investigated, reviewed, and closed out in a rigorous manner. Instead of



TODAY, AS I LOOK AT THE ENGINEERS WHO “GREW UP” ON THAT PROGRAM AND NOW HAVE SPREAD THROUGHOUT GODDARD, I SEE THE FRUITS OF THAT CULTURAL CHANGE AND THE EFFECT IT STILL HAS IN HELPING TO ENSURE RELIABLE SPACEFLIGHT HARDWARE.

A great deal of plasma (hundreds of millions of tons) is unable to escape the gravitational pull of the sun after a prominence eruption and falls back down as “plasma rain.”

Photo Credit: Goddard Space Flight Center/Atmospheric Imaging Assembly

making our project seem more risky, he claimed that fully documenting issues would enhance the overall reliability and, accordingly, the confidence we and our NASA center would have in our finished product. He worked with the project manager to change the culture of the engineering team, promoting the proper use of the problem-reporting tool and actively correcting the misperceptions that formally documenting problems would mark the project as troubled. This effort changed the project engineering team culture and the manner in which we investigated, addressed, and closed out issues.

Today, as I look at the engineers who “grew up” on that program and now have spread throughout Goddard, I see the fruits of that cultural change and the effect it still has in helping to ensure reliable spaceflight hardware.

Find a Mentor

On my first flight project, our team presented a spacecraft communication-interface approach we had developed to our NASA review team. Although we were young and relatively new to the world of spacecraft design, we had come up with an approach we were proud of. So it was a huge disappointment when a senior member of our review team quickly demonstrated the complex and cumbersome nature of our implementation. He offered a simple, elegant alternative that was a significant improvement over our “homegrown” concept.

Immediately after the review, I thanked him for his input and asked if we could talk to him about other aspects of our design implementation. This was the beginning of a long and fruitful working relationship. He became a trusted mentor and friend not only to me, but to other members of my team.

Systems engineering covers an astonishingly broad area of mission requirements, design/implementation details, and operations concepts. It is impossible for any individual to possess sufficient experience or expertise to understand the complete system and its nuances and issues. A wise systems engineer will build an informal list of more experienced engineers as go-to contacts for dealing with the many technical (and non-technical) issues that will inevitably arise. This fellowship of mentors and peers will become one of the most valuable tools in the systems engineer’s toolbox.

Don’t Reinvent the Wheel

When our systems team was assembled on SDO, one of the first things we did was ask ourselves, “Who has done this type of mission before and what can we learn from them?” We sought out knowledgeable people from other missions and picked their brains for helpful implementation details and lessons learned. Even so, we missed obvious mission contacts who, in retrospect, would have helped us tremendously.

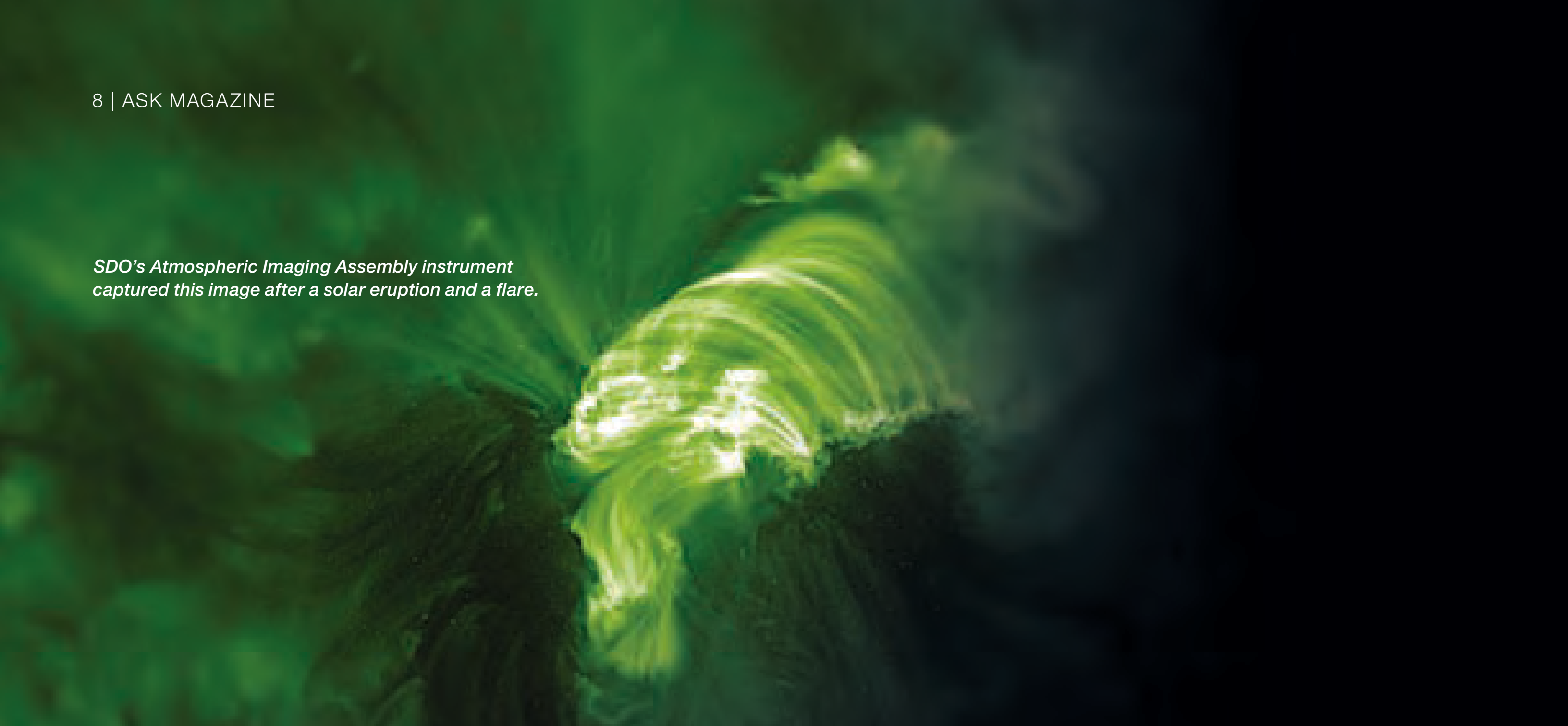
For example, while we aggressively pursued information and design details from other solar-science missions, we didn’t contact other missions that used geosynchronous orbits until much later in our development effort. It would have been very helpful to spend more time talking to the geosynchronous spacecraft designers to discover issues they faced that differed from our previous orbital-design experiences.

Engineers often spend tremendous effort trying to come up with a unique solution rather than build on the foundations of others. A wise individual I once worked for was fond of saying, “When you are in college and you copy someone else’s work, it’s called plagiarism, and it can get you kicked out of school. In the world of engineering, this is called good engineering practice, and it often results in awards and promotions.”

Aggressively avoid the trap of “not invented here” that prevents you from tapping the experience of those who came before. You will be the better for it and, in the process, you might further build your informal network of peers and mentors.

Realize That People, Not Positions, Get the Job Done

Selecting the right people for specific positions, roles, and responsibilities will always make the difference when storms



SDO's Atmospheric Imaging Assembly instrument captured this image after a solar eruption and a flare.

(technical or otherwise) hit. This may seem obvious, but it is astonishing how often some leaders are content to fill positions rather than build a team.

Anyone who has worked in a team environment can probably recall an example of a well-intentioned individual who, for whatever reason (lack of experience or underdeveloped interpersonal or communication skills, among others), was a poor fit for a key role on a team. When this occurs, the rest of the team struggles to compensate for the deficiency. This often means either forcing the team to add unplanned additional personnel to augment shortcomings in this key role or learning to "work around" the individual in question.

Having the right person can make a huge positive difference. I recall a time on SDO when the value of talent was recognized and used to augment the existing team. Late in the development effort, we brought in a highly skilled individual to perform technical reviews. After they were completed, rather than let this valuable individual go, I went to the project manager and requested bringing this engineer on full time. I confessed that I hadn't thought through the specific role this individual would fill but emphasized the principle that skilled people are rare, and we should grab them first and ask questions later.

Fortunately, our project manager agreed, and this engineer stayed through the rest of the project, solving many technical issues and performing as a key member of our systems team. Even though we didn't have a particular position that needed filling, we saw the value of a specific individual, realized the potential benefit to the team, and grabbed him.

Tear Down Barriers to Open Communication

On every project there are people who choose not to communicate openly with their counterparts. As a result, communication lines atrophy, slowing or stopping the transmission of critical information and risking technical disconnects. A wise team lead will aggressively address communication issues as they arise. Sometimes all it takes is to remind people of the need to communicate and the potential consequences of dropped information.

The corollary principle must also be followed—make every effort to promote positive and open communication, whether it is by face-to-face meetings, walking around and touching base with team members, or doing whatever it takes to foster regular, open communication and build positive working relationships.

Recognizing the importance of clear and open communication in solving and preventing problems, our SDO systems engineering team instituted a weekly team meeting. It became a valuable time to not only solve technical issues, but to work through disagreements and differences. In addition, occasionally we would meet to self-assess our team and honestly discuss how we were doing and whether there were areas that could be improved. Outside the meetings, I would make a point to follow up with team members to make sure there were no hidden issues or concerns that were not getting adequate exposure in our group meeting.

These simple actions are not remotely groundbreaking, which is exactly the point: communication does not need to be elaborate or innovative, it just needs to happen.

Talk to the People Who Actually Do the Work

One of my engineers came into my office to talk about a technical problem, quietly indicating that what I thought was a technical issue was really due to issues in the working relationships between key individuals. When I asked why no one had told me about this, he sighed and said, "Of course no one at the working level is ever going to approach the mission systems engineer to have that kind of conversation."

This was the first time I realized that I had now risen to a place in the organizational chart that created barriers that would impede my understanding of daily issues on the work floor. From that day onward, I started making a deliberate effort to "walk the floor," asking questions and listening to the answers (whether I liked them or not).

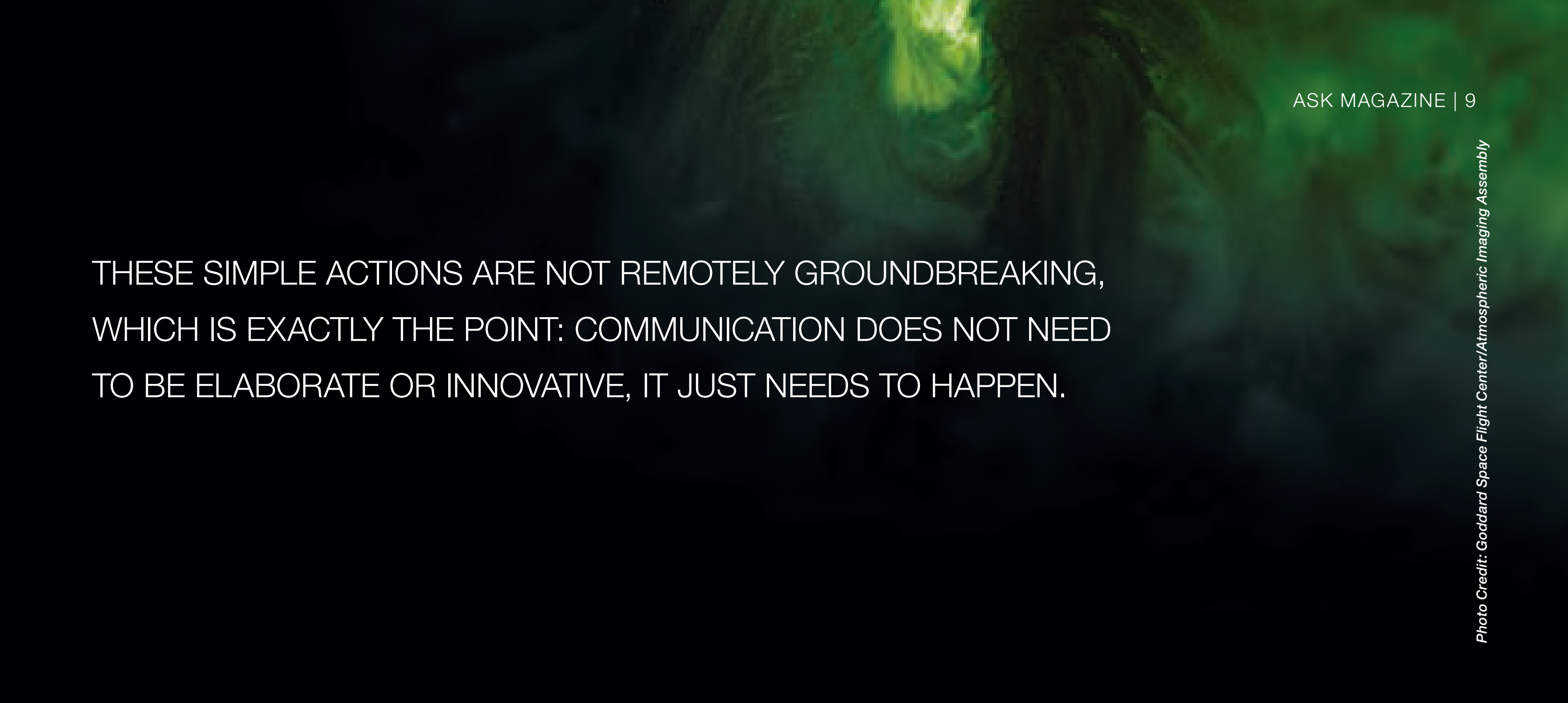


Photo Credit: Goddard Space Flight Center/Atmospheric Imaging Assembly

THESE SIMPLE ACTIONS ARE NOT REMOTELY GROUNDBREAKING, WHICH IS EXACTLY THE POINT: COMMUNICATION DOES NOT NEED TO BE ELABORATE OR INNOVATIVE, IT JUST NEEDS TO HAPPEN.

This lesson should not have been a revelation. When I was a young engineer, I struck up a friendship with a senior manager of the engineering directorate at Goddard. Every two or three months, he would give me a call, invite me into his office, and we would talk about how things were going, what I liked about my work and the organization, what I didn't like, and what needed improvement. I learned years later that this was part of a calculated effort on his part to stay in touch with people within his organization. He regularly met with junior members of the department to gain a "boots-on-the-ground" perspective of what was really going on.

On every project, there are the people who are in charge and the people who actually do the work. These key workers often can tell you the most about what the problems really are, what to watch out for, and how to creatively solve problems—and they will figure out quickly if you really want to listen. A team lead who walks the floor will be far better equipped to accurately gauge the issues, understand their impacts, and formulate appropriate responses than one who stays in his office.

Beware "Groupthink"

We admire finely tuned teams that share philosophy and culture and can almost finish each other's sentences because of their excellent teamwork. Therein lies a trap that must be avoided: becoming so well integrated that groupthink creeps in and eliminates valid opposing viewpoints, causing a team to miss alternative approaches or, even worse, miss hidden concerns until they become real problems. The team lead must take pains to cultivate an environment where outside reviews and internal minority opinions are not only acceptable but actually sought out as part of the normal process of doing business.

On SDO, our project management and systems engineering teams worked hard to cultivate an environment where the team took the review process seriously as a valuable tool (rather than a necessary evil) and saw our review teams as partners in developing a successful mission. After our design passed through the critical design review, our project manager made a habit of updating critical review team members, briefing them on significant issues or changes, even when these fell outside the normal review "gates." As a result, we developed a positive working relationship with our review team and kept them abreast of issues, helping them to be better educated in their review and assessment of our progress.

Internally, we focused on creating an environment where the systems team regularly reviewed and questioned major design decisions and issues. Our weekly systems team meeting served as an anchor to ensure that honest and open discussion occurred, and frank communication also occurred at other project meetings, including design/development meetings and risk meetings. We had no shortage of people willing to challenge the status quo and take on devil's advocate positions. While this give-and-take discussion could sometimes be frustrating, in the end it resulted in a better team and a more reliable mission.

Build and Preserve a Sense of Ownership and Responsibility

One of the biggest challenges for a strong, dynamic leader is to guide team members without diminishing their sense of ownership and responsibility. When we started SDO, many of us were new to our leadership roles and excited about the opportunity to shape this new project. The in-house design teams typically see in-house missions as a prime place for pushing the technical design boundaries in order to advance the state of the art, however, and had their own ideas about design and new technology approaches. This often led to conflicts between the systems engineering and subsystem design teams.

Ultimately, the systems team is the technical conscience of the mission-development effort and has the responsibility to ensure that the trades and compromises made are in the overall best interest of the mission. Looking back, I suspect there were times where our focus and sense of ownership may have unintentionally caused some of our design teams

TIME AND AGAIN, I SEE THE FRUSTRATION SENIOR ENGINEERS MAY HAVE WITH THOSE LESS EXPERIENCED SLOWLY MELT AWAY AS THEY UNDERSTAND THE VITAL ROLE THEY HAVE IN PASSING THEIR KNOWLEDGE AND EXPERIENCE TO OTHERS.

to feel that their own sense of ownership and responsibility was undercut.

When talented individuals start sensing that their ownership or technical responsibility is being eroded or second-guessed, they may fight back, attempting to reassert their roles, or they may recognize the futility of their efforts and become passive. The challenge of the team lead is to prevent both outcomes by not usurping the roles of those underneath him or her, but guiding them in a constructive fashion while preserving the higher-level system goals.

Train Your Replacement

A wise senior systems engineer often reminds me that any job has two primary components: to do your work with excellence and integrity, and to train your replacement.

Until you train your replacement, you cannot leave your current position, since your departure would leave a hole behind. Also, the train-your-replacement mentality creates a fertile environment where the skills of an organization are continually replenished through mentoring and passing of the baton. Finally, having a train-your-replacement mind-set transforms the way we view and deal with other members of our team. Time and again, I see the frustration senior engineers may have with those less experienced slowly melt away as they understand the vital role they have in passing their knowledge and experience to others. Not only does this promote open technical interchange, it also creates a nurturing and team-building environment.

On an earlier mission, when I was ready to take on the new challenge of a systems engineering role, the project manager insisted that I first identify and train an individual to take my place as a flight-component lead. The individual assigned to take my place had far more skill and experience in detailed flight-hardware design than I did, but he had never had the role of coordinating design and testing of a flight component. I was able to work closely with him to broaden his already impressive skills into a new area. In the same way, the systems engineering lead on the project was helping me grow into my new role. The added benefit of this approach is that the mentoring relationship provides a natural safety net of peers and mentors in the event that a person struggles in a new role.

Be Aware

My list of non-technical issues is almost certainly incomplete. My aim is not to exhaustively catalog all the non-technical threats that engineers may face, but to raise awareness of the impact these kinds of issues can have on a technical-development effort. That awareness is the first step toward developing a mind-set that proactively scans the horizon for these threats, and learning the skills and approaches that help the team mitigate and address them as they occur. The more prepared a team is to identify and address these issues as they arise, the greater the likelihood that they can be dealt with before they significantly damage the team or the development effort. ●

JOHN RUFFA served as part of the in-house Goddard Space Flight Center development teams for the Rossi X-Ray Timing Explorer and the Wilkinson Microwave Anisotropy Probe. Most recently, he served as the mission systems engineer for the Solar Dynamics Observatory, which successfully launched from Cape Canaveral in February 2010.

MOON MISSION ON A SHOESTRING

BY HALEY STEPHENSON AND MATTHEW KOHUT

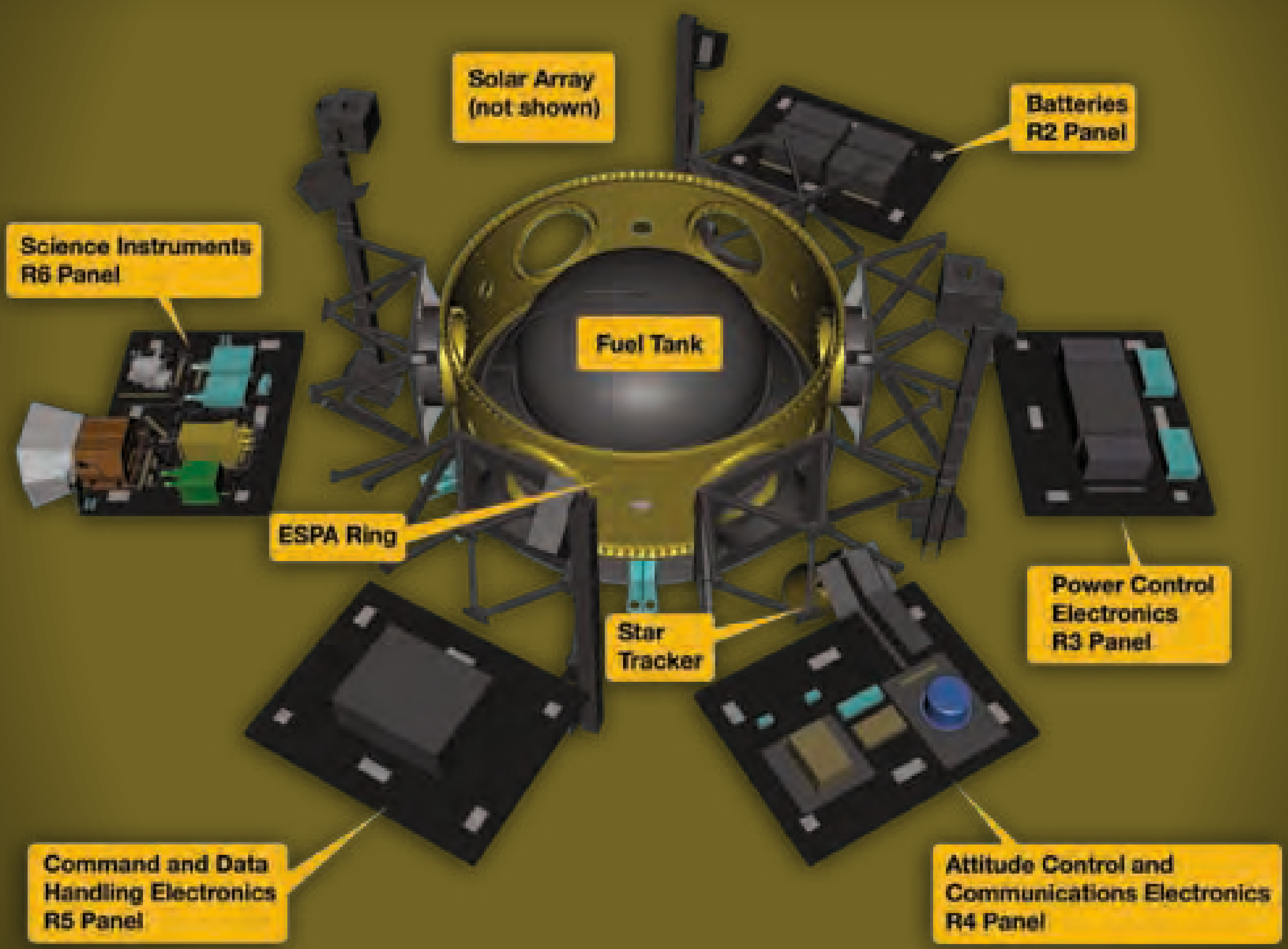


Image courtesy Northrop Grumman

The LCROSS spacecraft employed a novel use of an ESPA ring.

When NASA announced that the Lunar Reconnaissance Orbiter (LRO) would upgrade from a Delta II to a larger Atlas V launch vehicle, a window of opportunity opened for an additional mission to the moon. The Atlas V offered more capacity than LRO needed, creating space for a secondary payload.

LCROSS WAS NOT ABOUT PUSHING THE TECHNICAL ENVELOPE. IT WAS ABOUT KEEPING IT SIMPLE—KEEPING IT GOOD ENOUGH.

At Astrotech Space Operations Facility in Titusville, Fla., LRO and LCROSS are united in preparation for fairing installation.

Close-up image of crater Cabeus A near the moon's south pole showing crater elevation. Yellow represents lower elevations.

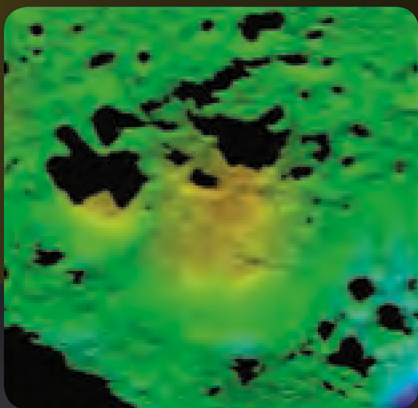


Photo Credit: NASA/Jet Propulsion Laboratory

Photo Credit: NASA/Jack Pfaller

The Exploration Systems Mission Directorate (ESMD) posed a challenge to interested secondary-payload teams: the chosen mission could not interfere with LRO; it could not exceed a mass of 1,000 kg; it could not cost more than $79 million; and it had to be ready to fly on LRO's schedule. Of the nineteen proposals submitted, ESMD chose the Lunar Crater Observation and Sensing Satellite (LCROSS)—a mission that sought to search for water on the moon by firing a rocket into the lunar surface and studying the debris resulting from the impact.

Dan Andrews, LCROSS project manager, was charged with assembling a team that could develop a satellite on a shoestring while coordinating its efforts closely with LRO. "It could have been a real recipe for disaster," he said. "There were plenty of reasons why this mission should not have succeeded."

The Good-Enough Spacecraft

From Andrews's perspective, the LCROSS spacecraft had to be "faster, *good enough*, cheaper." He made clear to his team from the beginning that LCROSS was not about maximum performance. "It was about cost containment," Andrews said. "LCROSS was not about pushing the technical envelope. It was about keeping it simple—keeping it good enough."

The LCROSS team had twenty-nine months and $79 million to build a Class-D mission spacecraft. Class-D missions, which are permitted medium or significant risk of not achieving mission success, must have low to medium national significance, low to medium complexity, low cost, and a mission lifetime of less than two years. The low-cost, high-risk-tolerance nature of the project led to a design based on heritage hardware, parts from LRO, and commercial off-the-shelf components.

LCROSS's status as a Class-D mission did not preclude the team from practicing risk management. "We were risk tolerant, but that doesn't mean we were risk ignorant," said Jay Jenkins, LCROSS program executive at NASA Headquarters.

"With the LCROSS instrument testing, we shook, cooked, and cooled the mostly commercial off-the-shelf parts that could potentially come loose during launch so that we were likely to have a tough little spacecraft, but we didn't test to failure," said Andrews.

LCROSS consisted of a Shepherding Spacecraft (SSC) and a Centaur upper-stage rocket. The SSC included a fuel tank surrounded by a repurposed Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adaptor, also known as an ESPA ring. The ESPA ring, conceived by the Air Force Research Laboratory as a small-satellite deployment system, had never been flown on a NASA mission. Its six bays can hold up to six small satellites, but on LCROSS those bays held the principal subsystems of the spacecraft. Using the ESPA ring offered a significant advantage: its sturdy design had already been tested, facilitating flexible, low-risk integration with the LRO mission.

The LCROSS mission operations team initiated power-up of the LCROSS science payload and saw this view of the moon.

The off-the-shelf payload instruments included imaging equipment found on army tanks, carpet-fiber recycling hardware, and instruments used to measure engine-block temperatures for NASCAR. The total instrument cost ran about 3 percent of mission cost—far lower than possible with custom-built instruments.

Andrews described this as a capabilities-driven approach. "The whole principle of LCROSS was, 'If there are investments that the agency or industry have made and it's something we can employ, then do it,'" he said.

While LCROSS was a Class-D mission, LRO, a Class-B/C mission, and the Atlas V rocket, a Class-A vehicle, were held to much higher standards. The launch vehicle provider expressed concern that LCROSS might interfere with the performance of LRO, the primary payload. "It became a lowest-common-denominator problem," said Andrews.

LCROSS didn't have the budget to meet the requirements of a Class-A mission, nor was it supposed to. Andrews raised the issue with the program office, which eventually facilitated some additional testing of its structural hardware to ensure that LCROSS satisfied the concerns of all the mission stakeholders.

Teamwork

Andrews knew he had to establish trust with the other teams involved in the mission. LRO, based at Goddard Space Flight Center, was understandably cautious about LCROSS hitching a ride to the moon with them. Andrews quickly moved to identify an LCROSS engineer who could take up residence with the LRO team to facilitate quick dialogue and build trust between the two missions. With good lines of communication, the two teams started to view each other as resources and "worked together like a team this agency hasn't seen in a long time," said Andrews. "These good relationships really pay off when things get tough."

The crossover and reuse of hardware between the LCROSS and LRO spacecraft allowed the teams to learn from and with one another. Sometimes they worked in tandem; at other times one team would be ahead of the other. "There were things that we missed that we either caught later, or missed and LRO caught, and vice versa," said LCROSS Project Systems Engineer Bob Barber.

A good partnership with Northrop Grumman (NG), the spacecraft contractor, was also essential. Neither Andrews nor NG Project Manager Steve Carman had ever managed spacecraft development before, though both had run spaceflight-hardware development projects. "We were both kind of new to the spacecraft side of things, but I told my management to provide me with an outstanding team, and Dan did the same," said Carman.

During the first six months, as the project underwent some acquisition-related contractual changes, Andrews and Carman began to develop a mutual trust. "Ultimately, communication was the hallmark of the partnership," said Carman. "The partnership was not something where we said, 'Sign here—we are partners.' It grew out of a relationship. … We showed them as we went along that we were indeed capable of doing this faster than anything we had done here."

For Andrews, trust grew out of a shared understanding of the way both organizations traditionally operated. "We talked plainly about budgets. We talked plainly about the NASA construct, and then we talked plainly about how hard it is to move NG's heavy institution," he said. "I was not holding anything back in terms of what I was sharing with them, and I think that set a tone within NG [so] that they behaved similarly."

By the time of the preliminary design review, a cooperative dynamic had been established that went beyond business as usual. "It was an 'open kimono'–type relationship where everything was kind of on the table," said Barber. "We wanted a really open and honest relationship with them." NASA team members took part in NG's risk management boards and were invited to staff meetings.

The relationships didn't end when people left the project. Both NASA and NG experienced turnover, which could have hurt the project. In this case, though, several former team members kept in touch with their successors. "That's when you know a team is more than just coming to work and doing stuff," said Barber.

Tightening the Schedule

To meet the aggressive schedule demands of LCROSS, Carman established a baseline project plan with very little margin and then challenged key team members to consolidate their subsystem schedules. "We had a schedule that was based on 'When do you need it?' and I was saying, 'How fast can you do it?' And so people found ways to modify the processes," said Carman.

For example, the lead propulsion engineer came back to Carman and said she could pull six weeks out of the propulsion schedule. As the work progressed, the team continued to make gains, eventually ending up eight weeks ahead.

Expediting the Review Process

The LCROSS schedule didn't allow time for a lengthy review process throughout the project life cycle. Andrews and Carman

WITH GOOD LINES OF COMMUNICATION, THE TWO TEAMS STARTED TO VIEW EACH OTHER AS RESOURCES AND "WORKED TOGETHER LIKE A TEAM THIS AGENCY HASN'T SEEN IN A LONG TIME …"

orchestrated a compromise that reduced the number of NG internal reviews and made the review process more collaborative.

Prior to each key milestone review, the teams held a peer review, which they called a design audit. Since both NASA and NG wanted to send managers and experts to check on the project, Pete Klupar, head of the Independent Review Board for NASA, jokingly threatened to give a short quiz at the beginning of the reviews to determine which stakeholders had done their pre-meeting reading and study. This made the point that the purpose of the reviews was not to educate the stakeholders, but to draw on their expertise.

By inviting stakeholders to the critical design audit near the end of Phase C, the team experienced a relatively smooth and quick critical design review. This process was so successful that the team then applied the same concept to the validation and verification process by instituting verification compliance audits. "This very informal, hands-on, roll-up-the-sleeves, no-ties-allowed stakeholder involvement right from the get-go is all reflective of that collaborative process," said Jenkins.

Risk Tolerance in Practice

The LCROSS team had to determine how far it was willing to go with risks. Too many changes to the spacecraft could turn an acceptable risk into one that was too great.

Early in the project, the team discovered that a capacitor responsible for protecting voltage input to a field-programmable gate array (FPGA) was identical to one that failed in the power system. If the capacitor regulating voltage to the FPGA failed, the FPGA would experience voltage stress; it was unclear how much stress the FPGA could handle. Loss of this FPGA would be a fundamental, unrecoverable problem, potentially ending the mission altogether.

"All the probability analysis said this should be a very low risk," said Barber, "but it was a mission killer if the wrong one failed."

The capacitor was built into a box that had passed all its testing and was performing well. The problem was that the location of the capacitor made remote viewing of its condition impossible. With little room for error in the budget or schedule, the team didn't want to invite more risk by opening up a tested flight box to check the capacitor, which could very well be fine. This was one of the most challenging risk trades this project would have to navigate. It wasn't until a change in the Atlas V launch manifest led to a delay in the launch date that the LCROSS team had the time and resources available to revisit its risk list. The team determined that the risk of going in to test the capacitor was lower than doing nothing at all.

"We took a risk [opening the box] to try and eliminate what we felt was our highest risk [the capacitor]. Then we ended up closing that risk, and we took it off the plate," said Barber.

Against long odds, the project met its cost and schedule constraints and passed its final reviews. It was time for launch.

Low on Fuel

The Atlas V launched LCROSS to the moon on Tuesday, June 18, 2009. One hour after launch, LRO separated from the rocket to head toward the moon and insert itself into lunar orbit. LCROSS took another path.

Two months into its journey to the moon, LCROSS experienced an anomaly while the spacecraft was out of contact with NASA's Deep Space Network. The spacecraft's inertial reference unit—its onboard gyro and primary means of measuring rotation rates around each axis for attitude control—experienced a data fault that resulted in the spacecraft's thrusters firing propellant almost continuously.

The operations team noticed this once the spacecraft was back in contact with the network. Engineers quickly identified a probable root cause and contributing factors. Immediate steps were taken to stop the thrusters from firing and prevent a similar occurrence. The team also adopted new ultra-low fuel-consumption means to conserve propellant. The specific cause of the fault remained unresolved, but the engineering teams determined that the spacecraft would have enough propellant to achieve full mission success even under worst-case conditions.

Smashing Success

Six weeks later, LCROSS lined up on its collision course with the moon. Once in position, the Centaur rocket separated from the SSC and barreled down toward the moon's Cabeus crater, where it crashed at twice the speed of a bullet. Following minutes behind the Centaur, flying through the vapor cloud created by the LCROSS impactor, the SSC took pictures, analyzed the debris, and sent the data back to Earth before it, too, smashed into what turned out to be a soft, porous crater floor. The whole sequence, lasting a mere four minutes and nineteen seconds, went off without a hitch. ●

REFLECTIONS OF A DEPUTY

BY CATHY PEDDIE

When Craig Tooley, the Lunar Reconnaissance Orbiter (LRO) project manager, offered me a job as his deputy, I reacted as I had to all decisions that have a great impact on my life: I slept on it and looked at it in the cold, cruel light of dawn. As I left his office, he had asked me if I was ready to follow him to the moon. I thought, catchy sales pitch, but I'm still following my process. I made the right decision the next day, accepting the position. Being the LRO deputy project manager has been one of the best experiences of my NASA career. LRO was launched on June 18, 2009. Flying in a 50 km polar orbit above the moon's surface, the orbiter will collect data sets for a year from seven instruments to provide a comprehensive atlas for future exploration. How cool is it to have been part of a historic mission that took NASA and the United States back to the moon after forty years?!

Goddard's Laser Ranging Facility directs a laser toward the LRO spacecraft in orbit around the moon.

Photo Credit: Goddard Space Flight Center/Tom Zagwodzki

Photo Credit: NASA

LRO Deputy Project Manager Cathy Peddie stands in front of LRO in a clean room.

Craig and I are different; we came to our partnership with complementary skills that proved to be a good formula for managing LRO. As in any relationship, we started out knowing the obvious differences but discovered others as we went along. Craig's mechanical background and interests came into play when we divided the project into our "watch areas" to help us meet the demanding LRO schedule. He took on the mechanical, thermal, and post-integration and testing areas, while I focused on project management, systems engineering, and mission operations.

Typically NASA projects do not staff adequately in the early stages. We like to keep them lean (and sometimes mean) until funding or other avenues are provided. Deputies are brought on when the go-ahead is given or the project manager screams for help. On LRO, I was brought in just prior to the preliminary design review (PDR) after a series of organizational and political changes drove the need for an expanded project office and additional staff.

I have had deputy positions before—as deputy project manager, deputy program manager, deputy chief, and deputy director. But in the midst of the LRO preparation for launch and early mission, moments of reflection brought home things that my mentors, family, and friends had been telling me all along. My thoughts on some common themes and threads in the variety of deputy positions I've held may be useful to those who are deputies or those who want to become deputies, or to help some decide that they don't ever want to become one!

Roles and Expectations

My general approach to each deputy position is to try to act the way I would want a deputy to work with me if I ever get lucky enough to be in a position to have a deputy myself. One of the first things I like to do is sit down with my new boss and talk about our expectations. I like to know why a deputy was needed, what environment we're in, why they hired me, and what they want from me. Expectations are a two-way street. The deputy also comes with a set of expectations, including what they want from the job, what skills and experience they bring to the table, and what they can offer that may not have been thought of previously. I like to do this on day one or even earlier to open the door for frank, interactive communication right away.

It is important to establish how you are going to work together to get everyone going in the right direction. Establishing roles and responsibilities helps alleviate confusion from the beginning. On LRO, we started with obvious project-manager and deputy-project-manager divisions of labor, knowing our roles would evolve as we learned more about each other and as project demands would dictate. Having worked on projects for many years, I took on the "easy" things in the project's daily-task listing while I came up to speed on what LRO needed. Within the first couple of months, I took care of the project management stuff the project manager had not had time to do (project plan, procurement shepherding, establishment and revamping of risk management and configuration management processes, and lead for the critical design review [CDR] that came eight months after PDR).

If you don't define roles and responsibilities clearly, you can run into the "too many cooks in the kitchen" syndrome and other confusions, conflicts, and inefficiencies. To make effective use of the deputy, it is crucial to delineate roles, responsibilities, and lines of authority and, above all, to communicate, communicate, communicate. Close communication between the deputy and his or her boss remains essential throughout the life of the project to make sure you stay on the same wavelength. That may mean talking every day, texting, using Facebook or Twitter—whatever works for the people involved.

On LRO, we had to implement a "divide and conquer" strategy in order to meet the aggressive schedule. Unfortunately, this meant that there had to be a separation not only in duties but geographical locations between the project manager and me. Keeping project activities going in concert under the circumstances presented a tremendous management challenge. Constant communication and support were crucial. When manager and

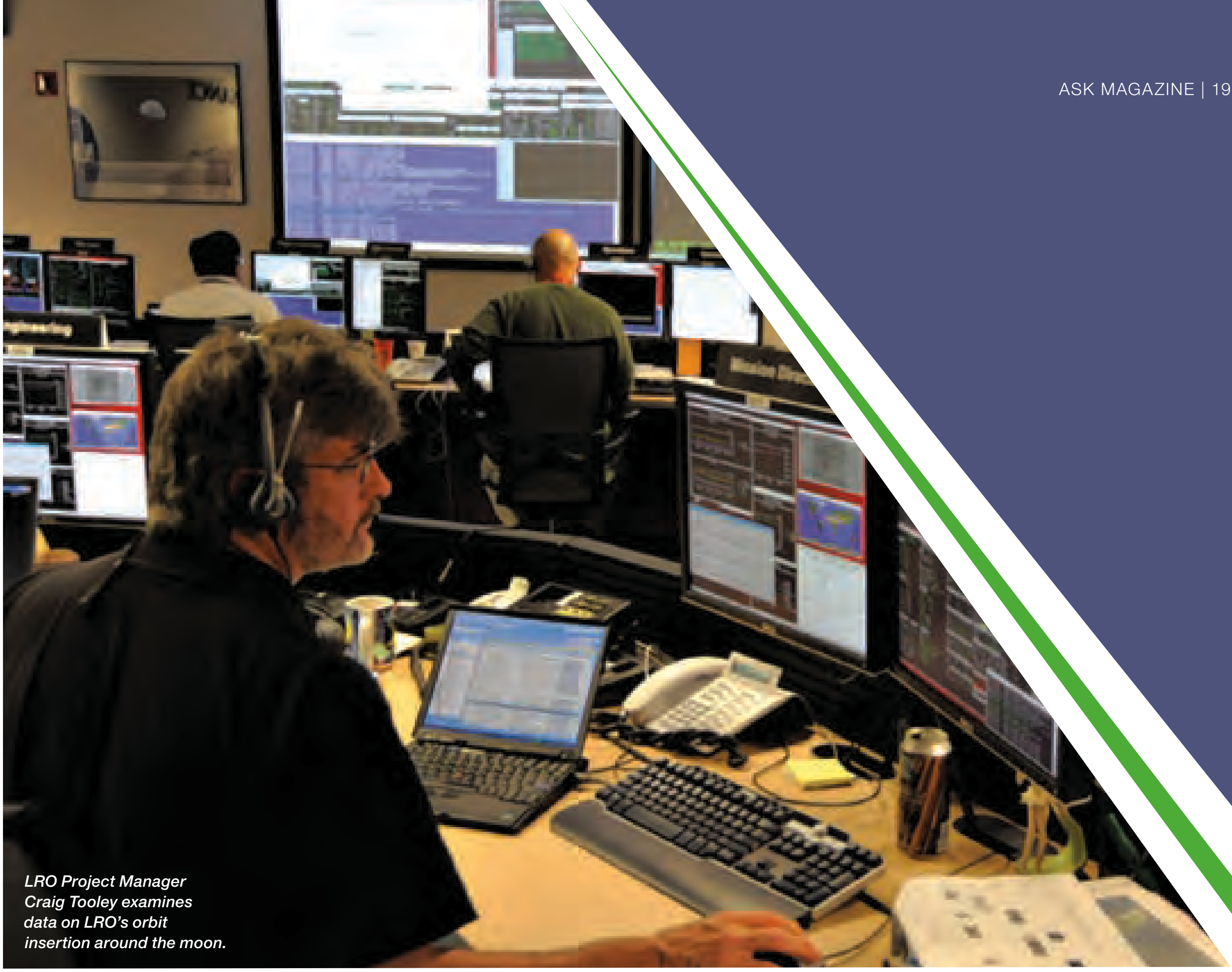


Photo Credit: NASA

LRO Project Manager Craig Tooley examines data on LRO's orbit insertion around the moon.

deputy have a shared knowledge and understanding of what the project needs, the deputy can step in instantly when needed.

Like any relationship, the manager–deputy relationship needs to be worked at continually. Lines of authority along with areas of responsibility must be clearly understood by all and worked out for the benefit of the project. In organizations and teams, people will sometimes try to play one off the other, like kids playing mom off dad. If they don't like your decision they may try out the other "parent." It is important to understand where authority resides. Above all, the deputy must be supported. I have always said, "The minute I'm not supported is the minute I can't help."

Using Differences

It is important to take advantage of differences in management styles, skills, and strengths and weaknesses in the context of the team environment. I have never been a clone of the person I was the deputy to. In fact, being different is often cited positively in my performance appraisal. In all my deputy positions, those differences have worked well for me and my bosses. Groupthink is a real danger in programs, projects, and organizations. Having a different perspective can help management see all sides of situations to make the best decisions possible.

The LRO project manager had worked with many of his team members for decades. I was the outsider who didn't grow up either with them or at Goddard. He was concerned about groupthink on the project and didn't want a "yes" person. This was challenging for both of us, as the inevitable human dynamics came into play when the "outsider" had a different opinion. You don't have to be belligerent about it, but you have to be able to provide that different perspective and say, "Before we make that decision, have you thought of …." It takes courage to speak up and do what's best for the team, the project, and the person you are deputy to, as well as yourself. Most of the LRO team did not have experience in mission operations and extended missions. They often did not understand nor want to focus on aspects beyond integration, testing, and launch. It often felt like a trial by groupthink to have to prove the need for focus on the requirements of LRO's unique mission to the moon. Understanding and appreciating that need came only after the orbiter reached its destination and successfully transmitted data back.

Ascertaining each other's management style (how each of you deals with people as well as managing the organization and project) will help ensure that the deputy and primary person play to one another's strengths and offset weaknesses. This assessment will help both determine how best to work together and how

Photo Credit: NASA/Debbie McCallum

A technician integrates one of the Lunar Reconnaissance Orbiter's narrow-angle camera instruments.

to deploy themselves when they inevitably need to divide and conquer to get the job done. It is also important to take the team environment into account. Managing a NASA in-house team is very different from managing a prime contractor, international team, or a virtual team with members across the country. Different styles and techniques are needed in each situation.

As a "people person," one of the first things I do in any job is get to know the folks I am going to work with. Knowing your people and what is going on in the organization can definitely help ensure things are running smoothly and give your boss a perspective that helps him or her make informed decisions.

Flexibility

Deputies wear many hats. They can be the backup or stand-in when the primary person goes on travel or is out sick or on vacation. They can be designated technical lead to focus on a particular area, lead a tiger team, troubleshoot an area, or pull the whole thing together. A deputy can be a business lead, ensuring that all the business processes are working well and the project stays within cost and schedule. They can also own project processes, ensuring that those processes work for the project, rather than dominate it. On LRO, I revamped the configuration management and risk management processes, making them tools that helped LRO as opposed to just "check the box" items or bureaucratic burdens.

A deputy can be a coach, helping team members work together to make the most of their diverse skills mix. They can be supportive, giving the much needed pat on the back that lets the team know when they are doing a good job. In this same vein, a deputy can be a trainer or mentor to those on the team. Sometimes people need a counselor, too. I often wish I had a psychology degree in addition to my engineering degree, since they don't really teach you about people skills in engineering school. You just figure it out along the way, or are lucky enough to have those skills to begin with. I swear there is an enormous sign above my office door that says, "Complaints Department." I've been trying to get rid of it for years! People may be afraid to speak to the boss to say things like, "Hey, you've messed up," or, "Let's try a different way." A deputy can be an emissary for someone who may be too afraid to speak up.

Many times a deputy is the lead pooper scooper, ensuring that things get cleaned up. They are the "closer" in some situations, tying up loose ends—a critically important project function.

The Power of Two

Having a deputy means having someone to share the burden and the workload. I've often told my bosses, "You are not alone. I've got your back, go ahead and do what you need to do." Having a deputy means having a readily available second opinion, another viewpoint, and a sounding board. Before a project manager makes a decision he or she may want to try it out on a trusted sidekick first—someone who won't hesitate to tell the truth. The combination of the manager's and deputy's different skills can make a dynamic duo and high-performing management team. Ensuring that you make the best use of that person you brought onboard can pay huge dividends.

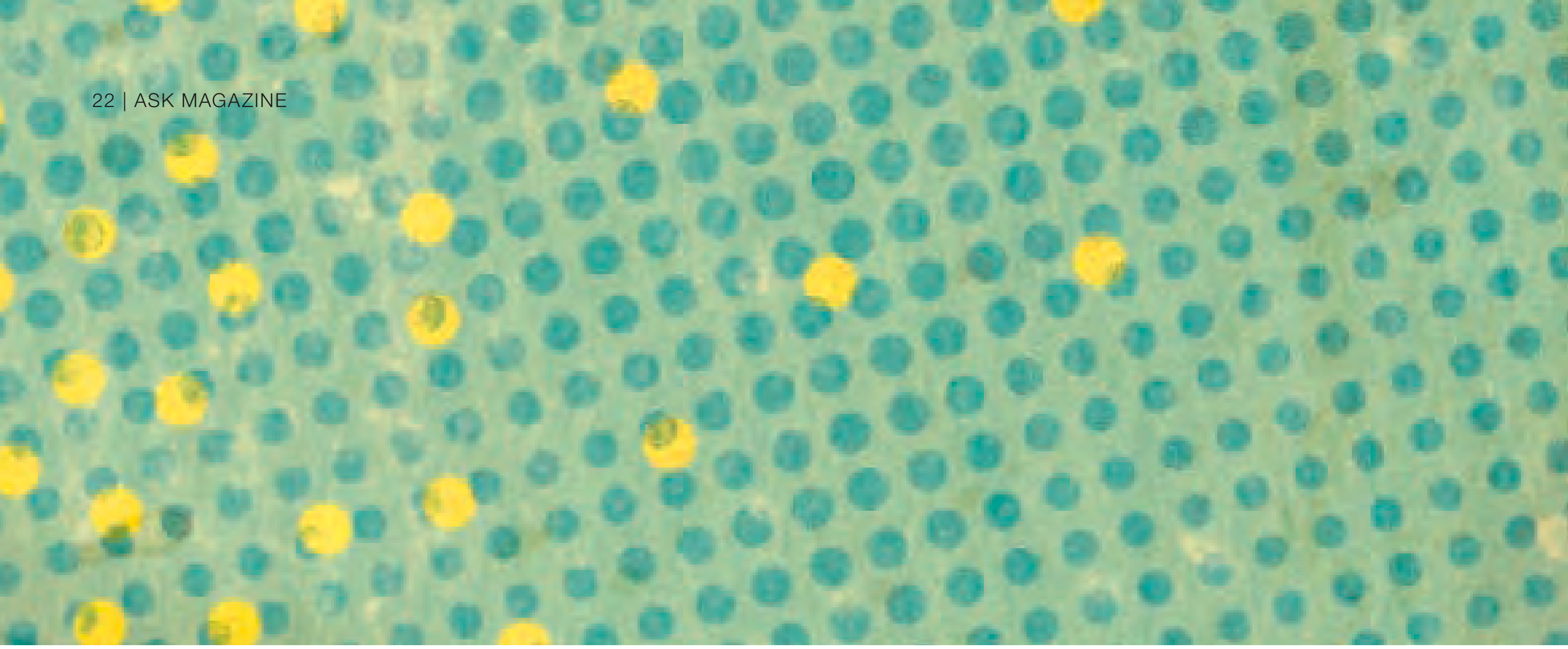
The LRO project experience helped bring home all these lessons for me. My project manager and I were partners, our skills were complementary, and we evolved our relationship throughout the project. We were flexible in how we worked and continued to shift and evolve as the situation demanded. Those things and our common passion for LRO helped us manage a historic project successfully. ●

CATHY PEDDIE is the deputy project manager for the Joint Dark Energy Mission project. She has enjoyed working on a variety of NASA projects and programs in both space and aeronautics. Prior to coming to NASA, she was in the U.S. Air Force working on spaceflight programs.

Islands and Labyrinths: Overcoming Barriers to Effective Knowledge Transfer

BY T.J. ELLIOTT

Organizations—and the people who make them run—expect and desire a return on the knowledge they possess. In economic terms, they wish to collect and maximize the "rents" possible from the application and combination of knowledge contained in patents, documents, and—most important of all—employees. Yet leaders of all types have reason to fear that such is not the case.



Capitalizing on organizational knowledge requires conveying it to people or groups who need it but don't have it. Why is this so challenging for people and organizations? A gap exists between and among human beings across which important tacit knowledge often cannot pass. Imparting what is in your head successfully to another person requires effort. It does happen, but neither automatically nor naturally.

Individual employees array like islands in the contemporary work world; their mode of work disconnects them from their fellow employees. Either they sit at their laptops working on individual projects with a small number of peers, unaware of the existence of others who possess knowledge that would prove useful, or they attend countless meetings with too many people, where competition for scarce resources makes them resist connection with others. Whether unaware or resistant, they lose opportunities to view situations differently, choose solutions more cogently, and devise innovations plentifully.

Organizations often make the problem worse. They become labyrinths that foil earnest attempts to find or use knowledge. Their systems, policies, and cultures often combine to render it harder—if not impossible—to make something out of the knowledge contained within their boundaries. Wittingly or not, they create bottlenecks, cul-de-sacs, and other barriers.

This insight is not original. The separation between the potential and actual value of collective knowledge was recognized before Peter Drucker even coined the term "knowledge worker" in 1959. But understanding this disjointed reality can cure the practitioner of arrogant plans and unrealistic aspirations while prodding productive experiments associated with individuals and organizations.

The issues with the "islands" include the following:

- The way we see ourselves—thinking we know more than we know and/or that we are always right.
- The way we see others—failing to listen to that which does not confirm existing beliefs.
- The way we make sense of what we see—a mix of biases, heuristics, and filters.

For eight years, participants in leadership development groups at Educational Testing Service (ETS) have been asked to solve "wicked problems." Invariably, the early sessions are replete with statements rather than questions: faced with the challenge of cutting overhead, they talk about turning off the lights; challenged to develop a new product, they present pet ideas. Only when they are directed to reflect and are shown the patterns of their early communication—all advocacy, no inquiry—do they ask questions of each other and question their own assumptions. What keeps us as islands at times is the recognition that allowing other knowledge into our space could work against our interests in multiple ways. In some instances, the effect is only irritation at having to change our views; in other cases, the consequence would be a loss of authority or rewards.

INDIVIDUAL EMPLOYEES ARRAY LIKE ISLANDS IN THE CONTEMPORARY WORK WORLD; THEIR MODE OF WORK DISCONNECTS THEM FROM THEIR FELLOW EMPLOYEES.

And organizations? Their very structure forms the first set of barriers. The organizational chart of the founders may erect "walls" among various personnel and functions rather than create conduits for communication. Successive designs repeat this

ONE OF THE REALITIES OF EMPLOYEES BEING SPREAD LIKE ISLANDS WITHIN AN ORGANIZATION IS THAT THEIR CONNECTIONS ARE USUALLY WEAK WITH ALL BUT THEIR SPECIFIC GROUP. BUT SO-CALLED WEAK (RATHER THAN NON-EXISTENT) CONNECTIONS ARE A GOOD SOURCE OF NEW IDEAS.

error. Matrix-, line-, market-, or geographic-themed structures create different versions of the problem, moving the walls but not tearing them down. Formalization of accountability can stifle ideas and isolate information as individuals are excluded from meetings or e-mail distribution lists, and differences of opinion are quietly discouraged. Systems grow so cumbersome that even when we see what needs to be fixed their structure disallows it because of the time or money involved.

Consider this example of organization as labyrinth: A customer service representative notices that the way in which a form is configured for registrations causes multiple errors by customers, which require human resolution. To solve the problem, a request for removal of *one word* in *one field* is made. The organization's systems are such, however, that the initial estimate of the cost to fix the software would be a prohibitive $2 million. The IT folks acknowledge also that they are concerned they would "break something" in the application if they made the change. They lacked the tools to "see" all the places in the application that would be affected by the name change for the field. Such a remedy requires dedicated testers and no budget existed for that resource. Important knowledge existed but the reality of the organization's systems prevented it from being applied profitably.

The intent here is not to vilify corporate structures or individual knowledge workers. The challenge is to focus less on regretting the labyrinth's frustrations or the individual's insularity and more on navigating to get what is needed to produce what is desired. Organizations may appoint centurions who keep knowledge away from leadership, breed groupthink, and focus on politics so much that knowledge is subverted, but it is impossible to accomplish complex work without the coordinating structures they provide. Similarly, individuals may dissemble, distort, defer, and dismiss the knowledge of others, but we should concentrate on those instances when collaboration and creation transpire.

Here are two approaches that have shown promise at ETS.

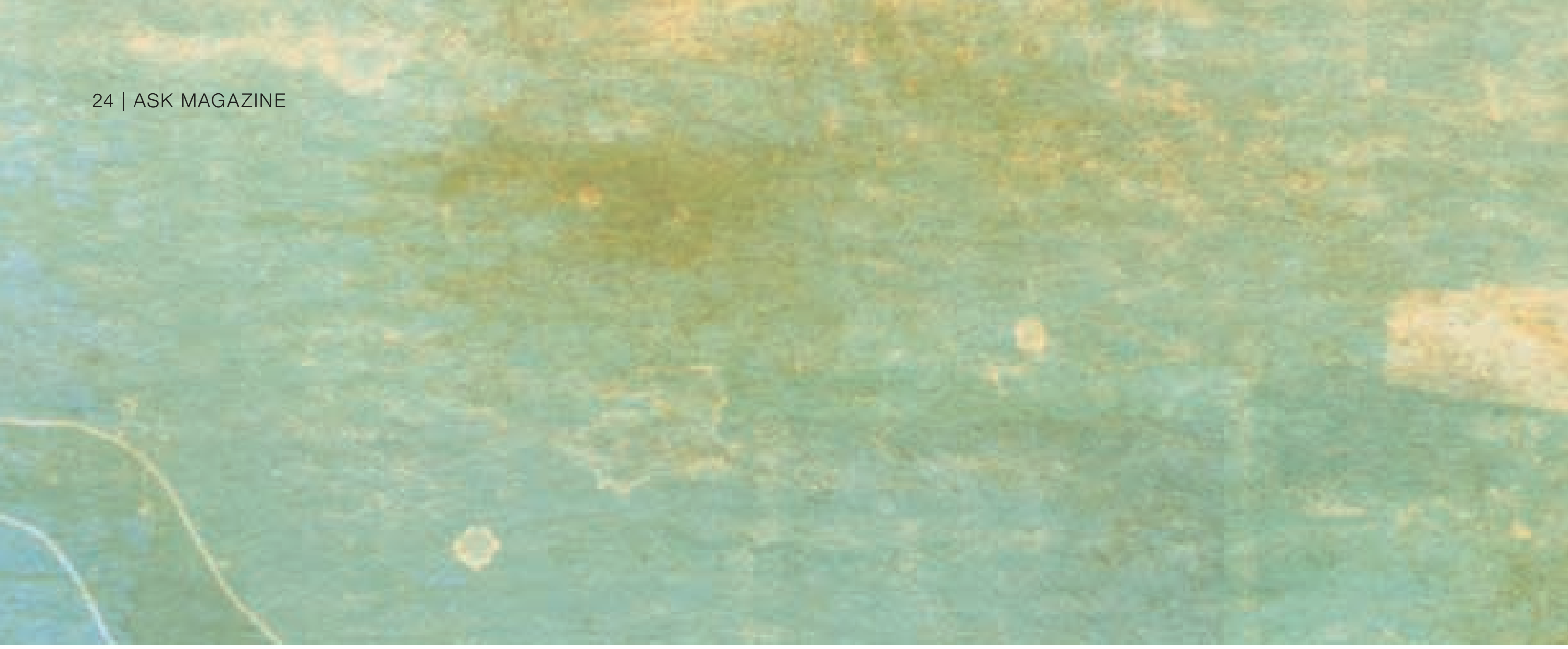
Blogs, Contests, and Weak Ties

One of the realities of employees being spread like islands within an organization is that their connections are usually weak with all but their specific group. But so-called weak (rather than non-existent) connections are a good source of new ideas. Sociologist Ron Burt makes the case succinctly: "The weak-tie argument is elegantly simple … people live in a cluster of others with whom they have strong relations. Information circulates at a high velocity within these clusters. Each person tends to know what the others know. The spread of information on new ideas and opportunities, therefore, must come through the weak ties that connect people in separate clusters." Having an area where employees can exercise these weak ties to encounter new expertise or ideas holds promise, but hosting a blog, wiki, or other social-media space without a specific purpose and facilitation will fail. Running contests in order to elicit knowledge that is held throughout the organization can motivate the sharing.

ETS ran "Margin for Mission," inviting staff to submit ideas for generating revenue or saving money. Each participant received a certificate for a free cup of coffee or tea, with larger prizes awarded at the end of each month for the best idea. The message was that as a not-for-profit we must increase our revenue and control our expenses to be able to fulfill our mission. The contest ran for ten weeks and had submissions from almost one quarter of ETSers that were read in turn by an equal number of "lurkers." The prizes were modest—a $250 gift certificate to Amazon—but the rewards were significant: employees were introduced to other individuals and their ideas.

Connect and Then Connect Some More

We established our "Knowledge Workings" blog to create different combinations of people by arranging forums where they are more likely to meet and converse with coworkers outside their disciplines. We started virtually and then built upon those connections for face-to-face events. For example, there were



1,259 online entries in 2009; fewer than 400 netted a reply. So we threw the "Blog Oscars" and had those who contributed the most stroll down a red carpet while all "lurkers" could watch and enjoy refreshments, bringing together colleagues who rarely interact. Such combinations help all to understand the tectonics of knowledge in the organization better. Then it becomes possible to create an "earthquake" by forming cross-divisional, cross-functional teams that have dual goals of solving wicked problems and learning about how they defeated the drooping entropy of human communication to do so. Invariably—when adeptly facilitated—they learn a great deal from each other.

BUILDING NEW SYSTEMS DESIGNED TO CAPTURE AND TRANSFER KNOWLEDGE DOES LITTLE TO OVERCOME INDIVIDUAL AND ORGANIZATIONAL BARRIERS TO KNOWLEDGE SHARING AND USE. EXPERIENCE DISCREDITS SUCH SYSTEMS.

In developing such connections, try to get the leaders out of the way. Bob Sutton has noted how some leaders brilliantly dilute their influence but stir their people by taking a backseat in some discussions. A senior leader in our San Antonio headquarters has held mixed lunches with every one of the four hundred people there. He speaks sparsely and almost always to prompt others to take the lead in discussing what they know that they think others should know.

Avoid the Folly of "Build It and They Will Come"

Building new systems designed to capture and transfer knowledge does little to overcome individual and organizational barriers to knowledge sharing and use. Experience discredits such systems. At ETS we now require leadership to build bridges among existing systems. Can the Quality Management System talk to the SharePoint platform and vice versa? Is there a map of all governance groups so that they know where they might find additional information? Do new hires receive an orientation that offers the obvious but often overlooked opportunity to meet other people? Are there interview series at which those with important information from the front lines of your business are questioned carefully and inventively in front of an audience of coworkers who don't know them? We undertook experiments based on each of the above questions to expose knowledge to a greater audience that either could not find it or didn't even know to look.

If the connecting happens and the weak ties deliver, then more people will know not only what others do, but also new things as knowledge combines, generates, and recreates. In such a circumstance, the islands are bridged and the labyrinth comes with a GPS. ●

As ETS's vice president of Strategic Workforce Solutions and its chief learning officer, **T.J. ELLIOTT** has overall responsibility for functions that include recruitment, benefit provision and compensation through knowledge, process and project management, performance improvement, and learning and development.

INTERVIEW WITH

Robert Braun

BY DON COHEN

Robert Braun was named NASA Chief Technologist in February 2010. His NASA career began at Langley Research Center in 1987. From 2003 until his return to NASA, he led a research and education program at Georgia Tech focused on designing flight systems and technologies for planetary exploration. Don Cohen and Academy for Program/Project and Engineering Leadership Director Ed Hoffman talked with him at NASA Headquarters in Washington, D.C.

COHEN: How do you see your role as chief technologist at NASA?

BRAUN: I am the administrator's primary advocate and advisor for technology matters across the agency. The president's FY11 budget request—yet to be approved by Congress—is what I would call a technology-enabled approach to exploration. That plan includes a wide variety of technology programs within the mission directorates and a new technology program outside the directorates. I directly manage the technology that's outside the mission directorates and work with the mission directorates' associate administrators on their technology portfolios. As a technology-oriented agency, it's very important that NASA communicate a single message about what we're doing in technology. One of my roles is to develop a coordinated policy to communicate the benefits of our technology programs, both to the space program and to life here on Earth.

COHEN: I know your job is new, but can you give an example of the kinds of things you've been involved in so far?

BRAUN: Coming into NASA from my university job, I thought I was going to be solely focused on developing plans for NASA's new technology programs. I have been doing that, but also much more. I go to the major policy meetings to

> "MARS MICROPROBE WAS A FAILURE **in the mission sense** … BUT **the lessons learned**, THE EXPERIENCE GAINED BY THE PEOPLE WHO BROUGHT US MARS MICROPROBE, WAS **directly utilized** IN THE DEVELOPMENT OF **a concept** THAT IS NOW **the baseline** FOR A VERY IMPORTANT FUTURE SPACE-SCIENCE MISSION."

speak up from a technology perspective. I've testified in the Senate Commerce Committee in a technology-oriented hearing along with the president's science advisor, Dr. John Holdren. I've spoken about the importance of technology at many of the NASA centers, at universities, and to industry groups. And I'm working closely with the mission directorates' associate administrators, helping to plan their technology programs.

COHEN: So the job is a lot more public than you expected.

BRAUN: It's a lot *more* than I expected. And more public.

HOFFMAN: Are there organizations out there that you'd like us to be more like or get closer to?

BRAUN: Yes. I've been meeting with my counterparts at other government agencies. I have a great relationship with Dave Neyland, the director of the TTO [Tactical Technical Office] at DARPA [Defense Advanced Research Projects Agency]. I've also spoken with leaders at AFOSR [Air Force Office of Scientific Research]. I'm meeting today with the director of ARPA-E, the new advanced research project within the Department of Energy.

For NASA to be successful in technology, we need to learn lessons from across the government. And we need a model that spans our many different kinds of technology programs. There is no one-size-fits-all technology program. We need programs that are wide open and searching for the best ideas across the globe—involving the NASA centers, our university partners, folks in industry, and our international partners. We also need the capability to fund high-value technology in strategic areas. And we need to have the flexibility to allow failure. If we take large risks, some of our technology programs will fail. In my view, that's a hard sell at NASA. The most frequent motto you hear at NASA is "failure is not an option." In our human spaceflight program, that is the correct mantra. But as we go from human spaceflight to large, flagship robotic missions, to small robotic missions, all the way down to technology demonstrations, we need to be able to dial up the risk we're willing to take. If we're afraid to fail down at the technology level, we won't make the major advances that are critical to our future and that our nation has come to expect of NASA.

HOFFMAN: If you tell project managers that you expect high performance within cost and schedule, the first thing they try to do is limit risk by limiting new technologies.

BRAUN: That's absolutely right.

COHEN: Can you create room in projects for three or four approaches to the same technology issue?

BRAUN: What we're going to do is identify the capabilities that we need. For instance, we need to be able to land the equivalent of a two-story house on the surface of Mars. There are several technological approaches to doing that—all in their infancy. You can imagine teams of folks from around the country or perhaps around the world responding with multiple technological solutions. What we would like to do is fund several of these to the point at which they're mature enough for us to make an intelligent decision about which solution is likely to pan out. Then we would put additional funds toward that particular solution and take it to a flight-test program. Only then, when it's been flight proven, would we bank on that technology.

COHEN: Is a willingness to fail one of the lessons learned from DARPA?

BRAUN: Absolutely. DARPA's philosophy is that about 10 percent of the missions they invest in will actually make it through to some future capability for the war fighter. That's their goal. They fund parallel teams taking parallel approaches, and they're willing to terminate these activities when they need to. They do that all the time. At NASA, we haven't had the fortitude to do that. We start technology programs and don't turn them off. We need to pursue advances which will not all succeed and use strong program management skills to terminate activities that are not bearing fruit.

COHEN: If people believe failure is not an option, that's hard to do.

BRAUN: I agree. Just last week two interesting news stories about failures came out a day apart from each other. The air force and DARPA together flew a hypersonic vehicle at Mach 20. Then they lost control of the vehicle, and it was terminated. The newspaper headline was, "DARPA breaks world speed record." Further down, the article talked about how the mission was a failure. Around that same time, NASA had a balloon crash in Australia. That was a headline story on CNN. Admittedly, there was a fairly dramatic video of the balloon crash—that's part of the reason it got hyped in the media. We are just now beginning to investigate the specifics of that particular failure. Was it a failure because we were attempting to take too large a step or because we made a mistake? In my view, if it was a failure because we were taking a large step, that should be acceptable.

COHEN: Jim March at Stanford has talked about the fact that the failure rate for innovative work is very high.

BRAUN: In its early days, NASA was good at taking risks and accepting the fact that not everything was going to succeed. Over time, we've gotten more and more risk averse. That's one of the things I'm trying to help change.

COHEN: In addition to trying to make failure more acceptable and funding potentially innovative work, are there things that can be done to foster innovation?

BRAUN: I think the amount of innovation in an organization is largely a function of how that organization values innovation. If you incentivize smart, creative people to be innovative, they will. If, instead, you incentivize them to work rigorously on one program for their entire career, they will do that. One of the things I think we need is more small projects. We need a greater diversity of projects and informed risk-taking so that we can stimulate innovation, particularly in the

NASA field centers. The centers are full of creative, bright, and talented people. We need to unleash their potential.

COHEN: So you see the issue as innovators ready to be unleashed, rather than having to train people to think innovatively?

BRAUN: Yes. Innovators are going to come out of the woodwork when they're incentivized to do so. Previously, there was no place in NASA for their ideas to go. There was no chance for those ideas to mature even a little bit, and they stayed in concept-land forever. In many cases, there wasn't even enough funding to write a paper, let alone take an idea from a paper study to a laboratory test or a flight test to prove that the relevant physics made sense. Over the last few years, funding to mature new ideas at NASA has become very tight. As part of the president's FY11 budget request, we are creating a new program called the Center Innovation Fund that the center directors will control and manage. They'll be getting some guidance from Headquarters on the kinds of activities the fund can be used for, but basically they'll be able to make quick decisions at the field centers about new ideas. Think of it as seed money to get new ideas moving so they can get to the point where we can see if they have any merit and, if so, how to transition them into a larger technology program or a flight program. Of course, I would also like to hire more people, and young people in particular. I'd like to hire one hundred young fresh-outs a year to each center. That would be another way of pushing innovation. You see this at Google, for instance. They are constantly bringing in new people and looking at new ideas. Not everything Google tries works. They accept failure and that helps their culture of innovation.

COHEN: In your earlier work with NASA or elsewhere, have you been part of innovative programs?

BRAUN: The first flight program I worked on as a young engineer at NASA was Mars Pathfinder. Pathfinder was our first attempt to go back to Mars after the 1992 failure of the Mars Observer, a billion-dollar orbiter that reached Mars, pressurized its fuel tanks, and then was never heard from again. Following that failure, the associate administrator for the Science Mission Directorate and a project manager at the Jet Propulsion Laboratory [JPL] put their careers on the line and created Mars Pathfinder. Pathfinder was designed to land on the Mars surface—something much harder than going into orbit around Mars—and that hadn't been done since Viking. And they were going to do it for $250 million, a quarter of the Observer budget. The best-known Mars Pathfinder innovation was the airbag system that allowed the lander to bounce and roll to a stop. The Sojourner rover was another—the first rover on another planet. Mars Pathfinder accomplished its science objectives and its technology objectives, but that's not the whole story.

Prior to Pathfinder, there was no Mars program in NASA and no Mars community of scientists and engineers. The public was not really engaged in the idea of sending spacecraft and eventually humans to Mars. You may remember that Pathfinder set a record for the number of Web hits after its landing on July 4, 1997. Public interest went through the roof. Shortly after that, the Mars program was established; it's been a funded line in the NASA budget ever since. The Mars Exploration Program Analysis Group, a collection of hundreds of scientists and engineers from around the world, was formed. That group provides scientific advice to the program on how it should proceed in the future. It has been so successful that there's now a VEXAG for Venus and an OPAG for the outer planets. My colleagues who cut their teeth on Mars Pathfinder went on to work on later Mars missions. Some worked on the Mars Exploration Rovers and on various Discovery and New Frontiers missions; some are now working on the Mars Science Laboratory. So when I think back on Pathfinder, I don't just think about its science and technology success. I think about the fact that for $250 million—a relatively small amount of money then and today—Mars Pathfinder was a game changer for the way we do planetary science. Innovative technologies can lead to entirely new ways for us to go about our business of aeronautics and space exploration.

COHEN: Among other things, they can create new communities.

BRAUN: Yes. New communities, new innovators, new businesses. They can affect the U.S. economy through technological stimulus.

HOFFMAN: People at NASA sometimes make fun of the term "game changing" because it's become so ubiquitous.

WHEN I STARTED AT LANGLEY, HAVING more senior people I COULD GO TO at any time WITH any question AND WHO NEVER TOLD ME THAT MY IDEAS WERE STUPID WAS a tremendous asset AND LEARNING EXPERIENCE.

Maybe you can talk about what game-changing technology means.

BRAUN: I think we'd all agree that the Internet was a game changer. That the cell phone was as well. These technologies changed the way we do business. Those are everyday examples. NASA can change the way we go about future missions. What we're doing in NASA's technology programs is investing in a broad portfolio of technologies so that the success of some of them will enable future NASA missions that we cannot even imagine today and will allow us to go about our currently planned future missions in entirely new ways that significantly reduce the cost or the travel time. What about enabling not only planetary exploration but interstellar exploration? We can't do that with today's technology because of the time scales involved. We're talking about investments that could allow entirely new ways of doing these missions. That's my definition of game changing.

COHEN: **So you see the new technology initiatives directly supporting NASA's flight missions?**

BRAUN: Yes. It's not that we need to do research and technology development instead of flight systems or operations. We need all three. But without research and technology development, we'd just be doing incremental missions. Science missions based on existing technologies would make scientific advances, but the pace at which those advances will be achieved would be slow. We certainly wouldn't be doing the kinds of human exploration missions that the president is talking about. We can't do human deep-space exploration without an investment in technology. What I believe is required, and the president's budget request highlights, is balancing these three long-standing core competencies at NASA: research and technology development, flight systems development, and mission operations. All three are required for NASA to be the cutting-edge agency that the nation expects it to be.

HOFFMAN: **Seventy percent of our scientific missions are international partnerships. Universities drive a lot of the science. Anything that comes out of here will permeate these other places.**

BRAUN: Reaching out broadly and partnering is a big part of the job. For an idea to succeed and be picked up by somebody else, a few things have to happen. First, you have to have the ideas, and I believe that NASA has

DARPA'S PHILOSOPHY IS THAT about 10 percent OF THE MISSIONS they invest in WILL ACTUALLY make it through TO SOME FUTURE CAPABILITY for the war fighter.

them. Second, you have to have a place to incubate and mature those ideas. That hasn't existed previously, but it will if the president's budget request is approved by Congress. Third, you have to make those ideas public, partnering with academia, with industry, with our international partners. If, for whatever reason, NASA can't capitalize on a particular good idea today, perhaps the commercial world will pick it up. Perhaps another government agency will pick it up. But they have to know about it first.

COHEN: Can you give another example of a mission you were involved in that generated valuable new technology?

BRAUN: Right after Pathfinder I worked on something called the Mars Microprobe mission, a New Millennium project. The New Millennium program within the Science Mission Directorate was the last significant program that enabled people to take technologies into a flight-relevant environment and prove them. Unfortunately, it's been in decline from a funding perspective over the last few years. In this particular New Millennium project, a handful of us developed a basketball-sized aeroshell called a single-stage entry system because it didn't have deployables: it didn't have a parachute, it didn't have airbags. This system was designed to fly all the way through the Mars atmosphere, impact the ground, and push a penetrator into the subsurface. We tested the system and it looked pretty good. We did a lot of analysis. We flew it. Two of the systems flew all the way to Mars along with the Mars Polar Lander in 1999. The whole New Millennium activity cost $25 million. They were lost with the lander. Some people would say that was a failure.

The next mission I went to work on was the Mars sample return Earth-entry vehicle. This is a highly valued component of a highly valued mission, something the Mars community is very interested in doing one day. The Earth-entry vehicle is the piece that would bring the samples back from Mars safely through the earth's atmosphere for recovery. My team was selected competitively to develop that system. We proposed a single-stage entry system based largely on what we had learned from the Mars Microprobe project. Mars Microprobe was a failure in the mission sense; I'm not trying to gloss that over. But the lessons learned, the experience gained by the people who brought us Mars Microprobe, was directly utilized in the development of a concept that is now the baseline for a very important future space-science mission. Single-stage entry systems have since been proposed by a number of organizations to return samples from comets and the moon. Another way you can tell whether you have a good idea is by the number of people who adopt it.

COHEN: You got $25 million worth of learning.

BRAUN: I learned just as much from the $25-million, rapid-development Mars Microprobe as I did working on the

$250-million Mars Pathfinder. One was a failure, one a success. Working on that "failure," I improved my skills as an engineer, I improved my systems knowledge, and I learned valuable lessons that I could apply to future systems.

HOFFMAN: A project is a project.

BRAUN: As long as you get to hardware and some sort of demonstration. It can be a ground-based demonstration; it doesn't have to be a flight. Too often we never get out of the paper phase. There are technologies for scientific exploration, human exploration, and aeronautics that have been documented in report after report for decades. A healthy technology program should allow people to take those technologies from the concept world, where they've been stuck for decades, and into the flight world (where "flight" can mean ground-based testing, atmospheric testing, low-Earth-orbit testing—whatever is needed to prove the core technology). That's what's been missing in NASA over the last decade.

COHEN: Are there ways, other than assertion, to create a culture where valuable failure is OK?

BRAUN: It's a long-term process. There are several approaches I'm working on. One is communicating. We need to assure the NASA workforce, industry, and academia that informed risk-taking is acceptable. The current system forces them to act as if failure is not an option even for a $25-million ground-based test. The second step is to design for failure through our acquisition strategy—to actually plan on having a certain percentage of failures. The third piece is to set up the technology development program with defined gates where one plans to terminate activities, and everyone knows that it doesn't mean the end of the world. If we're going to have five parallel efforts for a given capability, at some point we're going to terminate four of them.

HOFFMAN: Today you get communities locked in to self-preservation, as opposed to going on to the next cool thing.

COHEN: When people hear stories of someone promoted because of an interesting failure, they'll be convinced.

BRAUN: I intend to celebrate failure. Not because we made a metric-to-English conversion error. Failure because we went after a large goal, made progress, and did all the right things, but didn't quite make it to that goal. I'm sure they're celebrating in DARPA today because they flew a Mach-20 vehicle. Did they succeed in their objectives? Absolutely not.

HOFFMAN: Before we finish, tell us about what prepared you for where you are today.

BRAUN: A breadth and diversity of educational and professional experiences prepared me for this assignment. I grew up with a father who pointed me in this direction at an early age. He was an electrical engineer at the Johns Hopkins Applied Physics Laboratory. I had excellent educational opportunities at Penn State, George Washington University, and Stanford. I've also worked for extended periods of time at three different NASA centers. I was always a Langley employee, but I was often on a development assignment: at Ames Research Center for a couple of years, at JPL for Mars missions. When I started at Langley, having more senior people I could go to at any time with any question and who never told me that my ideas were stupid was a tremendous asset and learning experience. Langley sponsored both my master's degree and my PhD through various Office of Education programs. Also very important was leaving the agency in 2003 and going to a major research university like Georgia Tech, where I could view the agency from the outside and see the immensely strong capabilities of the outside world. Previously, inside NASA, I hadn't looked outside as much as I should have. Coming back from the outside, I see the value in these partnerships much more clearly. ●

ENGINEERS

BY KERRY ELLIS

According to the World Bank, more than 1.1 billion people do not have access to clean, safe water, and 1.6 million children die each year as a result of illness related to inadequate water supply and sanitation. Engineers Without Borders–USA (EWB-USA), a volunteer organization, is working to change that.

Founded in 2001 at the University of Colorado, EWB-USA has grown to more than 250 chapters comprising 12,000 volunteers working in 45 developing countries. One of the founding volunteers, Evan Thomas, began working at the Johnson Space Center in 2004 and started a local chapter for the NASA center. In their time off from work on human spaceflight, NASA engineers, scientists, astronauts, and contractors work with local professionals and students to help solve energy and water-supply problems in areas much closer than space, but still challenging to reach. In the process of serving those communities, they have developed skills that serve their NASA work as well.

Planning and Partnership

Every EWB-USA project requires careful planning, because a solution that has worked in one location may not work in another. For example, a water-treatment system in Rwanda the Johnson chapter worked on required a very different approach than a system in Aguilar, Mexico, another community in which they've worked.

Traditional water systems for developing communities often begin with drilling wells. If wells aren't feasible, other options such as water protection, rainwater catchments, and point-of-use water treatment, which are small-scale systems that may treat a couple liters per hour, are used. None of these proved to be a perfect solution for Rwanda. "It's so mountainous, wells aren't feasible. So densely populated, you can't isolate areas for source-water protection. It's so poor and densely populated, point-of-use systems aren't practical. You'd have to distribute millions of them, and people can't afford the replacement costs," Thomas explained.

Rwanda needed a new solution. "We looked at all these options and didn't see anything that we could adapt, so we ended up inventing our own water-treatment system," Thomas said. The result was a gravity-fed system that runs water first through a gravel filter, then a rapid sand filter, and then through a solar-powered ultraviolet disinfection system. According to Thomas, "It's kind of a hybrid between the small-scale, simple technologies and the higher-tech, higher-volume technologies." The system can treat up to 50,000 liters of water a day for 3,000 people, and it can be maintained for less than one-fifth of a cent per liter—about one cent per gallon.

The process—from identifying a community in need to implementing a solution—can take years. EWB-USA wants to ensure all volunteers involved not only present viable, sustainable engineering solutions, but also commit to seeing their projects through to implementation. Planning, review, and commitment are key parts of EWB-USA's success in managing projects around the world, even in the most remote areas.

Before anything is built, a few members of a chapter will visit a community to learn more about its needs and resources. "We sit down with the community members; identify what their critical public health needs are; work with them on what we might be able to contribute, what they'll be able to contribute, potential timeline; and then go back and start developing technologies," said Thomas. This initial visit also helps begin the partnership that is crucial to these projects succeeding.

"The first time you go to a community and see they aren't drinking clean water, you want to get back as soon as you can to solve that problem," said Dan Garguilo, a systems

WITHOUT BORDERS

Photo Credit: EWB-JSC/Evan Thomas

Primus, an orphan at the Mugonero Orphanage in western Rwanda, drinks the first glass of water from EWB-JSC's water-treatment system.

Photo Credit: EWB-JSC/Evan Thomas

engineer at Johnson and current president of the EWB Johnson (EWB-JSC) chapter, "but we still have a lot of steps and project-approval processes to ensure that what we're doing is going to be sustainable and appropriate and maintainable by whatever community we're working in."

Every project requires at least a five-year commitment from volunteer chapters, during which time members of the community will learn about the system and how to maintain it. Only a few members of the team that helps design, build, and test new systems in Houston make the journey for installation, since traveling to Rwanda is expensive. Cost also prevents engineers from being able to fly in to make repairs or replacements on any system they install, so EWB-USA partners together closely with the communities they help to ensure people within the community are trained on the minimal maintenance the water-treatment systems require.

Problem Solving in Rwanda

Relying on local maintenance and supplies requires any EWB-USA engineering system to be a relatively low-tech, sustainable, and functional solution. "We call it 'appropriate technology,'" said Thomas. "Our water-treatment system is a good example of that. We use gravity, which is always there, plus gravel, sand, and drums that are available locally."

The only high-tech element the Johnson chapter used in their water-treatment system at a local orphanage was an ultraviolet light, which could treat thousands of liters of water a day instead of a couple of liters an hour. "Our decision to use an ultraviolet light was not trivial," Thomas explained. "It's important to make sure we have a supply chain for replacing, properly disposing, and maintaining those lights."

The limited time, people, and resources available to EWB-USA creates a challenging environment in which to problem solve when things go wrong. "We prototype all our systems in Houston and try to work out all the kinks here, but you never get everything figured out," explained Garguilo. "Without fail … there's always a new problem that presents itself. You don't want to leave not having a project implemented, so there's a lot of scrambling and trying to problem solve on the go in places where you can't pop down to a hardware store. You have to figure it out right there with whatever you brought with you or what you can find locally."

= < 1¢ PER GALLON

THE SYSTEM CAN TREAT UP TO 50,000 LITERS OF WATER A DAY FOR 3,000 PEOPLE, AND IT CAN BE MAINTAINED FOR LESS THAN ONE-FIFTH OF A CENT PER LITER—ABOUT ONE CENT PER GALLON.

Far Left: EWB-JSC volunteers in Muramba, Rwanda.

Left: EWB-USA volunteers after the installation of an early water-treatment system. This design has evolved into iterations treating water across the country.

During one trip, the volunteers discovered a problem that compromised the entire water-filtration system at an orphanage—two days before they were scheduled to leave.

"Most of the projects we've done have been a variation of a rapid sand filter for clean water. The concept is pretty straightforward: filtering water through sand," Garguilo explained. "When you buy sand here in the states, you can buy nice, clean, sifted sand. The sand we got locally in Rwanda, people went down to the beach for. We were prepared for that. We brought the necessary equipment to sift the sand to get the right particle size, but it's very dirty. How do you clean sand without reliable access to water?"

The orphanage helped the EWB-JSC engineers by grabbing the jerricans they use to haul water and retrieving water from a nearby lake so the sand could be washed. What the volunteers didn't know was that some of the cans had previously been used to haul kerosene.

"We were running water through the system to clean it, and we started to smell something," recalled Garguilo. "It was in the middle of the night, too. Since time is of the essence, and it gets dark at 6:00 p.m., we oftentimes work well past darkness."

They realized the next morning the entire system was coated with oil from kerosene residue. "You couldn't just go grab a hose and plug it in somewhere and start flushing out the system," Garguilo said, "we had to find something locally that could work. Luckily, we happened to find some apple blossom shampoo a previous volunteer had left. Of course, soap reacts with oil to break it down."

The volunteers poured the shampoo into the system to rinse it as best they could, and there was just enough soap to break down all the oils and flush out the system. "The water smelled like apple blossoms for a little while, but it was at least clean," Garguilo recalled with a chuckle. "The smell eventually washed out, but that was one of those, 'Oh no, we're screwed,' moments. Working with limited resources is always a challenge."

Learning from the Challenges

Many of the Johnson volunteers find themselves using their field experience from Rwanda and Mexico at their day jobs, not the other way around. Their hands-on experience and problem solving with EWB-USA has proved helpful when they are designing systems for space.

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

"The similarities are very strong," added Thomas. "You're living in a very harsh environment with very little maintenance and resupply. You have to keep people alive and healthy for a long period of time, and you have dirty water, you have dirty air, you need sustainable sources of power and energy. Keeping people alive on a lunar outpost, in my opinion, is far, far more similar to keeping people alive in Rwanda than it is even to keeping people alive on space station."

If the water processor on ISS failed, engineers would not be able to see or touch the system, and the information they could receive about the problem would be limited. "That's similar to when I'm sitting in my apartment in Houston and I have a really sketchy e-mail trying to explain why my water-treatment system in Rwanda isn't working anymore," said Thomas. "That's a challenge, but it also makes you think about how you design these systems and how you train people to maintain these systems to keep them simple so they don't fail all the time."

EWB-JSC gives engineers an opportunity to build and repair systems in Rwanda relatively quickly compared with systems in space; they also benefit from being able to work on a project from start to finish. "It takes a long time to develop this technology at NASA," said Thomas, who works in water recovery and water management systems in the life-support branch at Johnson. "Most civil-servant engineers don't get to spend too much time in the lab or tinkering with hardware. Through EWB-USA, I've gotten my hands dirty, I've built water-treatment systems, I've implemented them, and we're treating drinking water for people on a daily basis. All that research, all that development effort, all that experimental design and implementation, I truly think makes me a better NASA engineer."

Volunteering with EWB-JSC also gives people who normally wouldn't work together within NASA a chance to collaborate, creating a network for sharing knowledge and mentoring that might not have happened otherwise. "It's a vibrant community," said Thomas, "and it's helped my day job. People that I normally would never have worked with, now I know them and can call them up. Knowing who the experts are and where and being able to call directly is invaluable. When you're getting dirty in the field, it really helps you get to know somebody." NASA center volunteers also partner with local university and industry volunteers, expanding their knowledge network to outside the agency as well.

Photo Credit: EWB-JSC/Evan Thomas

EWB-JSC volunteer Evan Thomas working in Muramba, Rwanda, to assess a surface-water pipeline.

EWB-JSC continues its work with the people of Rwanda and Mexico on a regular basis, helping install new systems and maintain existing ones. Despite the distance, the communities and EWB-JSC make every effort to stay connected through e-mail, phone calls, and periodic visits.

The relationships go both ways. Astronaut Ron Garan, who volunteered with EWB-JSC and has since created a non-profit organization to help with EWB-USA's maintenance efforts, made certain the children of the orphanage in Rwanda knew that he had not only become a part of their community, but they had become a part of his. Last year, he flew photos from the orphanage with him into space, and those photos now hang in Rwanda for the community to enjoy.

Featured Invention:
NASA Helps Extend Medicine's Reach

BY BO SCHWERIN

Mediphan's MedRecorder and DistanceDoc devices enable the remote-ultrasound techniques developed for space to be employed on Earth.

Image courtesy NASA Spinoff

In spring 2008, Dr. Scott Dulchavsky diagnosed high-altitude pulmonary edema in a climber more than 20,000 feet up the slope of Mount Everest. Dr. Dulchavsky made the diagnosis from his office in Detroit, half a world away. The story behind this long-distance medical achievement begins with a seemingly unrelated fact: There is no X-ray machine on the International Space Station (ISS).

On the ISS, diagnosing an injury or other medical issue can be problematic; bulky medical-imaging devices like X-ray, CAT, or MRI machines are too large and heavy for costly transportation into space. And while crew medical officers receive some diagnostic training, the nearest doctors and fully equipped hospitals are 250 miles away on Earth. Future astronauts on long-term moon or Mars expeditions will face even greater challenges.

The ISS does have an ultrasound machine—at 168 pounds, much smaller than its imaging-technology counterparts—installed as part of the Human Research Facility for experiments on the effects of microgravity on human health. During medical use, the ultrasound machine's hand-held transducer emits high-frequency sound waves that partially reflect at points of differing density, such as between soft tissue and bone. The machine's computer translates the echoes into a two- or three-dimensional video representation. On Earth, ultrasound is commonly used for imaging fetus development, abdominal conditions like gallstones, and blood flow in patients with arterial disease. Unconventional applications, like diagnosing broken bones or collapsed lungs, were not explored given the ready availability of X-ray and MRI machines in hospitals and the high density differences of bone and air, which completely reflect the ultrasound waves and prevent clear images of deeper tissue.

That changed in 2000, when NASA approached Dr. Dulchavsky, chair of the Department of Surgery at Henry Ford Hospital in Detroit, to make ultrasound a more versatile diagnostic technique and to adapt it for remote use on the ISS. Dr. Dulchavsky tested new ultrasound applications and found that, in many cases, such as with collapsed lungs, the technique worked better than X-ray imaging. He became lead investigator for the Advanced Diagnostic Ultrasound in Microgravity (ADUM) experiment, a collaborative effort between Johnson Space Center, Henry Ford Hospital, and Wyle Laboratories Inc. in Houston.

Aided by Onboard Proficiency Enhancer (OPE) software, cue cards, and direct communication with doctors on Earth, ISS crewmembers with only minimal ultrasound training (about three hours as opposed to about five hundred hours for a professional) used nontraditional ultrasound techniques pioneered by Dr. Dulchavsky's team for capturing images of a wide range of body parts. These novel ultrasound techniques can evaluate infections in the teeth or sinus cavities or judge the effects of spaceflight on the central nervous system by measuring changes in the diameter of the eye's optic nerve sheath as a gauge of pressure around the brain. Experts on the ground received diagnostic-quality images from the ISS through a satellite downlink, demonstrating the effectiveness of ultrasound as a multipurpose, remote-diagnostic tool in space.

In keeping with NASA's mandate to translate space technologies into applications for terrestrial use, Henry Ford Hospital doctors and Wyle engineers worked to find ways to overcome a major obstacle to bringing the ADUM-developed remote-ultrasound procedures down to Earth: There were no cost-effective, technologically viable methods for sending ultrasound scans over long distances without a loss of image quality.

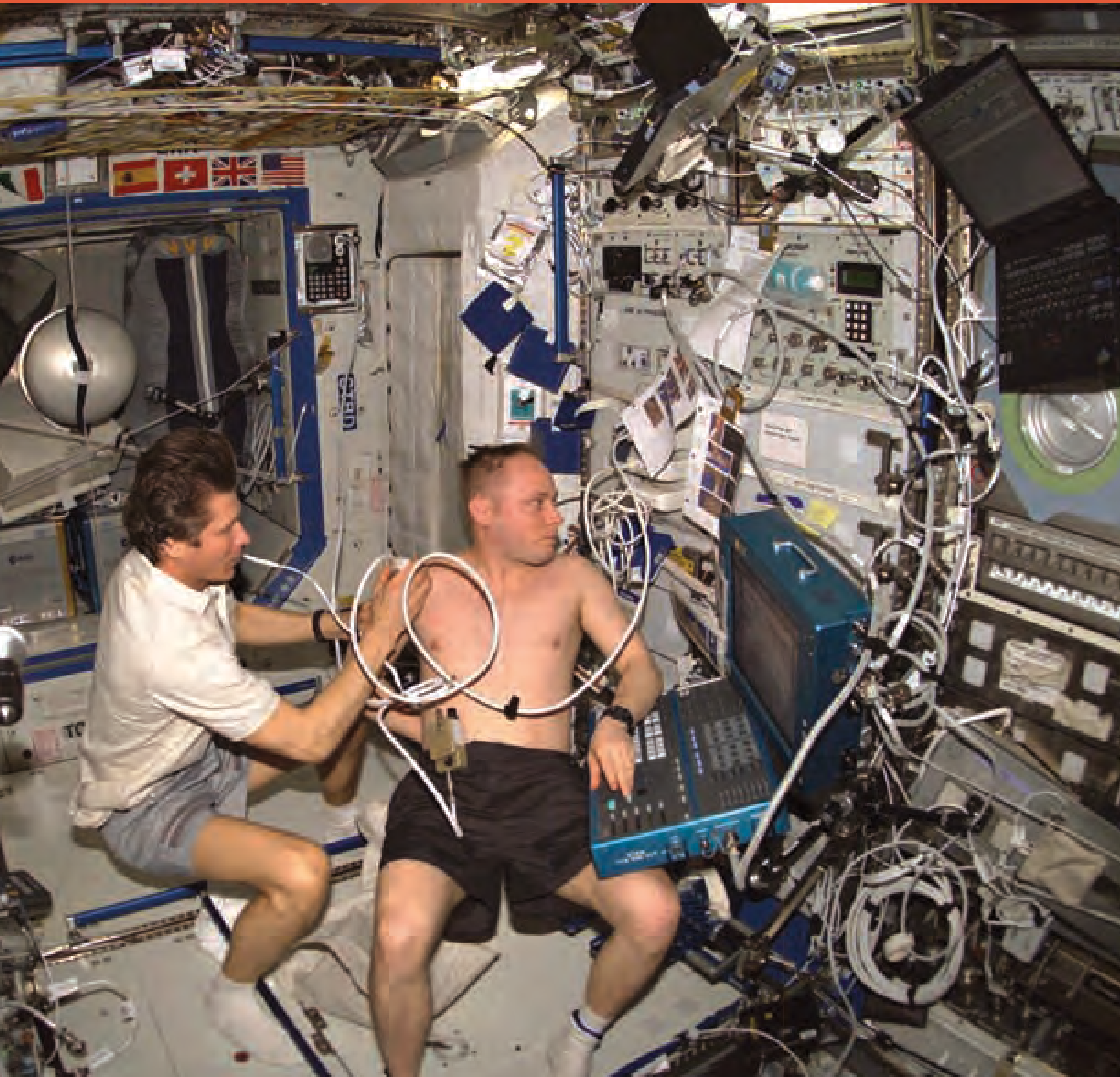
"We have a great satellite hookup and a big telemedical network at NASA, but we don't have these for common terrestrial use," said Dr. Dulchavsky.

To overcome this problem, they collaborated with Epiphan Systems Inc., a computer-imaging industry leader headquartered in Canada with offices in Springfield, New Jersey. The cooperation resulted in the formation of Mediphan, a remote–

Right: This climber was diagnosed with high-altitude pulmonary edema while more than 20,000 feet up the slope of Mount Everest—miles from professional medical personnel.

Below: Remote ultrasound procedures help provide for medical diagnoses on the International Space Station.

Photos courtesy NASA Spinoff



WE COULD UTILIZE THE TECHNIQUES AND TECHNOLOGIES THAT WE DEVELOPED FOR USE ON THE ISS TO DIAGNOSE A WIDE VARIETY OF MEDICAL ISSUES …

medical diagnostics technology company. Mediphan drew on NASA expertise to adapt Epiphan's video-streaming innovations into a practical solution and has developed and commercialized two tools for terrestrial telemedical use.

DistanceDoc, an external video-frame grabber, makes use of Epiphan's video graphics array (VGA) capture technology to take diagnostic-quality and Digital Imaging and Communications in Medicine (DICOM) standard stills or video from the ultrasound monitor (or any other medical device with a video display, such as an electrocardiogram or ventilator). It then allows the ultrasound operator to transmit the images securely over the Internet in real time and at near-original resolution. The second tool, MedRecorder, is a similar device that captures diagnostic-quality and DICOM imaging, then stores and archives it for later reference, like an external hard drive.

Each device plugs into the VGA port of any standard ultrasound machine and then connects to a computer by a universal serial bus, or USB, 2.0. A non-physician can, with minimal technical know-how, install Mediphan's technology and use it to send medical imaging for consultation with experts. Coupled with the highly portable General Electric LOGIQ laptop ultrasound machine and the NASA-developed OPE instructional software now modified for broader use, even the medically inexperienced can consult with distant doctors to diagnose medical issues when and where they occur.

"Immediacy in point of care is essential," said Dr. Dulchavsky. "We can now have non-skilled individuals on site doing what traditionally only highly skilled individuals are able to do."

The applications of remote-ultrasound diagnostic capabilities are widespread and increasing. The major professional sports teams in Detroit are all using the ultrasound procedure, OPE software, and Mediphan devices for immediate locker-room diagnoses of injuries that happen during practice and games. Olympians at the 2006 Winter Olympic Games in Torino, Italy, benefited from the telemedical procedure, as did athletes at last year's Summer Olympic Games in Beijing, China. Currently, the procedure is used for day-to-day oversight of Olympians in training facilities across the United States. It also allows trainers to establish baseline evaluations of athletes' body structures, making for easier recognition of damage due to injury. More than 345 musculoskeletal ultrasound examinations have been performed on Olympians and professional athletes so far, a number of these with remote guidance.

The technology is also helping improve education, allowing a medical student on duty to share diagnostic information with an attending doctor elsewhere. The MedRecorder offers medical students the ability to archive personal portfolios documenting proficiency in diagnostic techniques and provides an affordable way to store and maintain records.

Meanwhile, the United Nations Millennium Project, which has among its goals improved maternal care in underserved areas, plans to use the telemedical procedure in developing countries. Dr. Dulchavsky and NASA engineers are currently working to create a highly versatile, environmentally robust device that could serve as a kind of information node connecting patients in remote areas to distant experts via Mediphan technology. Then, Dr. Dulchavsky said, "we could utilize the techniques and technologies that we developed for use on the ISS to diagnose a wide variety of medical issues, such as traumatic injury, problematic pregnancies, and certain infectious diseases."

Last year, working at a distance with a NASA team in the Mars-like environment of Devon Island in northern Canada, Dr. Dulchavsky performed the first-ever remote guidance of a simulated appendectomy. One day, the same technique may be used to do the real thing in a village in Madagascar, on the slope of Everest, or on Mars itself. ●

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Nurturing Trust

BY RON TAYLOR

“If you fail to honor your people, they will fail to honor you.”

– Lao Tzu (604–531 B.C.), founder of Taoism

In my father’s generation, leaders were expected to give orders and workers were expected to take them. You did what you were told to do or you were fired.

In my generation, leaders are expected, in style if not in spirit, to take their workers’ views into consideration. People expect their jobs to be challenging, interesting, and engaging. The leaders of successful organizations know this, and know how to keep their employees challenged, interested, and engaged. They do it by recognizing that their own success depends on how well their employees perform and by investing time and energy in helping others succeed.

The Challenges

The Washington, D.C., chapter of the Project Management Institute (PMIWDC) has nearly nine thousand members. The position of president and CEO, which I was proud to hold in 2007 and 2008, came with interesting challenges:

- The sheer size of the organization. The nearly nine thousand members of the PMIWDC chapter paid us to work for them. Practically speaking, each member was also a client, so we had nearly nine thousand clients. That meant nine thousand sets of demands.
- Leading and motivating a large group of volunteers. I had a staff of approximately 260 people, of whom 255 were volunteers. That meant they could leave at any time for any reason without any consequences. My job was to keep them involved, engaged, and on the team.
- I could not use any of the traditional means of motivating my staff. I could not hire anyone, fire anyone (without a lot of pain), promote anyone, demote anyone, or give anyone a corner office, company stock, or a coffee cup.

During my two years as CEO we increased our membership an extraordinary 25 percent, doubled our revenue, and implemented nearly 120 new initiatives.

We were selected PMI’s Chapter of the Year in both 2007 and 2008 (we won the “Recognition of Excellence” award in 2008); three of our major programs were so successful they also received PMI’s Recognition of Excellence awards; two of our volunteers were given awards for their service; and I was named PMI 2008 Leader of the Year.

How did we accomplish all this? The first thing we had to do was establish and then nurture a climate of trust.

Nurturing Trust

Trust is foundational—you can accomplish wonders with it and very little without it. A reputation for trustworthiness and your willingness to trust others are worth more than just about anything else. Like many things of value, trust is fragile. Like many fragile things, it requires a great deal of care.

Some leaders cite the importance of “building” or “establishing” trust. I have found it to be more important to nurture trust—to keep it alive through constant attention. You nurture trust by acting in accord with the recognition that everything you say and everything you do either contributes to or erodes trust.

Trust is hard to earn and easy to lose. During my presentation on leadership at the 2009 NASA Project Management (PM) Challenge, I asked if anyone had experienced a loss of trust. One man volunteered his story about how his boss had violated his trust. The more he talked the more agitated he became. His emotion suggested that the incident must have been quite recent. I asked him when this happened and he said it was twenty years ago, but the wound was still fresh and the pain was still raw.

Use Your Leadership Moments

Most leadership moments are little ones: a conversation with a colleague or a response to an e-mail message. They are available to everyone, regardless of where they are in the organization. You’ll probably have at least fifty leadership moments today. Leadership moments represent opportunities to demonstrate your ability to lead and to share your leadership philosophy. Use them to nurture an atmosphere of trust.

Use Team Meetings

The way you conduct team meetings can allow you to nurture trust at both the individual and corporate level.

Consider a person we'll call "Adrian." Adrian was a leader who said all the right things, but betrayed his true nature in team meetings. He professed to value everyone's opinions, but he really believed that life was a war and his team members were his troops.

SOMETIMES WE BOUNCE IDEAS OFF OTHERS TO HELP CLARIFY OUR THINKING. THAT CAN BE A USEFUL AND PRODUCTIVE STRATEGY. IF YOU ALWAYS GO TO THE SAME PEOPLE, HOWEVER, YOU MAY WANT TO ASK YOURSELF WHY YOU'RE LIMITING YOUR OPTIONS.

That meant you were either with him or against him. Team meetings became "battles." Before each one he would hold private "strategy sessions" with a small group of people to plan how they would handle agenda items so he could have his way.

As the team meeting unfolded, each person in the strategy session would play his or her part, and dissenting opinions would be politely, or not so politely, dismissed.

It wasn't long before the rest of the team learned what was happening. The net effect was that Adrian divided the team, drove a wedge between those who attended the strategy sessions and the other team members, and reduced the team meetings to playlets. Even those in the strategy sessions began privately referring to the team meetings as "kabuki" and became as disengaged as their colleagues.

Adrian was not capable of trusting the opinions of others. He was so afraid of taking that risk that he surrounded himself with what he thought were his supporters in the strategy sessions and bulldozed his way through the meetings. As a result, he missed out on the value of additional information, insights, and solutions. Ultimately, he won the battles and lost the team.

Throughout my career I have viewed my job as helping others reach the best decisions about things we all thought were important, not jamming my ideas through. To accomplish this I have had other people suggest agenda items for meetings rather than selecting all the items myself.

In that way we would be sure to include topics they were interested in, and give each of them an opportunity to discuss what they had been doing and their proposals for new initiatives. This placed the emphasis where it belonged—on the team, not me.

Speak Their Language

Sometimes we bounce ideas off others to help clarify our thinking. That can be a useful and productive strategy. If you always go to the same people, however, you may want to ask yourself why you're limiting your options. If it's because they all speak your language, perhaps you need to learn another one.

I made it a point not to go to the same people each time. I am especially interested in learning the opinions of the quieter people. Asking them in a casual one-on-one conversation encourages them to eventually share their opinions in team meetings, to everyone's benefit.

I also wanted to make sure everyone felt like part of the team, and I wanted to learn not only what they thought but how they thought.

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I learned what people thought by simply asking for their opinion. That can provide valuable information, and some leaders stop there. They take the answer back to their cave and add it to the pile of opinions. It was more important to me to know how people thought, because that gave me insight into the way I could best work with them.

As you get to know the people in your organization or on your team, you will be able to understand both what and how they think—but only if you make the effort. Learning this technique allows you to nurture trust with them more easily because you're communicating on the same frequency.

Choose Your Words Carefully

This is especially challenging when you're stressed, or so focused on a task that you forget the importance of nurturing trust at every moment. There is a huge difference between telling someone, "That's your job," and saying, "I trust your judgment." In the former instance, your conversation is directive and confrontational. In the latter it is directive and supportive. Imagine what it would feel like to be on the receiving end of those conversations and it is easy to make the right choice.

Ask for Help When You Need It

One of the best ways to nurture trust is to ask for help. Admitting, for example, that you don't know how to drive business to a Web site doesn't make you weaker, it makes you more human, more approachable, and ultimately more respected.

Some leaders try to have all the answers all the time. They subscribe to a kind of "ninja leader" act that is as unreasonable as it is unattainable. They become so wrapped up in the act that they don't realize they're getting in their own way.

There is, in fact, both great freedom and great power in being occasionally vulnerable. Like everyone in your organization, you have your own strengths and weaknesses, so admit that you cannot do or know everything.

You have to be selective in your vulnerability, of course. If you are the CEO, I don't recommend that you tell people you have no idea what the strategic direction of the organization should be and you would like someone to handle that for you.

Use your common sense to know when to ask for help, but don't be afraid to be human. By asking for help you allow someone else to solve a problem that you have admitted you can't solve. You not only empower other people, you also encourage them to take on additional responsibilities and establish a bond of trust based on your vulnerability and their capability.

Never Compromise Your Integrity

Sometimes, in the course of leading others, you have to make a trade-off among virtues. You may have to act like everything is fine when you would rather curl up in a ball. There is one thing you simply can't do: compromise your integrity.

To nurture trust, you can't be mostly honest or mostly fair. You can't take a moment off. You always have to deliver honesty and trust.

As soon as you lie, cheat, or act dishonestly, you have broken trust, and you may never regain it. Worse yet, you can safely assume that the person whose trust you have broken will tell other people (remember the man at the 2009 NASA PM Challenge?) and that your damaged reputation will follow you. Lying, cheating, or acting dishonestly will do more damage to you than to others, diminishing you as a human being. ●

RON TAYLOR is the founder of the Ron Taylor Group, which specializes in project management and leadership training. He is past president of the Project Management Institute (PMI) Washington, D.C., chapter and was named 2008 PMI Leader of the Year.

The Decision

BY HARVEY SCHABES

’Twas the night before the night before the night before Christmas, a cold and snowy night.

The call came in at approximately 4:30 in the morning. The information was provided. I asked for the caller’s recommendation, and I made the decision, a decision that has haunted me ever since. Did I do the right thing? Would I do it again?

In November 2004, I was named the deputy director of the Center Operations Directorate at Glenn Research Center. It was my first position at this level of management and responsibility. As a rookie, I tried to learn as much as I could from those around me. I consider myself a reflective learner, always asking why, what, and how so as to learn and benefit from each situation and experience and be better for it in the future.

Which brings us to December 22.

As the holiday season neared, many people at Glenn began to take time off, so temporary assignments and acting positions were common. When the director of Center Operations talked to me that day, he informed me that he was leaving for the remainder of the holiday season and that I should do what was necessary to keep things moving. He also said that, since he was going to be out of town, the center’s Emergency Preparedness coordinator would call me for any required action if there were any emergencies. He mentioned as well that the center director, his deputy, and the associate director were also going to be on leave the next day. As the afternoon drew to a close, the weather people in the Cleveland area were predicting snow, but their predictions frequently don’t come to pass. In any event, I went about my normal activities and went home and to bed that night not really concerned that I would be required to do anything special.

But at 4:30 a.m. on Thursday, December 23, my cell phone rang. It was the center’s Emergency Preparedness coordinator. He informed me that many local highways were impassable, none of the center’s roads or parking lots had been plowed (many of the people who would have normally performed this function weren’t able to get in to work), and the police were advising against travel. He recommended that the center be closed for the day. I asked some questions about snowfall amounts and

THE KEY LEARNING THAT I AM LEFT WITH IS THIS: IF ASKED FOR A DECISION, MAKE IT; IF ASKED FOR AN OPINION, GIVE IT; IF GIVEN THE OPPORTUNITY TO LEAD, LEAD!

locations across the city and what was being predicted for the next few hours and then said, "Yes"—do what is necessary to close the center and notify the appropriate authorities.

After hanging up, I lay there wondering, what have I done? I just closed the center! I quickly turned on the TV and was somewhat reassured by news reports about the severity of the storm, but all I kept wondering was, what have I done? At about 8:00 in the morning I called the associate director and told him what had happened. He assured me I did the right thing. We would talk several times throughout the day, eventually deciding that the snow had subsided and the roads improved enough to open the center for second-shift operations.

When I came to work on Monday, December 27, the deputy center director wanted to know who the hell shut down the center. He had decided to come to work that Thursday. After driving through bad weather that tripled his commute time, he got to Glenn only to be told by security that the center was closed. I raised my hand and sheepishly said, "I did." A week later, I went in to the center director's office and said with a smile on my face, "Forgive me; I am the guy who shut your center."

He smiled and said, "You did the right thing!"

Word spread quickly; I was given a new title: the "guy who shut the center." Even today, six years later, whenever snowflakes begin to fall, people still say, "Hey, Harvey, are you going to shut the center again?"

Over the years, I have reflected on that phone call and my decision. I always come to the same conclusion: I would do it again. I also have tried to understand what lessons from that experience I can apply to future situations. The key learning that I am left with is this: if asked for a decision, make it; if asked for an opinion, give it; if given the opportunity to lead, lead!

A leadership lesson I received early in my career also comes to mind. It was taught to me by John Hodge, a space visionary and great leader whom I was exposed to in the early days of space station. I was lucky to have known and learned from him. One of the things he told me was, "Ask for forgiveness, not for permission." At the time, I wasn't sure what that meant or when I would apply it, but in fact I have used it many times and in many situations. I am not so confident in my abilities or my opinion that I don't have doubts or allow others to question or challenge me, but when faced with that critical moment when I have to step up or step aside and wait for "permission," I remember John's words. I give it my best shot and live with the consequences.

I have also never shied away from answering a question, even if the answer is, "I don't know." As I reflect (something else John Hodge and others have instilled in me as a virtue) on why I act this way, I recognize that it is essential to me that I share what I know, realize what I don't know, and learn from all situations. Knowledge can be viewed as power, but the truly powerful share their knowledge with others. There is so much that each person brings to a team or life situation; it is incumbent on each of us to share what we know and learn from what others know.

I also believe that the deputy center director who wanted to know who the hell had closed the center ultimately came to view me in a different light—as someone willing to take responsibility and be accountable for his actions and, therefore, as a capable manager with great potential. While I am not today in a position likely to give me even temporary authority to shut a NASA center, I still try to follow the same maxim: if asked, answer; if leadership is needed, lead. ●

HARVEY SCHABES is the operations integration manager for the Engineering Directorate at Glenn Research Center. He has been at NASA for more than twenty-seven years and has served as a researcher, project engineer, project manager, and manager in both technical and administrative organizations.

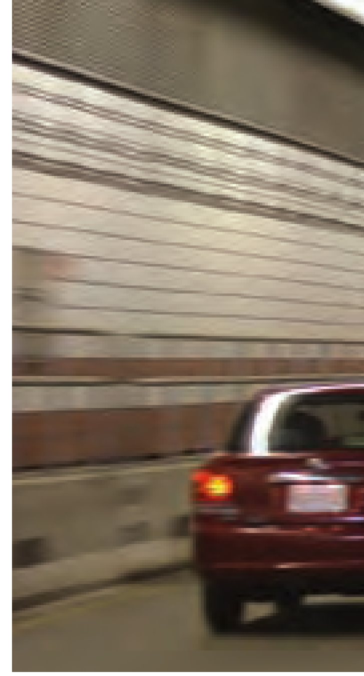
The Big Dig:

Learning from a Mega Project

BY VIRGINIA GREIMAN

Photo Credit: Rick Berk

The Leonard P. Zakim Bunker Hill Bridge, part of the Big Dig project in Boston, is the widest cable-stayed bridge in the world.



Boston's Central Artery/Tunnel Project, commonly known as the Big Dig, was the largest, most complex, and most technically challenging highway project in American history. Larger than the Panama Canal, the Hoover Dam, and the Alaska Pipeline projects, it was built through the heart of one of the nation's oldest cities. Its list of engineering firsts include the deepest underwater connection and the largest slurry-wall application in North America, unprecedented ground freezing, extensive deep-soil mixing programs to stabilize Boston's soils, the world's widest cable-stayed bridge, and the largest tunnel-ventilation system in the world.

Interstate 93 tunnel in Boston, part of the Big Dig.

Photo Credit: Rene Schwietzke

The Big Dig is also famous for cost increases. Its initial estimated cost was $2.56 billion. Estimates increased to $7.74 billion in 1992, to $10.4 billion in 1994, and, finally, $14.8 billion in 2007—more than five times the original estimate. The reported reasons for the cost escalation included inflation, the failure to assess unknown subsurface conditions, environmental and mitigation costs, and expanded scope. Mitigation alone required 1,500 unanticipated, separate agreements.

The Big Dig was led by Bechtel/Parsons Brinckerhoff, one of the largest and most experienced teams in infrastructure design and construction. Extensive environmental feasibility studies, risk assessments, and other documentation were completed prior to the project's start. Nonetheless, costs increased across all contracts throughout the project's life cycle despite enormous efforts to transfer, mitigate, or avoid risk and contain costs.

In other words, things can go dramatically wrong despite the best efforts. Few infrastructure projects have used as many innovative tools and programs to control project risk and cost as the Big Dig. These included an owner-controlled insurance program that saved $500 million by providing group coverage for contractors, subcontractors, and designers and an unprecedented safety program; a cost-containment program that saved $1.2 billion; an integrated audit program that identified and mitigated existing and potential overruns and delays; a labor agreement that established a no-strike, no-slowdown guarantee for the life of the project; a quality-assurance program that was recognized by the Federal Highway Administration as one of five noteworthy accomplishments; and a dispute-resolution process that avoided extensive litigation costs.

Causes of Cost Escalation

To address major problems in mega-project management, Boston University, through its Mega-Project Research Program, has begun researching mega projects to help understand current practices, develop new practices and frameworks, and learn how to prevent or reduce risks before they cause serious problems or even project failure. Our research on the Big Dig has shown us that no single catastrophic event or small number of contracts caused costs to escalate. Multiple decisions by project management across all contracts contributed to the increases. The critical cause was a lack of experience and knowledge about dealing with the complexity and uncertainty that giant projects bring with them.

Using preliminary Big Dig data, we studied the impact of inflation, often claimed to be a major cost-escalation factor. The Big Dig reported that about half the cost growth was caused by inflation, but official inflation rates over the life of the project do not support the claim. Some of the increase can be attributed to an unrealistic initial cost estimate. Research shows that mega-project costs are consistently underestimated, a practice often attributed to the desire of project advocates to have their projects approved.

Design and Construction Risks

The most difficult problems on the Big Dig involved the means and methods used to address issues raised in the project's design and drawings, and the failure to properly account for subsurface conditions during the construction process. Project documents show that the challenges of subsurface conditions were substantially underestimated. The sheer size of this project and the fact that construction occurred in a busy city resulted in having to deal with many unanticipated conditions and a large volume of claims and changes.

The surprises included uncharted utilities, archeological discoveries, ground-water conditions, environmental problems, weak soil, and hazardous materials. The project faced safety and health issues, frequent design changes, and changes in schedules and milestones. The unexpected discovery of 150-year-old revolutionary-era sites and Native American artifacts was one surprise complication and source of delays, requiring approvals from yet another diverse set of stakeholders, including historical and preservation organizations and Native American groups.

TRUE INTEGRATION CALLS FOR A DESIGN-BUILD MODEL FROM THE BEGINNING OF THE PROJECT. … UNDER A DESIGN-BUILD MODEL, DESIGNER AND CONTRACTOR ARE RETAINED AT THE SAME TIME, DEVELOPING A STRONG WORKING RELATIONSHIP FROM THE START THROUGH SHARED GOALS AND METHODOLOGY.

Underground Utility Protection

To protect against losses caused by the disruption and failure of underground utilities, a Big Dig utility program relocated 29 miles of gas, electric, telephone, sewer, water, and other utility lines maintained by thirty-one separate companies in 1996. Some of this infrastructure was more than 150 years old; a complete lack of knowledge on the age, condition, and location of most of the utilities required submission of "as-built" drawings by all project contractors—drawings of existing conditions rather than planned or proposed construction. The project had to deal with utilities that were shown on as-built drawings but never installed, and damage and flooding caused by underground sewer pipes not identified on the drawings. With large buildings located within feet of construction, the risk was high that damage to the infrastructure would shut down the operations of Boston's major financial centers. One wrong move could have shut down the Federal Reserve Building and affected the country's financial system for days, months, or even years.


The Big Dig during construction.

Photo Credit: adm

During the span of the project, 5,000 miles of fiber-optic cable and 200,000 miles of copper cable were installed. This required more than 80,000 hours of construction and 5,000 construction workers operating 24/7. Between 1996 and 2000, the rate of utility damage decreased 86 percent, with cost savings approximated at $50 million. Despite many problems and risks, the utility program improved safety, quality, schedule, budget, insurance costs, and public relations.

Delayed Integrated Project Management

The Big Dig relied heavily on a collaborative, integrated project-management team that involved all participants in decision making. Unfortunately, the Big Dig's project organization was not fully integrated until July 1, 1998, when design of the project was 99 percent complete and construction was 45.9 percent complete. If there is a single cause for the massive cost escalation on the Big Dig, it probably involves the management of the project's complex integration.

Integration problems were exacerbated by the project's organizational structure, which separated design from construction through its traditional design-bid-build model and required managing thousands of stakeholders. True integration calls for a design-build model from the beginning of the project. Because contracts were negotiated separately with designers and contractors, there was little room for collaboration among the project's most important stakeholders. Under a design-build model, designer and contractor are retained at the same time, developing a strong working relationship from the start through shared goals and methodology.

Problems in integration resulted in part from the sheer number of internal and external stakeholders, their interactions, and the ever-changing dynamics of managing the relationships. Each of the Big Dig's 110 major contracts involved intensely complicated technical, legal, and economic issues and numerous processes and procedures as well as a complex regulatory scheme. The Big Dig may have suffered not from too few processes and procedures, but too many complex processes that made it difficult to monitor and enforce in a uniform manner.

In the early phases of the project, there was little communication between and among many of the internal and external stakeholders, other than an impressive outreach to the local community, particularly residents living close to several of the project's major worksites. Community and social costs were vastly underestimated on the Big Dig. No one ever envisioned the full cost of dealing with the media, community interests, numerous regulatory agencies, auditors, and neighborhood stakeholders.

The government served in a dual role as regulator and owner of the Big Dig. The project organizational structure required that some managers report directly to the governmental owner, while other managers reported to the project's design and construction program manager. A truly integrated project should centralize decision making and accountability for all core functions of the project.

Signs from the Big Dig construction area.

Photo Credit: Stephen Gore

The Value of Partnering

The concept of "partnering" was first used by DuPont Engineering on a large-scale construction project in the mid-1980s, and the U.S. Army Corps of Engineers was the first public agency to use partnering in its construction projects. Partnering is now widely used by numerous government and construction entities around the world. It involves an agreement to share project risks and to establish and promote partnership relationships. Partnering is a team problem-solving approach intended to eliminate the adversarial-relationship problems between owner and contractor by focusing on mutual interests with the help of a neutral facilitator. On the Big Dig, partnerships were used to improve schedule adherence, quality, safety, and project performance, as well as to reduce costs, claims, disputes, and litigation.

Partnering at the Big Dig was initially implemented in 1992, primarily on construction contracts, but its success in construction led to its use elsewhere. Almost one hundred partnerships existed on the Big Dig, based on contract values ranging from $4 million to half a billion dollars. Though partnering is not always contractually required, on the Big Dig it was included in all construction contracts with a duration of at least one year and a value of $1 million or more.

Partnering sessions were held on a regular basis to discuss project needs, to resolve problems, and to improve controls. Partnering activities included leadership training, seminars, and executive meetings. Federal and state government officials and the contractors' project management teams met regularly with an independent expert to assist in developing a single, integrated team. Sharing knowledge, risk, and liability, partnering reduced the cost of contractor claims, increased the number of value-engineering savings proposals, and helped keep projects on schedule.

Here's one example. Big Dig leaks, which delayed construction, often had several causes and flow paths. Assessing responsibility for leaks in the Fort Point Channel tunnel area, government lawyers, aided by an independent expert engineer with substantial marine geotechnical experience, spent more

PARTNERING REQUIRES FOCUS ON DETERMINING THE ROOT CAUSE OF PROBLEMS, NOT ASSESSING BLAME.

than two thousand hours trying to establish the exact cause of the leak, but could not do so with certainty. The leak was attributable to unexpected site conditions and to contractor performance issues compounded by pressure to complete the job quickly. To avoid costly litigation, the Metropolitan Transit Authority decided to mediate the issue before two sitting judges on the Armed Services Contract Board of Appeals. The mediation process took three months and succeeded in convincing the parties that liability should be shared between the owner and the contractor.

Given the scope and complexity of the Big Dig, experts have concluded that the project would have been simply unmanageable without partnering. Though the benefits of partnering on the Big Dig have not been quantified, there is sufficient data to support the conclusion that partnering contributed significantly to the reduction of claims and the avoidance of expensive and time-consuming litigation.

These are the most important lessons about partnering learned from the Big Dig experience:

- Partnering requires focus on determining the root cause of problems, not assessing blame.
- Subcontractors should be included in the partnering sessions; they can be crucial to the success of the project and help balance the teams.
- Risk should be shared jointly among partners whenever possible to encourage innovation and continuous improvement, particularly where the technology is new, the risks are unknown, and the stakes are high. On the Big Dig, risks were shared among the owner and contractors to facilitate tunnel jacking, deep underwater connections, and technology interfaces between contractors.
- Teaching problem-solving skills is a major benefit of partnering.
- Partnering should never replace independent and rigorous oversight of the project.

Learning from the Big Dig

Mega projects will always struggle with unforeseen events, massive regulatory requirements, technical complexities, community concerns, and a challenging political environment. What we have learned from the Big Dig can help future large projects. Of the many lessons this huge undertaking has provided, these are the major ones:

- Project integration is critical to success.
- Goals and incentives must be mutual and built into contracts throughout the project life cycle to ensure quality, safety, financial soundness, and a commitment to meeting budget and schedule.
- Continuous improvement and rigorous oversight are both essential.
- Doing things as they have always been done does not work for complex projects that require constant innovation and a culture of collaboration. ●

VIRGINIA GREIMAN is an assistant professor at Boston University and former deputy general counsel and risk manager of Boston's Central Artery/Tunnel Project.

Redesigning THE FUSE MISSION

BY WARREN MOOS, DENNIS McCARTHY, AND JEFFREY KRUK

Image Credit: NASA/Casey Reed

This artist's illustration depicts the binary system LH54-425, which consists of two very massive stars. Using FUSE and ground-based telescopes, astronomers were able to determine properties of this rare, young binary-star system.

The Far Ultraviolet Spectroscopic Explorer (FUSE) was conceived in the early eighties as a follow-on to the Copernicus mission, launched in the early seventies. Using modern detectors, FUSE would have ten to a hundred-thousand times more capability and reach billions of light years into the universe, compared with the few-thousand-light-year limit of Copernicus. FUSE looked at the far ultraviolet (905–1,187 Å) region of the astronomical electromagnetic spectrum, complementing the capabilities of the Hubble Space Telescope, which has a sensitivity that drops rapidly below 1,200 Å. It was launched June 24, 1999, and was decommissioned on October 18, 2007.

In its more than eight years of operation, FUSE addressed interesting astrophysical problems: What is the abundance of atomic deuterium in the Milky Way galaxy? Are the "missing" baryons in the nearby universe in fact hidden as hot plasma? Does a giant halo of hot plasma surround our galaxy?

The science harvest was rich. FUSE obtained 65,000,000 seconds of observations on approximately 2,850 different objects. The data were analyzed by both the principal investigator science team and guest investigators selected by NASA in highly competitive proposal competitions, with the majority of observations going to guest investigators. So far, there have been more than 1,300 publications based on the data, with no end in sight. The FUSE grating and detector technology were adapted for the cosmic origins spectrograph, installed on Hubble during Servicing Mission 4 in May 2009.

All this from a mission that was officially canceled in 1994. The success of the restructured program for a technically demanding mission is a tribute to the discipline, focus, and cooperation of the mission team members.

Cancellation and a New Direction

The development of the FUSE mission was delayed because of the *Challenger* accident in 1986 and NASA's budget environment at the time—a delay that made changes in the technical approach possible, which significantly reduced technical and schedule risk. The grazing-incidence telescope design was replaced by normal-incidence optics coated with silicon carbide coatings, a technique invented in 1988. Aspheric gratings were replaced by easier-to-make spherical gratings with holographic correction of the major optical aberrations, another development of that period.

A high-Earth orbit was specified on the grounds that operating an astronomical observatory in a low-Earth orbit would be complex and expensive. One of the triumphs of the restructured FUSE program would be the demonstration that low-Earth astronomical observations were feasible in a modest-cost mission.

By the summer of 1994, the mission was ready to start Phases C and D, but budgetary pressures stretched out the schedule even further, causing the estimated cost to balloon. At the same time, NASA's "faster, better, cheaper" mantra signaled the drive to increase launch frequency. The FUSE project was about to receive a major setback, one that actually led to an earlier launch and highly successful program.

On September 6, 1994, NASA Headquarters informed Principal Investigator Warren Moos and Project Manager Dennis McCarthy that FUSE was canceled. Serious negotiations began with NASA (with John Bahcall and others playing important roles) to preserve the science program. A meeting was held with Wes Huntress, NASA Associate Administrator for Space Science, on September 9, 1994. Huntress directed Johns Hopkins University to prepare a proposal for a $100-million mission that would retain the essential science. The principal investigator would assume control of all segments of the mission while NASA would be responsible for the launch.

A proposal for Phases C/D of that mission was due in January '95. An intense four months followed. The core spectrographs were retained, but anything "nice but not crucial" was eliminated. A low-Earth orbit instead of a high-Earth orbit became possible because Hopkins showed (with Space Telescope Science Institute help) that it need not be overly complex. After extensive review, including a non-advocate review, NASA gave approval for the "new" FUSE mission to enter Phases C and D.

Phases C and D of the mission began January 25, 1995. To keep development and flight-operation costs low, we established these principles and practices:

While a crane lifts NASA's FUSE satellite, workers at Hangar AE, Cape Canaveral Air Station, help guide it toward the circular payload-attach fitting in front of it.

- Maintain a cost-conscious management and engineering philosophy, and continually involve systems engineering in all aspects of design and test
- Maximize use of existing team-member facilities, equipment, and personnel
- Reuse existing ground-support equipment designs and equipment from previous programs
- Extensively use component, subsystem, and system tests rather than complex analyses and simulations to verify and understand actual performance and design margins
- Establish a "quick react" process to respond to critical component failures during integration and testing
- Give design engineers formal accept/reject responsibility for their components, with concurrence from the Johns Hopkins product assurance manager
- Develop a malfunction and software-problem reporting process to give accept/reject responsibility to engineers at the integration level, with Johns Hopkins product-assurance concurrence

The FUSE restructured team tailored documentation to meet unique mission requirements, centralized systems engineering, integrated the team to ensure maximum communication at minimum cost, and streamlined the management team, with the Johns Hopkins principal investigator responsible for the mission and Goddard Space Flight Center providing contract administration and oversight. As a result, it was able to design to cost and maintain a fixed schedule.

The team developed a formal de-scope process. The detailed de-scope plan was a primary tool for managing risk and dealing with circumstances that could have an unacceptable impact on cost or schedule. We had identified de-scope options and

PEER REVIEWS MADE MAJOR CONTRIBUTIONS TO DEVELOPING THE PROPER SUBSYSTEM DESIGNS, INTERFACES, DESIGN MARGINS, ANALYSES, IMPLEMENTATION PLANS, AND TESTING.

contingencies during the remainder of Phase B. The principal investigator and science team prioritized the requirements on the mission and its systems, and defined the minimum performance floor.

In addition, Hopkins formed a small, highly experienced, standing review team to review and evaluate the FUSE program semiannually. These reviews were tied to the semiannual Goddard review and other reviews, including non-advocate review, preliminary design review (PDR), critical design review (CDR), and pre-ship spectrograph, pre-ship spacecraft, pre-test satellite, and pre-ship satellite reviews.

Hopkins also conducted informal incremental "peer reviews" at the subsystem level between expert teams as part of the process leading up to major project reviews. Technical experts from the university, Goddard, and other institutions engaged in informal roundtable reviews of plans, designs, and implementations at key development stages. The results of each individual peer review were presented at each major program review. Peer reviews made major contributions to developing the proper subsystem designs, interfaces, design margins, analyses, implementation plans, and testing. The Hopkins review team presented their findings to Goddard independently prior to launch.

Testing and Flight

The integration and test plan was shaped by cost and schedule constraints, and by the unique demands of far-ultraviolet (FUV) optics. Testing at FUV wavelengths requires the entire instrument to be under a high-vacuum environment. In addition, FUV optics are extremely sensitive to molecular contamination, requiring careful material selection and rigorous cleaning and handling procedures for ground-support equipment as well as flight hardware. Also, the lithium fluoride overcoat on the aluminum optics was susceptible to degradation by water vapor, requiring a near-continuous dry-nitrogen purge.

Our general approach was to perform rigorous acceptance testing of subsystems prior to delivery and to perform extensive testing of the integrated satellite, but to limit testing at intermediate levels of assembly. Thermal vacuum testing of the satellite included an optical end-to-end test, with full-aperture FUV illumination of all four telescopes. This gave us comprehensive performance testing and mission-sequence testing in a flight-like environment.

How did things turn out? On-orbit instrument spacecraft and instrument performance met or exceeded all requirements. There were some problems to overcome, however. One was that the co-alignment of the four telescopes was affected by changes in the spacecraft orientation relative to the sun; testing such effects during integration and testing is one example of something that was not feasible given our cost constraints. This particular problem was solved by changes to operational procedures at a modest cost to observing efficiency.

There were also several instrument-software problems not caught by the usual suite of stress-test configurations. These problems became manifest over the course of days and weeks of uninterrupted running, which would not have been practical when testing with the integrated satellite. A high-fidelity simulator dedicated to use by the operations team would have made such tests possible, and generally would have helped to reduce some of the demands of the integration and testing schedule.

The on-orbit problems that did have a significant impact on the mission were the eventual failures of most of the gyroscopes and all the reaction wheels. These problems, too, were overcome (until the failure of the last reaction wheel) by means of extensive redesign of the spacecraft and instrument software, and of the observation-planning system on the ground.

FUSE satellite control center at Johns Hopkins University.

This would not have been possible without the continued involvement of the original software developers for these systems. Was the low-cost development approach a factor in these failures? The gyros were selected based on cost, and it is conceivable that more expensive gyros would have lasted longer. Even without the flight-software redesign, however, gyro failures would not have terminated the mission until well after FUSE's planned three-year lifetime. The reaction-wheel failures would have terminated the mission after roughly two and a half years had we not developed a work-around, but cost was not a factor in selecting the wheels, and there were no hints prior to launch that they would have a limited life. Had there been such hints, cost would not have precluded having a fully redundant set of wheels.

FUSE was the first principal investigator–class astronomy mission managed by an academic division of a university. Our *modus operandi* was to procure an "off-the-shelf" spacecraft and ground system at a fixed price, and develop the instrument. Buying two and developing only one made it possible to maintain cost and schedule.

The spacecraft cost less than $35 million, the ground system was less than $4 million, and the science team "got religion" on holding the instrument to a fixed cost. They were realistic in deciding what capabilities we had to keep and what we could sacrifice. The integrated nature of the team meant sufficient two-way interaction between the scientists in operations and instrumentation with the engineering staff to generally communicate and clarify requirements and keep them realistic. The total program cost $120 million, 60 percent less than the proposed cost of the original FUSE. With contributions from the Canadian Space Agency (fine-guidance sensor) and France (diffraction gratings), the launch date was accelerated by two years, and the instrument retained a majority of the original FUSE science capabilities.

This restructured project flew two years early at substantially reduced cost and produced a comprehensive program that operated for eight years and achieved high-priority science. ●

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DENNIS McCARTHY is currently a consultant to NASA. Previously, he was program director for FUSE. Other positions he held include deputy associate director of flight projects at Goddard for Hubble Space Telescope, associate director for the Space Sciences Directorate, and deputy project manager for the Cosmic Background Explorer, which won the Nobel Prize in Physics in 2006.

JEFFREY KRUK is a principal research scientist in the Department of Physics and Astronomy at Johns Hopkins University. He is currently working on development of the Joint Dark Energy Mission, a collaborative effort of NASA and the Department of Energy. He was the system scientist for FUSE prior to its launch, and the mission systems engineer and deputy chief of observatory operations following launch.

The Knowledge Notebook

Believing in Science and Progress

BY LAURENCE PRUSAK

One of the great questions in history is why the Industrial Revolution that started in the eighteenth century and went on to radically change almost every aspect of the way people live developed in the West, and especially the northwest corner of Europe. While it is relatively easy to understand more or less exactly *what* occurred, there are many and varied answers to the question of *why* it happened where it did. The question has become even more interesting with the development of a more global historic perspective than we in the West had a few decades ago. We now know that China and India were as technologically advanced as the West as late as the seventeenth century and that these two countries had many of the ingredients that could have brought about an industrial revolution in those countries. So why the West?

A wonderful new book has recently been published that, to my mind, gives the best and most sensible answer to this question. The answer offers valuable lessons for the present that may be especially relevant to NASA's future.

Joel Mokyr is a distinguished professor of economics and history at Northeastern University. He has written many important works, including *The Gifts of Athena*, the best book available on our knowledge-based economy. His new book, *The Enlightened Economy*, is the culmination of his many years of studying how and why ideas interact with material conditions and culture to produce economic change. It is a long and wonderfully written account of how and why England in particular—that small island—was the first society to actively industrialize and thereby transform the world.

What makes this book so important today is Mokyr's insistence that ideas have great consequences. He argues that it was the ideas in people's minds in England that made the Industrial Revolution happen there. While this may seem obvious to many of us, it surely isn't obvious to the authors of many economics and even history texts who seem to ignore the very possibility that ideas have the power to shape events.

Mokyr identifies two related English notions that made the advances we sum up as the Industrial Revolution possible. One is a deep and sustained belief in science; the other is the belief that science applied through technologies can bring about material progress. Those beliefs had a long lineage in England dating back at least to the seventeenth century, observable in the writings of Francis Bacon on the scientific method and the founding of the Royal Society in the middle of that century. Why these developments occurred there and then is still a controversial subject, but there is some consensus on the importance of several factors: considerable individual freedom, the lack of a single dominant religion and the growth of religious dissent, high literacy rates, and the relative prosperity that encouraged a belief in progress—perhaps aided and abetted by some Calvinist religious beliefs.

In any case, the early industrial pioneers in England not only had some *knowledge* of various sciences but—even more important—they *believed in* science, progress, and technology. The Enlightenment—often thought to be mainly a French phenomenon—was just as strong a force in England and had the added benefit there of being more strongly supported by English institutions than in any other eighteenth-century country. It was also far more widespread in terms of classes of people. These factors combined to drive the continuous quest for progress and material experimentation that led to the dramatic changes of the Industrial Revolution.

We can easily see a similar set of beliefs in many of our American enlightenment figures—Franklin and Jefferson come immediately to mind—and it is no coincidence that the United States became the second-strongest industrial power a hundred years or so after England, and then forged ahead to develop great economic and technical strengths.

It is not hard to see why these lessons are of great value today. Widespread belief in science and progress—and the support that follows from that belief—seems to be waning in the West while it remains or (more to the point) has grown increasingly powerful in the East. So many other things dominate our lives and thoughts here, including the remarkable and constant floods of trivia that absorb so much of our attention. If we are ever to have another great leap of material, economic, social, and technical progress similar to those that took place in the eighteenth and nineteenth centuries, we will have to find ways as a culture to once again fall in love with science and renew our faith in the idea of progress. ●

IF WE ARE EVER TO HAVE ANOTHER GREAT LEAP OF MATERIAL, ECONOMIC, SOCIAL, AND TECHNICAL PROGRESS SIMILAR TO THOSE THAT TOOK PLACE IN THE EIGHTEENTH AND NINETEENTH CENTURIES, WE WILL HAVE TO FIND WAYS AS A CULTURE TO ONCE AGAIN FALL IN LOVE WITH SCIENCE AND RENEW OUR FAITH IN THE IDEA OF PROGRESS.

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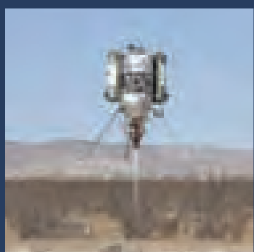
NASA in the News



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Summer of Innovation

NASA Administrator Charles Bolden kicked off the agency's new Summer of Innovation initiative in June while at the Jet Propulsion Laboratory. The pilot program, a cornerstone of the Educate to Innovate campaign announced by President Obama last November, will engage thousands of middle-school students in science, technology, engineering, and mathematics (STEM) during the summer months. Summer of Innovation is designed to improve STEM teaching and learning in partnership with federal agencies, academic and informal organizations, nonprofits, and industry. To learn more about this program and the opportunities available, visit www.nasa.gov/soi.

Web of Knowledge

Learn about new discoveries in Earth science as they happen, and from the people making them happen. NASA's "What on Earth" blog provides regular updates about NASA missions that shed new light on Earth. Posts regularly include new images, videos, and facts, sharing "the evolution of scientific debates, the practical application of NASA science, and—most of all—sharing the fun of watching science in progress," according to the site. Learn more about our planet at blogs.nasa.gov/cm/newui/blog/viewpostlist.jsp?blogname=whatonearth.

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