National Aeronautics and Space Administration

Academy of Program / Project & Engineering Leadership

Year in Knowledge 2010

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Foreword

"We construct a narrative for ourselves, and that's the thread that we follow from one day to the next."

- Paul Auster

Everything we do is a story.

There is always a challenge, a reaction, a solution, and an outcome. There are success stories and tragic stories. Stories of glory and stories of failure. In the end, the success of any project comes down to the story that is told. We rarely remember the details as time unfolds, but we always remember the story. Just as important is the opportunity a story provides for learning. It enables improvement and growth—for an individual, a team, or a community. Everyone has a need to understand his or her own story, to develop it, learn from it, and share it. The reflective practitioner is constantly learning and constantly getting better.

The NASA Academy of Program/Project & Engineering Leadership has been collecting and sharing stories about projects and engineering for over a decade. Success in programs and projects comes down to the ability to tap into knowledge and talent, and the Academy is committed to helping NASA optimize both of these resources. From the start, we have based our approach on four principles:

- Practitioners know best.
- Reflection is a critical element of continuous improvement and development.
- Learning organizations have cultures that embrace sharing and open communications.
- Stories are powerful means of conveying knowledge.

Today the Academy is a broker for stories and ideas across NASA as well the broader project, engineering, and aerospace communities. We've expanded from our initial efforts at collecting practitioner stories into other areas, including practitioner-based case studies featuring multiple perspectives, articles about new developments of interest to practitioners, and white papers about trends we've identified in project management and professional development.

As we reviewed our output this year, we began to see how a collection that features a cross-section of articles could provide practitioners with a knowledge resource that is as broad in scope as the grand challenges in aeronautics and space that NASA pursues everyday. We welcome your feedback.

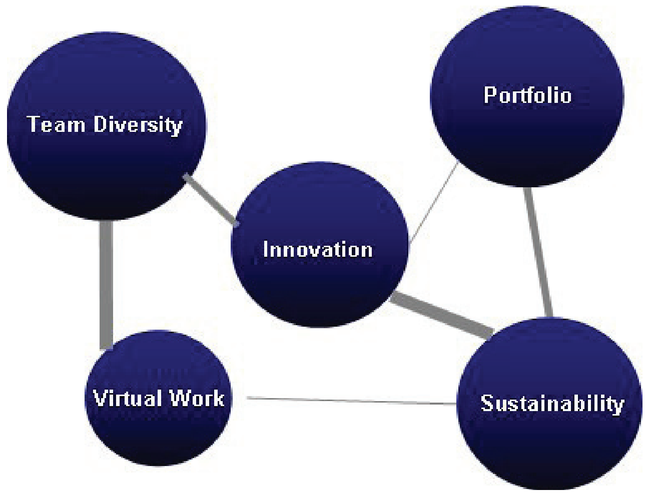
Dr. Ed Hoffman
Director, NASA Academy of Program/Project & Engineering Leadership

Trends in Project Management

Trends in Project Management

March 2010

Five key themes are reshaping the practice of project management today. These themes—team diversity, virtual work, innovation, portfolio management, and sustainability—reflect the increasing complexity and global nature of project management. This white paper offers a brief synopsis of the latest research on each of these trends.



Five project management trends emerged in 2009.

Team Diversity

Diversity has multiple meanings in the context of project management. In 2009, scholars primarily addressed three dimensions of team diversity: cultural, cognitive, and geographic. As projects become more complex, technically challenging, and costly, they also become more globalized, compelling project managers to learn how to lead diverse teams.

Skillful management of cultural diversity in teams is of particular interest to project organizations like NASA. The future of space exploration hinges upon the ability to collaborate with government space agencies, industry, academic institutions, and nonprofit organizations. While understanding differences in the ways people communicate (e.g. the high-context culture of Japan versus the low-context of the United States) is essential, strategic differences—visions, goals, resources, politics, budgets, and national security concerns—are also important factors that shape the cultural diversity of a multinational project team.[1]

Research shows that project teams thrive on cognitive diversity.[2] Cognitively diverse teams include varying levels of education, experience, age, training, and professional background. Without careful attention, studies show that various aspects of cognitive diversity can affect an overall team's performance by hindering knowledge transfer or causing teams to fall back on default processes.[3] Successful project management of this kind of team diversity involves managing and integrating the team's knowledge and skill sets.

The last (and perhaps the most obvious) dimension of team diversity is geography. Developing an environment that facilitates meaningful communication and productivity is difficult when team members are not collocated. Once considered a hindrance to effective team productivity, geographic diversity can now be managed, thanks to advances in technology. The F-35 Joint Strike Fighter is a case in point: it is a collaborative effort among eight international partners, including the United States, Turkey, Denmark, and Australia. While this ambitious program poses many political and national security challenges, the team has developed a framework that enables suppliers, partners, and customers to view status updates worldwide, thereby facilitating constant communication and openness.[4]

Virtual Work

The success of geographically diverse teams is closely tied to a project manager's ability to support a virtual work environment. With a boom in collaborative technologies, the means of communication are no longer an obstacle. NASA is one of several organizations to use the virtual "islands" in Second Life to host gatherings. Companies like AT&T and Proctor & Gamble have either partially or fully eliminated traditional offices. At IBM, 42 percent work remotely at some point in their careers, while 15 percent work from home on a regular basis.[5]

While contacting people is no longer a problem, connecting with them is. Previous observations of virtual work show that it offers project managers the ability to attract and recruit talent from anywhere in the world and decreases project cost. On the other hand, virtual work also threatens effective knowledge transfer, eliminates "water cooler" conversations, isolates workers, cuts down on managerial support and oversight, and blurs the line between one's work and personal life. Additionally, managers of virtual projects must account for differences in time zone, uniformity of virtual interfaces, and the balance of team members across locations.

Much of the recent research on virtual project management revisits the advantages and disadvantages of virtual work, but the bottom line is that there aren't definitive answers about virtual work. For now, project managers must take care to document best practices and lessons learned on virtual projects to increase understanding of this type of work. Virtual collaboration technology is still evolving, and project managers should understand that virtual work is not better or worse—it's just different.[6]

Innovation

Project organizations everywhere are hungry for innovation. Organizations are looking for ways to encourage members of their workforce to see all the dots and connect them in different ways. This includes practitioners taking ownership of challenges and managers providing a clear vision, empowering their people, and encouraging the free flow of ideas.

Today's NASA project managers operate in a landscape that offers different avenues for innovation than in the Apollo era or even the Shuttle development era. The explosion of information technology and the increase in international partnerships mean that NASA now has access to new ideas and technologies from around the world. While "not invented here" syndrome, a classic 20th-century organizational bottleneck, still persists in some corners, today's complex projects depend on the integration of expertise from strategic partners in all sectors.

Portfolio Management

Portfolio management reflects the context in which project-based organizations operate today. No project exists in a vacuum, and organizational success is not a matter of managing a single project successfully. The larger challenge is managing a portfolio of programs and projects in order to execute the organization's strategy. In NASA's case, its four mission directorates function as its portfolio management organizations. The consequences of the success or failure of a project in one portfolio depend on its relative weight, which can be gauged in terms of resources, visibility, and importance to the overall organizational mission.

Portfolio management is an executive function that calls for decision making about programs and projects based on a strong understanding of the organization's mission, goals, and strategy. These decisions involve resource allocation (e.g., talent, funding, and physical capital) in the context of maintaining a balance among portfolios that aligns with organizational needs. As project-based organizations continue to grow around the world, portfolio management will increase in importance.

Sustainability

Sustainability has arrived as a permanent feature of the landscape for project-based organizations. In 2009, publications like *Harvard Business Review* and *MIT Sloan Management Review* dedicated entire issues to the topic of sustainability. Smart organizations are preparing to "leapfrog" over the transition by learning to think in terms of sustainable systems. The past year saw NASA hold its first Green Engineering Masters Forum and the completion of the green Flight Projects Center at the Jet Propulsion Laboratory.

While some use sustainability as a synonym for "environmentally friendly," others interpret it more broadly to refer to principles and practices that enable long-term societal progress. Sustainability is above all a systems thinking challenge. Project management has taught aerospace project managers to think about life-cycle costs. Sustainability tackles questions of life-cycle impact, which can extend far beyond the duration of a project.

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Messages from the Director

Virtual Project Teams and Learning

September 30, 2010 — Vol. 3, Issue 9

Virtual teams are a permanent part of the landscape for complex projects. How do we learn to thrive in this environment?

Virtual teams are nothing new at NASA. Early projects like Apollo and Viking featured vast teams distributed around the country at the agency's field centers and partners in industry and academia. The difference today is that many teams are global, spanning oceans and continents. Teams are also more fragmented than in the past. Thirty years ago, a complex project might have included teams in California, Virginia, Florida, and Massachusetts. Now projects include teams and individuals connected by the Internet and cell phones working from any number of locations. International teams pose additional cultural, institutional and legal challenges (e.g., ITAR restrictions on information sharing). The majority of NASA's missions now include some sort of international partnership or involvement.

There's no doubt that virtual teams pose challenges. Just scheduling teleconferences can be difficult when a team spans 10 time zones. Cultural differences add another level of complexity to the mix. I once heard from a European colleague that Americans like to engage in small talk first before getting down to business, whereas in his culture people take care of business first and save the small talk for last. It's an anecdotal example, but one that hints at the kinds of subtle differences that international teams deal with every day.

Microsoft's research group has been studying virtual teams for years and identified some common difficulties that they confront. One of the difficulties that remote team members face is maintaining awareness of what their colleagues are doing. Without the benefit of informal communications such as "water cooler conversations," remote team members miss out on the continuous flow of updates that become part of the shared experience and knowledge base of collocated team members.

At the same time, virtual work enables teams to gather expertise that is untethered from geography. This promotes cognitive diversity, which researchers such as Scott Page have shown is critical to outstanding team performance. Virtual teaming arrangements also offer flexibilities for workers, making it easier to attract talented performers.

Given that this is the context of projects today, how can we enhance our ability to connect to one another when face-to-face encounters are limited by geography and travel budgets?

One technical solution that Microsoft's research unit has recently employed is an "embodied social proxy," also jokingly referred to as "crazy webcam remote cart thing." The principle is simple: a two-way webcam device provides continuous videoconferencing availability to connect remote team members with a hub of colleagues in a home base location. The Microsoft pilot project relies on sturdy, reliable technologies in an effort to make virtual contact through the webcam as common as phone calls or email. It is not far-fetched to expect that proxies of one sort or another will become increasingly common in our work environments.

A key to adapting to this new way of working is to learn in the same modality in which we work. When the Academy first started, nearly all of our courses took participants away from their home centers to Wallops Island, where training took place in an isolated classroom environment. While traditional training is still an important part of how we convey essential knowledge and skills, we are also developing new offerings in technology-enabled learning that will bring the experience of training closer into line with the experience of working at NASA. Since we already work virtually, our training strategies need to include learning in a virtual environment as well.

I will be writing more in the months ahead about the Academy's technology-enabled learning as we roll out virtual courses and learning opportunities. In the meantime, I'd love to hear from you if you've had a positive virtual learning experience. With so many virtual learning tools and methods available today, it seems clear that the future will allow for increasing customization rather than one-size-fits-all solutions.

Innovation and Professional Development

August 31, 2010 — Vol. 3, Issue 8

Can innovation be taught or learned?

NASA's ability to execute missions of increasing complexity depends on continuing innovation. So how do we prepare our workforce to innovate?

Let's start by considering what we mean by innovation. Most talk about innovation centers on technology development. The hybrid automobile, the smart phone, and stem cell transplants are all examples of transformative innovations driven by new technologies. That's clearly one facet of innovation, but it's not the only one.

There are also process innovations that produce dramatic gains in efficiency and/or quality. These kinds of innovations can happen at the line level when practitioners are empowered to make improvements, or they can result from the incorporation of best practices or lessons learned. Sometimes process innovations originate internally, while other times they are adapted from the outside.

Similarly, there are management innovations that enable organizations to direct resources in order to meet their objectives. In The Secret of Apollo, historian and NASA engineer Stephen B. Johnson argued that the systems management approach that NASA developed for Apollo was a great innovation that allowed NASA to accomplish its mission. Other innovations such as critical path methodology have been vital to NASA's success.

Former Cassini project manager Dennis Matson shared a story at the Academy's second Principal Investigator Forum that captures the innovative spirit of NASA in this age of highly complex projects. By any standard, the original Cassini mission was complex. The science team alone included 260 scientists in 17 countries spanning 10 time zones, making it challenging just to schedule teleconferences. All the scientists involved wanted to maximize the opportunity to conduct experiments on this once-in-a-lifetime mission. All were equally aware that on a flagship mission like this, runaway costs would likely lead to de-scoping—the mission would be simplified, and some science instruments would get cut.

With 18 instruments slated to fly on the spacecraft, Dennis developed a free market system to manage payload reserves. After negotiating contracts with each of the Principal Investigators (PIs) for the instruments, he distributed the payload margin for each instrument—the dollars (per fiscal year), mass (in kg), power (in watts), and data rate to the spacecraft bus (in kilobytes per second)—directly to the PIs. This gave the PIs control over the fate of their respective instruments. He and his team then established a mechanism that enabled the PIs to trade those resources with each other, with all offers and trades recorded electronically. (The project manager, project scientist, and payload manager maintained veto authority over any trade.) The trades became quite complex, sometimes involving three or four parties and a "broker" to facilitate multiparty exchanges. The "Casino Mission," as the teams dubbed it, established a win-win ethos among the PIs and a strong sense of teamwork. In the end, all 18 planned instruments ended up flying on the spacecraft.

Dennis didn't learn about resource trading exchanges in a project management training course. Faced with a dynamic environment, he adapted and innovated. In a context where decentralized teams, international partnerships, and working alliances among government, industry, universities, and nonprofit organizations are increasingly the norm, the leadership of complex projects requires the ability to respond rapidly and creatively. In short, it requires innovation.

So what is the role of workforce development in innovation? I would argue that it's a big one, since learning is a prerequisite for innovation. Professional development activities can promote a culture of innovation and the practice of sharing tools, techniques, and success stories. The Academy supports innovation at NASA by providing courses such as Innovative Design for Engineering Applications (IDEA), which

Technological Innovation	Process Innovation	Management Innovation
Miniaturization enables new class of small satellites	Use of tools, (e.g., TRIZ, Design for Manufacturability and Assembly) during design phase	Systems management approach pioneered during Apollo

There are multiple forms of innovation, including technological, process, and management innovation.

introduces a wide range of tools that engineers can use to help conceive, develop, and test new design concepts. It provides knowledge sharing forums for practitioners like Dennis Matson to exchange stories about innovative ideas, practices, and processes. Its publications and case studies help spread the word about past and current innovative projects at NASA, from Solar Max to LCROSS to FASTSAT.

As long as we continue to explore, the pressure to innovate will always be with us. And in order to innovate, we need to learn.

Change Management and Adaptive Challenges

July 30, 2010 — Vol. 3, Issue 7

What do we mean when we talk about change management?

Change is an inevitable part of the life of an organization. Regardless of why it happens, it is always difficult and painful for many people.

One metaphor that's helpful for understanding change in an organizational context comes from evolutionary biology. In *The Practice of Adaptive Leadership*, Ron Heifetz, Marty Linsky, and Alex Grashow recall that humans have been practicing adaptation for millennia:

"Our early ancestors' process of adaptation to new possibilities and challenges has continued over the course of written history with the growth and variation in scope, structure, governance, strategy, and coordination of political and commercial enterprise. So has the evolution in understanding the practice of managing those processes, including in our lifetimes what we call adaptive leadership."

They go on to define adaptive leadership as "the practice of mobilizing people to tackle tough challenges and thrive," noting that they use the term "thrive" as an evolutionary biologist would when describing the three characteristics of a successful adaptation: "1) it preserves the DNA essential for the species' continued survival; 2) it discards (re-regulates or rearranges) the DNA that no longer serves the species' current needs; and 3) it creates new DNA arrangements that give species the ability to flourish in new ways and in more challenging environments."

This concept of thriving is the essence of change management. Core values and practices remain intact, while the organization modifies or closes out activities that no longer match current needs, and develops new ones to meet current and anticipated future needs.

Heifetz, Linsky, and Grashow suggest that organizations typically encounter one of two types of issues: technical problems and adaptive challenges. With a technical problem, the problem definition is clear, the solution is clear, and process takes place through established lines of authority. Adaptive challenges are altogether different. Both the problem definition and the solution require learning, and the primary decision-making takes place at the stakeholder level.

NASA currently faces an adaptive challenge. It has faced them before, and it has thrived. Doing so again will require learning across the enterprise.

When NASA has gone through periods of transformation and rigorous self-examination in the past, the Academy has served as a change agent by facilitating learning through professional development activities. The precursor to today's NASA Academy of Program/Project & Engineering Leadership, the Program and Project Management Initiative, was established in 1988 as part of NASA's response to the Challenger accident. The focus was on ensuring that the workforce retained fundamental knowledge about NASA's project management practices.

A decade later, in the aftermath of the back-to-back failures of the Mars Climate Orbiter and the Mars Polar Lander, NASA Administrator Dan Goldin made it clear that he expected the Academy to find a way to support teams, not just individuals. It was a wake-up call that helped set the Academy on its present course. Similarly, a report by the Government Accountability Office (GAO) in January 2002 that looked at the Mars failures found "fundamental weaknesses in the collection and sharing of lessons learned agency-wide." This spurred us to expand the scope of our knowledge sharing efforts.

After the Columbia accident in 2003, the Columbia Accident Investigation Board concluded that "NASA's current organization...has not demonstrated the characteristics of a learning organization." The Academy increased its support to project and engineering teams and looked for new ways to address communications, organizational learning, and technical excellence.

In short, all of the Academy's core initiatives came about in response to change initiatives that demanded learning.

Unlike some of the examples above, the adaptive challenge NASA faces today is not driven by failure. Like the transition from Apollo to Shuttle, it is the result of changes in the political, social, economic, and technological context in which the agency operates. As a government organization, the agency's mission has always been shaped by stakeholders in the White House and Congress in response to the world around us. This is as true today as it was in the age of the "Space Race" between the Soviet Union and the United States. As the new national space policy notes, the space age began as a race between two superpowers for security and prestige. Today, the benefits of space activities are ubiquitous in everyday life, and the space community includes increasing numbers of nations and organizations around the globe.

A new challenge is here. It's time to thrive.

Lessons from Torino

June 30, 2010 — Vol. 3, Issue 6

The demands of excellence are the same the world over.

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 like an unlikely combination: craftsmanship, standards and processes, and cutting-edge technology.

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, served as a reminder that in an extremely competitive sector like the automotive industry, having a workforce that's highly skilled in project management is a competitive advantage. On the shop floor you see robots doing work that is highly routine, standardized, precise, and sometimes dangerous. There is a drive to develop standards and processes that optimize efficiency for repeatable tasks. At the same time, as a supplier producing components and subsystems for others, there is a clear understanding 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 it emphasizes learning how to think from a systems perspective. Thales also gave me a tour of an immersive learning and working environment it has developed that is a three-dimensional representation of everything we know about the solar system. This simulation, which is based on data from ESA, 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 originally founded as a local entrepreneurial venture, and there is still a strong sense of connection to the community. The importance of story is immediately clear. As you enter the facility, there are 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 empowered as experts 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. At the end of the line, the cars themselves bear a closer resemblance to works of art than 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 leveraging knowledge, lessons learned, and best practices in pursuit of quality and continuous improvement. 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*.

Knowledge Explosion

May 28, 2010 — Vol. 3, Issue 5

NASA is undergoing a knowledge explosion—and not a moment too late.

When the Academy first began sponsoring knowledge sharing forums and publications in the late 1990s, there was a degree of skepticism in some corners of NASA about the purpose of these activities. In an engineering organization, how could stories enhance the probability of mission success?

The twin failures of the Mars Polar Lander and the Mars Climate Orbiter were a watershed moment that drove home the criticality of knowledge sharing for NASA. In the aftermath of these failures, the General Accounting Office (now the General Accountability Office) released a report in January 2002 recommending, among other things, that NASA develop ways to broaden and implement mentoring and storytelling as means of conveying lessons learned.

Since then there has been a veritable explosion of knowledge sharing efforts across the agency. The Academy just completed a comprehensive survey of technical workforce development across the agency, which found that all 10 centers use informal sharing and lessons learned sessions (e.g., Pause and Learn activities, after-action reviews, brown bag lunches, and "lunch'n'learn" sessions). Nine of ten centers have academic or research portals, and eight employ discipline or specialty network videos or case studies. Other knowledge sharing practices include: project team lessons learned workshops, comprehensive "knowledge capture" activities (e.g., Space Shuttle Main Engine and Ares I-X), the Office of the Chief Engineer's Joint Engineering Board, and the Academy's forums, publications, videos, and case studies. Technology is also a big part of knowledge sharing. All 10 centers use portals, wikis, social networks, or team micro-sites. Most also use discipline or specialty networking technology, blogging, YouTube, and social bookmarking sites.

In short, knowledge sharing has taken root broadly across the agency. This is how it should be. To paraphrase former House Speaker Tip O'Neill, all knowledge is local. At NASA, experts in specific disciplines are the keepers of a great deal of local knowledge. The role of the Academy is to help build an agency-wide community of reflective practitioners who establish a culture in which sharing is the norm. The Academy also plays the part of a facilitator, providing channels through its forums and publications to ensure that local knowledge can reach the broader community.

Knowledge sharing will only be more important in the years ahead as NASA pursues an aggressive research and technology agenda. One of the keys to innovation is finding new uses for technologies and processes that were originally developed for other purposes. Knowledge flows across the agency will be critical to those kinds of connections. The community that has grown across NASA in the past decade has its work cut out for it.

Working and Learning Together

April 26, 2010 — Vol. 3, Issue 4

The International Space Station has served as an orbiting laboratory for working and learning together in space.

Later this year the International Space Station will celebrate 10 years of continuous habitation. As its assembly nears completion, we can look ahead to a full decade of utilization of this one-of-a-kind facility.

As I write this, ISS is hosting 13 crewmembers, including four women—the most women ever together in space at one time. ISS is changing our conception of what it means to live in space together. Over the next decade we will continue to learn from ISS about human factors and how teams work and live together during extended stays in space.

The ISS partnership points the way to the future of global space exploration, but it's not the only model for an extended mission with multiple partners. As a single integrated facility, ISS requires the highest level of coordination among the partners. Future missions will have different requirements that may permit combinations of highly integrated systems with more autonomous elements.

In July 2009, the five primary ISS partners published “”International Space Station Lessons Learned as Applied to Exploration,” a compendium of 56 lessons divided into seven categories (mission objectives, architecture, international partner structure and coordination, external communications, operations, utilization, and commercial involvement). The authors identify it as a living document, noting that lessons will be added as the program evolves. The appendices include the unedited contributions submitted by each of the international partners.

This document is remarkable because it discusses lessons learned in the context of future exploration. Even though ISS has another decade of life ahead, it looks forward to other exploration challenges that have not yet been identified. This demonstrates a shared commitment to continuous learning that can serve as a model for other long-duration missions with international partners, regardless of whether the mission is conducted by humans, robots, or a combination of the two.

ISS represents a quantum leap toward becoming a space-faring civilization that simultaneously lives in space and on Earth. As President Obama said when he visited Kennedy Space Center in mid-April, “Our goal is the capacity for people to work and learn, and operate and live safely beyond the Earth for extended periods of time, ultimately in ways that are more sustainable and even indefinite.”

The International Dimension of Project Leadership

March 31, 2010 — Vol. 3, Issue 3

Complex projects are increasingly international, making project leadership a more dynamic challenge than ever.

Space exploration has always been international. NASA's first international mission dates back nearly 50 years, and the agency has had more than 3,000 agreements with over 100 countries in its history. What has changed in recent years is the complexity of our projects, the capabilities of our partners, and the number of space-faring nations that seek the benefits of exploration. The way we work together has also evolved.

The James Webb Space Telescope (JWST) serves as an example of the current model of international collaboration. JWST will ride into space on an Ariane 5 rocket launched from French Guiana. Two of its four instruments draw on expertise from NASA and the European Space Agency, with the other two coming from the Canadian Space Agency and the University of Arizona. Five industry partners and the Space Telescope Science Institute will also play important roles. The involvement of multiple government, industry, and academic partners broadens the project leadership challenge far beyond the traditional parameters of cost, schedule, and technical performance.

The highlight of PM Challenge 2010 for me was the first-ever international track, which explored the international dimensions of NASA's missions from several angles, including human space flight, science missions, Earth observation, the role of industry, and the shared challenges of workforce development. I was struck by Cassini program manager Bob Mitchell's observation that the greatest collaborative challenges with his program have been reconciling differences among members of the science community. "Where we have had issues on Cassini, it has not been along national lines," he said. In other words, working with international partners is just part of the job, and it's not always the hardest part.

The day after PM Challenge concluded, I met with counterparts from other space agencies as well as representatives from professional organizations including the Project Management Institute and the International Astronautical Federation (IAF) to share ideas about our respective approaches to professional development and explore potential avenues for future collaborations. We face many of the same challenges: attracting and retaining top talent, providing hands-on opportunities for learning, and facilitating the integration of best practices and lessons learned. There was strong agreement about the potential benefits of finding ways to work together, much as our project teams already do. Many colleagues expressed interest in establishing an International Project Management Committee under the auspices of the IAF.

On March 25, I will meet in France at the IAF Spring Meeting with these same colleagues for a preliminary planning meeting of this group, which will be open to government space agencies, industry, and professional associations. Its core principles will be inclusion, appreciation, and the exchange of ideas. I will share more details in this column as our work progresses.

One thing seems clear: in the years ahead, the trend toward greater collaboration in space exploration will continue to accelerate. Getting into space is expensive, and no single organization has all the answers. European Space Agency Director General Jean-Jacques Dordain summed up the imperative for international collaboration in his keynote address at PM Challenge. "There is no alternative," he said. "We shall have to invent the future together."

ASK Magazine

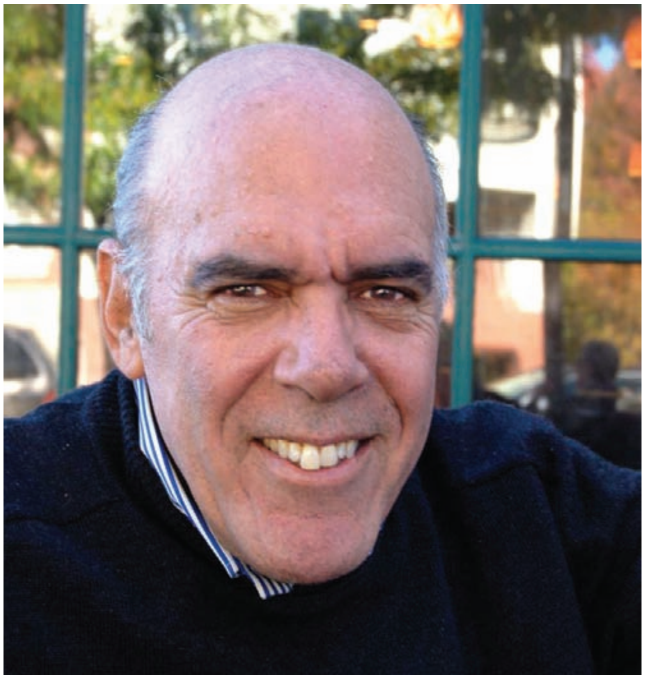
HOW ORGANIZATIONS LEARN ANYTHING

Issue 37, Winter 2010
By Laurence Prusak

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

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

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



Laurence Prusak

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

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

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

ANATOMY OF A MISHAP INVESTIGATION

Issue 38, Spring 2010
By Rick Obsenschain

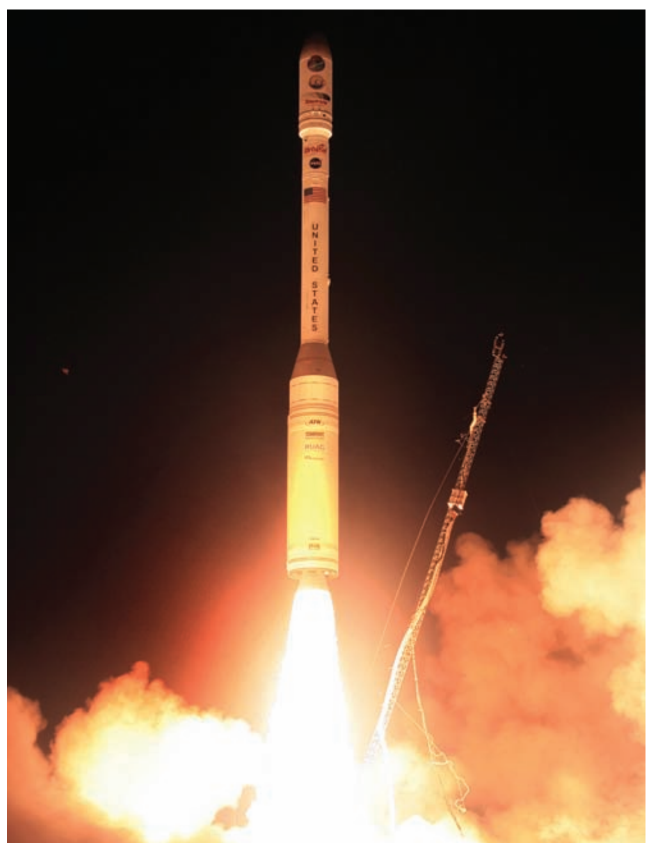
On February 24, 2009, a Taurus XL launch vehicle carrying the Orbiting Carbon Observatory satellite lifted off from Vandenberg Air Force Base in California. The satellite was designed to measure atmospheric carbon dioxide to provide precise information about human and natural carbon-emission sources. The spacecraft failed to reach orbit and instead plunged into the ocean near Antarctica.

The likely source of that failure quickly became apparent: the fairing—the clamshell-shaped cover that protects the satellite during the early stages of the flight—had not separated as expected from the upper stage of the Taurus XL, and the extra mass of the still-attached component prevented the launch vehicle from reaching orbital altitude and speed. But the reason for that malfunction was far from clear.

The day after the accident, I was asked to lead the Mishap Investigation Board (MIB) that would try to understand why the fairing failed to separate and recommend design and process improvements to prevent similar problems in the future. NASA Headquarters challenged the board to get from day one to a final report in sixty days—a dramatically shorter span than most past mishap investigations. We did it in eighty-four days, which is still remarkably fast given the amount of work that needed to be done.

THE MIB TEAM

Most of the credit for that efficiency goes to our down-to-earth, focused, dedicated team members, who often worked literally seven days a week. Some other important factors contributed. One was my decision to keep the team as small as possible, given our managerial and technical needs. There were fifteen of us, six board members and seven advisors—consisting of technical experts, legal, public affairs, external relations—plus two consultants we brought in toward the end of the process to deal with specific technical issues.



NASA's Orbiting Carbon Observatory and its Taurus booster lift off from Vandenberg Air Force Base. A contingency was declared a few minutes later. Photo Credit: NASA

The Orbiting Carbon Observatory on the launchpad at Vandenberg Air Force Base in California. Photo Credit: NASA/ Randy Beaudoin

We also worked hard to be in close and constant contact. Team members from various locations got together at Goddard Space Flight Center to start the process, and we met frequently in person at Goddard and other sites during the whole course of our investigation. All in all, members met for fifty days at Goddard and twenty-five days elsewhere. In addition, we had daily "tag-ups" and other teleconferences to share information and ideas. A central online repository of documents helped us work together over the distances among our locations.

We were further helped by the openness of Orbital Sciences Corporation, the supplier of the Taurus launch vehicle, and the Kennedy Space Center Launch Services Program. They shared information from their own investigations and cooperated fully with ours. They were as determined as we were to discover and correct the cause of the failure.

Looking for the Root Cause

Our job was to try to discover both the intermediate cause or causes of the fairing separation malfunction—the particular component or components that failed to function as expected— and the root cause of those failures: the organizational behaviors, conditions, or practices that ultimately led to the production and acceptance of what proved to be faulty mechanisms. If you find and fix the intermediate, technical problems but ignore the underlying sources of those problems, they are likely to persist and lead to other failures, so identifying the root cause is important.

In the first three weeks, we conducted more than seventy interviews to collect as much data and information about the mishap as possible. Then we used NASA's Root-Cause Analysis tool to look for that fundamental cause. I admit to starting out with some skepticism about the tool, which requires adherence to demanding, detailed analytical processes. Having worked as an engineer earlier in my NASA career, I have always been concerned that some formal processes supposedly designed to support the work may actually get in the way of developing the product. In actual fact, though, what initially looked like a process that might be too rigid turned out to be usefully rigorous. Had we not gone through all the steps required by the Root-Cause Analysis tool, we could easily have missed possible contributors to the launch failure. In situations as complex and ambiguous as this one, relying on an informal sense of where the fault probably lies just doesn't work. We ultimately offered a few suggestions for improving the tool, but they were ways to make it more user friendly; in general, it proved its power and usefulness.

Using root-cause analysis, we ended up with a fault tree that had 133 branches—133 factors we needed to evaluate with the tool. That process eliminated 129 of them, leaving four possible causes of the fairing-separation failure. Although some of those four seemed more qualitatively likely than others, none could be ruled out.

Chief among the reasons that we were not able to identify the cause was that we didn't have access to the failed hardware that probably would have given a definitive answer. It was at the bottom of the ocean near Antarctica. Not having that clear answer, we were not able to determine a root cause either.

The MIB Report

Our report detailed the four factors that could not be discounted as possible intermediate causes of the mishap. Along with our description of these possible causes, we offered recommendations for how to ensure

Inside Building 1032 at Vandenberg Air Force Base, technicians install the Orbiting Carbon Observatory spacecraft inside the payload fairing. Photo Credit: NASA that they would not pose a risk on future missions. Briefly, these are the possible causes the board identified and our recommendations for improvement.

Frangible-joint base ring may not have fractured as required.

An incomplete fracture of the frangible-joint base ring that holds the fairing halves together and attaches them to the upper stage of the rocket could have prevented fairing separation. We could not discount this possibility because Orbital Sciences did not have complete information on the characteristics of the aluminum used in this component. We recommended that future aluminum extrusions for this component have a traceable "pedigree" to aluminum lots that have been appropriately and thoroughly tested.

Electrical subsystem may have failed.

The responsible subsystem might not have supplied enough electricity to fire the explosive devices that released the fairing. This remained a possibility because telemetry sent from the launch vehicle was not designed to measure and report the amount of current needed. We recommended changing the telemetry so that it would provide this information.

Pneumatic system may not have provided enough pressure to separate fairing.

We could not prove that the pneumatic system—a hot-gas generator, thrusters, and pneumatic tubing—supplied enough pressure to separate the fairings. We recommended design modifications and improved testing of the hot-gas generator system design to provide pressure to the thruster. If those changes prove impractical or impossible, we recommended using an alternate system.

Flexible, confined detonating cord could have snagged on part of frangible joint.

This seemed an unlikely failure cause, but we could not rule it out. We recommended rerouting the cord or adding a physical barrier if further analysis and testing could not eliminate the possibility.

In the days since we presented our report, continuing efforts of the Kennedy Launch Services Program and Orbital Sciences have shown that electrical system malfunction and detonating cord snagging were not contributing factors to the failure. The specific recommendations made by the MIB are being incorporated to ensure that these potential failure modes are prevented in the future.

A Valuable Investigation

All the skill and hard work of the board members and the many others who helped us did not get us to the clear-cut intermediate and root causes we had hoped to find. Instead, we "surrounded" the actual cause by identifying multiple possibilities. A few people have suggested this means that the Orbiting Carbon Observatory MIB "failed." I don't agree. The detailed and extensive testing and analysis that allowed us to identify the four potential intermediate causes should go a long way toward ensuring that the fairing problem will not recur. And our recommendations, although they do not get at a definitive root cause, do speak to small but meaningful shortfalls in testing, inspection, quality control, and manufacturing that will help guide the recovery activities.

One general conclusion that our work supports is the importance of rigorously adhering to the procedures designed to eliminate and minimize as much risk as possible. This is especially true when the project team has only sporadic experience with a particular vehicle, as was the case with the Taurus XL used to launch the Orbiting Carbon Observatory satellite. Only eight Taurus rockets have been launched, with typically several years separating launches. Many of the people involved with launching the Orbiting Carbon Observatory had little or no experience with this launch vehicle. The less often you launch, the more attention you should pay to the formal procedures that embody much of the information and knowledge past practitioners have acquired about how to launch successfully.

Bio

Rick Obsenschain has worked at NASA for more than forty years in positions ranging from discipline engineer to project manager five times, to director of engineering, to director of flight projects. He is currently the deputy center director at Goddard Space Flight Center.

Rick Obsenschain

Open-Door Innovation

Issue 38, Spring 2010
By Andrew Petro

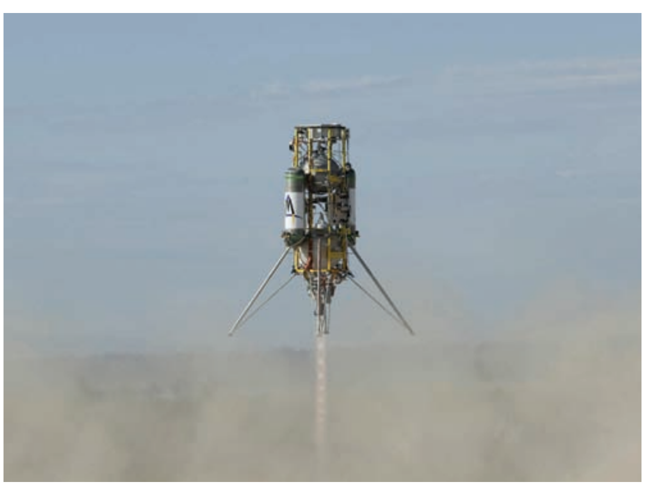
The team from Worcester Polytechnic Institute stands with their excavator Moonraker, which won them $500,000 in the Regolith Excavation Challenge.
Photo Credit: California Space Authority/Jamie Foster

The idea behind NASA's Centennial Challenges program, which offers cash prizes for successful solutions to important and clearly defined technical problems, is that innovation can come from anywhere. The program originated in 2003 and its name refers to the centennial of the Wright brothers' historic flight at Kitty Hawk. The inventiveness of those two bicycle mechanics is a model of the kind of independent, groundbreaking inventiveness the NASA program hopes to inspire.

Opening the door to all interested individuals and groups and providing the incentives of prize money and publicity increase the chances that valuable new technologies will be developed. As part of that openness, we at NASA don't manage the activities of the competitors at all. We set the challenges; teams work on their own and show up with their solutions. The Centennial Challenges program does not offer awards for good proposals or designs; only ideas that have been demonstrated to work in the real world receive awards.

Most successful innovations are built on repeated failures that show innovators what does not work and point the way to what might—failure is an investment in learning. But closely monitored budgets and schedules and constant scrutiny make it hard for most large organizations, including NASA, to tolerate much failure. The small start-ups, academic teams, and individuals who enter the challenge competitions can give themselves permission to fail, and their failures sometimes lead them to valuable new ideas.

Prize competitions are only one of many ways to pursue research and development at NASA, and they offer some unique features not found in conventional contracts and grants. Prize competitors do not only need to meet a given budget, schedule, and set of performance requirements. Challenge teams need to do things as inexpensively as possible since they are spending their own money. They not only need to meet a schedule, they need to do things more quickly than their competitors. And they not only need to meet the performance requirements, they need to exceed them by as large a margin as possible if they expect to win a prize. The prize competition ensures that solutions are found in a cost-conscious and effective way, and the government expends no money at all unless a solution is demonstrated.

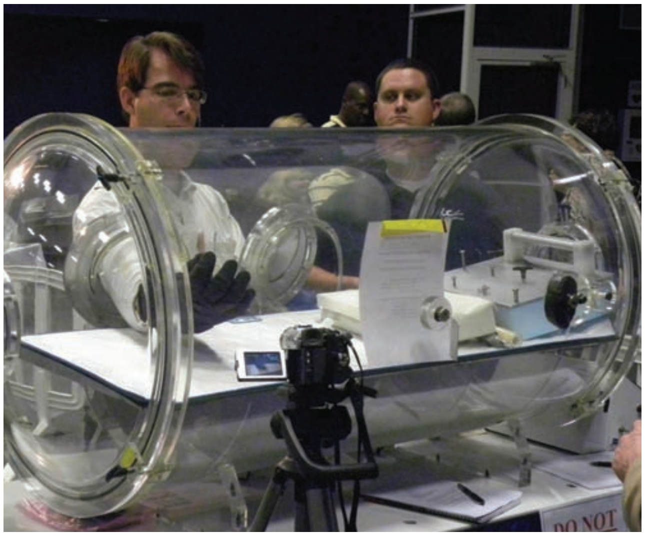


Masten Space Systems' "Xombie" vehicle ascending during its first flight. Photo Credit: NASA/Tony Landis

Defining the Challenges

Not all interesting technical problems necessarily make good prize challenges. The goals need to be both measurable and relevant to present and future NASA missions. Ideally, a challenge should involve a technological advancement that is interesting and valuable but not on the critical path for any existing program, since the outcomes are naturally unpredictable. And they must have the right degree of difficulty—achievable, but hard enough to require real innovation and be a meaningful advance on existing technologies. Technology areas with the potential for commercial opportunities are good for challenges since that provides an important added incentive to competitors.

Among the challenges offered so far have been development of a new, more flexible spacesuit glove; a reusable rocket that can make two successful flights with accurate landings in a fixed time period; wireless power transmission; super-strength materials; and a regolith excavator that can dig and transport lunar soil. A new green aviation challenge under way is to build an aircraft that can fly at least 200 miles in less than two hours with an efficiency equivalent to 200 passenger-miles per gallon. In the 2009 Power Beaming Challenge, creating the



First-place winner Peter Homer demonstrates his glove during the 2009 Astronaut Glove Competition. Photo Credit: NASA

competition venue was as much of a technical challenge as the competition itself. The contest requirement was to drive a robot climber up a vertical cable using only power transmitted from the ground. In previous years of the competition, a cable was suspended from a crane, but that became impractical when the target height rose from 100 meters to 1,000 meters. The solution was to connect a cable from the ground to a helicopter 1,300 meters overhead, something that had never been done before. After several unsuccessful tests, a scheme was found for safely maintaining cable tension, and the result was a stable vertical racetrack into the sky. In the end, LaserMotive, a team from Seattle, Washington, drove their climber to the top at a speed of almost 4 meters per second.

We are currently in the process of choosing some new challenges. We have solicited ideas from scientists and engineers within NASA and from the public. Almost two hundred ideas were submitted, and some of them will be reflected in the new prize challenges. In addition to benefiting NASA missions, we are also interested in prize challenges that address national and global needs such as energy, climate change, health, and education.

Innovation from Anywhere

The winners of the challenges show that innovation comes from diverse and sometimes unexpected sources. The first Astronaut Glove Challenge was won by Peter Homer, who developed his design working alone at his dining room table in Maine. Homer conducted dozens of failed experiments that helped him arrive at the winning design. After winning the prize he formed his own company to manufacture pressure-suit gloves and related products. Another competitor in that challenge, Ted Southern, is a costume designer from New York who partnered with a former rival and won the second-place prize in the latest astronaut glove competition.

In the first two years of the Regolith Excavation Challenge, no team came close to meeting the requirements: to create a self-propelled robot that could dig up and dump at least 150 kilograms of lunar soil into a container in thirty minutes. Then, in 2009, three of the twenty-three participating teams far surpassed the requirements. The winner of the $500,000 prize was a team from Worcester Polytechnic Institute led by undergraduate Paul Ventimiglia. Their excavator moved 440 kilograms, almost three times the amount required.

Many prize competitors are existing small businesses; these small companies find that the prize competitions allow them to focus their efforts and provide them with visibility and credibility not easily attained in fields that are often dominated by large corporations. That was the outcome for Armadillo Aerospace, based in northern Texas, and Masten Space Systems of Mojave, California, the two Lunar Lander Challenge winners. Both companies have been recognized nationally as entrepreneurs and are pursuing new opportunities with potential commercial and government customers.

The LaserMotive team prepares their climber prior to launching on their prize-winning climb. Photo Credit: NASA

The Citizen-Inventor

One goal of Centennial Challenges is to help stimulate a stronger culture of innovation across the nation. We have seen teams from Maine to Hawaii in the competitions. The teams that attack these challenges include businesses and university students but also groups of garage inventors that even draw family members into the quest. Young people who have been part of these hands-on efforts at real-world problem solving are obviously attractive to future employers and will likely carry on the spirit of innovation. Another goal of the program is to push the culture of innovation at NASA in a new direction; that is, to cultivate a willingness to consider ideas coming from outside our own organizations. That kind of openness will strengthen NASA and create a real link between the citizen-inventors and their government's aeronautics and space program that will benefit everyone.

Bio

Andrew Petro is the program executive for the Innovation Incubator in the Innovative Partnership Program Office at NASA Headquarters. His responsibilities include the Centennial Challenges program and several other public–private partnership activities. Most recently, before moving to NASA Headquarters, he was the Ares launch vehicle integration manager for the Mission Operations Directorate at Johnson Space Center.

Andrew Petro

Petrobras and the Power of Stories

Issue 38, Spring 2010
By Alexandre Korowajczuk and
Andrea Coelho Farias Almeida

One afternoon in October 1986, after more than thirty years searching for petroleum in the Amazon region, we were drilling the last authorized well in the Urucu region. There was tension in the air. Finally, the petroleum gushed, and whoops of excitement reverberated round the small camp. This discovery rewarded the persistence of geologists and geophysicists who had believed, all along, in finding oil, based on a geological model developed for the region. They had made the dream come true of finding petroleum in the Amazon region.

The challenge, following the discovery, was how we would produce oil in such a sensitive environment as the Amazon rainforest. We had great expertise in finding, extracting, transporting, and refining petroleum, but that environment was a totally new challenge. We summoned a group of scientists, specialists in the Amazon region, to guide how to develop our project with the least environmental impact. We presented our project to them, took them to the production site. They gave us a series of recommendations that became known as "The Manaus Charter." This basically was guidelines setting out what we had to observe during the project development. That decision to summon those scientists brought an enormous benefit to the project, because today our project is internationally recognized as an example of social and environmental responsibility.

I heard this story in 2005, when I visited the Urucu region in the middle of the Amazon rainforest. Despite having, at that time, twenty-five years with Petrobras, the past fifteen in managerial functions, I had no knowledge of these interesting and important aspects of this project. The visit and the stories motivated me to deepen my own knowledge and to promote knowledge dissemination throughout the company. The young team who accompanied me on that Urucu visit, all with less than three years at Petrobras, suddenly had access to managers, field coordinators, and operators of the Urucu project. They became more motivated, interested, and knowledgeable in this innovative project.

Following the Urucu visit, we agreed that we would develop a robust method for disseminating lessons learned during important company projects. Learning from the past would prepare for the future.

Petrobas

Petrobras is a Brazilian integrated-energy company operating in more than twenty-seven countries. It has a tradition of overcoming project challenges. Its project environments have become more technically complex, from exploring and producing oil and gas onshore and in shallow waters, to deep water (2,000 meters) and now ultra-deep water (7,000 meters), with the pre-salt layer discoveries. These high-risk projects demand innovative solutions using leading-edge technology. The projects

Urucu Operational Center. Photo courtesy Petrobras

have to consider not only the proximal environment but also the social impact on communities—those near the production facilities and those along the pipeline infrastructure. All this complexity demands project team excellence at a time when we face the imminent retirement of our most experienced staff and the recruitment of about 25,000 new employees. In addition, our strategic plan foresees doubling our oil and gas production capacity and a major investment in alternative energy, such as biofuels, over the next ten years.

We will need the knowledge developed during the fifty-seven years of company history and what we learn in the future to achieve our business objectives and adapt to the higher speed of decision making in an increasingly complex political and economic environment.

THE HIDDEN OBJECTIVE OF LESSONS LEARNED

Explicit knowledge, most frequently related to technical and operational aspects, can be registered and disseminated through documents in various media. But understanding the many risks and uncertainties associated with project execution requires a different approach. This knowledge can only be disseminated through interaction among employees who build together an understanding of implications of the knowledge and the context in which it was developed. When dealing with employees with similar experience, we focus on fine-tuning their skills. With new employees, the focus has to be on developing and integrating their skills into the context of the company's activities. To illustrate how we can merge these demands, let me tell the story of a lessons-learned workshop that I attended at the end of an important project.

During an oil refinery major-revamp project, some unpredicted events affected the cost and project schedule. To identify the causes, a lessons-learned workshop was organized with the main project participants, most of whom had coincidently worked on its original construction twenty years earlier. The knowledge management manager related to this project asked why no new employees had been invited and was told none of them had participated in the project and they had no practical experience. But he insisted and two new employees were invited, on the condition they would be only spectators. After several meetings over the course of two weeks, the main conclusions about the causes of the cost and schedule problems were presented at the final meeting. Because the reasons were already known in some way by the experts, they felt the workshop had been a waste of their time.

But one of the new employees took the floor and commented that their participation had been extremely beneficial as they had learned a lot during the discussions. They had particularly enjoyed listening to the stories about the problems and had gained a better understanding of the risks and uncertainties associated with project changes. He ended by commenting that most of the workshop participants had had the opportunity to learn from the revamp and even from the original refinery construction, but they were approaching retirement and the new employees would be taking over the responsibility for this and future refinery projects.

After a short silence, the veterans came round to the conclusion that one hidden objective of a lessons-learned workshop was not just to extract technical lessons learned, but to develop new employee skills through the dissemination of knowledge and experience gained during important projects. These veterans understood that they needed to have more time to interact with the younger employees, because not only were they going to teach them, but they would also have an opportunity to learn with them during future project work.

BUILDING THE "PETROBRAS CHALLENGES" PROGRAM

In 2003, the "Memories of Petrobras" project was launched as part of Petrobras's fiftieth anniversary

The objective of this robot is to collect environmental information from a wide range of complex Amazon regions, technology developed by the Petrobras robotics laboratory (CENPES). Photo courtesy Petrobras celebration. The objective was to recover company history from the employees' point of view, hearing their career stories and stories of their families and the communities that interacted with the company. This project gave voice to the "other side of the story"—not just the company's view. This project helped veteran employees recover the memory of their work experience and gave new employees a sense of the real-life challenges of project work and a better understanding of company culture. "Memories of Petrobras" helped shape what became the "Petrobras Challenges" program to use storytelling to communicate essential knowledge to new employees.

We initially defined three aims for this new program:
1. Develop a systemic vision of the studied project to focus on events that presented important moments of reflection and changes to solve problems.
2. Use interaction among employees who worked on the project and employees who are studying the project.
3. Prepare new project managers for decision making in complex environments.

The Urucu Project of the discovery, production, and transportation of oil and gas in the Amazon region was used as a pilot for program construction. During the recording of the stories by the main project "actors," it became clear that the challenges that arose during project execution were the most important learning opportunity, demanding a lot of reflection and elaboration of alternatives.

To record and disseminate knowledge about an important project, we developed this methodology:
1. Development of a timeline divided into three parts:
   a. Prior to the project beginning, describing the context that surrounded project creation.
   b. The project trajectory, focusing on the decision and change moments/events.
   c. The project future, its continuation or the vision of the future execution of equivalent projects.
2. Descriptions of project changes along the timeline in the form of text case studies, based on stories from the main actors for each important aspect of the project.
3. Construction of a video based on stories obtained from the project actors, to better understand the project context.
4. Workshops for project case studies, using the text case studies and video with the project stories.

The pilot project concluded with a one-day workshop that included discussion of the previously read case-study text, organized by theme (for example, project management, innovation, logistics, partnerships, social responsibility); video presentation of project stories; a "Coffee with Energy" panel with the participation of two project actors; and discussion of lessons learned and future project development.

The "Coffee with Energy" panel exceeded our expectations. The two important project actors in the case studies were employees with more than twenty years of company experience and are today important technical consultants or business managers. Most of the workshop participants were employees with between one and five years' experience. The participants raised issues related to the case study that the actors answered in an informal way, creating an extremely friendly and trustworthy climate.

The new employees' satisfaction was clear from the attention they gave to the experienced employees; the veterans were gratified by the new employees' interest. The "Petrobras Challenges" program effectively transmitted company culture and values to the new employees that were implicit in the stories and expanded on in the workshop program.

So far the "Petrobras Challenges" program has developed four case studies of important projects. Workshops were held in Rio de Janeiro and Manaus in Brazil and in Bogotá, Colombia. The "Petrobras Challenges" program methodology is expected to be employed by the Petrobras Corporate University beginning in 2011.

The Power of Stories

I will give the last word to Librarian Andrea Coelho Farias Almeida, the person responsible for the "Petrobras Challenges" program, who is herself one of the 25,000 new employees recruited by the company in the past five years. Her experience demonstrates the power of stories.

Right from the start, our objective was to contribute to the decision-making quality of Petrobras leadership in an environment marked by profound changes, including the increasing importance of sustainability. The thought that we could contribute to a more effective decision-making process, enabling our leaders to anticipate new business needs, preparing Petrobras for the future, affected me strongly.

The idea that I would work with lots of senior employees was a bit daunting. Naturally, I was not part of their relationship networks, having only worked for Petrobras three years at that time. But because we were aiming to transfer knowledge from these executives, I felt that the organization was conceding me the opportunity to access the company's precious gold, on condition of sharing it with all the other Petrobras employees. I was fascinated by the idea that I would have the privilege of hearing the stories of the experiences of these executives and senior specialists, and the challenges they had faced.

The acquisition of this knowledge gave me the confidence to develop my work. In some situations I felt that I was one of the few people to know about certain events and this awoke in me a feeling of urgency. It felt vital that the practices we had developed be disseminated and the knowledge incorporated into the organization—there was so much hidden treasure. Also, my manager witnessed the surprise of the executives when they discovered that I had been with the company so short a time. Being exposed to that knowledge and experience contributed to my professional maturity.

Alexandre Korowajczuk

Bios

Alexandre Korowajczuk graduated with a degree in electronic engineering in 1975 and has been working for Petrobras since 1978. For the past seven years, he has been working as the manager of Corporate Knowledge Management, located in Development of Management Systems Unit at Petrobras Headquarters in Rio de Janeiro, Brazil.

Andrea Farias Almeida Coelho is a librarian archivist, formed by Federal University of Bahia, and specializes in project management by the Foundation Getúlio Vargas. For more than six years she has worked to transfer knowledge throughout the Petrobras, and she is responsible for the "Petrobras Challenges" program, which is based on storytelling and case studies.

Andrea Farias Almeida Coelho

Islands and Labyrinths: Overcoming Barriers to Effective Knowledge Transfer

Issue 39, Summer 2010
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.

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 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.

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.

T.J. Elliott

Bio

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.

Ten Systems Engineering Lessons Learned

Issue 39, Summer 2010
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.

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.

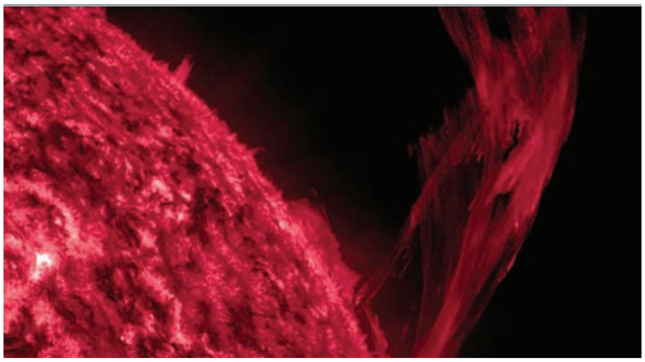
Most systems engineering training focuses on the technical issues, often with very little focus on helping the systems engineer understand and learn to deal with the non-technical minefields that are part of every project. Like technical issues, non-technical issues also have the potential to slow or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



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

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 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.

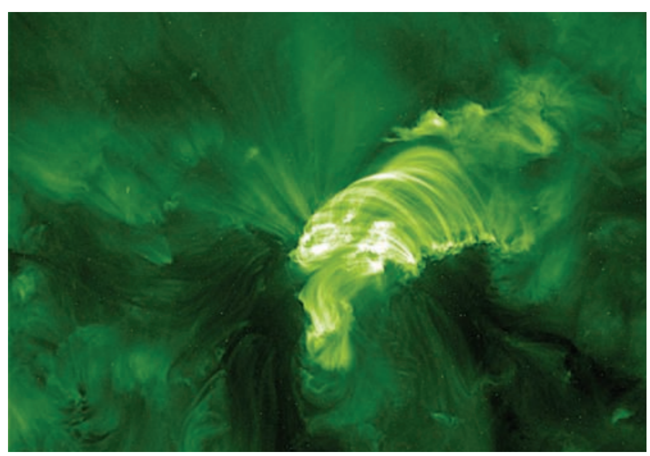
Today, as I look at the engineers who "grew up" on that program and now have spread throughout Goddard, I see the fruits of that cultural change and the effect it still has in helping to ensure reliable spaceflight hardware.

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



SDO's Atmospheric Imaging Assembly instrument captured this image after a solar eruption and a flare. Photo Credit: Goddard Space Flight Center/Atmospheric Imaging Assembly 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.

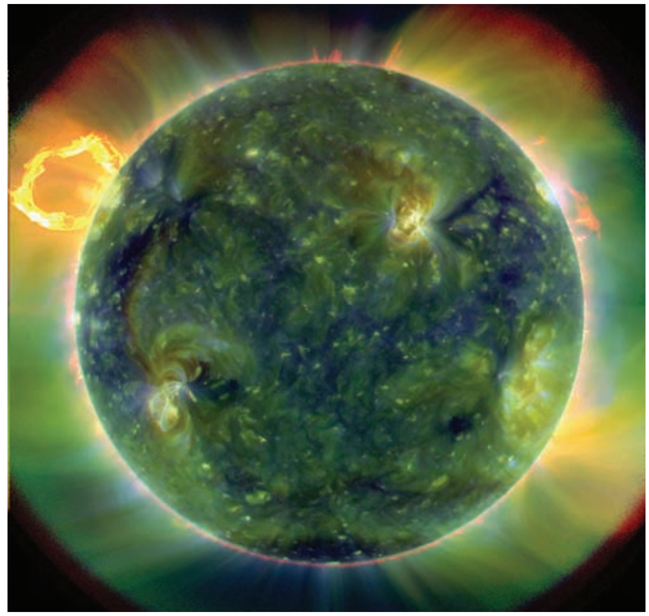
Engineers often spend tremendous effort trying to come up with a unique solution rather than build on the foundations of others. A wise individual I once worked for was fond of saying, "When you are in college and you copy someone else's work, it's called plagiarism, and it can get you kicked out of 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 (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.



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

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).

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.

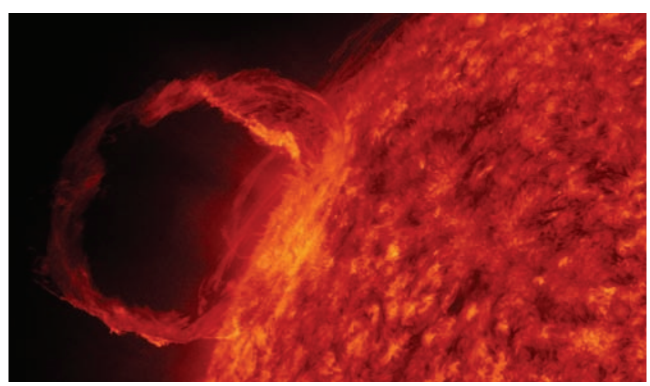
On every project, there are the people who are in charge and the people who actually do the work. These key workers often can tell you the most about what the problems really are, what to watch out for, and how to creatively solve problems—and they will figure out quickly if you really want to listen. 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



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. Photo Credit: Goddard Space Flight Center/Atmospheric Imaging Assembly 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 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.

Bio

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.

John Ruffa

Phaeton: Learning by Doing

Issue 37, Winter 2010
By Johnny Kwok

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

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

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

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

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

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

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

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

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

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

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

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

More Than Engineering and Science

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

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

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

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

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

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

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

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

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

Johnny Kwok

Bio

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

The Next Big Thing is Small

Issue 38, Spring 2010
By Haley Stephenson

Satellites that can fit in a backpack are shrinking technology, reframing satellite science, and providing valuable mission training and experience to the next generation of engineers.

They come in sizes small, micro, nano, and pico, with masses ranging from 500 kg (small) to 1 kg (pico). Over the past two years, global interest has grown rapidly in satellites a fraction of the size of Sputnik-1 (a beach ball weighing about 80 kg), which are ushering in a new era of missions and engineering opportunities.

CubeSat, Meet NASA

A decade ago, two professors concluded that educational satellite missions took too long and were too expensive. There had to be a better way to do them, thought Jordi Puig-Suari of California Polytechnic State University (CalPoly) and Bob Twiggs, then at Stanford University. "Education satellites were not performing the education tasks well enough," said Puig-Suari. "They were too complex, too large, and we had to change it."

The change came when Twiggs went down to a plastics store in Mountain View, California. After working on the Orbiting Picosatellite Automatic Launcher satellite that carried six Klondike-bar-sized picosatellites into space in January 2000, Twiggs sought to make picosatellites more cubical to support more solar panels. The store had what he needed to bring his vision to life: nearly cubical plastic Beanie Baby boxes. "And that's how it came about," said Twiggs, "modeling with a Beanie Baby box, a four-inch cube."

Twiggs's group at Stanford started developing a satellite bus—the subsystems that support the satellite—to house the picosatellite payload while Puig-Suari's group at CalPoly went about developing a deployment mechanism called the Poly Picosatellite Orbital Deployer (P-POD). The result was CubeSat, a 10 cm3 picosatellite weighing 1 kg. Three fully autonomous CubeSats can be configured together to form a nanosat no larger than a loaf of bread. (Nanosatellites are those that are less than 10 kg.)

Engineers at Ames Research Center started collaborating with Twiggs. John Hines, currently the chief technologist of the Engineering Directorate at Ames, maintains close relationships with the university programs that propelled the NASA Small Satellite Program into action. "Our whole nanosat program is based on the shoulders of the university nanosatellite activities and the CubeSat activities," said Hines.

Ames conducted a pilot study, asking scientists to think about the kinds of science that could be done on nanosatellite platforms. Satellite experiments involving biological specimens typically had to be taken into space, brought back to Earth, and then analyzed after their return. Miniaturization of analysis systems offered an alternative: do everything in space. "The idea to analyze and do all of your processing and measurements in situ was something that had not been done a lot," said Hines.

A partnership developed between Ames and three California universities: Stanford developed the satellite buses, CalPoly provided the P-POD, and Santa Clara University performed the mission operations. After ensuring that the hardware under development at the universities met NASA standards for spaceflight projects, engineers at Ames began to hone their understanding of nanosat capabilities and then push them further.

Nanosats: Not Toys

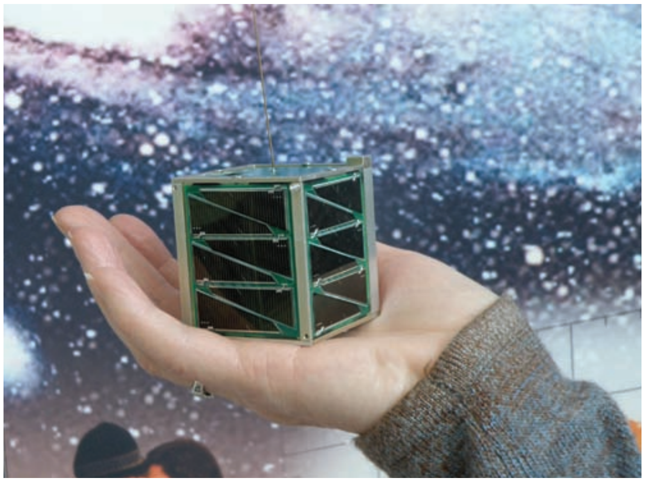
Because of their size, the value of nanosats has often been overlooked. "Everybody laughed at us," said Twiggs, laughing. "They said, 'That's absolutely the dumbest idea we've ever heard of. Nobody's ever going to do anything with those toys.'"

"Four or five years ago," Hynes recalled, "people would pass by and look at these things as toys. Now you see [those same people] showing how they are building their own and starting to have their own programs."

University satellites are primarily geared toward education and training. For NASA, nanosats offer a low-risk, low-cost, low-visibility platform for innovation, as well as the ability to use launch vehicles that are not designed for large spacecraft.

"We're starting to do real science, real technology validation, and risk reduction, and gain flight heritage on new techniques and technologies. It's still a spacecraft, and it's still a mission," said Hines. "It has every element and every aspect of a large spacecraft, just smaller and less expensive and sometimes less complicated. But it has all the pieces, all the elements. It's managed exactly the same. We use the same flight project management standards—7120.5D—that big missions are required to do for all NASA missions. You have to go through the whole design, development, integration, test, missions operations, and management processes just as you would for a full mission."

Puig-Suari said that the biggest constraint in the field is mind-set, not resources. "People are trying to shrink a big spacecraft," he said, "but if you do it that way, it's not going to work." He believes the way people think about the capabilities of nanosats is shifting. "People will initially say, 'I cannot put my component on that box because my component was designed for a big spacecraft,'" explained Puig-Suari, "but now we're starting to have people say, 'Okay, what can I put inside that box?'"
Early versions of nanosatellites included Bio NanoSat and GeneBox, which carried a variety of organisms and molecules such as genes, bacteria, and yeast cells.



PocketQub femtosatellite being developed by Bob Twiggs at Morehead State University. Photo Courtesy Bob Twiggs

These nanosatellites paved the way for the development of NASA's first deployable, autonomous nanosatellite, GeneSat. "We started to miniaturize something that we already thought was impossibly small into something even smaller," said Hines. GeneSat launched in December 2006, taking nanosatellite experiments to a new level of visibility in the aerospace community.

Prepping Gen Y

With a majority of NASA's engineers currently eligible for retirement, the next generation coming up through the ranks has a lot to learn before the knowledge of those leaving walks out the door. With their low cost, risk, and visibility, small satellites can offer an excellent training opportunity for hands-on learning.

"As a seasoned project manager, I have a responsibility, just as my peers did when I joined the agency, to train the next generation of space enthusiasts and spacecraft developers," said Mark Boudreaux, project manager of the Fast, Affordable, Science, and Technology Satellite Huntsville (FASTSAT-HSV) microsatellite at Marshall Space Flight Center.

Small satellite missions also offer young engineers the opportunity to acquire and practice essential engineering management skills such as team communication and project documentation, regardless of their specific area of expertise.

"We want to make sure that we're training those replacements to continue the things we worked so hard to get to," said Hines. "You get the discipline of having to see something all the way to the finish rather than doing it as a school exercise, doing something that you've done on paper design and then you're finished," he said. "You've got to make the thing work."

At the university level, Puig-Suari sees a noticeable change in how students approach their projects. "Interacting with industry really puts them in the right mind-set as far as the quality levels, level of seriousness, and documentation," he said. "You need to prove that it works, write it up, and show it to the right people."

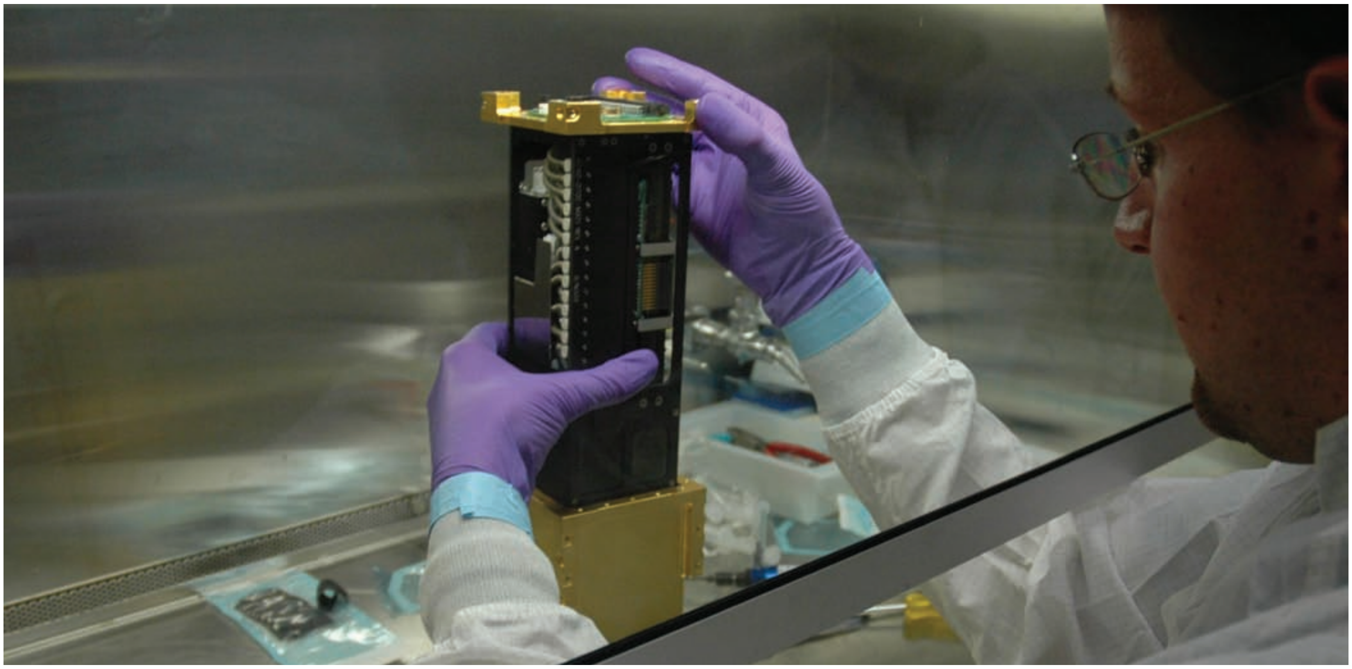
Learning from NanoSats

In August 2008, Boudreaux and Hines saw NanoSail-D (Marshall) and PRESat (Ames) take off on the third SpaceX Falcon 1 from Omelek Island, one of the Marshall Islands in the Pacific. The launch vehicle never reached orbit and plunged into the Pacific Ocean.

Despite the launch failure, there were lessons learned. "We learned a lot about the integration process," said Boudreaux, noting that this was their first involvement with Falcon. "That was a new paradigm for us." Working with new commercial launch providers offered valuable experience. Two years prior to the Falcon launch, the Ames team had configured GeneSat to launch on the Orbital Sciences Corporation's Minotaur-1 rocket.

"We were able to look at different launch-integration capabilities, different launch sites, different launch operations, different mission and range considerations, as well as [gain experience in] deploying a spacecraft and payload to a very, very remote launch site," said

GeneSat 1 payload assembly with Chris Beasley in Gene Sat Test and Integration Lab N 240.Photo Credit: NASA



Christopher Beasley, NASA Ames mechanical engineer, places the PRESat payload into a gold press vessel.
Photo Credit: NASA Ames Research Center/Matt Piccini

Hines. The remote location of the SpaceX Falcon launch site tested NASA's ability to react to a launch delay. The launch vehicle was grounded long enough for the specimen to expire and forced NASA to replace the living specimen inside PRESat. "We got a big operational logistics effort under our belt with that as well," Hines said.

The quick turnaround from authority to proceed to launch was also notable. Marshall started integrating NanoSail-D into an Ames CubeSat in November 2007, delivered the product in April 2008, and launched the following August. "There were processes that we streamlined," said Boudreaux. "Sometimes these things can take years, but this took months, providing valuable insight into private-sector processes. We learned a lot about a short, tailored, very efficient, fast development process."

There were also cross-agency benefits. "Ames transferred knowledge to us," said Boudreaux. "We learned from Ames the important elements associated with building a CubeSat."

The relatively low cost of the satellites made it possible to build backup units. While PRESat and NanoSail-D never made it into space, their twins still have a chance.

Leveling the Playing Field

Before nanosatellites, satellite projects were primarily limited to well-funded, established space programs. This is no longer the case. Nanosats have opened up space exploration to a wider world.

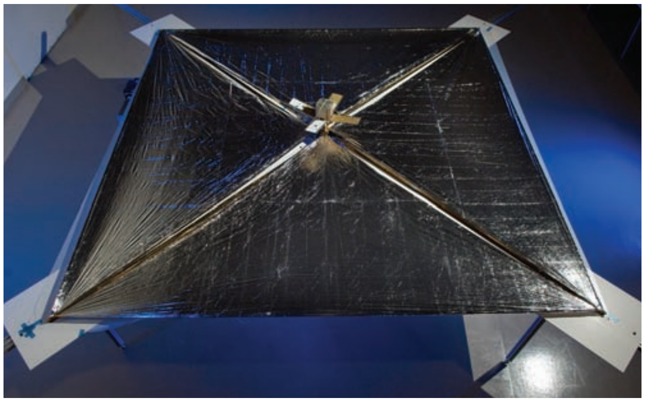
The CubeSat program has expanded to South America, Asia, Europe, and South Africa. "The playing field has leveled," said Puig-Suari. "A lot of people are doing it." He cited the launch of Colombia's first satellite, Libertad-1, a 1-kg picosatellite. "Those guys were so excited. It was a very simple spacecraft, but it had national implications."

The Next Wave

Next year, the Department of Defense Space Test Program will launch several NASA small satellites, including the Organics and/or Organisms Exposure to Orbital Stresses (O/OREOS) managed by Ames, and the second NanoSail-D managed by Marshall. These nanosatellites will be two of six instruments riding on FASTSAT-HSV-1—a spacecraft bus designed to carry multiple experiments to low-Earth orbit—which will be launched aboard an air force Minotaur-4 launch vehicle from Kodiak Island, Alaska. The second NanoSail-D is a proof-of-concept demonstration of a miniaturized solar sail that Marshall hopes to build on a large scale for solving propulsion and space travel concerns. "It's a stepping stone to larger-class technology," said Boudreaux.

For Ames, nanosats are stepping stones toward a new class of missions. O/OREOS will investigate how components of life like amino acids respond to radiation and microgravity, one of many missions in line for nanosat technology.

Scientists are starting to get interested. Biologists were the first to see the potential, followed by astrobiologists and astrophysicists. Now nanosat programs are popping up at places like the National Science Foundation, the National Reconnaissance Office, and the air force.



NanoSail-D in its expanded form. Photo Credit: NASA

From the National Science Foundation's space-weather nanosats to the Cube50 project, which will launch fifty nanosats into the lower thermosphere (dubbed the "ignorosphere" because so little is known about it), to the even smaller femtosatellite called PocketQub Twiggs is currently developing, the capabilities of these satellites are only just emerging. Nanosats are not replacements for their larger counterparts; they offer another approach to spaceflight. "People started saying, 'Wait a minute, what else can I do with this?'" said Puig-Suari. "And it was just a chain reaction at that point."

Peer Assist: Learning before Doing

Issue 40, Fall 2010
By Kent A. Greenes

Knowledge workers in NASA work on the edge, carrying out complex projects that have never before been attempted. It shouldn't be a surprise to discover that teams working on these projects cannot possibly know everything they need to know to perform to the highest standards. In many cases, they haven't had the opportunity to learn from previous experience, or they haven't had ready access to those who have "done it before."

It's not always easy to admit we don't know everything, but once we do and ask for help, the process of gaining new knowledge has already begun. It takes time and effort, though, to get the right knowledge to flow and transfer when and where it's needed. Fortunately, there is a proven knowledge management technique that can help. Called a peer assist, it accelerates the transfer of knowledge from those who have it to those who need it in many organizations.

The Peer Assist

A peer assist is a facilitated work-session, held face to face or virtually, where peers from different teams and organizations share their experiences and knowledge with a team that has requested help in meeting an upcoming challenge. Knowledge in the form of good practices, lessons learned, and insights is typically shared through relevant stories told by the people who experienced them. A peer assist does three things:

- Targets a specific technical, mission, or business challenge
- Acquires assistance and insight from people outside the team and identifies possible approaches and new lines of inquiry
- Promotes sharing of learning and develops strong, and often new, connections among staff, partners, suppliers, and customers

I recently facilitated a peer assist for a health care provider in Alaska whose aim was to develop a capital business plan that would gain approval from budget holders outside Alaska to renew aging facilities and grow capability for long-term health care. A preliminary version of the plan had met resistance from these decision makers; the Alaska team was told to go back to the drawing board and develop a plan that required significantly less investment. The team had been working for months at reducing the cost and had gotten to a point where they exhausted what they knew and the knowledge they were able to get their hands on. They called me in to plan and facilitate a peer assist.

After calls with potential peers from the provider's operations in Washington and Oregon, we held the peer assist in Anchorage with the home team and eight visiting peers. The peers openly shared the lessons they learned from developing capital plans for long-term-care facilities in their regions. It was clear by early afternoon on the first day of the peer assist that their advice to the Alaska team was to reduce their capital plan by remodeling and repairing existing facilities.

The Alaska team insisted that their environment and customer needs were different from those in the northwestern United States and remodeling wouldn't provide the long-term care needed to attract, serve, and retain potential Alaskan customers. Later that afternoon (and planned as part of the session) the peers visited several long-term-care facilities. The experience made all the difference in the world. The visitors now understood the Alaskan context for long-term care and changed their advice. They felt new facilities were warranted in Alaska and spent the second day of the session developing new options and approaches for capital-plan submission with the home peers.

One of their recommendations was to perform a new survey of the aging population in the region. The peer from the Oregon provider operations had recently done something similar and offered a set of questions and a survey approach that were geared to providing design input for the development of long-term-care facilities. On the spot, the peers modified the design of the survey to address the Alaskan environment, native Alaskan culture, and other unique aspects of the aging customer base in that region.

The session led to a breakthrough in the Alaska team's thinking and capital plan. Not only was their plan approved, but the visiting peers benefited from the experience as well. An e-mail received by the Alaska team leader reinforced this: "Thank you again for the wonderful opportunity to work together last week. I really applaud your willingness to hear new ideas and your dedicated commitment to the people you serve. Kent, you taught us a new appreciation for the power of coming together to harness our collective knowledge to fulfill our mission. It was an enlightening two days for me, and I am very grateful for the experience."

Many of the peers who came together for those two days continue to communicate and collaborate on a routine basis.

Why It Works

A peer assist works because peers more readily share their knowledge with each other—and accept knowledge from each other—than through hierarchies or official channels, where politics and other issues often hamper free exchange. And they are more likely to tell the truth about problems they have encountered.

When the peer assist occurs is critical. People are more open and inclined to use knowledge they gain from others if they get it before they commit to a specific plan of action. Once we start down a certain path, it's hard to get ourselves to think differently. So the key to a successful peer assist is to convene the session after a team has exhausted what it already knows and created its plan, but before the start of actual work.

Peer assists are most successful when the participants have time to socialize and get to know and understand each other. This helps people open up and share their hard-earned expertise, especially the wisdom gained from painful experience.

When I was with British Petroleum (BP), our retail business wanted to enter the Japanese market. The international team responsible for creating the business in Japan hosted a peer assist to learn from other BP retailers before they implemented their plan to enter this new market. Peers came from all over the world to share their experience. The hosting team didn't want to spend much time on the process, but we convinced the leader that the session should take two days. On the first day, the home team showed the peers their proposed station sites, visited competitor sites, and shared their building plans and challenges. When they asked for the peers' input, the quality and amount of contributions were very low.

In side conversations and in private, however, they all said Japan had too mature a retail market for our typical new-entry approach. Plus, there was a "gas war" going on in that region. But nobody dared say openly that they thought the Japan team's approach was seriously flawed. After dinner that night, we went to karaoke bars then to a Japanese bath, where we all had to get naked, as is the tradition in Japan. The next morning, the feedback, storytelling, and sharing differed phenomenally from the day before. The peers honestly and openly shared their skepticism and their own tough experiences. As a result, the Japan team modified their plan in a matter of days and went on to an accelerated, successful entry into the market. I have no doubt that taking time to build relationships and trust during the peer assist enabled the participants to open up and share their knowledge truthfully.

Who Can Help You Learn

It's surprisingly easy to find people with relevant knowledge. One of the easiest and most effective methods is to tap your personal network to find who might have experience in the particular challenges you are facing. Even if the people you contact don't have relevant experience themselves, they will likely know "someone who knows" and may offer to connect you to them.

The other obvious approach is to search your company intranet for people with relevant skills and relevant experience. Better yet, if your organization has internal social networking sites, blogs, and wikis, these can be quickly and conveniently searched for potential peers. Similarly, you can contact people in relevant communities of practice, professional forums, and networks to ask for help or contacts. Sometimes it is helpful to involve people with diverse experience who can push boundaries and lead to innovative thinking in the session. In some organizations, teams announce their intent to do a peer assist by posting the subject and associated challenge on their company's intranet or electronic news facility. This enables people with relevant expertise to offer their help.

Engineering for Success

Based on my experience facilitating hundreds of peer assists, here are some critical things to do to ensure a successful outcome:

- Define the problem or opportunity that you are facing, and decide whether a peer assist is the most appropriate process.
- Write and disseminate a brief description of your need to peers, giving them the chance to self-select for participation.
- Look for diversity, that is, people who will help your team confront the problem from different perspectives.
- As soon as possible, identify people who can participate on your selected dates—fitting into their schedules is critical.
- Identify an experienced facilitator who understands the learning process.
- Design the event to ensure plenty of time to reflect.
- Allow the peer-assist team members time as a group during the session to analyze their findings.
- Ensure the key lessons and good practices shared during the session are captured. This may require some followup work to gather sufficient detail for

those who did not participate.
- Agree to a set of actions.
- Make your findings accessible to others outside the group.

Peer Assists in a Virtual World

One of the things that limits the application and impact of the peer assist is a team's ability to hold the session in a timely manner. Virtual meeting technologies can really make a difference. I have facilitated many virtual peer assists online using standard web-conferencing tools. Yes, it's tougher to socialize and build the respect and trust needed for open sharing and transfer. But what you lose by lack of face-to-face interaction you gain by making it feasible for peers to participate. More often than not, you are likely to get the right peers to participate because they don't have to travel.

Virtual peer assists are most effective when the challenge is specific and bounded. A good example is one I facilitated for an international oil company that was drilling their first high-pressure, high-temperature well in thirty years off the coast of Norway. The Norwegian government had set very high standards and extensive requirements for drilling in this deepwater environment, which included how the well was cased in cement to prevent gas blowouts and other operational risks.

The team was two months away from setting casing when they realized their plan for cementing the well was way beyond budget. To make up for their lack of local experience and knowledge about procuring and setting casing in such an extreme environment, they had over-engineered a solution that required a greater amount of cement to minimize risk. I was brought in to facilitate a peer assist targeted at optimizing the cement-casing job. After eight hours of phone calls and personal networking, the Norway engineers were able to identify seven engineers across their global operations who had relevant experience and could spend a few hours on short notice in a virtual peer-assist session.

They reviewed well schematics online and in downloaded form, and asked lots of questions. Although most of them never met or knew each other, in a two-hour session the peers shared enough cementing knowledge to significantly change the Norway plan, reducing costs by $2 million.

Not a Silver Bullet

The effectiveness of a peer-assist technique in transferring knowledge in real time from those who have it to those who need it has been demonstrated over and over again. But that doesn't mean it will always lead to improvements in performance. There are times when a peer assist is not really needed or the cost outweighs the benefits.

Also, transferring knowledge is one thing, and getting people to use it is another. Knowledge doesn't matter until the receivers apply it to make a difference. This is something I learned early on in my years applying this technique in BP. Recently, a lot of people have asked me, "If BP had such great knowledge-exchange techniques, how come they've screwed up so badly?" My simple answer is peer assists work, but they can't force people to use the knowledge they make available.

One thing I do to address this issue is try to get the home peers to agree in advance to allow me to do some follow-up facilitation to complete the knowledge-transfer process. Basically, this involves tracking their work after the peer assist is over and prompting and provoking them to apply the knowledge they gained from the visiting peers.

This article is based on the work and experiences of the author and the knowledge management team at BP from 1995 to 1999.

Bio

Kent A. Greenes is founder of Greenes Consulting. Previously, he was head of knowledge management for British Petroleum and chief knowledge officer of SAIC.

Kent Greenes

Rocket + Science = Dialogue

Issue 37, Winter 2010
By Bruce Morris, Greg Sullivan, and Martin Burkey

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

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

Ares V is part of NASA's Constellation program for resuming human exploration beyond low-Earth orbit, starting with missions to the moon. In the current mission scenario, Ares V launches a lunar lander into Earth orbit. A smaller Ares I rocket launches the Orion crew vehicle with up to four astronauts. Orion docks with the lander attached to the Ares V Earth-departure stage. The stage fires its engine to send the mated spacecraft to the moon. Standing 360 ft. high and weighing 7.4 million lbs., NASA's new heavy lifter will be bigger than the 1960s-era Saturn V. It can launch almost 60 percent more payload to translunar insertion together with the Ares I and 35 percent more mass to low-Earth orbit than the Saturn V. This super-sized capability is, in short, designed to send more people to more places to do more things than the six Apollo missions. That kind of heavy-lift capability, the Constellation program believes, would be a national asset potentially useful to endeavors other than human spaceflight.

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

Participants believe that both the venue and format of the meetings were important to their success. Worden's "weekend workshop" format had already proved successful and was adopted for these important summits: one for astronomy, another for planetary science. Scheduling a weekend meeting was probably the only way to quickly bring together busy key managers and scientists whose calendars are always full. And it guaranteed the commitment of attendees. "As Pete likes to say, only serious people come to a weekend workshop," said Dr. Stephanie Langhoff, Ames chief scientist and head of the organizing committee for both workshops.

Meeting of the Minds

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

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

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

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

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

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

The advantage of heavy lift was easily illustrated. The revolutionary Hubble Space Telescope's main light-gathering

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

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

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

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

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

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

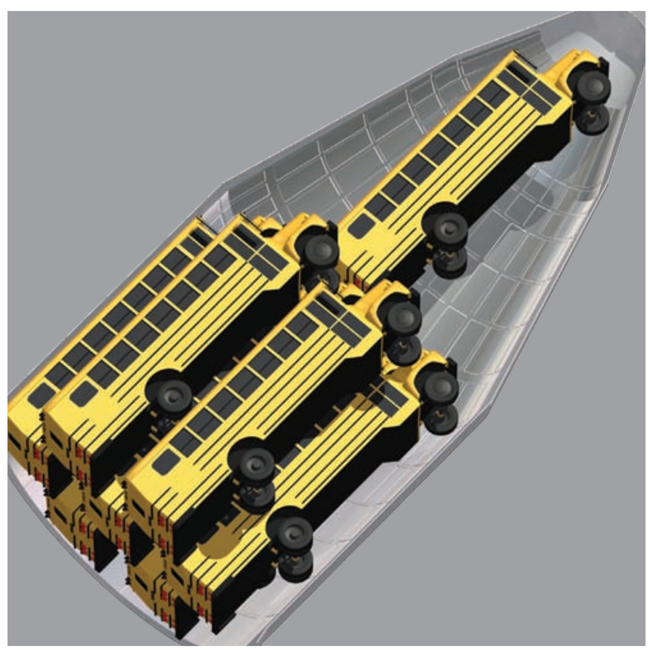
Dan Lester, an infrared astronomer with the University of Texas at Austin, could easily visualize that theory becoming reality with heavy-lift capability. His concept for an infrared telescope requires it to be folded like origami inside an existing launcher. Ares V would change that, he said.

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

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

Insights and Connections

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



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

The Ares V lifts off in this artist's illustration. Image Credit: NASA

telescopes.' I think we came away with just a little better understanding. I think it was really very fruitful."

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

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

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

"In some ways, it's serendipitous," Spilker mused. "Like anytime when you start a large project, it takes a while to wrap your arms around all the things that need to be done.

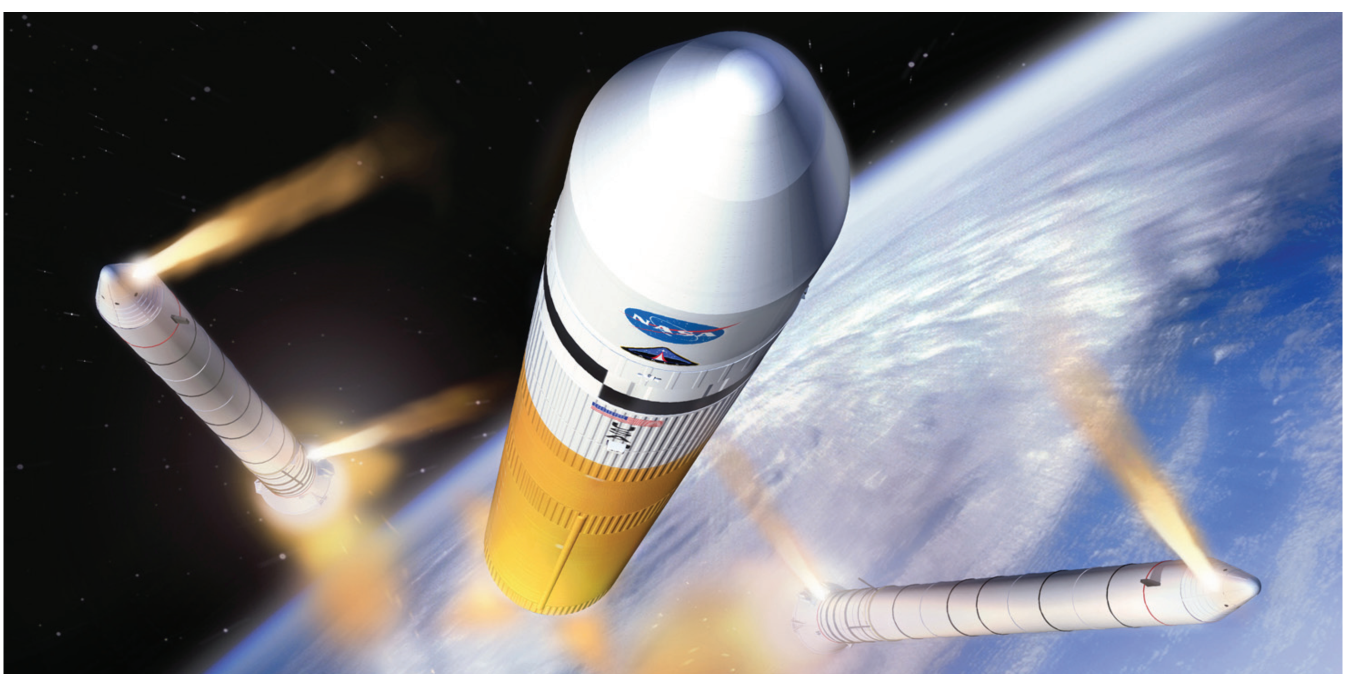


Illustration depicting booster separation from the Ares V. Image Credit: NASA

Rather than thirty minutes for presentations and five for discussion, there was more time for open-forum discussion. Then there was time for panel discussions and breakout groups to discuss in a less structured format various aspects. We had several breaks and lunches where we all stayed together. If you wanted to talk to somebody and didn't talk to them, it was probably your fault. "

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

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

Bios

Bruce Morris

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

Greg Sullivan

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

Martin Burkey

Martin Burkey supports NASA's Ares projects as a technical writer with the Schafer Corp.

Case Studies

Collaborative Problem-Solving: The STS-119 Flow Control Valve Issue

On November 14, 2008, as Space Shuttle Endeavor rocketed skyward on STS-126, flight controllers monitoring data during the ascent noted an unexpected hydrogen flow increase from one of the shuttle's main engines. The increased flow did not occur in response to an automated command from the system. Despite this in-flight anomaly, the launch proceeded smoothly—since three flow control valves (one per main engine) work in concert to maintain proper pressure in the hydrogen tank, one of the other valves reduced flow to compensate for the greater flow from the valve that malfunctioned. The likely causes of the malfunction were either an electrical failure or a mechanical failure, which might have resulted from a broken valve. This would require immediate attention as soon as STS-126 landed safely.

The challenge this problem would pose was a familiar one. To ensure the safety of future shuttle missions, management, along with the technical community, would need the best possible analysis to understand the causes of the failure and its implications for future missions. They would have to promote and ensure open communication among the multiple organizations involved in the shuttle program so that all relevant information would be available to decision makers with the responsibility to approve or delay future shuttle flights.

First Impressions

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

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

A Complex Assembly and Resupply Schedule

The shuttle program schedule had ten missions left before the planned end of the program in September 2010. These ten missions, which were tightly integrated with international ISS resupply launches by the Progress, ATV, and HTV vehicles and with crew exchange via Soyuz launches, represented a very complex manifest for the Shuttle and Station Programs. The next launch, STS-119, was scheduled for February 12, 2009. Its mission was to deliver to the final set of solar arrays needed to complete the International Space Station's (ISS) electricity-generating solar panels, and to enable the ISS to support its expanded crew of six.

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

Broken Valve

Since the flow control valves are part of the space shuttle Orbiter, discussions began at once between the

Orbiter project team and the Johnson Space Center (JSC) and Marshall Space Flight Center (MSFC) engineering organizations about whether to remove the valves from the Orbiter for inspection or to take an x-ray of them in place within the vehicle. The flow control valves involved organizations at JSC, home of the Orbiter Project and the JSC engineering organization, and MSFC, home of the Space Shuttle Main Engine and the Main Propulsion System engineering organizations. Dan Dumbacher, Director of Engineering at MSFC, said, "The flow control valve is in that interesting world of complex interfaces. It can influence what happens on the propulsion side of the equation, but yet it's owned and the responsibility for the hardware is all on the Orbiter side. Immediately you realize that you're going to have some complex interfaces between centers, between contractors, and all of the above." The cultural differences within these organizations helped shape their respective approaches to problem solving, which led to occasional differences of opinion about the best path forward.

An x-ray taken December 19 showed evidence of a problem with a poppet in the valve. Engineers removed the valve and shipped it to VACCO, the only vendor certified to disassemble it. VACCO shipped the disassembled valve to Boeing's Huntington Beach facility, where inspection determined that a fragment had broken off the poppet, the first time such a problem had occurred during flight. In 27 years, the shuttle program had never experienced a valve failure like this. There had been two similar failures in the early 1990s during testing of a new set of flow control valves for Endeavour, but the hardware had always performed as expected in flight. "We knew we had a pretty significant problem well outside our experience base at that point," said Orbiter Project Manager Steve Stich.

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

Struggling to Bound the Problem

Analysis of the cracked valve showed that the failure resulted from high-cycle fatigue (a condition in which a material sustains damage after experiencing numerous cycles of stress). This raised the question if STS-126 had presented an unusual environment, or if another valve was likely to break in flight due to fatigue-related damage. It also led to complex questions about likelihood and consequences. What was the likelihood of another broken valve? What would be the worst-case consequences of a break? Engineers needed to determine the probable size and the maximum size of a loose particle, understand how it would move through the propulsion system, and what the system could tolerate without experiencing a potentially catastrophic rupture in its lines.

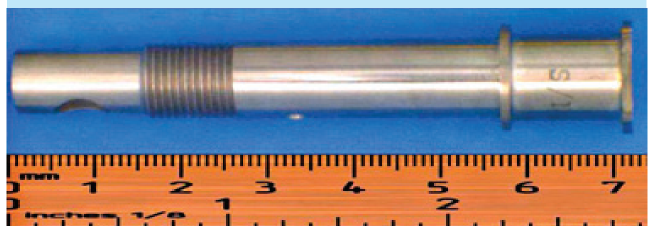
Searching for Cracks

Several teams worked on the problem from multiple angles, including materials, structural dynamics, computational fluid dynamics (CFD), and fracture mechanics. The initial efforts relied on visual inspection and a number of non-destructive evaluation (NDE) techniques, including dye penetrant inspection, magnetic particle inspection, and scanning electron microscope. Electron microscopy could only discover small cracks after the poppet was polished, however, and that polishing invalidated the flight certification of the hardware even as it provided greater ability to inspect it. "A polished poppet could upset the flow balance of the valve rendering it unusable for flow management. In this case the valve could get stuck in the high- or low-flow positions, which could cause a serious issue in flight," said Steve Stich. "In order to ensure that a polished poppet was properly balanced required testing on the flow test system that had been shut down at the White Sand Test Facility in the mid-1990s. So we were in a bit of Catch-22 situation with respect to performing the best possible NDE."

The Hydrogen Flow Control Valves

During ascent, the external tank provides the main engines with liquid oxygen and hydrogen propellant. As the engines consume the propellant, ullage volume forms (i.e., empty space opens up) within the external tank. To maintain the integrity of the tank, a small amount of the liquid hydrogen is tapped off of each engine's low pressure fuel turbo pump (LPFTP) in the gaseous state and is pumped back into the tank's ullage to maintain the correct pressure. The three flow control valves (one for each engine) regulate this flow of hydrogen gas moving from the engines to the tank.

Each valve has a poppet that resembles a tiny sprinkler head, which pops up and down regulating the flow of gas through the valve. The valves have two rates: high and low. During a launch they switch between the two rates approximately fifteen times.



GH2 flow control valve and poppet. (Source: NASA)

This meant it could only be used on non-flight hardware, such as an older configuration of the valve known as a -361 valve. Initially the scanning electron microscope inspections discovered no cracks in all eleven unpolished flight poppets and in all but one of the older -0361 poppets. "We felt like that was pretty good flight rationale in that the problem was not pervasive throughout the fleet" said Steve Stich. Around the same time, though, testing of a polished -361 valve did reveal cracks, raising questions about the value of the inspection technique for valves that would actually fly.

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

February 3, 2009: Flight Readiness Review #1

With the launch scheduled for February 19, the program scheduled a Flight Readiness Review for February 3. At the review, it quickly became clear that the engineering and safety organizations felt that significant work needed to be done before sound flight rationale could be established. Steve Altemus, Director of Engineering at Johnson Space Center, summarized the knowledge gap from the JSC engineering community's point of view: "We showed up at the first FRR and we're saying, 'We don't have a clear understanding of the flow environment, so therefore we can't tell you what the likelihood of having this poppet piece come off will be. We have to get a better handle on the consequences of a particle release.'" The most important outcome of the meeting was the establishment of new lines of inquiry that could lead to better understanding.
"At the end of that FRR, we laid out some criteria that I thought were important to understand before we went to 'go fly,' and left that with teams to go work," said Bill Gerstenmaier, who chaired the FRR in his role as Associate Administrator for Space Operations.

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

The Flight Readiness Review

As described in NASA Policy Directive 8610.24B, a Flight Readiness Review "is held to update the mission status, close out actions from the previously held LVRR [Launch Vehicle Readiness Review] and Customer MRR [Mission Readiness Review], and certify the readiness to proceed with initiation of the launch countdown." As the definition suggests, the FRR typically evaluates work done on issues identified at earlier reviews, and gives the teams responsible for various aspects of the mission an opportunity to make sure those technical questions have been adequately dealt with and to raise any additional concerns.

Impact Testing

After the first FRR, the Orbiter Project authorized three different lines of impact testing to learn more about whether a particle would puncture the pressurization lines downstream from the valve. At Glenn Research Center, testing focused on the material properties of the flight hardware and the impact of particles striking the material at a certain velocity and orientation, along with testing several Orbiter and ET components from the same material as in the actual gaseous hydrogen flight hardware. JSC Propulsion Systems Branch Chief Gene Grush traveled to Stennis Space Center to set up a test stand that fired particles through a full-scale mock-up of the propulsion system within the External Tank. Grush also coordinated efforts with White Sands Test Facility to run a similar test stand focusing on the Orbiter part of the system near the flow control valve exit.

The Orbiter analysis divided the Orbiter's Main Propulsion System into seventeen discrete areas that a particle would travel through and considered the type of material used and the thickness of the wall in each area. The data from these tests and other analyses contributed to a probabilistic risk assessment of the entire flow control valve hydrogen repress system.

At the same time, the computational fluid dynamics (CFD) analysts improved their characterizations of the environment inside the propulsion line, figuring out the velocity and spin of a given sized particle as well as the probable path it would travel through the elbow-joint turns in the pipe.

As data began to come in from these tests, the program decided to convene a second FRR on February 20, 2009. Prior to the meeting, some members of the engineering and safety organizations expressed doubts about the timing of the review. Chris Singer, Deputy Director of Engineering at Marshall Space Flight Center, told Steve Stich that the charts depicting the Orbiter Project's flight rationale did not bode well for the review.

Scott Johnson, Chief Safety and Mission Assurance Officer for the Shuttle, thought the review was premature. "The majority of the safety community was concerned about the amount of open work in front of us, and as a result I recommended that we delay the FRR," he said. "We were doing impact testing that was not complete and was not due to be complete until basically the day of the FRR. We still had a lot of the analysis work going on. We weren't really that close to being able to quantify the risks."

Senior leaders of the shuttle program and engineering teams had a meeting prior to the review with FRR board about what to expect. "We talked a lot about flow control valves," said Steve Altemus, "but what we didn't talk about were the agency-level constraints, and leveling risk across the programs and the international partners—what it really meant to delay flight past the Soyuz cutout versus taking this risk of flying with the potential to break this poppet."

Right before the second FRR, the engineering team learned about deficiencies in the processes used to inspect the poppets. Joyce Seriale-Grush, Orbiter Chief Engineer, said, "Before we went into the FRR, a few of us were pretty much of the opinion that we should stand down and take these valves off, refine our inspection processes further, and either put ones on that had been inspected with the new processes or re-inspect these."

FEBRUARY 20, 2009: FLIGHT READINESS REVIEW #2

The second FRR for STS-119, on February 20, 2009, was far from typical. The session lasted nearly fourteen long hours, and the outcome was not clear until the end. "It was much more of a technical review than typical Flight Readiness Reviews. There was lots of new data placed on the table that hadn't been fully vetted through the entire system. That made for the long meeting," said FRR chairman Bill Gerstenmaier.

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

Despite the tremendous amount of analysis and testing that had been done, technical presentations on the causes of the broken valve on STS-126 and the likelihood of that happening again were incomplete and inconclusive. Unlike at most FRRs, new data such as loads margins computations that couldn't be completed in advance streamed in during the review and informed the conversation. A chart reporting margins of safety included "TBD" (to be determined) notations. The Orbiter Gaseous hydrogen line summary chart displayed several areas where the worst-case loads margins exceeded the standard 1.4 factor of safety, which allows for material properties variations for components manufactured from different lots of material.

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

Ralph Roe, director of the NASA Engineering and Safety Center (NESC) and a longtime veteran of shuttle FRRs, noted how unusual this review proved to be:

"Usually the projects come to the flight readiness review with all their flight rationale worked out and you hear it and there may be a question or two. But in this particular case they obviously hadn't gotten to complete flight rationale yet so there was pretty enthusiastic debate. Different people had different opinions about what the data meant, and they were able to voice that in that forum, which was good."

NASA Chief Safety and Mission Assurance Officer Bryan O'Connor characterized the openness of the discussion as excellent. "Gerst [FRR chairman Bill Gerstenmaier] was absolutely open. He never tried to shut them [the participants] down. Even though he could probably tell this is going to take a long time, he never let the clock of the day appear to be something that he was worried about. I thought, that's bad in one way, it says we're probably going to have a long day, but it's good in another, and that says that you don't have the chairman of this panel putting undo pressure on people to sit down or be quiet," he said.

Toward the end of the meeting, Gerstenmaier, who had spent the day listening to presentations and eliciting comments, spoke about the risks of not approving Discovery's launch: risks to the International Space Station program and to the shuttle schedule. A few participants perceived Gerstenmaier's comments as pressure to approve the flight. Others saw it as appropriate context setting, making clear the broader issues that affect a launch decision. After he spoke, he gave the groups forty minutes to "caucus," to discuss what they had heard during the day and decide on their recommendations. When they came back, he polled the groups: "go" or "no-go."

THE PROCESS WORKS

When Gerstenmaier polled the room after the break, the engineering and safety organizations and some Center Directors in attendance made it clear that they did not find adequate flight rationale. Many felt there were too many uncertainties that the extensive, ongoing testing and analysis had not yet resolved. With no precise way of calculating the level of risk the flight faced, a launch decision could not be justified.

"As a community, we never really got our arms around the true risk," said Steve Altemus. "There were varying degrees of uncertainty in all the different pieces of analysis and test data that were out there, both in the likelihood of occurrence and the consequences of failure."

"One of the key tenets of flight rationale that most individuals and organizations were looking for was a maximum bound on the potential particle release size. This statement was repeated by many of the board members in the final discussion going around the table. This action had been in work for some time, but proved to be a difficult problem to solve. We knew this answer was important and would play hand in hand with the other elements of flight rationale especially in understanding the consequence and risk of release," said John McManamen.

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

Several participants thought it might have been better to break off the meeting and reconvene the following morning—it was unquestionably an over-long, exhausting day, and people would undoubtedly have felt sharper after a night's sleep. But no one thought that the outcome would have been different.

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

Moving Forward

With the launch postponed after the second FRR, Bill Gerstenmaier had doubts about the likelihood that the work could be completed in time to make the Soyuz cutoff date. His experience told him to reserve judgment. "Rather than me make the random decision to go move somewhat arbitrarily at this point based on the data we saw in the meeting and where I thought we would be, (I decided) I'm going to go ahead and kick it back to the team, give them the action, see what they can go do and see how it comes out," he said.

The testing and analysis continued on all fronts. In addition to the work at JSC, MSFC, Glenn, and White Sands, there were efforts across the country starting well before the second FRR. The Boeing facility in Huntington Beach, VACCO, the NASA Shuttle Logistics Depot (NSLD) in Florida, Pratt Whitney Rocketdyne, and Ames Research Center were all engaged, and experts from the NASA Engineering and Safety Center (NESC) provided support to the NASA engineering teams. At the peak, roughly one thousand people were working to solve the problem.

A New Inspection Tool

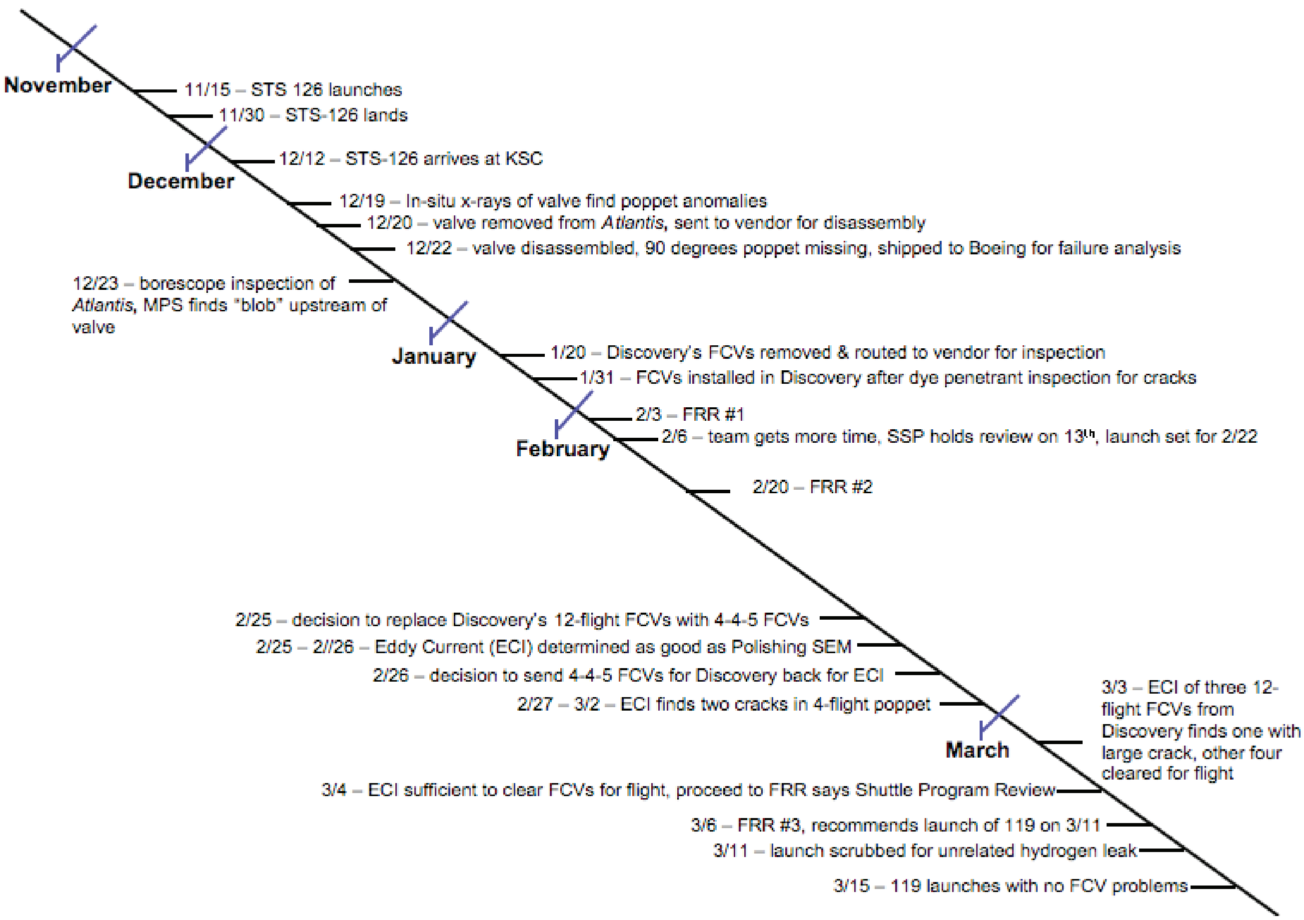
Early in the investigation, the eddy current inspection technique had been ruled out because the probe head was the wrong size for the job and because of magnetism concerns. Charles Bryson, an engineer at MSFC, used his eddy current probe equipment, with a relatively large probe head, to inspect a poppet sent to MSFC for fractography review from the Boeing facility at Huntington Beach. His inspection, as confirmed by fractography work, indicated that the eddy current inspection technique showed promise in finding flaws.

While at the FRR on Friday, February 20, Rene Ortega, Propulsion Systems Engineering and Integration Chief Engineer at MSFC, told colleagues from the Materials and Processes (M&P) Problem Resolution Team (PRT) about Bryson's inspection results and offered Bryson's expertise to inspect poppets at Boeing's facility. After a few phone calls, Ortega helped arrange for Bryson to examine several poppets at the Huntington Beach facility with his eddy current setup if he could fly out over the weekend. Bryson traveled and remained there refining the technique for several days. He then worked collaboratively with a team from JSC led by Ajay Koshti, a non-destructive evaluation (NDE) specialist with expertise in eddy current investigations. Koshti brought an eddy current setup with a better response than Bryson's, and together using the more suitable setup, they arrived at a consistent inspection technique.

Ortega explained how the new eddy current technique supplied a missing piece of the puzzle. "Once we were able to screen flaws with the eddy current and there wasn't a need to polish poppets with that process, then we had a method by which we could say that we had a certain size indication that we thought we're pretty good at screening for non-polished poppets."

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

Steve Altemus thought Koshti's efforts exemplified the engineering curiosity that NASA needs to succeed, and he viewed it as an engineering leadership responsibility to create an environment in which new and diverse ideas could receive a fair hearing. "It's important to recognize that we're not always the smartest one in the room, that perhaps there's somebody over there in the corner of the room, and that we have to pull out of them what their thoughts are, because they've got the answer. He had the answer."



Timeline of key events and developments.

MARCH 6, 2009: FLIGHT READINESS REVIEW #3

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

"By the time we eventually all got together on the last FRR the comfort level was very high," said Bryan O'Connor. "For one thing, everybody understood this topic so well. You couldn't say, 'I'm uncomfortable because I don't understand.' We had a great deal of understanding of not only what we knew about, but also what we didn't know about. We had a good understanding of the limits of our knowledge as much as possible, whereas before we didn't know what those were." Steve Stich summarized the progress that had been made. "By the third FRR, there was no new test data or analysis coming in late. We had better characterized the risk of damage in the Orbiter and ET due to a poppet fragment through our impact testing and stress analysis. We had better characterized the worst case even if the poppet fragment ruptured the line, along with what hole sizes would be required to cause enough hydrogen to meet the flammability limits in the ET and in the orbiter. Overall, we had a much better characterization of the risk by the time we got to that third and final FRR. Plus, we were able to use this new eddy current technique to say with more certainty that the poppets did not have any significant cracks prior to launch. Even though we didn't have total root cause, we knew we weren't starting with large cracks. We had also begun some materials testing at Marshall that showed it was very unlikely to grow a crack from a very small size to failure in one flight. So we ended up having extremely good rationale for that third FRR."

The Flight Readiness Review Board agreed, and at the third and final FRR, STS-119 was approved to launch on March 11, 2009.

EPILOGUE

After delays due to an unrelated leak in a liquid hydrogen vent line between the shuttle and the external tank, STS-119 lifted off on March 15, 2009.

Two months after the completion of the mission, Bill Gerstenmaier spoke to students at Massachusetts Institute of Technology (MIT) about the flow control valve issue. In an email to Shuttle team members, he shared a video of the lecture and wrote, "I am in continue to learn mode. There is always room to improve."

LCROSS

LRO Plus One

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 go to the moon. The Atlas V offered more capacity than LRO needed, creating space for a secondary payload.

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 1000 kilograms (kg), it could not go over a $79 million cost cap, and it had to be ready to fly on LRO's schedule. Of the 19 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.

Ames Research Center served as the lead center for LCROSS. Dan Andrews, the 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 29 months and $79 million to build a Class D mission spacecraft. (See below for a brief explanation of NASA mission risk classifications.) 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 it 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. Unlike a Class A mission, LCROSS did not have the luxury of "buying down" all risks with its budget.

Class D Mission

"Class D" refers to NASA's mission risk classification system as described in NASA Procedural Requirements (NPR) 8705.4. All NASA missions are assigned a risk classification ranging from Class A ("All practical measures are taken to achieve minimum risk to mission success.") to Class D ("Medium or significant risk of not achieving mission success is permitted."). Class D missions like LCROSS have low-to-medium national significance, low-to-medium complexity, low cost, and a mission lifetime of less than two years.

"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 Dan Andrews.

LCROSS consisted of a Shepherding Spacecraft (SSC) and a Centaur upper stage rocket. The SSC included a fuel tank surrounded by a repurposed EELV (Evolved Expendable Launch Vehicle) Secondary Payload Adaptor, also known as an ESPA ring. The ESPA ring was conceived by the Air Force Research Laboratory as a small satellite deployment system, but it had never been flown on a NASA mission or as a spacecraft bus. It has six bays that could hold up to six small satellites, but on LCROSS, those bays held the principal subsystems of the spacecraft. (See Figure 1.) This novel use of the ESPA ring offered a number of advantages. It was already tested, developed, and very sturdy, facilitating flexible, low-risk integration with the LRO mission on the "back" of LCROSS.

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THE TEAM

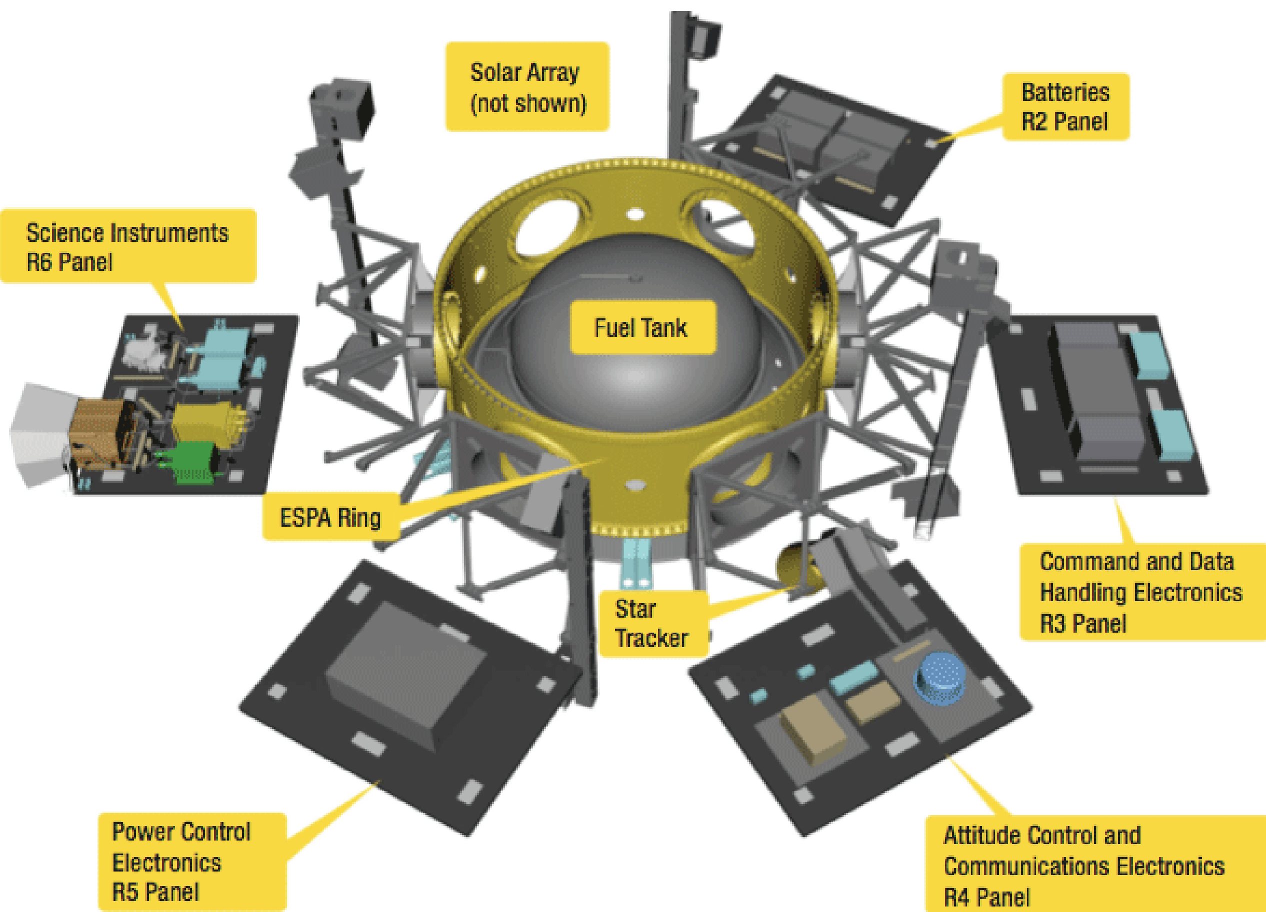
Andrews knew he had to establish trust with both the LRO team and Northrop Grumman (NG), the contractor building the spacecraft.

The LRO team, which was based at the Goddard Space Flight Center (GSFC), was understandably cautious about LCROSS hitching a ride with them to the moon. Andrews quickly moved to identify an LCROSS engineer to take up residence with the LRO team to facilitate quick dialogue and build trust between the two missions, which worked perfectly. With good lines of communication and the crossover of hardware, the two teams started to view each other as resources and "work[ed] 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."

Given the tight schedule and limited budget, the partnership with NG was also essential. Neither Andrews nor NG Project Manager Steve Carman had ever managed a spacecraft development before, though both had run space flight 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.

Andrews noted that the key was to find common purpose between NASA and NG, so that we are collectively and individually interested in seeing this mission be successful while meeting the challenging cost cap. Carman, who had spent his career managing payload development projects, had a different vantage point. "This spacecraft was big compared to what I was used to building," he said.

Over the first six months, as the project underwent a number of contractual changes related to acquisition means, 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 was something that grew



The LCROSS spacecraft employed a novel use of an ESPA ring. Image Credit: Northrop Grumman out of a relationship, and we began to see we could see how you could gain insight into how we were operating. We showed them as we went along that we were indeed capable of doing this faster than anything we had done here."

For Dan Andrews, the trust grew out of a shared understanding of the way that both organizations traditionally operated. "We talked plainly about budgets. We talked plainly about the NASA construct, and then they 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 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 Bob Barber. "We wanted a really open and honest relationship with them." NASA team members took part in NG's risk management boards and were welcome to attend staff meetings.

The relationships didn't end when people left the project. Both NASA and NG experienced turnover, which could have hurt the project dramatically. 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. "There was a friendship and a professionalism that was there. I've worked on projects that when guys leave you can't get information out of them to save your life."

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. "Basically I said, 'I think you've got some contingency in your schedule. I know you think you need every minute of it, but I'll bet you can move faster," Carman said. "As they went along, we kept finding ways to improve the schedule."

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. "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.

Expediting the Review Process

The LCROSS schedule wouldn't allow time for a lengthy review process throughout the life cycle. Andrews and Carman 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 that he would give a short quiz at the beginning of the reviews to determine which stakeholders had done their pre-meeting reading and study. The point of this dialogue was to reinforce that the reviews are not there to educate the stakeholders, but to derive value from their expertise. The project team would happily discuss and questions, but it was not their job to educate an unprepared reviewer.

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 Jay 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 even bigger.

LCROSS held monthly risk management boards, increasing the frequency to biweekly if necessary. The meetings were painful but essential. "No one was having fun, but everyone there knew that this was a very necessary thing," said Dan Andrews.

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

The capacitor was already built into a box that had passed all of its testing and was performing fine. The problem was that the location of the capacitor did not enable remote viewing of its condition. 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 test 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. The capacitor was performing fine, and the project's top risk was retired.

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

Low on Fuel

Fires lit and smoke pluming, the Atlas V launched LCROSS to the moon on Tuesday, June 18, 2009. One hour after launch, LRO, sitting at the top of the stack, 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 (DSN). Data from 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. This led to a chain of actions, resulting in the spacecraft's thrusters firing propellant almost continuously. The operations team noticed this once the spacecraft was back in contact with the DSN. Engineers quickly identified a probable root cause and other contributing factors. Immediate steps were taken to stop the thrusters from continuing to fire and to prevent a similar occurrence again. The team also adopted new ultra-low fuel consumption means to conserve propellant until the lunar impact. While there was no precise way to measure what remained in the tank, analysis showed that LCROSS had expended 150 kg of its 200 kg of propellant. The specific cause of the anomalous data fault remained unresolved, but the engineering teams determined that even under worst-case conditions, the spacecraft still had minimally enough propellant to achieve full mission success.

Smashing Success

LCROSS journeyed for another six weeks before lining up on its collision course with the moon. Once in position, the Centaur rocket separated from the SSC and barreled down on the moon's Cabeus crater, where it crashed at twice the speed of a bullet. Following minutes behind the Centaur, the SSC took pictures, flying through the vapor cloud created by the LCROSS impacter, analyzing the debris, and sending the data back to Earth before it too smashed into what turned-out to be a very soft, porous crater floor. The whole sequence lasted a mere four minutes and nineteen seconds, going off without a hitch.

Interviews

Interview with Robert Braun

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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 of 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 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

Robert Braun

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. 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 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.

Interview with William Gerstenmaier

ASK Magazine, Issue 38, Spring 2010
By Don Cohen

William Gerstenmaier is NASA's Associate Administrator for Space Operations. In that capacity, he directs the agency's human space exploration and oversees programs including the International Space Station and Space Shuttle. Don Cohen spoke with him at NASA Headquarters in Washington, D.C.

Cohen: Let's talk about your responsibilities and the kind of guidance you got at the beginning of your NASA career.

Gerstenmaier: I came to NASA, to Lewis [now Glenn Research Center], in 1977 directly out of school. I was assigned a couple of mentors to work with. For me it was a great time because the folks who wrote my aerodynamics textbooks in college were the folks I was working with. Because of significant cutbacks, there hadn't been many new people hired, so they all treated me like their kid and would spend time to educate me on what was going on and help me understand what I didn't quite understand in school—I could pass the test but I couldn't quite do the real work.

They assigned me to start doing wind-tunnel tests right away. I had just come out of college and now I'm in

William Gerstenmaier

charge of a multimillion-dollar test facility, with maybe seven technicians. For two nights I sat with someone else watching them do tunnel activities, then I was on my own. It was a tremendous responsibility, but a tremendously nurturing environment. I couldn't think of a greater place to start my career. The folks wanted to make sure I really understood; they really challenged me. They gave me top-notch tough jobs to do and let me work as hard as I wanted to. Also, being in testing was very good. When you put something in the wind tunnel, you did your own analysis, putting the probe in if you're going to measure the flow behind the model, for example. You had to do your own stress calculations, your own safety report. That was a scary experience because if this little probe breaks off and goes into the turbine at the end of the tunnel, I'll have caused a multimillion-dollar mishap. I would do all the calculations, then I'd find three or four engineers who had done this before and say, "Would you make sure that I really did this right because I don't want to mess something up?" I had lots of responsibility, yet I could really learn. So I gained a ton of firsthand experience, a lot of detailed engineering stuff, and even management skills, managing these technicians in the evenings when we were running the tunnel, keeping people on schedule, keeping things moving.

Cohen: Do recent NASA hires have anything like that kind of opportunity?

Gerstenmaier: Today, we have to contract out, and things are a little bit slower. At Lewis we had a fabrication shop, where we made wind-tunnel models, and an instrumentation shop, all run by civil servants. I didn't have to contract out to procure a piece. I could do a design on my desk, take it to the machine shop, have it machined that afternoon, and have it in the wind tunnel that night. In operations today, new engineers can go in the control center; they can learn from experienced people and get the same nurturing that I was able to get. NASA still gives us a pretty good chance to learn. I think the test environment is a great place to start because you get a lot of hands-on experience. In school you get the academics, you understand the theory, the calculations; you understand how to run the computer code. When you're actually doing the testing, you get to see how it works in the real world.

Cohen: Did you get mentoring in management as well as technical mentoring?

Gerstenmaier: At the research center, the focus was on technical excellence. Managing and project management skills at that time were not stressed. We were pushing the state of the art of technology; we were writing peer-reviewed papers. The things that were really valued were technical excellence and the research side. I had a new employee individual development plan, much like we do today. Each year I got reviewed to make sure I was moving forward. I think what was even more valuable than the plan was the fact that the personnel there took an unbelievable amount of time to help me learn.

Cohen: What came next in your career?

Gerstenmaier: In 1980, I got called by Steve Bales at the Johnson Space Center. They wanted someone with propulsion experience, which I had from Cleveland. I went down to Houston and sat on console for the first roughly sixteen shuttle flights. I was in the back room for the first shuttle flight, STS-1.

Cohen: What was the environment like there, compared with Lewis?

Gerstenmaier: Very different. Johnson was very competitive; people competed to get on console in a certain position. Growing and learning happened, but you had to do it yourself. I was in a very competitive group, the propulsion group. I tried to pick areas other people didn't like, so I worked in the thermal area, the electrical area, and computer software. I got to write a lot of the detailed test objectives that were done on the early shuttle program to show how the shuttle performs in various attitudes, pointing at the sun, getting hot and cold. I also got to understand how the software works to control thrusters and guidance, navigation, and control. I did rendezvous procedures. I learned a ton in Houston, but it was a different kind of learning. You had to be more of a self-starter. It was a competitive environment that forced me to be at the top of my game and keep pushing my ability to perform, execute, and deliver to new levels. Then I became a section head in '84 or '85, in charge of the payload section. We were responsible for all the payloads that were deployed by the shuttle arm. The Hubble Space Telescope, the Spartan payloads were managed by our section. That was a hard transition, to go from the technical world to the management world. Frankly, it's even uncomfortable for me today. I still very much like the technical stuff, understanding the detail of how things work. The softer people-management skills are mandatory and critical in my job now, but my passion is still the technical piece. Then I got assigned to a project called the Orbital Maneuvering Vehicle project, which was to be a space tug that would grab things out of geosynchronous orbit and bring them down for servicing. It was a chance for me to set up an entire operations organization from scratch. That was a tremendous organizational-management experience. That then got canceled.

Cohen: I'd like to hear about your space station experience.

Gerstenmaier: Initially, it was going to be assembled totally on orbit. The truss was so long you couldn't fly it up in pieces. That approach got canceled. Then we found out because we had shrunk the truss size so much, we could fly it up in preintegrated pieces. We could build trailer-size pieces and plug them together. I was in charge of the group that laid out all the operations concepts and processes to build the station.

Cohen: This was before the Russian involvement?

Gerstenmaier: In 1992, I left NASA to work on a PhD. That's when they brought the Russians in and space station went through another redesign effort to bring in the international partners. When I came back to NASA, the propulsion systems were gone; they're given to the Russians. Some of the attitude control systems were given to the Russians, with U.S. [responsible for] control-moment gyros; some of the life-support systems were given to the Russians. But the basic concept was there; 90 percent of the station was still the same.

Cohen: How did you learn to work with the Russians?

Gerstenmaier: I went to Russia in '95 and '96, when Shannon Lucid was on Mir. I was her ground person. I was the first American to go to Russia as an ops lead in charge of her science program and stay there for an extended period of time. Prior to that, folks would come for a couple of weeks, then they would go back to the U.S. and another person would come. I was the first person that stayed the entire time (approximately six months). And because I had background on shuttle and station and propulsion, I wasn't the typical science person that's fresh out of school. I actually had a lot of experience in short-duration spaceflight that the Russians were not used to seeing. I had to negotiate the contract with the Russians for the program I was going to have to implement—phase 1 operations.

Cohen: Was that a hard negotiation?

Gerstenmaier: It was tremendously hard, but it was good because I knew what was possible and what wasn't. I got requests from the U.S. and NASA to negotiate things that were physically not possible, like more communication time than was available because of the satellites and ground stations they have. We could never achieve that capability. So I immediately took those things out. The Russians had never seen anyone who would just drop stuff because it's not technically feasible. They weren't used to having someone on the other side of the table who was knowledgeable enough. It was a hard negotiation, but it was good. I got accepted into their control center just like a Russian flight controller.

I established a relationship with the Russians. They'd be doing a telecon with the Americans and I would be sitting in the back of the room while the Americans were negotiating a position with the Russians. And they would go to me and say, "This is crazy. You know we can't do this." I actually got to see what a NASA-American looks like to a Russian through their cultural eyes. Later I became deputy program manager for space station, working with the same Russians. I know these folks personally; I've worked with them; I lived in their country. They know me. I know their culture.

Cohen: Do you think it should be a rule of international cooperation that someone actually be there?

Gerstenmaier: I don't know that it's mandatory, but you really have to have that cultural appreciation because the cultures are so different. You either need to be very intuitive and perceptive and be able to accept and understand those differences or you have to have some experience.

Cohen: Are there lessons from space station that NASA needs to take to heart?

Gerstenmaier: Cooperation will be important in the future. Because of the cost and complexity of space missions, it's difficult for any nation to do them alone. During Apollo, we got to the moon a lot faster because our goal was to beat the Russians and show our prowess. Station is very different, a cooperative activity. I think cooperation will have much-longer-lasting results, but it may take longer to achieve your goals. Having the Russians around after Columbia, when we had no ability to transport our own crew to the station, kept our crews on station. And the Russians learn a lot from us.

Cohen: For instance?

Gerstenmaier: During their spacewalks they typically wouldn't work during the night passes because they didn't have lights on their spacesuits. They were able to adapt their spacesuits to use our lights. We also carry a helmet camera so we can see what the astronauts are doing. We've adapted our helmet camera to work on Russian spacesuits so now they use our lights and our cameras on spacewalks. We use a lot of Russian wire ties: those little copper things that tie down cables. We have a body-restraint tether which holds the spacesuit fixed in one position. The Russians are using that now. So there's been a tremendous amount of learning on both sides. I think that's the wave of the future.

Cohen: The space station lessons you describe are all examples of people seeing something in action, not reading a report about it.

Gerstenmaier: I think internationally that works better. The cultures are so different that if I just gave them a report, they wouldn't understand it with the same cultural mind-set that I have. But when you physically see it work, you see it through your own cultural lens and your own activity so adaptation and absorption are quicker. In diverse cultural environments, demonstrating a capability is more effective than academic proof that a concept or a device works.

Cohen: Maybe the same holds true between NASA centers and NASA and contractors, which are somewhat different culturally.

Gerstenmaier: I agree, because we all carry our own biases based on our own experiences. But if something is demonstrated to you and you can perceive it through your own lenses and filters, you can judge for yourself whether it's valuable or not.

Also, dependence drives learning: I need you to do this component because I don't have the resources to do it. That builds a much stronger tie. If you have your own capability and they have their own capability, you can cooperate in space but not really get that learning. Before Columbia occurred, we used to test our own air and water samples on station and the Russians did theirs. Russian and American air and water specialists didn't have to interact. When we lost Columbia, we had no way to return our samples. We had to bring our specialists to Russia to see how they analyzed air and water. That forced a deeper cooperation than would have been there if we were not interdependent. So when you think about doing a project, where you choose somebody to be in the critical path or where you're going to be dependent upon them needs to be a very strong strategic decision because that will drive learning and technology. You should consciously think about where you put those dependencies in. It's not appropriate for you both to have full capability. That's essentially two programs running in parallel, which is not effective.

Cohen: From what you're describing, it sounds like you need trust to work together, but trust comes from working together.

Gerstenmaier: We had almost ten years of working with the Russians before Columbia. When Columbia occurred, we were going to have to use the Soyuz on a routine basis. But you couldn't immediately have gone to that dependence and interaction without some lower-level, non-risky interaction that built confidence before the crisis. You almost have to stage the relationship such that you learn and gain this trust. Now we have a very strong relationship with the Russians. We do [also] with the Europeans, the Japanese, and the Canadians. We can use the space station partnership to leverage even more challenging, more dependent things for exploration as we think about going beyond low-Earth orbit.

Cohen: The process you describe— working together to develop trust, facing crises that will make or break the relationships—sounds a lot like marriage.

Gerstenmaier: I think that's life in general. In a very stressful situation, that external stimulus either drives you closer together as a team or you splinter apart. The key is to figure out what drives people together—people in combat situations, people in extremely stressful situations—what builds team cohesion under challenges, because the challenges will come. How do you as a program/ project manager think about how to build this underlying environment such that when the stress comes the team actually gets driven together?

Cohen: We're talking a few days before the new NASA budget is announced. What do you think some of the challenges posed by the new budget will be?

Gerstenmaier: What I've learned throughout my NASA career is that, as a program/project manager, you have to have some streak of optimism or you would have quit a long time ago. You've got this impossible schedule: you're given three years to build something. You can never plan a project totally and understand all the details, so there has to be something in you that's eternally optimistic. They talk about it as "realistic optimism." Another thing I learned from the Russians: they always have the goal in mind. They may take the most circuitous route to that goal you could ever imagine, but they are 100 percent focused on that goal. They are going to get there no matter what. So, back to NASA: I don't know exactly what is going to come, but I have an optimism that we're going to do something very productive in the future, pushing technology, giving challenges to students to learn science, technology, engineering, and math. I think NASA can provide that excitement for students. What specific things we'll be working on, I don't know at this point. We're blessed in this country; we're given a pretty good portion of the budget. Even though it's only seven-tenths of a percent, it's still big compared to what other countries get. We have the ability to do a lot of technology and explore and work with industry. I think we've got enough tools so that when we're given whatever the plan is, we'll figure out a way to craft a program that will be exciting and innovative and invigorating for students and other folks in the future. I don't know the specifics, but I've been through a lot in my thirty years with NASA. If you roll with the punches and deal with what you've got, you can make some amazing things.

Cohen: Do you think the NASA spirit has been essentially the same over all those years?

Gerstenmaier: I think so. Look at station. Station is a miracle. At those first reviews, when we were looking at building the truss in space, I said, "This thing is never going to get built." Then we got directed to go preintegrated truss and figured out how to do that. Then we're adding the Russians; they're taking away all these critical systems. That should be the end of the world; that's never going to work. But now we've got 850,000 lbs. in low-Earth orbit with all these international partners; we've got control centers in Japan, in Russia, Europe, and Canada all supporting space station. Looking forward, I'd say it's going to look momentarily tough, but if you just keep chugging away with that perseverance and that little bit of optimism, it's amazing what these teams can do at NASA. The folks here are phenomenal. We had the external tank problem—6,000 dings on the tank— and they came to me and told me they wanted to repair this tank, I thought, "No way," but I saw that spirit in their hearts. They said, "We can do this." Lo and behold, they got this tank ready to fly and it worked out extremely well. I see that same thing now. We'll be given something that looks impossible; that's okay. Dissect it, parse it down into small pieces, and we'll make something out of what we get. It's a good time.

Five Questions for Wayne Hale

ASK the Academy, July 30, 2010 — Vol. 3, Issue 7

On the eve of his retirement, former space shuttle program manager Wayne Hale looks back on a storied career at NASA.

Since March 2008, Wayne Hale has been the deputy associate administrator for strategic partnerships, responsible for coordinating interagency and intergovernmental partnerships for the Space Mission Operations Directorate at NASA Headquarters. He announced his retirement from NASA effective at the end of July 2010.

Hale began his career with NASA in 1978 as a propulsion officer at the Johnson Space Center, and later became a flight director in Mission Control for 41 space shuttle missions. He held numerous roles in the space shuttle program, including launch integration manager, deputy program manager, and program manager. He has received many honors and awards, including the NASA Space Flight Awareness Leadership Award, the NASA Outstanding Leadership Medal, the NASA Exceptional Service Medal, and numerous NASA Group Achievement Awards.

Wayne Hale in Houston's Mission Control Center prior to the launch of STS-92. Credit: NASA

Wayne Hale (center) with LeRoy Cain (left) and Jeffrey Bantle (right) waiting for the launch of STS-106 in 2000. Credit: NASA

ASK the Academy: Throughout your career you worked in the shuttle program at just about every conceivable level, from propulsion engineer to flight director to program manager. Which jobs presented the steepest learning curves, and what did you do to get up to speed?

Wayne Hale: The first job that I had coming in as a "fresh-out" from college — trying to learn how to be a flight controller, trying to learn about the space shuttle and its systems, particularly its propulsion system — was a big challenge to me because it was unlike anything I'd ever done academically or with any other part of my career. It's a special culture, a special mindset. You take your engineering background, but you have to put it to use in ways that are completely different in operation than what they teach you in the university.

Fortunately, I was mentored quite a bit by some of the Apollo veterans who were still there in the group in the early days before shuttle. They helped teach us not just the facts, figures, and technical items, but how to think, how to make decisions, and how to communicate those decisions. That was a big change.

I got to be Flight Director, and going from being a person in Mission Control sitting in one of the consoles being responsible for one discipline, to being a Flight Director where you have to understand all 23 different disciplines that are present in the Shuttle Flight Control Room was also a big step. It was like going back to school again. There was so much technical (knowledge), so much rationale behind why things are done the way they're done. It's a huge amount of knowledge you have to amass to be able just to ask the right questions to lead the team toward having a safe and successful shuttle flight.

Then when I made the transition to the Space Shuttle Program Office, first as Launch Integration Manager, then Deputy Program Manager and finally Program Manager, I found out that there were gaping holes in my knowledge base and background, in particular regarding contracts, law, business, accounting, budgeting. All of these were things that for 20 or so years of working for NASA, I had never had to deal with. I had to learn about all of those things in very short order.

So each one of those jobs presented a different challenge, and the only way I know to get through any of those is the same thing that I've done every step of the way, which is to buckle down, and you talk to people who know how to do what you're attempting to do. You get a list of subject matter that you need to study, and you just roll up your sleeves and get after it. And of course you watch the people who are doing it, who are experts, and you ask a lot of questions. At some point you get to spread your wings and see how you can do, and sometimes you soar with the eagles, and sometimes you crash. That's part of the learning experience too.

ATA: You mentioned that you had mentors early on. Who were your mentors? Did you have different mentors at different stages of your career?

WH: I absolutely had different mentors at different stages. At the end game when I was in the program office, having never been in a program office before, Bill Parsons was a great mentor to me. He was the Program Manager. He taught me a tremendous amount about running a big program, about the things I didn't know, the things that I needed to learn. I also learned a lot from Lucy Kranz, who was our procurement/business office manager. In all those parts of my education that were blanks, she helped fill in. A large part of what I know about federal acquisition regulations, contracts, procurement, and how to do budgets comes from Lucy Kranz, who continues to do great work on different programs for the agency.

When I worked in the Flight Directors Office, the boss was Tommy Holloway, who was a master Flight Director. I also learned from some of those who had preceded me, like Chuck Shaw and Ron Dittemore. They were all great mentors to me. Going back to right when I walked in the door, there were several Apollo veterans who were ready, willing, and able to teach young graduates what it meant to work in Mission Control, and what sort of things you needed to prepare yourself for. And of course Gene Kranz was in charge of the organization in those days, and you learned a lot at what we used to call the Gene Kranz School for Boys. He taught us in no uncertain terms what was expected.

ATA: Nearly a year after the Columbia accident, when you were serving as Shuttle Deputy Program Manager, you wrote your team an email (which you reprinted in your blog) that said, "...we dropped the torch through our complacency, our arrogance, self-assurance, sheer stupidity, and through continuing attempts to please everyone." Do you have any thoughts on how large organizations can keep their edge and continue to improve even when they succeed?

WH: The best advice I ever got — Tommy Holloway told us over and over, "You're never as smart as you think you are." If you ever get to the point where you think you've got it under control, you really don't, and you need to be always hungry and looking out for the indications that things aren't going well. It's a difficult thing in a big organization to keep that edge, and it's particularly difficult when things are going well. The shuttle had had a long run of success. I think we flew 87 flights that were all successful in a row.

In particular, the political leadership in charge expected us to do more with less. They kept telling us that the space flight was routine and mature, and that we had solved all the major problems and just needed to not slip up on little things, and that it ought to be easier and faster and less expensive.

The truth of the matter is that with the current state of the art, space flight is extremely difficult. It is fraught with danger because of the high speeds and extreme environments involved. It requires extraordinarily close calculations on the amount of material and the physical structure of the space ship, because mass is at a premium in everything we do.

After a while of getting it drummed into your head that, "This is not as hard as you think it is. This is mature technology and a mature vehicle with large margins. We know what we're doing." Even though deep down in your heart you know that's not true, you begin to fall into that trap. I've seen that happen in other industries and other organizations that have had a long run of success. The fact of the matter is that particularly in space flight, you cannot let yourself get arrogant. You cannot think that you've got everything under control. You've got to be vigilant. I think that's true for any kind of high-risk, high-technology kind of endeavor, though it may be true in other fields as well.

A lot of us wish space flight were easier. I do. I wish it were easier and less costly. I wish it were like getting in your car and driving to the grocery store. But it's not there. There are many things in the media where people profess that it is easy, that it should be simple and cheap, and that somehow those folks who are currently in the field have not done a good job, and therefore it's costly and looks hard. I just don't believe that to be true. I believe it's a very difficult thing to do that requires a great deal of dedication and precision. And unfortunately it's not inexpensive at this point in history.

ATA: What are you most proud of from your tenure as shuttle program manager?

WH: The thing that I am most proud of is building a team that has been as successful as it has been in the last five years after we returned the shuttle to flight. Things have been going very well. Being basically I'm a worrier, I worry about things when they're going well, but the team is doing very well because I think they are paying attention to the fundamentals and looking very hard at the symptoms of things that are not going as well as one might wish. So I'm very proud of the team and the culture change that we brought about. You would think that returning the shuttle to flight would be at the top of the list, and it is in some ways, but the thing I'm most proud of is building the team that has been able to carry on and be so successful.

ATA: You mentioned the culture change. I'd like to get your perspective on what it was and what it became.

WH: Again, the culture change had to do with a mindset, an arrogant mindset that basically said, "We have been doing this for so long so well that we know what we're doing. We have got this difficult subject, this difficult environment under control, and we know we can get by with cutting corners because we know there's a lot of margin in the system." The culture change was to take a step back and say, "No, we really don't know." To go back to what Mr. Holloway taught me, we're not as smart as we think we are. This is a very difficult thing to do. The margins everywhere are very small. It's not ordinary, routine, or mature. And therefore we have to take great care with what we do.

And oh, by the way, our political overseers had kept cutting our budget to where we had emaciated our safety and engineering systems. We had to go back and tell them that that just would not do if we intended to fly this vehicle safely. It was going to take the resources to provide the proper oversight and insight, and we were able to convince them of that. And so it goes. I think that was a huge culture change, both for those of us that worked in the program and for those who were outside the program and in positions to make decisions about national resources.

ATA: In your blog, you've shared a lot of "stories from the trenches" of the shuttle program that had not previously seen the light of day. In your first post, you said you wanted to start a conversation. Did the purpose of the blog change over time for you?

WH: The purpose of the blog was outreach, to tell people a little bit about what it takes to fly human beings in space and run a big program, and (share) a little bit of "behind the curtain" of what goes on inside NASA, because I think people are interested. So much of what we at NASA put is what somebody once termed "tight-lipped and technical." Not very interesting, very arcane. This is a human endeavor, and there are people involved in it. The things that happen show us to be frail and mistaken at times, but strong, resolute, and innovative at other times, which is the way it is with people. I've enjoyed sharing some of these stories. Trust me, there are more out there, some of which I may never share (laughs) and some of which I have in mind to share, because it's not just about space flight. It's about people, and how people can rise to the occasion, react under pressure, and do something that is very difficult, with great élan and great pride in what they do.

It's been a lot of fun. I do get a conversation. We get feedback. People get to make comments and post them. I get to review those comments before they go out, which is an interesting process. I originally thought I'd just approve them all. Then you find out that there are certain features of the Internet where people perhaps are trying to do some things that are not appropriate. You really do have to read them and evaluate whether or not they're appropriate to post. Those that are appropriate have been thoughtful in many cases, and frequently they have brought to mind another topic that I need to discuss. So it has been a conversation.

Jim Crocker on Systems Engineering

ASK the Academy, September 30, 2010 — Vol. 3, Issue 9

Veteran systems engineer Jim Crocker of Lockheed Martin talks about doing the right things versus doing things right.

James Crocker is widely regarded across the aerospace community as a leading practitioner of systems engineering. At the Lockheed Martin Space Systems Company, he is responsible for space science, planetary exploration, and remote sensing, including programs for the Spitzer and Hubble space telescopes; Defense Meteorological Satellites; International Space Station; Geostationary Operational Environmental Satellites; Mars Odyssey, Reconnaissance Orbiter, Scout; Phoenix; Juno; Jupiter Orbiter; and the GRAIL lunar mission. In the early 1990s, Crocker conceived the idea for the COSTAR system to correct the Hubble's flawed optics.

As director of programs for the Center for Astrophysics at Johns Hopkins University, he led the system design effort for the Advance Camera for Surveys (ACS), a scientific instrument installed in the Hubble Space Telescope in February 2002 that improved the performance of the telescope by an order of magnitude.

As head of the programs office at the Space Telescope Science Institute, Crocker led the team that readied the science ground system for operation of the Hubble Space Telescope through orbital verification and science operations on orbit. Crocker previously designed electronics for scientific experiments on Skylab in support of NASA's Marshall Space Flight Center.

He is the recipient of numerous honors including the Space Telescope Science Institute Outstanding Achievement Award and two NASA Public Service Medals for work on the Hubble Space Telescope.

Scientist-astronaut Edward G. Gibson after exiting Skylab on February 3, 1974. Credit: NASA

Crocker spoke with *ASK the Academy* in August about how his career and his reflections on the discipline of system engineering.

ASK the Academy: Hubble has been intertwined throughout your career. What was your first involvement with it?

Jim Crocker: 1983 was the first time I was officially involved. The first time I got a glimpse of something related to it was actually down at Marshall. I was supporting the Marshall Space Flight Center in the mid-1970s, working on Skylab. We were getting to store some spare solar rays in a facility there, and there was this full-size model of this thing called the LST—the Large Space Telescope—and I thought, "Wow, that's cool. I'd like to work on that." Seven or eight years later, I was.

ATA: What was your job?

JC: I was at the Space Telescope Science Institute. AURA (the Association of Universities for Research in Astronomy) had won the science operations contract for Hubble. I was hired to help get the ground system ready, and ended up head of the program office there, getting a lot of the support systems for science operations, guide star systems, and other things ready to go on Hubble.

ATA: You started your career as an electrical engineer. How did you come to be a systems engineer?

JC: Much of my early career—and even today—focused on scientific instruments of one sort or another. When you think about it, Hubble is just one huge scientific instrument. A lot of my career has been focused on instruments, and when you get into building instruments, it drives you into systems engineering. Instruments are usually dominated by electrical engineering and optical engineering, which in most instances is kind of a sub-field of electrical engineering. It's usually taught in the electrical engineering department. As a result of that, you have to know thermal and optics and computers and software and all those ancillary disciplines beyond electrical engineering. It drives you in the direction of systems engineering.

When I went to school, I don't know that there were any formal systems engineering courses. You certainly couldn't get a degree in it. Since electrical engineering had expanded to include hardware and software as major sub-disciplines as well as electro-optics, it was kind of a place that a lot of systems engineers of my generation came out of. I think particularly the exposure to instruments early in my career started pushing me in that direction—at least giving me the background that I needed to do systems engineering.

A lot of the best systems engineers I've seen seem to come out of instrument backgrounds. There's another one (common background) too: a lot of them come off farms. I really think that when you're on a farm, you work on mechanical things and electrical things. Maybe it gives you that "having to understand something about everything" mentality. That's anecdotal, but I think a lot of people would concur with the (value of an) instrument background, because of the broad discipline scope that you have to have and the opportunity to do that. They're usually small enough where you can get your arms around the whole thing. It makes a great training ground for systems engineers.

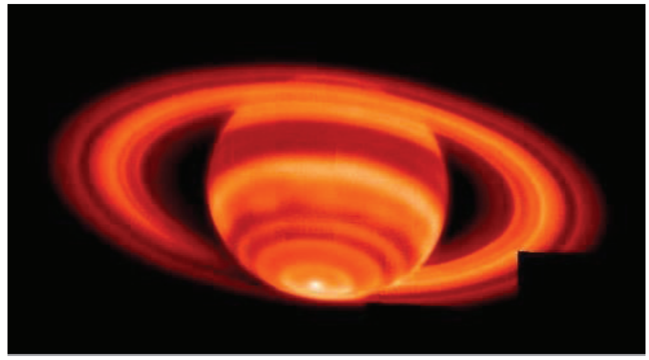


Image of Saturn's temperature emissions taken from the ground by the W.M. Keck I Observatory in Mauna Kea, Hawaii on February 4, 2004. Credit: NASA

ATA: You've said that a systems engineer has to have broad knowledge. How did you broaden your own knowledge base over time?

JC: It goes back to instruments. I'd been driven in the instrument arena to learn about these other disciplines. Once you get to a certain level of proficiency, it allows you to go deeper into a subject. I know when I was at the Space Telescope Science Institute, for example, part of my responsibility was being the liaison between the scientists at the institute and the engineering teams around the country who were building the instruments for the telescope. While I was familiar with optics from a cursory point of view, doing instruments for the Hubble Space Telescope, where the optics were very complicated, very precise, and very large—that gave me the opportunity to broaden my understanding of optics, and it forced me to take some more formal coursework beyond the cursory coursework I'd done in college. That sparked a lot of my interest in larger optical systems, and because of that, I ended up going over to Europe with Riccardo Giacconi, who was the director of the Space Telescope Science Institute, when he went over to run the European Southern Observatory, where they were building four ground-based eight-meter telescopes.

It's not just depth. You go broad, and then you go deep. And then you go broader in another area, and then you go deep. It's very easy today just to continue going deeper and deeper in a narrower and narrower niche. To get out of that, you have to go broader, and then as you go broader you go deep, and then you find another area to go broad in again. It's a combination of expanding your knowledge about things and then going fairly deep into them.

Systems engineering is not just knowing the theory behind something. The real trick as you mature in these areas—the "going deep" part—is understanding how things are fabricated, what the risk in fabrication is. In optics, for example, you learn all about optical coatings and all the idiosyncrasies about how these coatings perform, how they get damaged and are not quite up to spec, and what in the process causes that. As you learn these things, it allows you to design systems that have more resilience. When you don't have at least an understanding of where the real challenges are, you'll design something that can't be built. You have to know enough to know what to stay away from, and what can and can't be done.

ATA: It's true of residential architects too.

JC: That's exactly the point. I use a lot of analogies to residential architects because people understand architecture and can relate to the fact that you have an architect and a builder. Systems engineering has this architectural part and this building part. Peter Drucker said it's more important to be doing the right thing than to be doing things right. Of course in our field, we have to do them both right, but Drucker's point was that it doesn't matter how well you do the wrong thing. A lot of my career in systems engineering has been focused on the architectural part—getting the thing conceived so that the end user gets what he or she expected.

ATA: What's an example of making sure you're asking the right question?

JC: I think we as a community are going through something right now that's relevant to that question. It has to do with cost and affordability. When I went over to ESA (the European Space Agency) and did a program review with Riccardo (Giacconi) to understand where this multi-billion dollar ground-based telescope program was—this was to build four enormous telescopes that were optically phased together, something that had really never been done before—I came to understand something at the end of the review. I said (to the team), "Let me tell you what I heard you say. What you said is that you are building the most wonderful, phenomenal observatory in the history of man, better than anything else in history, regardless of how long it takes or how much it costs." And they said, "Yeah, that's exactly what we're doing." I said, "Well, we have a problem then, because there's only so much time and so much money. On the time part, if we don't get this telescope built here on this new schedule that we're laying out, the Keck Telescope that the U.S. is building and others—the Gemini—their scientists will skim the cream. Theirs may not be as good as yours, but they will skim the cream. And there's only so much money. So we have to build the best telescope that's ever been built, but within the cost and schedule that circumstances are going to allow us to do, because getting there late is going to mean we're not going to be the first to do the science." That was a real paradigm change for everybody, and understanding that really led us to a place where we did come in within a few months of our schedule and right on our cost. It was a big paradigm change.

I think we're going through something similar to that now. Certainly in NASA programs, and I think in DOD programs as well. We've had this emphasis on schedule and now on cost. The thing I worry about—and here it gets into "make sure you're doing the right thing." In the "Faster, Better, Cheaper" era, people got focused on cost and schedule, but they missed the fact that what was increasing was risk. There was not a clear communication about what the real problem was, and because of that lack of clarity about understanding the right problem, what actually happened was we pushed the cost performance to a point that was so low that the missions started to fail and we weren't able to articulate what we were trying to solve. People thought we were just continually trying to do cheaper, cheaper, cheaper. Einstein said you should make things as simple as possible, but not simpler. My twist on that was that you should make things as cheap as possible, but not cheaper. Because of that, we got into mission failures across the industry as we pushed below a point while not clearly articulating what the problem was other than "Well, let's make it cheaper." It went off the cliff.

As we get into this next reincarnation of this cycle that we go through, we have to do a much better job of articulating the problem and knowing what it is we're trying to achieve. What we're trying to avoid here really is overruns—the unpredictability of a lot of our programs. We get into situations where not one but a large number of programs overrun. I'm not sure the desire is really to do it cheaper. It's certainly not to do it cheaper than possible. It's to do it predictably—both on cost and schedule—and still have mission success. At the end of the day, if you do it faster and cheaper and the mission fails, you've really wasted the money. So it's important to make sure this time that we've really understood what we're trying to accomplish and articulated it well, so that we can all be solving the right problem.

Remember the game "Telephone," when you were a kid, where you whisper something in somebody's ear? You go through ten or fifteen people and it comes out the other side, and you wonder, "Where did that happen?" What's fun is to go along the way and get people to write down what they've heard. You go back and you see where these things get very slightly changed from person to person, and it's totally different at the end.

In companies the size of ours (Lockheed Martin) and in agencies the size of NASA, when we try and communicate some of these really challenging goals, the ability to really crisply and clearly articulate the problem we're trying to solve is enormously important. It's how we go wrong and end up in a ditch.

ATA: Your point about predictability is interesting. What we're trying to do is say we can reliably deliver on the cost and schedule that was promised at the baseline.

JC: That's right. We get into this thing of "We have to do it cheaper," and we've already started to miscommunicate.

In some instances, that's not true. Today if you look at the launch vehicle situation and the retirement of the Delta II, if we continue doing business the way we've been doing business, right now there's just not a Delta II class vehicle available, so you either have to go much smaller (Minotaur) or much larger (Atlas). So people say launch costs are unaffordable. That's true, but it doesn't necessarily mean you need a cheaper launch vehicle. It could mean you need to do more dual launches with a bigger launch vehicle. That has its own problems. Or maybe we can figure out how to do missions on smaller buses with smaller payloads and fly them on smaller vehicles. It's just so important in systems engineering to understand and be able to communicate to everybody what the problem is that you're trying to solve.

Delta II rocket carries Kepler spacecraft into space on March 6, 2009. Credit: NASA/ Regina Mitchell-Ryall, Tom Ferrar

I think Dan Goldin's "Faster, Better, Cheaper," which everybody thinks was not successful, actually was successful. Dan said we're going to do more missions, they're going to cost less, we're going to have more failures, but at the end of the day we'll have done more with the money than otherwise. He said, "I think as many as three of ten could fail." Three of ten failed. If you go back and look, we did the other missions for less money with that approach. Two things happened. One, I don't think we had the buy-in of everyone involved, and we didn't properly communicate expectations. Two, we got into this thing where we might not have had any failures if people had understood where to stop, and that had been clearly communicated.

That's why I say it's important as we articulate where we're going this time that we understand is it "cheaper, cheaper, cheaper until we break," or do we want predictability so we can plan to do things right with no surprises?

ATA: What are the signs that you might not be working on the right question?

JC: I don't know who invented Management by Walking Around.

ATA: I've heard it was Hewlett and Packard.

JC: I've heard that too. I don't know if it's anecdotal or true. I think it was actually Packard who was the MBWA person. I certainly learned early in my career that as a systems engineer responsible for the architecture, getting around to the people who are flowing the requirements down to low-level systems and actually going as far down the path as you can and talking to people about what they're doing and what their objectives are and having them explain them to you is really the proof in the pudding. There are two pieces to this. One is you have to do the right thing, and then it gets distorted because of the "Telephone" effect. That's where going down and talking to people who are doing critical subsystem design—just talking them to make absolutely sure that you understand that they understand what the essence of this thing is all about. That's number one.

The second one is really making sure at the front end that you understand and you can communicate and have somebody tell you back at the high level what they thought you heard. Then you really have to capture that in the requirements. I'll use Faster Better Cheaper again as an example. Goldin said, "We're going to do this," but I don't think he articulated it well enough to get it into requirements. It's that first translation step into DOORS where you have to make sure that what got into DOORS, what got into the requirements database, really does the high-level thing that you want to accomplish.

There's really a third component too. We have a tendency in our business not to understand who the real true end-user is. Certainly we don't spend as much time as we often should really deeply understanding their needs operationally. This feedback of testing what you're going to accomplish with the end user is critical. That's a problem because you don't speak the same language that they do. One of the things that we (Lockheed Martin) actually do here in our Denver operations is really interesting. We actually have people who rotate through all the life cycles of a project. They might start a program in the proposal phase, and then many of those people will end up in the implementation and the design phase (and go) all the way into the assembly, test, and launch. And then, since we fly missions as well, they'll go in and fly the mission. That's where you see the light bulb go on in somebody's head when they say, "I'll never do that again." It really feeds back into the front of the design, and it makes people have a very rich understanding. A lot of times when we as systems engineers haven't had the experience of actually operating some of the systems that we build, we just don't know any better.

If you've ever changed the oil on a car, you sometimes ask yourself how the engineer could have been so stupid to put the oil filter where it is. It seems like it's just impossible to get to sometimes without pulling the engine. (Laughs.) But then you go back as the engineer, and you realize he probably didn't have visibility into the fact that a wheel strut was going to block access to the oil filter. So it's only when you've been there trying to change the oil filter that you really understand that you need to know about more than just the engine to decide where to place the oil filter. That's an important aspect of it too.

I think those three things, if you exercise them, can help you know that you're not doing the wrong thing.

Five Questions for Dr. Scott Page

ASK the Academy, June 30, 2010 — Vol. 3, Issue 6

Dr. Scott Page shared insights with ASK the Academy about complexity, cognitive diversity, and the learning opportunity posed by international teams.

Dr. Scott Page is the author of *The Difference: How the Power of Diversity Creates Better Groups, Firms, Schools, and Societies* and *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*. At the University of Michigan, Dr. Page is the associate director of the Center for the Study of Complex Systems and a research professor at the Center for Political Studies. His research focuses on the theory behind diversity, complexity, incentives, and institutions.

ASK the Academy: You've written that complexity comes from simplicity, using a children's game of tag to illustrate how a complex environment comes from the simple actions of running, trotting, and standing. When it comes to teams, what are the simple actions that create a complex team environment?

Dr. Scott Page: Complex systems consist of diverse interacting individuals whose actions influence the behaviors of others. In groups, diversity, feedback, influence, and the dynamic interchange of information can produce complexity when the underlying problem is challenging. On easy problems, someone likely knows a good answer so the team environment tends not to be very complex.

ATA: In your book *The Difference*, you made the case that cognitive diversity provides multiple perspectives (how a problem is viewed) and heuristics (how that problem can be tackled), which results in better teams. For organizations like NASA, which face grand challenges such as landing humans on Mars, what advice do you have for leaders in managing the complexity of decision making for tasks like this?

SP: A first step is to recognize the nature of the task. Is NASA making a forecast? Is it trying to solve a difficult problem? Is it trying to coordinate across tasks? Let's take a specific forecasting task—such as when a part of the project is likely to be completed. One approach would be to ask the person in charge to give an estimate. Another would be to cast a wider net and to seek input from people involved in a range of activities involved with the project. The second approach probably works better. Or, let's take a specific problem—like reducing the weight on a spacecraft. Here again, opening the problem to more sets of eyes is likely to produce new ideas.

ATA: Many organizations face the challenge of integrating a new generation of workers who have come of age in an era of social networking and no expectation that they'll remain in a single job for more than a few years. How do generational differences like these play into organizational complexity?

SP: Good question. I'm not sure. The empirical question lies outside my area of expertise. What I can say with some confidence is that increasing generational diversity will likely increase complexity as well. The nomadic expectations are a mixed bag. True, the new generation may feel they have less skin in the game, but they'll also be more willing to share novel ideas, as they'll be less concerned with reputation and more interested in just having fun and learning.

ATA: Increasingly, large projects such as the Large Hadron Collider and the International Space Station are achieved by international teams. Working with international partners adds new levels of diversity and complexity to projects. What are the key challenges you see in determining how to leverage this diversity and manage complexity on international projects?

SP: International teams offer several immediate opportunities. On technical problems, you have a good chance that people have learned the relevant material from different sources and have mastered slightly different techniques. That diversity can be useful. If you have all Ph.D.s from the University of Illinois or Purdue, you're likely to have people who all sat under the same bright lights poring over the same textbooks. With an international team, you've got a broader set of basic understandings. In contexts that involve the human element, international diversity produces diverse lenses on the human experience and leads to deeper understandings. Permit me a brief anecdote. The recent Netflix prize competition was won by an international team of collaborators. People from different countries brought different understanding of why people like moves and how to classify movies.

ATA: You have a book coming out on diversity and complexity. Can you give us a preview of what to expect?

SP: It's a book that should appeal to scientists. It's not an airplane book. It's a book that says—here's how people measure diversity (and variation), and here's how scientists—be they biologists, engineers, or economists—think about the roles that diversity plays in complex systems. For people who want to move beyond metaphor and gain a deeper understanding of how the diversity of species, firms, ideas, and ideologies creates good outcomes (like robustness and resilience) and also bad outcomes (like market crashes and mass extinctions), the book will be worth reading. I recently did a DVD course for The Teaching Company on complexity. This book is a wonderful follow-on to the DVD.

ASK the Academy

PM Challenge International Forum Roundup

February 26, 2010 — Vol. 3, Issue 2

PM Challenge's first-ever international forum featured representatives from over a half dozen space agencies as well as industry, academia, and nonprofit organizations.

With international cooperation and collaboration poised to play an increasing role in NASA's future, the international forum at PM Challenge 2010 provided an opportunity for NASA to bring together partners from around the world to share perspectives, challenges, and opportunities.

Greg Balestrero, President and CEO of the Project Management Institute (PMI), kicked off the forum with an overview of the context for global projects. Challenges such as space exploration require an enabling environment, he said. "The enabling environment is here, and we have to talk about in terms of a global solution."

Michael O'Brien, NASA Assistant Administrator for External Affairs, set the stage by describing the extent of NASA's international partnerships. Historically, the agency has had over 3,000 international agreements with over 100 countries. It currently has 458 active international agreements with 118 countries, with just 10 partners accounting for half of those agreements. He emphasized that the successful implementation of existing agreements is critical for NASA's credibility. "Do what you say you're going to do," he said.

Representatives from three partner agencies provided their perspectives on working with NASA. Andreas Diekmann of the European Space Agency (ESA) suggested that a new trend might be toward more integrated cooperation, with missions that are jointly planned and developed. He contrasted this with past and current international missions that have emphasized discrete contributions from partners. Yoshinori Yoshimura of the Japanese Space Agency (JAXA) noted that changes at NASA can have a dramatic impact on JAXA, and he said that when difficulties arise, partners should try to indicate a common path and build consensus. "The best agreements are difficult to negotiate but don't have to be referred to later," said Benoit Marcotte of the Canadian Space Agency (CSA). "They have to be fair for both or all parties."

Looking at the current framework for international collaboration, Kathy Laurini of NASA's Space Operations Mission Directorate provided a brief overview of the Global Exploration Strategy, written by 14 countries in 2006, and the associated International Space Exploration Group, composed primarily of active participants in the ISS. She said that that partner interdependencies and full utilization of the ISS are two of the greatest challenges that need to be addressed in the future. "It's up to all of us to make sure we take advantage of that," she said of the ISS.

Representatives from some of the active ISS partner agencies, including Benoit Marcotte, CSA, Kuniaki Shiraki, JAXA; Alexi Krasnov, Russian Space Agency (RSA); and Bill Gerstenmaier, NASA Associate Administrator for Space Operations; shared their lessons learned from the station. Gerstenmaier prefaced remarks by NASA's international partners by referring to the lessons learned document that the ISS partnership released in the summer of 2009. Noting that Japan's Kibo module for ISS was in development for 20 years, Shiraki mentioned the need for sustainable support from partners as well as the public. Marcotte said it was important to be prepared to "seek and work compromises." Krasnov echoed a similar theme. "We can do better together," he said.

The forum also considered new opportunities for international collaboration in space exploration. European Space Agency (ESA) Director General Jean-Jacques Dordain emphasized the longstanding close relationship that ESA enjoys with NASA. "We don't know what it means not collaborating with NASA," he said. At the same time, he held up ESA's success in running a space agency with 18 stakeholder nations as an example others could learn from. "If there is one field ESA can teach the world, it is international cooperation." Dordain spelled out the reasons for international collaboration in space exploration and constructed three plausible future scenarios, concluding that the future should be based on the partnership of the International Space Station (ISS). "The most important asset of the station is the partnership," he said. "We should not take any risk to weaken that partnership."

One of the key areas for international collaboration in the future is Earth observation. Michael Freilich, Director of the NASA Earth Science Division in the Science Mission Directorate, said, "The problem of understanding and predicting climate change is far too large for any single agency or even any single nation, and therefore we must have good collaborations." Jean-Louis Fellous, Executive Director of the Committee on Space Research (COSPAR), explained that climate change is hard to monitor because of the long-term, precise measurements required to make meaningful predictions. Fellous identified four challenges posed by Earth observation — financial and geographical; compatibility among measurements; modeling and forecasting; and knowledge and innovation — and encouraged the idea of developing virtual constellations that would image the land surface, and measure ocean surface topography and global precipitation. The next challenge, said Freilich, is in understanding how these individual pieces interact in the larger system. To do this data must be rapidly collected, reliable, and available to all. Project managers in Earth observation must identify partners early to sort out overlapping political and scientific interests as well as to determine commonalities among agency operations and visions.

Space science also holds high potential for continued international collaborations. Bob Mitchell, program manager of the Cassini mission, pointed out that difficulties in multinational missions do not necessarily stem from cultural or geographic differences. "Where we have had issues on Cassini, it has not been along national lines," he said. Rather, there were often disagreements among scientists about the mission's priorities. (For instance, those involved with the Huygens probe had different interests than those working on the Cassini orbiter.) Peter Michelson, Principal Investigator of Fermi (also know as the Gamma-Ray Large Area Telescope, or GLAST), said that Fermi handled one of its management challenges by forming an international finance committee so that finance committees from different partner nations could meet to review the status of their commitments to the project. "They developed a working relationship in which they could talk frankly," Michelson said.

The forum made clear that there is significant variation in international approaches to spaceflight project management. Himilcon de Castro Carvalho, Brazilian Space Agency (AEB), said that project management in his organization is under severe budget and human resources restrictions, and that as a result, the focus is on work breakdown structure (WBS) planning, activity definition and sequencing, quality and verification planning, and risk planning. B.N. Suresh of the Indian Institute of Space Science and Technology described the overall management processes, milestone reviews, and quality management processes, which bear some similarities to those of NASA. Dr. Paul Spudis of the Lunar and Planetary Institute provided an overview of his involvement with the Chandrayan-1 lunar mission launched by the Indian Space Research Organization (ISRO) in 2008. Spudis was the Principal Investigator for the Mini-SAR imaging radar experiment on Chandrayan-1, one of 11 instruments on the spacecraft. He spoke of the challenges of dealing with a foreign press environment on an international mission. "Follow your partner's lead with the press," he counseled. "Keep quiet and let them set the tone."

The commercial space sector will clearly play a key role in future international collaborations. Andy Aldrin of United Launch Alliance (ULA) noted that the United States government spending currently accounts for the majority of global spending on space, but that flat U.S. budgets and growing expenditures abroad will lead to changes in that balance in the coming years. Bo Behmuk, former General Manager of Sea Launch for Boeing, said, "The international way of doing business is our future." Greg Pech of ULA emphasized the importance of maintaining close contact with partners and suppliers around the world. "There are times when you just have to get off the phone, get on the plane, and go visit them, sit across the table and face to face, and really connect. There's just no substitute for that."

Increased collaboration in space exploration will also place greater demands on the international program/project management community. Edwin Andrews of PMI said that PMI forecasts a 31% increase in the global number of project-oriented employees in project industries between 2006 and 2016, which translates as 1.2 million new project-oriented jobs annually. The international space agencies represented at the forum varied widely in their approaches to the development of their project workforces. Takashi Hamazaki of JAXA said that on-the-job training accounts for most of JAXA's professional development efforts. Bettina Bohm of ESA explained that her agency focuses on ensuring that there is a qualified applicant pool, providing training courses for project managers, selecting individuals for key assignments, and extending lessons learned across the agency. Dr. Ed Hoffman, Director of the NASA Academy of Program/Project & Engineering Leadership, offered an overview of the Academy's framework to promote individual, team, and organizational learning.

The NASA Academy of Program/Project & Engineering Leadership organized the international forum in collaboration with the PM Challenge organizing team. The Academy received significant assistance from James Zimmerman of International Space Services.

Learning from Failure: OCO-2 Gets Underway

April 26, 2010 — Vol. 3, Issue 4

The Orbiting Carbon Observatory team is applying lessons learned in a unique way after getting a rare second chance to fly.

Taurus XL launch of OCO at 1:55AM PST from Vandenberg Air Force Base, California. Credit: US Air Force photos/Airman 1st Class Andrew Lee

The early morning of February 24, 2009 was cold, wet, and beautiful. Patrick Guske, Mission Operations System Engineer for the Orbiting Carbon Observatory (OCO), sat in the Orbital Sciences Mission Operations Center in Dulles, Virginia. On a big screen, he saw the Taurus XL rocket rumble away from ground at Vandenberg Air Force Base in California. The rocket carried OCO successfully into the air with a bright blue streak trailing behind it—but not for long.

OCO came down much sooner than anyone expected. "I [saw] people starting to get a little nervous," Guske recalled. "Then they got very nervous. Then they got very quiet." OCO had missed its injection orbit and plunged into Antarctic waters.

The OCO team later learned that during ascent, the payload fairing (the nose-cone covering that protects the satellite as it goes through the atmosphere) failed to separate from the launch vehicle. The additional weight prevented the final stage from boosting OCO into the injection orbit.

Guske had planned to stay at the Dulles site for two weeks. He boarded a plane to California in a matter of hours.

The Mission

OCO was an Earth System Science Pathfinder project run by the Jet Propulsion Laboratory (JPL). Its mission was to make precise, time-dependent global measurements of atmospheric carbon dioxide (CO2) that would help scientists better understand the processes that regulate atmospheric CO2 and its role in the carbon cycle. The observatory had three high resolution spectrometers dedicated to measuring Earth's carbon dioxide levels.

Scientists know that carbon dioxide from humans and natural processes is absorbed into "sinks," like the ocean and growing plants. "But we know that we have put more carbon dioxide into the atmosphere than we see," said Guske, "and we're not sure where all of this carbon dioxide is going. How is it being absorbed and where? Are there seasonal variations?" While OCO didn't have the opportunity to answer these questions, OCO-2 can.

OCO-2 will follow OCO's original plan. It will join the Afternoon Constellation (A-Train), a track formation of six satellites orbiting Earth and studying various aspects of Earth's natural systems. OCO-2 will compare its data with measurements from other instruments and observe daily and seasonal variations of atmospheric carbon dioxide.

"We have met the customer and he is us."

Within 24 hours after the launch failure, project closeout for OCO began. This included capturing lessons learned, a process that is often treated as a pro forma activity resulting in "lessons listed." Though no one knew it at the time, this had a different significance for OCO, because unlike most missions, it would ultimately get a second chance to fly.

Guske led the OCO lessons learned effort. He thought it was important to consider the people who would be reading the document his team was charged with creating. With cartoonist Walt Kelly in mind, Guske said, "We have met the customer and he is us."

"We wrote these lessons learned to ourselves because we're going to use these lessons learned," said Guske. The lessons had to be written so the team could understand them. "There is a difference between how we dealt with lessons learned on this project, OCO, and how other missions deal with their lessons learned," he added. For OCO, the lessoned learned would be active, not passive

From Listed to Learned

The process began with Guske sending out an email to everyone on the team: engineers, scientists, contractors, librarians, and secretaries. He asked for feedback regarding what worked and what didn't. When the responses came back he sorted through all of them to generate a streamlined list.

In total, Guske collected 78 lessons learned. Lessons ranged from secretaries asking that team lists be kept up to date to larger programmatic issues such as sorting out lines of authority and clearly defining deliverables. At their simplest, each lesson met three specific criteria: it was positive, didn't point fingers, and offered a solution to a problem. Guske welcomed all of the feedback – the good and the bad – and evaluated each of the lessons based on these criteria and how they would affect the team for the next time around.

During this process, Guske emphasized the dangers of "better is the enemy of good enough." The team wanted to avoid any attempt to make the spacecraft "better"—they wanted OCO-2 to be as close to the original as possible. Changes were considered only if improvements would reduce risk, or if components didn't have spares or had become obsolete. For the most part, OCO-2 is a near-clone of OCO.

Guske assigned each member of the OCO team specific lessons to implement when rebuilding the observatory. He also began documenting the implementation of the lessons learned effort, with the intention of conducting a post-launch evaluation of the effectiveness of the process.

Testing

One of the lessons the OCO team learned had to do with testing. Given the mission's low cost and compressed schedule, the team decided not to test the instrument detectors in flight-like conditions, instead accepting the detector screening done by the vendors. However, the screening processes did not mimic the operational use of the detectors.

After integrating the instrument and putting it into the thermal vacuum chamber, the team discovered a problem: the instrument had a residual image. The effect is similar to the bright spot you see after someone takes your picture with a flash, explained Guske. Faced with two choices—replace the detector or correct for the anomaly—the team decided to develop an algorithm that would correct for the residual image.

This time around, the OCO-2 instrument manager had time and money to test the detectors in flight-like conditions. By screening the detectors ahead of time, the team will know if there are any problems.

Transfer

Another lesson learned by the OCO team related to data transfer. While testing the observatory in the thermal vacuum chamber, the mission operations team in Dulles, Virginia, downloaded raw data from the instrument in three gigabyte-sized files (one for each spectrometer). It then had to send the data to JPL, which had responsibility for analyzing the data, but the JPL team couldn't receive it because of security firewalls at each location.

Since this problem cropped up late in the schedule, the solution the OCO team developed involved transporting the data on portable hard drives back and forth on commercial air flights. Although it was slow and inefficient, this fixed the problem for the time.

At one point, when the OCO team was asked to remove the observatory from the thermal vacuum chamber, it was hesitant to do so because it had not received and analyzed all of its instrument data (which was on a plane somewhere over the United States). There was the possibility that the team would not have all of the measurements needed for fully assessing the instrument and its operation.

The team went ahead and removed OCO from the chamber without the data. When the data did arrive, it was incomplete. Fortunately, the OCO team was able to reconstruct the necessary dataset using an ambient temperature chamber. Despite this successful mitigation, however, the OCO team added this experience to its lessons learned. For now, the team has discarded air travel as a method of data transfer and is exploring more efficient options.

Getting to Fly... Again

OCO made it to launch. Its design was mature and approved for flight. Since OCO-2 is nearly identical, the team has been granted what Guske called a "free pass" on reviews before their Critical Design Review in August. The Project is conducting a "tailored formulation phase" to ensure the updated OCO-2 is developed correctly and completely.

The team is still holding peer reviews for a few interface changes that resulted due to a lack of spare parts, but on the whole they are "just making sure things fit together and flow together," according to Guske.

The OCO-2 team will track the status of each of the 78 lessons learned. Guske said he believes the process is going well, and he looks forward to evaluating the process in hindsight after the launch in February 2013. "We're doing it," he said. "People have the battle scars to show the lessons they have learned, and they're getting to implement those changes now."

Academy Brief: Congressional Operations Seminar

April 26, 2010 — Vol. 3, Issue 4

A group of NASA systems engineers peeked behind the curtain of the legislative process, learning what it takes to manage projects in a political environment.

Capitol Hill sits three blocks east and three blocks north of NASA Headquarters. While the distance between these buildings is short, the differences are vast. For four days, the

Government Affairs Institute (GAI) at Georgetown University designed and conducted a program for civil servants at NASA Headquarters, which included participants from the Systems Engineering Leadership Development Program (SELDP). The program took NASA through the halls of the House and Senate, giving them a crash course on the legislative branch of government, covering everything from the budget to the future of U.S. human spaceflight.

Blame Oliver Cromwell

NASA's introduction to the Hill began with a story by Charles Cushman, professor of political management at George Washington University:

Once upon a time, shortly after the Puritans landed at Plymouth Rock, King Charles I (reign 1625 – 1649) ruled the United Kingdom. He managed to start and lose a war with Scotland, start and lose a civil war in England, and eventually lose his head in the end. His ultimate antagonist was Oliver Cromwell, leader of the opposing army in the English civil war of 1648. Cromwell, the victor and hero, became the Lord Protector and tyrant of the United Kingdom until his death in 1658.

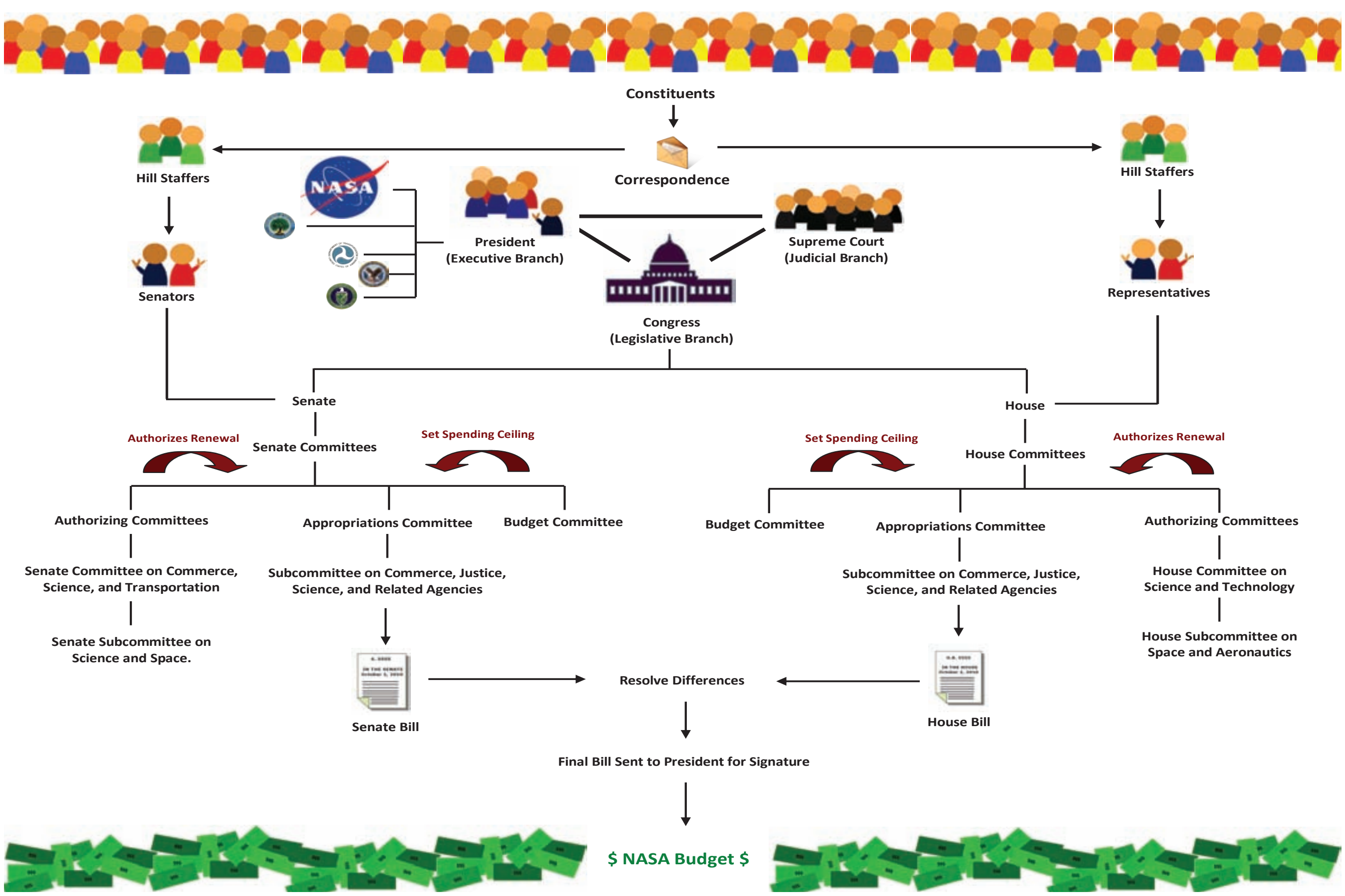
Over a century later, when the Framers of the Constitution gathered to form a more perfect union, the story of Cromwell's transformation from hero to tyrant was fresh in their minds. They were terrified of power, and as a result created a form of government best described as a "friction maximization machine."

American government is meant to be slow and frustrating. Only the agendas with significant support survive, and no single entity or individual has the ability to acquire power quickly enough to pull a Cromwell. It has been said that our federal government is 3% efficient, remarked Cushman, and the Framers might say that our government is 97% tyranny-free.

Bills, Laws, and Power of the Purse

The resulting Constitution created three branches of government: executive, judicial, and legislative. While NASA is positioned under the executive branch, it was created by the legislators in Congress.

Congress passed the National Aeronautics Space Act in 1958, turning the National Advisory Committee on Aeronautics (NACA) into NASA. The driving force in the



The budget for NASA is proposed by the President and then reviewed by the House and Senate Budget Committees.The budget is finalized once it has gone through the House and Senate Appropriations Committees, committee differences have been resolved, and the President signs the final bill.

Senate behind the Space Act was Majority Leader Lyndon Baines Johnson. Contrary to popular belief, this was not simply a response to the Russians launching Sputnik. As the launch of Explorer I in January 1958 showed, the United States had been preparing to launch its own satellite well before Sputnik.

The transference of military rocket hardware, engineering experts like Wernher von Braun, and facilities like the Jet Propulsion Laboratory and Langley Field to NASA, combined with the passage of the National Defense Education Act in 1958 (which pumped money into engineering education) transformed NASA into the agency that would put men on the moon. All of this depended on money from Congress.

NASA's existence hinges on the support of Congress. Members of the House of Representatives and Senators are elected to represent the needs of their constituents, but they must also balance national needs. After President Kennedy made the moon landing a national priority in the 1960s, NASA received four cents of every dollar in the federal budget. Today it receives just over one-half cent of every tax dollar.

Hill staffers explained the budget process to the SELDP group. Simply put, it begins when the President rolls out the budget request. The White House budget then goes to Congress for authorization and then appropriation. The last two steps must be approved by both Congress and the President. Congress must pass appropriations bills to fund agencies like NASA—although they're not always done on time, which means using stopgap maneuvers like continuing resolutions to keep things moving until the process is finalized.

The devil is in the details. Authorizing committees pass bills which call for the establishment or renewal of a program or agency. The House and the Senate have their own authorizing committees and subcommittees that pertain to NASA. In the House, the Subcommittee on Space and Aeronautics falls under the Committee on Science and Technology. In the Senate, the Subcommittee on Science and Space falls under the Committee on Commerce, Science, and Transportation.

Once authorized, appropriations committees are in charge of setting expenditures for discretionary funds. The expenditure ceilings for these committees are set by House and Senate Budget Committees, who see the president's budget first. Like the authorizing committees, there are appropriations committees for the House and for the Senate that pertain to NASA. The names of the appropriations committees are the same for both the House and Senate: Committee on Appropriations. The subcommittees also have the same name: Subcommittee on Commerce, Justice, Science, and Related Agencies. Communication between appropriations subcommittees and the agencies they fund is essential. Ultimately, the House and Senate subcommittees play a zero-sum game with limited resources, and have to agree on how to distribute funds among the executive branch departments and agencies.

Another challenge comes from differing timelines. "NASA looks at a lifecycle. We try to plan and manage the unknowns, over a long-term lifecycle," said Scott Glubke, MESA Division Chief Engineer at Goddard Space Flight Center. "Congress wants to do cut and dry, one year at a time... It's two totally different systems, speaking two totally different languages."

SELDP Take-Aways

Knowing how Congress does its job and learning how to work with them is vital to NASA successfully working with them as a partner. This means forming relationships with representatives, senators, and staffers in their home districts, states, and on Capitol Hill. It means project managers talking to program directors at field centers and NASA headquarters so the correct information can effectively travel the six blocks to decision makers on the Hill. It means finding ways to communicate more clearly, eliminating jargon, and speaking a common language. It also means realizing that all American citizens have say in the process.

"Before I went into the course I was pretty 'civically challenged,' but I think I certainly benefitted a lot from this," said Rick Ballard, J-2X Engine SE&I Manager at Marshall Space Flight Center. He noted his rediscovery of the power of writing to Members of Congress to voice opinions. (Each Member and Senator has legislative correspondents, whose sole responsibility is to respond to individual letters and convey constituent concerns to decision makers.) "I do plan on going back to Marshall and telling the people on my team and trying to keep them held together."

Many SELDP participants said that they would think differently about how to plan and manage their projects and teams now that they better understand the context in which the agency operates. While over the course of the week many voiced frustrations with the Congressional system, they realized that the system is not theirs to fix.

"I started out always being frustrated with Congress and the budget process…and I think I came to the conclusion pretty early that everyone that we talked to was completely practical," said Matt Lemke of the Orion Project Office at Johnson Space Center. Over the course of the week, participants raised many questions concerning ways to solve the problems of government, but, as Lemke discovered, that isn't that point. "I came to the conclusion days ago that we're not going to solve those problems. It's not a problem that is solvable. We need to learn how to live within this chaos."

When asked how NASA should tell people to support NASA, Goddard Space Flight Center scientist John Mather replied, "[That] is…the challenge of life, isn't it? How do you explain to the world that the thing you want is the thing we all should want?" This is what NASA must do more effectively through closer relationships with Congress and better communication.

In the end, this is the way our federal government operates. NASA lives and dies by this system. The agency must address the needs of Congress in order to thrive, not the other way around. Don't like it? Then blame Oliver Cromwell.

NASA on the Hill: Lessons Learned about Volcanic Ash Impact on Aviation

May 28, 2010 — Vol. 3, Issue 5

In response to recent volcanic activity that disrupted European air travel, the House Subcommittee on Space and Aeronautics held hearings to learn about the impact of volcanic ash on aviation.

The Eyjafjallajökull volcano in Iceland erupted on April 14, 2010, canceling 100,000 flights and costing the airline industry $1.7 billion in revenue. The House Committee on Science and Technology asked for witness testimony about unsafe flying conditions caused by the latest eruptions. In a hearing on May 5, 2010, witnesses included Dr. Tony Strazisar, Senior Technical Advisor for NASA's Aeronautics Research Mission Directorate; Dr. Jack Kaye of NASA's Earth Science Division; Victoria Cox, Senior Vice President for the FAA's NextGen and Operations Planning; Captain Linda M. Orlady, Executive Air Safety Vice Chair of the Air Line Pilots Association, International; and Roger Dinius, Flight Safety Director for General Electric Aviation.

In addition to the witnesses formally called for the hearing, Subcommittee Chairwoman Gabrielle Giffords (D-AZ) asked Thomas Grindle, a propulsion engineer at NASA Dryden Flight Research Center, to share the story of a NASA DC-8 that flew through an ash cloud in February 2000. Grindle recounted the incident:

"The scientists on board were the ones that alerted the flight crew that we were currently flying through the diffuse ash cloud from the Hekla volcano. The pilots noticed no onboard indications whatsoever. Engine parameters were normal, no smells in the cockpit, because it was night we looked for the Saint Elmo's fire, no indications whatsoever. The scientists were the only ones because of their instrumentation on board to notice that we were flying through the cloud. The incident lasted for about seven minutes and the aircraft continued on to Sweden.

"Once there, they contacted us back at NASA Dryden and asked about what they should do and we recommended to do a complete visual inspection on all the leading surfaces of the airplane, the windshield the leading edges, to look at the engine fan blades, the engine cowls, anything that could have had any abrasive damage or anything.

"They performed those inspections and we found no damage whatsoever. Our recommendations from Edwards was to then replace the air conditioning filters and the engine oil on all four engines and hold samples for us once they were returned back to NASA Dryden.

"They flew for about sixty-eight hours in Sweden doing other atmospheric research missions and returned back to Dryden where we were able to do a complete engine borescope on all four engines and there we noticed some clogged cooling holes and abraded leading edges on the turbine section. We removed one of the engines, which was getting close to an overhaul maintenance requirement, and sent it to the engine manufacturer in Strother, Kansas. They tore it down and found more damage inside. We then removed the other three engines and sent them to the same manufacturer as well and upon those teardowns they found the same contaminations inside and the same damage listed in all four engines."

In response to a follow-up question from Representative Giffords about lessons learned and the application of this knowledge, Grindle replied:

"Prior to us leaving Edwards we knew about the eruption, and so we purposely made our course as far north as possible and in fact we added another two hundred miles so our total distance from the volcano was almost 800 miles. At the altitude and the latest information we had gotten from the London Volcanic Ash Advisory Center we were well north of any kind of ash cloud whatsoever. Upon the engine teardown and the scientific data evaluation, some of the particles we flew through were less than one micron in diameter, and even at those limits we didn't experience any engine parameter failures or any indications whatsoever, but the engine manufacturer who did the work specified that we probably would have started seeing performance degradation in some of the engines in as little as 100 flight hours because of the loss of cooling and other things and as far as I know, we were the only aircraft to fly in that area through the ash cloud and once we did realize we were in it, we updated the London Center and told them that we had experienced in that area and they were able to update their predictions in those areas as well."

Knowledge Brief: Goddard Hosts "All Things KM" Forum

August 31, 2010 — Vol. 3, Issue 8

Before Google, if you had to find out if a whale has a spleen, how many phone calls would it have taken?

The question above is known as the "whale spleen problem." Try to answer it. Who would you call? An aquarium? A university? The point is that the ability to find the knowledge to solve a problem, run a program, or build a team is vital to organizational success. This was the topic of a two-day forum on knowledge management hosted by the Office of the Chief Knowledge Officer at Goddard Space Flight Center (GSFC).

From an 8,000-pound balloon payload dragging through a line of parked cars to an oil well hemorrhaging crude into the ocean, government and industry participants shared stories, lessons and insights on the importance of managing knowledge. As one attendee put it, knowledge management is the lifeblood of organizations—without it, survival is tenuous. But this is not always apparent.

Orlando Figueroa, GSFC Deputy Center Director for Science and Technology, opened the forum by discussing the importance of support from leadership for knowledge management. Leadership support is growing at Goddard with continued efforts to host forums, storytelling events, and wikis. The support of leadership is a strong indicator of successful knowledge management, said Dr. Ed Rogers, Goddard's Chief Knowledge Officer. When the leadership knows who you are and directs project managers to you, you know you're doing your job and having an impact.

The forum also featured external perspectives from Raj Datta, MindTree Consulting; Kent Greenes, Greenes Consulting; Brian Hackett, Apex Performance; and Rob Johnston, Chief of the Lessons Learned Program at the Central Intelligence Agency (CIA). Politics, change, the pace of work, and resources all influence a program's success within an organization, but leadership support is vital. At the CIA, according to Johnston, the lessons learned program went through several iterations before succeeding. Johnston attributed their success largely to the support of the leadership within the organization. Greenes has observed that successful knowledge programs show, celebrate, and demand the impact of what they are doing. But most importantly, he said, successful programs keep knowledge management on the leadership's agenda.

Doug McLennan, Beth Keer, Sandra Cauffman, and Bob Menrad of GSFC's Flight Projects Directorate shared insights about success, failure, and learning. All agreed that listening to others and self-assessments are essential to the learning process. These activities are always works in progress, noted Cauffman. To this day, Menrad revisits the work of his mentors. Learning also involves being wrong and humbled. When McLennan left working in the lab, he was convinced that managing the technical knowledge would be the hard part, he recalled. Wrong. "Every problem you're going to run into will have to do with people," he said, "but you also have to realize all of your successes will be because of people."

Other presenters included Jon Verville, who is leading the wiki movement at GSFC; Michelle Thaller, Assistant Director for Science Communication and Higher Education, who offered insights about how knowledge circulates in the world of scientists; Peter Hughes, GSFC Chief Technology Officer, who discussed the knowledge coordination across center technology offices; Steve Denning, author of several books on knowledge management, who discussed radical management principles for keeping knowledge management on the agenda; and Jay Pittman, Chief of Range and Mission Management Office at Wallops Flight Facility, who spoke about organizational silence.

Larry Prusak, Editor-in-Chief of ASK Magazine, moderated the final panel, which included Adrian Gardner, Chief Information Officer at GSFC, Robin Dixon, GSFC Library Director, and Mark Goans of the Systems Review Office. The panel discussed the use and expansion of embedded "knowledge medics" on project teams. These individuals, who could be librarians or information officers, would fit in seamlessly with the team and function to fill knowledge gaps.

The forum closed with a trip to the Goddard Visitor Center to see the "Science on a Sphere" exhibit and reflect on the forum's discussions. A common sentiment was that knowledge management, while critical to organizations, is passed off as a supplement for success. In order for an organization to thrive, knowledge cannot be static, whether the work is launching rockets, selling computers, or drilling oil.

Leadership Brief: Masters with Masters Features Bolden and Dordain

October 29, 2010 — Vol. 3, Issue 10

NASA Administrator Charlie Bolden and European Space Agency (ESA) Director-General Jean-Jacques Dordain shared reflections and stories in a special Masters with Masters program.

Bolden and Dordain traded ideas about international collaboration and fielded questions from the audience in a lively discussion moderated by Academy Director Dr. Ed Hoffman at the 61st International Astronautical Congress in Prague on September 28, 2010.

Dordain emphasized that cooperation among space agencies is strengthened by personal relationships. "Behind any cooperation there are people. The personal relationship is very important. Yes, there is cooperation between NASA and ESA...but behind that cooperation, there is cooperation between Charlie Bolden and Jean-Jacques Dordain." He recalled that the first time he heard of Bolden was in the 1980s, when he headed ESA's astronaut office and Bolden was a NASA astronaut. ESA astronauts who were training in Houston at the time were being excluded from meetings with their American counterparts. "The one who took them by the hand and brought them to the meeting of the NASA astronauts was Charlie Bolden," said Dordain.

Bolden spoke about collaboration in terms of diversity and inclusion. "Diversity is a difference of ideas, a difference of philosophy, a difference of skills, a difference of geographic background. It's just differences that makes us strong," he said. "The inclusiveness means we listen to everyone's voice."

Jean-Jacques Dordain, Director-General of ESA, and Charlie Bolden, NASA Administrator, participate in the Masters with Masters knowledge-sharing session at the International Astronautical Conference in October 2010.
Photo Credit: ESA/S.Corvaja 2010

Both agreed that competition and cooperation were not mutually exclusive. "We need competition, but provided that that competition is organized to reach common objectives," said Dordain. "I think that cooperation is to set the common objectives: what are we ready to go do together? I think that is the sense of cooperation. But to reach these common objectives, I think that competition is very healthy."

"There should be very healthy competition of ideas," Bolden said. "I think if we ever stop competing for ideas, then we're dead."

Audience members posed questions about navigating bureaucracy in complex organizations. Dordain acknowledged that bureaucracy was inevitable within ESA. "When you are working with 18 governments, you have to accept the bureaucracy, but...a significant part of the bureaucracy is coming from a lack of trust," he said. "You cannot buy trust. You have just to build up trust, and that takes up time."

Bolden emphasized the importance of being able to compromise. "Many people today...feel that compromise is a weakness, that if you are willing to compromise, then you are not going to win," he said. "If you are not willing to compromise, in my mind, then you will never win."

Risk Brief: Jay Pittman on the "Anatomy of a Dragon"

October 29, 2010 — Vol. 3, Issue 10

A twelve-year-old accident serves as a constant reminder that "there be dragons" in NASA projects.

In 1998, a commercial jet approached the research runway at the Wallops Flight Facility to perform an engine water ingestion test. This test was supposed to be routine—just like the many that had come before it. All jet-powered aircraft designs flown in the United States are required to pass it. However, this particular test, the eleventh run in a planned series of twenty, did not end like its predecessors.

The plane approached the flat runway, which had a pool of water strategically placed for the plane to land in. Manned, high-speed cameras surrounded the area to capture the imagery for later analysis. As the plane touched down, a crosswind caused the plane to swerve and flip over—just missing a cameraman. The aircraft burst into flames, destroying a nearby support vehicle. Miraculously, no one was hurt.

Later review showed that the test that day was not, in fact, business as usual. The operations team had made a series of small changes to the planned procedures. The puddle's position on the runway moved several times. The cameramen were repositioned for a better shot. No one openly questioned these seemingly harmless changes for what was perceived as a routine operation.

"To this day, [that incident] marks my standard of worry," said Jay Pittman, Chief of the Range and Mission Management Office at Wallops. For nearly a decade, he has been responsible for granting flight permission at Wallops. Worrying about risk is his job, and he takes great care to remain cognizant of it.

"There comes a comfort level with things that you've done before, and that can be a dangerous thing," said Pittman, who was not part of the team involved in the incident that day. "I don't believe that there was a specific instance of intentional negligence on the part of the team that oversaw what ended up being a disastrous event, but there was a slow and silent accumulation of a number of things." What seemed like very small additional requirements and unreviewed changes added up to a dramatic change that brought new risks, explained Pittman.

As a leader, Pittman wanted to be able to convey to his teams the seriousness and helplessness that emerges when conducting risky missions—even the ones that seem routine. To him, risk looks like a dragon. "The dragon for me is this notion of quiet risk that accumulates into a critical mass and then explodes in your face."

This metaphor of a dragon comes from the story The Hobbit. Pittman recalled the fear of the residents who live below Smaug, the dragon, who inhabits the Lonely Mountain above. When living in such an area, argues Pittman, how can you not factor in the risk a dragon imposes on your daily life?

For Pittman, the anatomy of the dragon includes a number of elements. Number one, he said, is complexity. "Don't tell me that you've done [something] before. Everything we do has incredible complexity, and it's ludicrous for us to say that it's not."
Schedule and cost pressure are also omnipresent.

Aerial photograph of Wallops Island. Photo Credit: NASA

Congress, NASA leadership, the mission directorates, and the public all want to see a final product, a mission. The pressure to make everyone happy is immense.

There is also the feeling of being 100 percent a part of a team, which is good, said Pittman, but there can also be a downside to this. "That means there's pressure not to be the stick in the mud," said Pittman. "You don't want to be the person who says, 'I'm not really comfortable. I'm not sure this will work. I'm not really sure this is the same as last time.'"

"Nothing is the same as last time because today is a different day," said Pittman. He looks for the uniqueness in each of his projects, particularly the ones that seem routine. It's too easy to be lulled by paperwork and checklists. During reviews, Pittman makes sure that he invites people who have never seen the project to every mission review panel. "It's the fresh eyes that keep us from doing truly stupid things that you could just drift into little by little."

He also emphasizes learning lessons rather than listing them. He thinks of lessons learned as actionable tasks that act as liens against projects. "If we haven't turned it into something real, then that lesson learned from some mission long ago is a lien against future missions." This generates what he calls "reasoned assessments" of why it's OK to keep going in spite of the lien. They keep the team ready in spite of a challenge, he explained. "It's that reasoned assessment that goes missing when we become comfortable."

Pittman offered his final thoughts on risk.

"Sometimes the leadership, managers like me, are too far removed from what is really going on. Sometimes everybody knows the real story except for the leader. It's the job of a leader is to find a way to make public what 'everybody knows.'" He offered a few examples of those types of things:

Everybody knows…
- What almost hurt someone last time.
- Who doesn't get along and how that affects communication.
- How stuff really happens and what rules to follow.
- What really went wrong.
- What almost went wrong.
- Lessons learned equals lessons listed.
- Places that don't get seen during audits.
- The checklist doesn't matter, the checkers do.
- Organizations don't fix problems, people do.
- Which managers you can go to…and which ones you can't.

Despite the risks that come with NASA missions, the NASA workforce certainly has something to be proud of, added Pittman. "We do things that normal people would never think of doing," he said. Things like putting a satellite in space, going to the moon, going to Mars, measuring the temperature of the universe, or quantifying the energy of a raindrop falling in the ocean.

At the end of the day, however, NASA teams are made up of people. "Sometimes people don't do what you expect," said Pittman. "We're capable of leaps of creativity and insight that nothing else can do, but sometimes you have a bad day… The fact that we are human means that we have strengths and weaknesses. It's our job as responsible leaders to maximize the strengths of our people and our teams and to enable them to see clearly the risks involved in our missions in spite of the fact that we are human."

YOUNG PROFESSIONALS BRIEF: KAT CODERRE

November 30, 2010 — Vol. 3, Issue 11

Kat Coderre's career started with a phone call from out of the blue. "Can you be in Houston tomorrow night?"

Kat Coderre in the Cockpit Operators Station Mockup, which is used to run rendezvous docking simulations for Orion. Photo Credit: Lockheed Martin

When Lockheed Martin won the Orion contract in 2006, it had Kat Coderre's application on file—one of 32,000. "We want you to come out," Coderre remembers the voice on the other end of the line saying.

"I flew from New York to Houston that evening," she says with a laugh. Fresh out of college with a degree in Aeronautical and Mechanical Engineering from Rensselaer Polytechnic Institute, Coderre was among 1,200 engineers asked to join the Lockheed Martin team. Standing with her peers, she recalls thinking, "I am fresh out of school and working on a spaceship. That's pretty cool."

The journey leading up to that phone call began with an early fascination with the moon, her first telescope, and a trip to Space Camp, where she later became a counselor. Four years after the trip to Houston, she is part of Lockheed Martin's Engineering Leadership Development Program, an active member in a variety of outreach programs, and a member of the Space Generation Advisory Council. In short, Coderre is part of the generation of young professionals who entered the aerospace workforce when the Vision for Space Exploration reshaped the landscape in the middle of the last decade. Today she's working to take her aerospace career and professional community to the next level.

Doing, Learning, and Mentors

"They'd let me go off and learn, and gave me tough tasks to do. They weren't holding my hand."

As a 22-year-old starting out as an engineer on the Orion Flight Operations Integration Team, her job was to make Orion a more operable vehicle.

"I didn't necessarily know what I was doing all of the time when I started, but there was a lot of encouragement, a lot of mentoring from the management, the more experienced folks," she says. "They'd let me go off and learn, and gave me tough tasks to do. They weren't holding my hand."

Her growth as an engineer continues with her participation in the Engineering Leadership Development Program (ELDP) at Lockheed Martin. For three years, Coderre will spend six months to a year broadening her skill set and capabilities by jumping from project to project, in addition to getting her Masters degree. Her first ELDP rotation placed her with the cockpit design team for Orion, working on displays and controls for the system. The experience exposed her to a high customer-contractor interface, a team dynamic that she hadn't yet experienced, and taught her how to work with the customer as a teammate. Coderre is now working on Lockheed Martin's International Space Station Cargo Mission Contract team.

Throughout her four years at Lockheed, she has appreciated her mentors and their open-door policies. "I can just wander in if I see them in their office or if I need to discuss anything," she explains. Her conversations range from technical discussions to broader topics such as uncertainty in the federal budget.

Working in Teams

Most of her professional challenges have revolved around people: learning how to work with different personality types, communication styles, and work styles.

She is quick to say that she has had great support, but has run into the occasional colleague who "looks at you like you're a youngin'." She views it as a challenge to prove that "I can do my job right, and do it well," she says. "And when I do fail, [I] fess up to it." Simply admitting, "I made a mistake," Coderre adds, can go a long way. "If you don't fess up to [a mistake], then they lose respect for you."

A wide view of the lab with the Human Engineering Structural Mockup in the foreground and the Cockpit Operators Station Mockup in the background. Photo Credit: NASA

Young, Old, and In Between

Her work and professional activities bring her into contact with people ranging from school children to retired aerospace veterans. She dedicates her time to public outreach, which started with her work at Space Camp, and expanded to volunteering at museums, the NASA Speakers Bureau, and the Challenger Learning Center. The next step to re-ignite the next generation's interest in space "is trying to get exposure into other areas where [kids] don't typically get [exposed to space]," she says. "It's our duty to really give back and be that mentor, be that spark of interest to a student, whether they are elementary school or college level."

At the other end of the age spectrum, Coderre looks to the generations above her to learn from their knowledge and experience from the past. "Spaceflight is a tough business," she says. "Taking those lessons and those various experiences, sitting down and talking with [the more experienced generation], showing them that we are interested and we want to hear what they've done [is important]." Coderre says that her generation is eager to make the most of lessons learned the hard way. "We respect their experience and we really do want to learn [from it]."

Kat Coderre in the Human Engineering Structural Mockup. This full-scale Orion mockup is used for crew evaluations such as ergonomic assessments and emergency egress operations. Photo Credit: Lockheed Martin

"The key is interaction; having as much small group interaction as possible." She remembers a conference where she was able to bring her questions and discussion topics directly to veteran engineers seated at various tables in a room. The forum was so effective that at the end of the evening, said Coderre, "no one wanted to leave."

As for her peers, Coderre advocates for flexibility and patience. "I believed in it (Orion). I put my heart and soul into it," she says. The nation's direction in human space flight changed, and her generation needs to respond appropriately. "The government and the way the government does business is changing." Her focus is to not get discouraged. With the aerospace industry being asked to do more with less, says Coderre, her generation as a whole must believe in what they do and continue to move forward.

International Collaboration: Wait and See

As a member of the Space Generation Advisory Council, a regular attendee of the International Astronautical Congress, and a team member on the ISS Cargo Mission Contract at Lockheed Martin, Coderre is no stranger to the international scene. She loves hearing colleagues speak different languages down the halls and in offices for her ISS work, and hopes to see international cooperation heightened in the future.

"The world is getting smaller, we're more connected, and we can learn a lot from each other."

In her conversations with international peers, there is always great enthusiasm about working with NASA. At the same time, she finds it is nearly impossible to talk with colleagues about international collaboration without discussing export and import regulations like ITAR, which are often viewed as stunting the expansion of international projects. Until things change, Coderre encourages her international peers to continue building their experience and developing their expertise.

"I believe in international cooperation," she says. "The world is getting smaller, we're more connected, and we can learn a lot from each other."

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