National Aeronautics and Space Administration

Year In Knowledge 2011

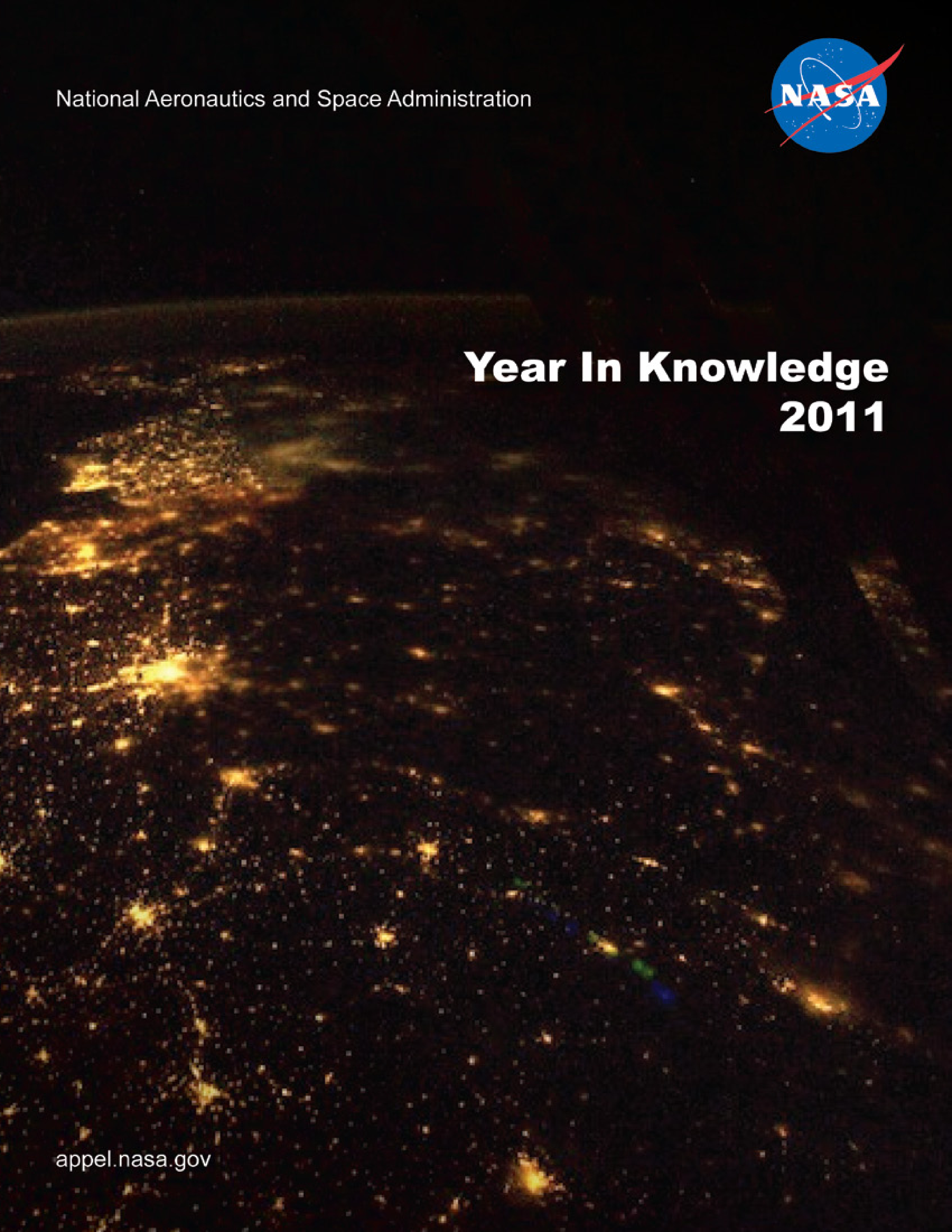

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Table of Contents

Foreword

"Storytelling reveals meaning without committing the error of defining it."
- Hannah Arendt

Acquiring knowledge is different than mastering information—otherwise, brain surgeons, auto mechanics, foreign language translators, and computer programmers would become experts through rote memorization. Knowledge doesn't work that way.

The need for highly specialized knowledge leads us to who we know, not just what. Getting the right people with the right knowledge at the right time in a project's lifecycle is one of a project manager's critical roles. Building a team that has the necessary knowledge or the means of accessing it is as important as getting the requirements right; one without the other is useless.

As NASA designs and develops systems of increasing complexity, it faces a critical need to transfer knowledge and expertise from those who have done this kind of work before to those who are doing it now. The agency also faces a well-documented generational challenge: a significant percentage of the workforce is currently eligible to retire.

So what's the connection between these knowledge-related problems and stories?

Stories are essential because they can convey context, meaning, and perspective. They enable us to:

- Transmit institutional memory from veterans to emerging leaders.
- Build a common understanding.
- Explore and learn from past decision points that led to successes or failures.
- Develop a community of reflective practitioners.

The ability to share knowledge effectively at NASA ensures the long-term sustainability of the agency. Great designs live on through heritage hardware for generations, but as they get passed down, the context and rationale for decisions and design choices tends to get lost. This is why the personal stories of practitioners are essential. We cannot anticipate when these stories will be critically relevant, but we do know that without them, the knowledge is gone. In a world where NASA practitioners are increasingly asked to do more with fewer resources, these are losses we cannot afford.

As always, we welcome your feedback.

Edward J Hoffman

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

Chapter 1

Trends in Project Management: The Macro View

[Editor's note: Dr. Ed Hoffman, director of the NASA Academy of Program/Project & Engineering Leadership, delivered the following remarks at International Project Management Day 2011.]

As part of our efforts to anticipate future needs, in 2008 we began tracking trends in project management. This effort included an extensive literature search as well as personal conversations with practitioners and thought leaders around the world affiliated with organizations such as the Project Management Institute (PMI), the UK-based Association for Project Management (APM), the International Project Management Association (IPMA), and the International Centre for Complex Project Management (ICCPM). We presented our first-year findings at the NASA PM Challenge in February 2009, and this became an annual activity.

The Academy's research into trends in project management over a three-year period led to the identificaiton of three broad categories of change. Image Credit: NASA APPEL

After three years, we assembled a master list of the eleven trends we had identified to date.

When we looked closely at the list for patterns, we noticed that the trends fell into three broad categories of change:

- The world around us
- Organizational capability, and
- The way we work as project practitioners

First, let's consider the world around us. There are four big-picture trends shaping the global business environment for project-based organizations.

Complexity

Complexity means different things to different people, but just about all spaceflight projects at NASA meet any definition. As projects become larger and involve more international and cross-sector partnerships, the project manager has to play a more active role in developing and maintaining support from a wide range of stakeholders. Since complex projects often have long time horizons, leaders need to sustain their projects through changing political, social, and economic circumstances. The skills required to succeed in this environment go beyond the traditional project management domains of cost, schedule, and technical performance. Organizations have to find new ways to give their project managers the knowledge and skills to deal with this dynamic environment. Our own framework for thinking about complexity in terms of technical, organizational, and strategic dimensions suggests that project-based organizations often underestimate the effects of organizational and strategic complexity. NASA engineers are world-class experts at finding ingenious solutions for technical problems. It is less clear how to work effectively with other organizations or stakeholders to achieve mission success.

Sustainability

Sustainability has arrived as a permanent feature of the landscape for project-based organizations. 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. In 2009, our organization partnered with the Office of Strategic Infrastructure to hold NASA's first Green Engineering Masters Forum. This coincided with President Obama signing an Executive Order that set sustainability goals for all federal agencies. Based on the success of that forum, we went on to develop a full-length training course on green engineering and hold other learning events on sustainability in government organizations.

Transparency

Projects exist in a more transparent, networked environment than in the past. President Obama's open government directive initiated a shift toward government transparency. Thirty-nine government agencies, including NASA, have developed open government initiatives. World Wide Web pioneer Tim Berners-Lee highlighted the work of Data.gov, introducing the possibilities (and controversy) that open data and ideas can offer, from new uses of satellite data to provide relief to earthquake victims in Haiti to WikiLeaks. Managers and leaders are expected to be open about their work. Information and decisions are no longer easily hidden.

Frugal Innovation

The growing demand for breakthrough technologies in engineering and management has led to the emergence of innovation grounded by cost. The watchwords of this practice are "reuse, repurpose, redesign." Cost-conscious innovators make use of existing hardware or technologies in novel ways that allow them to achieve ambitious goals with limited resources. Associated with products like the Nokia 1100 and the Tata Nano, this innovation paradigm can be seen in aerospace projects like the Lunar CRater Observation and Sensing Satellite (LCROSS), CubeSats, and Johnson Space Center's Project M, which sought to put a humanoid robot on the moon.

Project-based organizations are also dealing with new trends in management.

Talent Management

As technology, globalization, and system requirements drive us toward ever-greater complexity, there is an increasing worldwide demand for professionals who are highly skilled in the integration of complex systems. These skills cannot be taught in a training course or even a graduate program; they are the result of experience acquired on the job. This means the talent pool of successful, experienced practitioners is limited. Since demand for these skills is high in a global economy, talent is an international commodity that does not sit still. A skilled knowledge worker may have opportunities in Dubai, Shanghai, and Seattle. Talent also crosses sectors more fluidly than ever before: people hopscotch between government and the private sector in search of the best opportunities for growth. Talent management is a shared responsibility. In a project-based environment, both project leaders and senior executives have to address the needs of knowledge workers in order to compete in the global battle for talent.

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. 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. In NASA's case, the mission directorates function as its portfolio management organizations. These decisions involve allocating talent, funding, and physical capital in order to maintain a balance among portfolios that aligns with organizational needs. 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. As project-based organizations continue to grow around the world, portfolio management will increase in importance.

Project Manager Certification

Project-based organizations are under pressure to demonstrate that their project management professionals are qualified to run highly complex and expensive projects. In the federal government, the White House Office of Management set out new project management certification requirements in April 2007. My team spearheaded NASA's response to this requirement by developing a process for certifying NASA project managers. Certification is likely to grow in importance as project complexity continues to increase around the globe.

Project Academies

In the fall of 2008, I participated in a meeting with representatives from other organizations that have started their own project academies. At this point, the total numbers are small, but the attention from other organizations since that event has been strong and growing.

In addition to global and organizational changes, project-based work is also changing at the practitioner level.

Team Diversity

Diversity has multiple dimensions in a project management context, including 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 crucial to project-based organizations. The future of space exploration hinges upon the ability to collaborate with government space agencies, industry, academic institutions, and nonprofit organizations. Research also shows that project teams thrive on cognitive diversity, which can result from varying levels of education, experience, age, training, and professional background. Geographic diversity poses challenges in developing an environment that facilitates meaningful communication and productivity when team members are not collocated. Once considered a hindrance to effective team productivity, great distances among team members can be managed more effectively than before thanks to advances in technology.

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. While contacting people is no longer a problem, connecting with them is. Virtual work offers project managers the ability to attract and recruit talent from anywhere in the world and decreases project cost. On the other hand, it 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. Despite a mountain of research, there aren't yet 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.

Smart Networks.

Complex projects are about collaboration, alliances, and teaming—you're only as good as your network. Today wikis, Facebook, Twitter, and other platforms are rapidly spreading and transforming the way practitioners connect. Cultivating "smart networks" that provide broad streams of information, a global perspective, and sophisticated tools to manage information overload is integral to success.

What do these trends tell us? To put it simply, they require a change in mindset. It's no longer sufficient to limit our conception of project management to cost, schedule and technical performance. The world around us shapes the context of our projects in increasingly sophisticated ways, and the ground beneath us is shifting even as we write this. I fully anticipate that this will continue for the foreseeable future. Change is the one constant we can count on.

Chapter 2

Messages from the Director

The Innovation Paradox

ASK Magazine Winter 2011, Issue 41

Sometimes organizational "support" kills good new ideas.

Entrenched ways of doing things and bureaucratic caution can and do discourage innovation in organizations, but even organizational support for new ideas can be a mixed blessing.

"Do what you want as long as I don't know about it," a manager once told me. I could run with any idea I wanted, but if something went wrong, it was my neck on the line. I found this both freeing and discouraging. While I had the freedom to experiment, it bothered me that I was left to deal with the consequences if my good idea didn't pan out. And I was even more discouraged by the fact that I had to bring my new idea to life under the radar, without the organizational resources and official recognition that I thought could help it happen.

I believed then (and still do) that if something went wrong, the responsibility for dealing with it rested with me. I also believed (and still do) that a good manager should acknowledge good new ideas and, if he thinks they are worth trying, should ask, "What do you need from me?" Isn't it the job of a manager to support efforts to solve organizational problems in new ways or develop new and better ways of working?

You'd think the answer to that question has to be "yes," but it's a "yes" that comes with some interesting caveats and qualifications.

Years after that manager advised me to not tell him about the new ideas I was working on, I had a discussion with some engineers at one of NASA's centers and learned about a unique tiger-team activity that could potentially save money and streamline operations in the center's business area. This activity was supported by the center but had almost complete autonomy and was unknown elsewhere in the agency.

When I recommended to one engineer that the Academy might highlight some of his team's good innovative practices, he seemed hesitant. I later learned that this reluctance stemmed from my "management" status. From this experience and others like it, I have come to find that the survival of good ideas, particularly quiet innovations in the way work is done, depends on their ability to fly under the radar, especially in the early stages of their development. When good ideas are exposed, they face two likely outcomes: either the organization looks for ways to "control" the innovative approach (which often means making it less innovative and weighing it down with rules and requirements), or management genuinely wants to help develop and exploit the innovation.

At first glance, the second outcome does not sound like a problem, but often it is. Especially in their early stages, good new ideas tend to be delicate creatures. They probably have some weaknesses that need to be discovered by trial and error; if they are genuinely new, people may need to develop some new skills before they can carry them out effectively. Embryonic new ideas strengthen and mature thanks to the efforts of a very small number of people who understand the purpose and potential of those ideas, the nourishment they need, the time they need to develop, and the context in which they can thrive. Premature and too-vigorous organizational help can mean too many cooks in the kitchen. The new idea can easily be distorted, or succumb to unrealistic expectations about how quickly it will show results. Plenty of good ideas have been discarded as "failures" because they didn't pay off as soon or as spectacularly as management thought they should.

Good ideas need support to be fully realized, but they also dread support that is likely to bring these unintended consequences with it.

So what is the solution? Many organizations live and die by good new ideas. The challenge they face is to cultivate good ideas by giving innovators just the right blend of freedom and support. One simple approach that is not taken often enough is to let the innovators themselves decide how the organization can help them develop their ideas. A manager asking, "What do you need from me?" has a good chance of finding the sweet spot between no support ("Do what you want as long as I don't know about it") and idea-killing interference.

> ***Plenty of good ideas have been discarded as "failures" because they didn't pay off as soon or as spectacularly as management thought they should.***

Some organizations give employees the freedom they need to come up with new ideas by specifying that a percentage of their work time can be devoted to anything that interests them, with no pressure to come up with a successful product or even report back to their supervisors on what they're doing. A policy of encouraging individuals to spend 20 percent of their time on personal projects has produced some valuable innovation at Google (though recent news stories about creative employees leaving the company because they think it has become too bureaucratic and slow to adopt their ideas suggest how hard it is for large organizations to maintain the innovative spirit that made them successful in the first place). For many years, 15 percent of 3M employees' time was reserved for creative work. That, combined with frequent opportunities to tell others about their work, famously brought together the scientist who had developed a lightly sticking adhesive with the researcher looking for a way to keep slips of paper in place in his hymn book. The result: Post-it notes.

These examples of individual freedom to create raise another tricky point about the process of turning a new idea into a mature innovation—a useful product or practice. When the people working privately do eventually bring their good new ideas to the attention of the organization, it is often hard for the organization to understand their value, and the more innovative an idea is, the more likely it is that the organization will fail to get it. The classic example of this dilemma is the Xerox PARC story. In the 1970s, Xerox gave a group of very smart researchers at the Palo Alto Research Center approximately five years of absolute freedom and adequate funding to come up with ideas about the office of the future. They did their job well, inventing the graphical user interface, the computer mouse, the laser printer, and Ethernet networking. In a way, these innovations were too innovative for Xerox decision makers; they didn't understand their potential—didn't understand that they would in fact define the office of the future. So Apple, not Xerox, was the first to build a commercial, graphical-user-interface personal computer—now the standard for all personal computers.

What does all this mean for NASA? Giving employees "free" time to develop new ideas is definitely a challenge for a public agency like NASA, with its tight budgets and tight project schedules, but I think there are ways the agency as a whole and managers locally can encourage individuals and small groups to work on innovative ideas. Accepting the possibility that a new idea might flop (and many will) and not penalizing people when it does is one important step. Asking, "What can I do to help?" and providing just the right amount of support is another. (Just as astronomers have started talking about "Goldilocks planets"— planets that may harbor life because they are just right, not too hot or too cold—maybe we should talk about Goldilocks support for innovation.)

And when the great new ideas that people at NASA can and will develop are brought to the attention of the agency's decision makers, those leaders need to have the openness and imagination to understand their value and support the sometimes lengthy process of successfully putting them to work.

None of this is easy, but the future greatness of NASA depends on doing it right.

On the Importance of Values

ASK Magazine Fall 2011, Issue 43

"If you don't live it, it won't come out of your horn." — Charlie Parker

In the early 1980s, I was involved in conducting a study to determine the effectiveness of a new initiative promoting a more participative organization, interviewing employees and managers.

One young woman assured me that leadership had no interest in a more participative environment. I gently disagreed, pointing to efforts under way to promote participation—

quality circles, training, and employee–manager dialogues. She countered by telling me about her recent experience. She had returned from a quality circle and was offering ideas for the office. Her manager told her, "Look, you've had your four hours of quality-circle participation; for the rest of the week, just do what I tell you." Over the next month of interviews, I discovered that her experience was typical. There was a complete disconnect between what managers believed and their superficial support of this change initiative.

The more management pushed formal participation programs, the more employees considered the change to be insincere. In my briefing to leadership, I recommended placing much less emphasis on formal tools such as quality-circle groups, a recommendation that came as a jolt to senior leaders.

This experience motivated my dissertation research on "the impact of the managerial belief system on participative behavior." I concluded that, when managers do not really believe in an organizational change, their informal behaviors communicating that lack of support are more powerful than formal approval.

Leader values and beliefs communicate to a team what really matters, but few project managers and teams take time to address the importance of values to their mission. This lost opportunity contributes to dangerous disconnects between desired and actual performance.

NASA has four core values—safety, integrity, teamwork, and excellence—and projects have unique requirements that make additional values essential to success. For example, the Lunar Crater Observation and Sensing Satellite (LCROSS) project depended on low-risk integration, intense partnering, and trust-building communication. NASA project manager Dan Andrews and industry project manager Steve Carman, Northrop Grumman, clearly communicated these core values to the team.

And look at how safety, excellence, teamwork, and integrity play out in the **STS-119 Flight Readiness Review**.

Successful leaders embody desired project values and tell stories that amplify them. Practice and talk about open communication and that's what you get; show and talk about lack of trust and you get that. It is no accident that the stories of successful and unsuccessful projects sound so different.

Every project team should take the time to clarify their critical values and beliefs, asking the following:

1. What values will drive us to success?
2. Are our behaviors consistent with those values?
3. Are the stories we tell about our project (and each other) helping or hindering our performance?
4. Do we have a governance framework consistent with our values?

Charlie Parker said you need to live it for it to come out of your horn. Leaders and teams need to live—and talk about—the value that drives their projects.

The Appeal of Space

ASK the Academy October 28, 2011 — Vol. 4, Issue 8

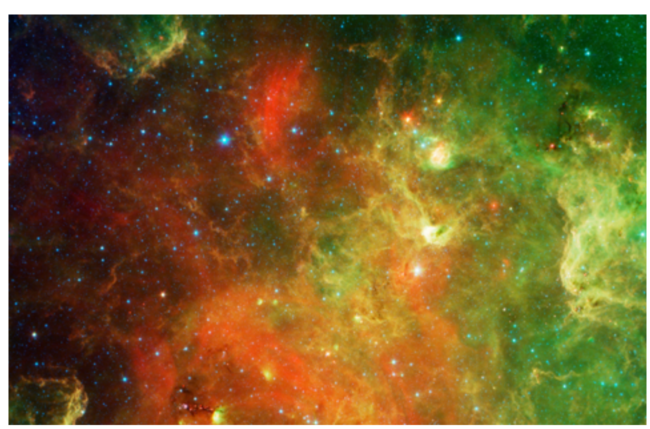
The first International Astronautical Congress (IAC) held on the African continent was a potent reminder that nations seek the benefits of space for many different reasons.

At an event commemorating the 40th anniversary of Apollo 8, former mission commander Frank Borman said, "The reason we went to the Moon on Apollo 8 was to beat the Russians."

I was reminded of Borman's words while I spoke with Dr. Peter Martinez of South Africa and Dr. Adigun Abiodun of Nigeria during a special Masters with Masters event at the IAC. Both had to blaze their own career paths in aerospace because there were not well-trod paths to follow in their respective countries; neither country had the capability to put a rocket into orbit. The odds were against them, but each persevered.

They were initially drawn to space by different motivations. Peter said he considered himself "one of the products of Apollo"—he was inspired by astronauts like Boreman. Ade was an engineer with expertise in hydrology whose interest stemmed from the potential of space applications—he was interested in learning what role satellites could play in understanding water resources in Nigeria. Both went on to work extensively with the United Nations' Committee on the Peaceful Uses of Outer Space (COPUOS), with Ade even serving as its chairman for a time.

The aspirations they hold for their countries in space are rooted in practical benefits. In the United States, on the other hand, we periodically engage in public debate about the merits of space exploration as a national priority. If we're no



This swirling landscape of stars is known as the North America Nebula. In visible light, the region resembles North America, but in this image infrared view from NASA's Spitzer Space Telescope, the continent disappears. Photo Credit: NASA longer trying to beat the Russians (to paraphrase Borman), some ask if space exploration is still worth the cost when there are many competing priorities for public expenditures. Peter and Ade did not talk about space exploration as an abstract concept. Each want their people to reap the benefits that more mature space-faring nations take for granted.

A common theme at IAC among individuals I met from emerging space-faring nations was the need to build local capability in space. Many said they do not want to continue relying on existing space powers; they want their own engineers and their own facilities. An educated workforce builds broader capability within an economy that leads to the ability to improve society.

In a time of transition and uncertainty at NASA, it's easy to lose sight of the big picture. Peter and Ade reminded me that space's power to inspire goes hand in hand with its power to improve the lives of millions in ways that many of us take for granted at this point. We can learn from them.

Chapter 3

ASK Magazine

Applied Knowledge: NASA Aids the Chilean Rescue Effort

By Don Cohen

Winter 2011, Issue 41

In the summer and fall of 2010, the world followed the story of thirty-three Chilean miners trapped nearly half a mile underground and celebrated their successful rescue in October. A team from NASA that included physicians, a psychologist, and engineers contributed to that success, providing knowledge gained from spaceflight programs to the government and experts dealing with this down-to-earth emergency. Traveling to the mine site in Copiapo, Chile, they developed a cooperative relationship with Chilean officials and specialists that made it possible to share their knowledge effectively.

The last of the trapped miners returns to the surface on October 13, 2010. Photo Credit: Hugo Infante/Government of Chile.

Making the Connection

The depths of a mine in South America are a long way from the Space Shuttle and the International Space Station, but there is a natural fit between what NASA knows and what the Chilean rescue team needed to know. Among other things, the space program has been an opportunity for decades of learning about the psychology and physiology of groups of people in confined spaces. And the agency's contingency planning—for instance, for rescuing the crew of a damaged shuttle—has included studying orbital equivalents of the miners' situation.

An existing relationship helped bring together agency experts and the Chileans. A NASA delegation that included Lori Garver, deputy administrator of NASA, and Al Condes, deputy associate administrator for International and Interagency Relations, had encountered Chilean space agency personnel at a meeting of the United Nations Committee on the Peaceful Uses of Outer Space. That connection led to a half-hour phone call between Dr. Mike Duncan, deputy chief medical officer at the Johnson Space Center (and eventual NASA team lead), and the Chilean Minister of Health. A teleconference later the same day provided NASA experts with an overview of the emergency. Using a mobile phone, the Chilean Minister of Health and several other Chilean health-care personnel at the San Jose mine summarized the health status of the miners and described their underground environment. Participating in the telecon from NASA were Duncan; Dr. J. D. Polk, chief of the space medicine division; Dr. Al Holland, operational psychologist; and three nutritionists: Barbara Rice, Sara Zwart, and Holly Dlouhy. These NASA experts e-mailed an initial set of medical, psychological, and nutritional recommendations to Chile shortly after that call.

Being There

During the teleconference, Duncan offered to bring a NASA team to the mine site, a suggestion that was readily accepted.

He made the offer, he said, because “experience tells you you get a better understanding out of being there.” That proved to be true, but better insight into the situation was not the only benefit of the five days the team spent in Chile at the end of August and beginning of September.

Being there allowed team members to develop relationships with their counterparts that were the kinds of social connections through which expertise can be understood, trusted, and put to use. Shared professional experience cemented these bonds and helped overcome differences in language and culture. NASA Engineering and Safety Center (NESC) Engineer Clint Cragg discovered that, like him, his Chilean counterpart had been a submariner. In addition to creating common ground, that background gave them both firsthand knowledge of what it meant to share a confined space with a group of men. They also had engineering in common, just as the physician-to-physician and psychologist-to-psychologist connections created common ground. (NASA psychologist Holland’s counterpart was named Alberto; sharing a name, though in most ways a trivial connection, also helped bring them together.) Physician Polk said, “We went down representing our government; we left as friends.”

Once in Copiapo, the team discovered that their earlier e-mails had never gotten to the people who needed them. That alone was a powerful argument for the value of being there. And the language difference, something of a problem during a teleconference or cell-phone conversation, ceased to be an issue working face to face, with Spanish speakers who had a good grasp of English and with the assistance of interpreters.

Applying NASA Expertise

Central to the medical expertise that NASA shared with the Chileans was an understanding of refeeding syndrome—the danger of overwhelming people who have been malnourished with the wrong kinds and quantity of food. After even a few days of starvation, a sudden influx of carbohydrates and calories can cause a rapid rise in insulin

Rescue workers practice a dry run with one of the capsules used to liberate the trapped miners at the San Jose mine near Copiapo, Chile, on October 11, 2010. Photo Credit: Hugo Infante/Government of Chile.

NASA Engineering and Safety Center Principal Engineer Clint Cragg (right) consults with Rene Aguilar, deputy chief of rescue operations for the Chilean mine disaster. Photo Credit: Cecilia Penafiel, U.S. Embassy in Chile

levels and associated metabolic effects that can lead to death. This lesson was learned the hard way after the world wars of the twentieth century, when well-meaning efforts to feed rescued prisoners of war and concentration camp internees caused many deaths. NASA has applied its understanding of the syndrome to contingency planning for the shuttle. The crew of a shuttle stranded at the Hubble telescope would have had to wait months for rescue, surviving on a diet of no more than 800 calories a day, so it was essential to plan for their safe renourishment.

The Chilean miners were starving, sharing very limited rations for seventeen days before the first supply hole was drilled. The four-inch diameter of the hole in effect imposed an appropriate level of refeeding, since it was impossible to send too much food to thirty-three men through such a narrow channel. But NASA’s refeeding expertise helped develop an informed plan for bringing the miners back from starvation that included keeping nourishment at an appropriate level when a second hole for delivering supplies became available. Polk said, “We knew we were making progress nourishing the miners when one of them sent back a dessert because it wasn’t what he wanted.”

Holland’s field—the psychology of confinement—is a rare specialty. His first task was to quickly give his Chilean colleague a framework for his recommendations. Once on site, he learned that the miners had more room than he’d thought; they had access to a little over a mile of tunnel as well as the garage-size space he knew about. This made it easier to find ways to deal with issues of privacy and hygiene while the men remained trapped.

All the members of the NASA team concluded that the Chileans, understandably focused on the rescue itself, had not yet thought through psychological and medical issues that would arise after they were brought to the surface. Chief among these was the importance of exposing the miners only gradually to family and others. Past space missions and the experience of prisoners of war had taught that it was critical to limit and carefully control contact during the first forty-eight hours.

NASA team members were impressed by the readiness of the Chileans to request and receive help from others, as well as the willingness of people throughout the country and around the world to contribute to the rescue effort—and their ingenuity. The miners were dealing with harsh conditions: a temperature of 90˚F, 90 percent humidity, and only hard, damp rocks to sleep on. Chilean officials put out a general call for sleeping cots that could be rolled up into cylinders no more than four inches wide. A few days later, thirty-three cots arrived at the site.

The Rescue Capsule

Once the second borehole was expanded to a diameter of a little more than 2 ft., rescue became possible. The initial requirements the Chileans devised for the rescue capsule were quite general, limited to maximum diameter, height, and weight, with no design specifics. The NASA team worked on recommendations for the capsule as soon as they returned to the United States.

Arriving home just before Labor Day weekend, Cragg sent out a request for engineers to help. The response was immediate and enthusiastic. On Tuesday morning, about twenty engineers met to formulate their recommendations.

The engineers worked with the physicians and psychologist on elements of the design that would ensure the well-being of the miners during what they were told would be a trip to the surface that could take between one and four hours. They recommended including devices that could deliver oxygen and measure oxygen levels during the ascent. Two-way audio and video communication was also recommended, to monitor the condition of the miners and lessen their sense of isolation as they slowly rose through a narrow, half-mile-long hole.

> ***Being there allowed team members to develop relationships with their counterparts that were the kinds of social connection through which expertise can be understood, trusted, and put to use.***

The final set of recommendations included a harness that would allow the occupant to escape back down the hole if the capsule became stuck, the requirement that a single person be able to strap himself in the capsule, and a strategy for dealing with friction in the borehole that could otherwise break the capsule after repeated trips. They recommended either Teflon pads or spring-loaded wheels. The second of those choices was adopted by the Chileans.

Cragg said he was impressed by how good the NASA engineers were at thinking the problem through and imagining what could go wrong. They also thought carefully about how to present the recommendations. Their initial plan was to organize them by functional area (for instance, power, structure, materials, and human factors). One of the engineers quickly realized that they should instead be divided into two sections, structure and support services, so that those elements could be worked on separately. Two Spanish-speaking members of the team helped make sure the recommendations would be clear to non-native English speakers.

On Friday, they had finished. Cragg noted, "The NESC routinely assembles teams on short notice to help solve problems. Our previous experience helped to get our list of suggested requirements done rather quickly." They sent the results to Chile. The message came back: "We understand it all."

Again at a Distance

Back home, the team members again experienced some of the difficulty of trying to work at a distance. Duncan said it was helpful to know people individually and have their direct e-mail addresses, but it was frustrating not to be sure that the information offered by the NASA team got where it needed to go. Holland talked about the difficulty of not being able to monitor changing psychological conditions directly, and the delay caused by having to translate e-mails sent back and forth between the two countries.

But the combination of personal relationships and new communication technology could work wonders at a distance. On a Skype call, Polk's Chilean counterpart asked him to recommend a safe speed for the rescue capsule, one that would not cause men in a weakened condition to black out. Polk, at home with his laptop, e-mailed a couple of colleagues, checked some web sources, and was able to provide the answer in a few minutes without leaving the couch he was sitting on.

Members of the NASA team emphasize that the Chileans were always the major players in the rescue effort, and that their determination and skill were key to its success. But NASA's expertise unquestionably contributed to that outcome. When, like the rest of the world, the team members watched the miners emerge one by one to be embraced by their loved ones, they knew they had helped turn a potential tragedy into a triumphant reunion.

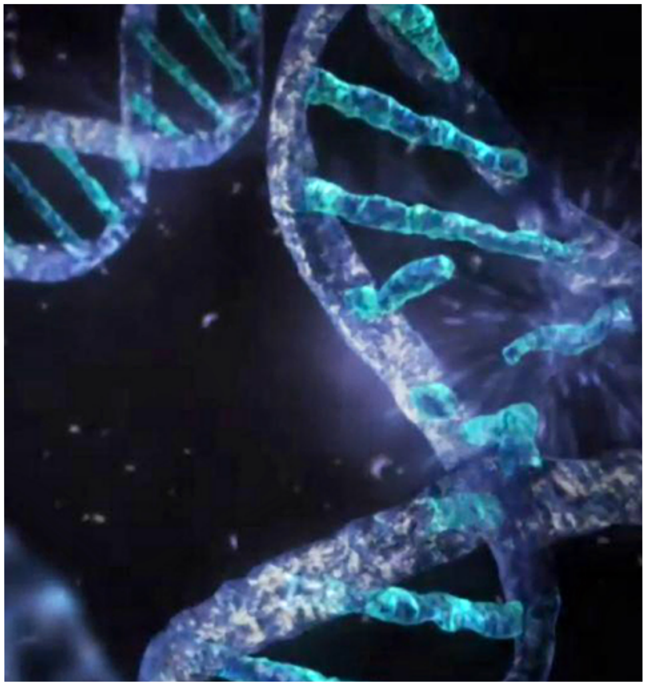
Factoring in Humans

By Haley Stephenson

Winter 2011, Issue 41

To a rocket scientist, you are a problem. You are the most irritating piece of machinery he or she will ever have to deal with. You and your fluctuating metabolism, your puny memory, your frame that comes in a million different configurations. You are unpredictable. You're inconsistent. You take weeks to fix. ... A solar cell or a thruster nozzle is stable and undemanding. It does not excrete or panic or fall in love with the mission commander. It has no ego. Its structural elements don't start to break down without gravity, and it works just fine without sleep.

~ Mary Roach, Packing for Mars



Space radiation hitting cell DNA. Photo Credit: NASA

The human body does weird things in microgravity. Bones weaken as they lose density, the heart periodically goes off beat, and muscles atrophy despite hours of mandated exercise. Flying in space is unnatural for terrestrial beings. With our sights set on flying humans in the harsh space environment farther and longer than ever before, engineering future space transportation systems with the human factor in mind has become more important and challenging than during the first half century of human spaceflight.

NASA estimates it will take ten months for astronauts to reach Mars for a yearlong mission, and ten months to return—a total of nearly three years. Currently, astronauts spend no more than approximately six months in microgravity on the International Space Station. When they return to Earth, their muscle tone is on par with an octogenarian, and they cannot walk away from a spacecraft on their own. These astronauts do not lack the "right stuff"—rather, this is the reality of how microgravity affects the human body in today's state-of-the-art spacecraft.

Before we flew anything in space, no one knew how we would function without a continuous gravitational field. Today, planning for long-duration space exploration is still a daunting task with big challenges such as radiation exposure and bone-density loss, and the less visible, but equally complex, challenges such as the response of neurosensory systems to prolonged microgravity. One piece of this puzzle is understanding the change in responsiveness that occurs in the human gravity-sensing vestibular system—that system in the inner ear that contributes to our sense of balance and spatial orientation. It is the neurosensory system that allowed us to take a small step and a giant leap on the moon but, if left in microgravity too long, may not allow for either to happen on Mars.

Gravity As Most of Us Know It

William "Bill" Thornton is a former NASA astronaut, medical doctor, principal investigator, and physicist. He is meticulous, rigorous, and precise about most everything. He also was part of the astronaut support crew during Skylab and flew as a mission specialist on shuttle flights STS-8 and STS-51B. He studied, among other things, changes in the vestibular system while in microgravity and during reentry to Earth.

"Here I am, sitting solidly in my chair," said Thornton. "I feel my joints are oriented … to the [force of gravity]." He then shut his eyes. "I still know which way I am oriented … primarily because of these remarkable little hair cells, microscopic hair cells, tens of thousands of them in each inner ear."

When these hair cells bend, the brain determines how the head and body are oriented with respect to gravity. But they can't bend on their own. They are set in a gelatinous layer that has little "stones" called otoliths (Greek for "ear stone") embedded on top of the layer. When gravity tugs on these stones, they tug at the gelatinous layer, causing the hair cells to bend.

"If I tilt my head forward just sitting here in my chair, [gravity] is going to deflect the [otoliths] and hair cells downward, which tells me one of two things," said Millard "Mill" Reschke, NASA's chief of neuroscience located at Johnson Space Center. "I've either turned my head forward or I'm accelerating in one direction backward."

> ***NASA estimates it will take ten months for astronauts to reach Mars for a yearlong mission, and ten months to return—a total of nearly three years.***

To determine which of these is happening, another vestibular subsystem is needed. This subsystem only detects head tilts and not the sensation experienced when riding in an elevator or accelerating in a car, which is called linear acceleration. If both the otoliths and this subsystem respond, then the brain interprets that the head is tilting. If only the otoliths respond, the head (and hopefully the body) are linearly accelerating.

"But," continued Reschke, "if I tilt my head in 0 g, what happens? Nothing. There's no signal from those hair cells to tell me that I have moved my head forward." This is when things get wonky.

"In the new environment where there is little gravity, the brain begins to learn that stimulation of the otoliths is only via linear acceleration," said Reschke, not tilts. Upon return to Earth, the brain continues for some time to interpret otolith responses just as it did in microgravity. "Making head tilts now feels like a linear acceleration."

A Hot Microphone

In the early 1970s, Reschke was teaching at a university when he got an offer to study neurosensory systems at

NASA. Not one for university professing, he said, “I made a beeline for [NASA].”

When he arrived, Apollo was ending and Skylab was gearing up. Reschke would study vestibular function in microgravity. His lab was small, three people at most, and he befriended Thornton. “He was the first astronaut I had ever met,” recalled Reschke, “and we immediately started debating.” Until Thornton retired, the two men spent most of their careers challenging one another in order to better understand vestibular instability that resulted from spaceflight.

Mission architecture limits the amount of equipment and procedures that will be available to treat medical problems. Limited mass, volume, power, and crew training time need to be efficiently utilized to provide the broadest possible treatment capability. Photo Credit: NASA

When Reschke started, conventional thinking held that if an astronaut didn’t move in his environment, he couldn’t adapt to it. Since the Mercury program, space capsules had only gotten bigger, and Skylab would offer the most room yet. More space for an astronaut to move around in meant a greater likelihood of possible changes in the vestibular system’s response and, consequently, the brain’s interpretation of movement. What they found was that these changes occurred more often than anyone realized.

“At the time, as far as anyone knew, motion sickness was not a common side effect of spaceflight,” said Reschke. “It wasn’t until the Skylab flights when [astronauts] finally admitted to motion sickness being a problem.” Their admission came after an astronaut asked where he should dispose of his emesis (vomit) bag. Unbeknownst to him, he had left his microphone on and the jig was up. A love of flying and the fear of being declared “unfit” made astronauts reluctant to report motion sickness.

In 1989, NASA started the Extended-Duration Orbiter Medical Project (EDOMP) to better understand the changes microgravity induced in humans. At that point, the shuttle hadn’t flown astronauts for more than ten days. When they returned, astronauts experienced difficulty standing up and sometimes fainted. With plans for building and inhabiting an International Space Station moving forward, NASA was concerned about a crew’s ability to land and exit the orbiter after long-duration missions in microgravity.

The EDOMP program led to the development of space exercise devices like treadmills and rowing machines to help mitigate some of the bone, muscle, and cardiovascular problems caused by microgravity. As for space motion sickness, there are some psychological training techniques NASA has up its sleeve, but most astronauts are prescribed medication to lessen the effects.

Microgravity As Few of Us Know It

“A first and basic problem of any animal that moves in space is to orient his body with the environment,” said Thornton. “Just imagine for a second now that you don’t know which way is up or down, or you don’t know which way to move your arm,” he continued. That is what space is like. There are no trees or buildings to tell you which way is up and which way is down.

After launch, when the astronauts unstrap themselves from their seats and start to move about the orbiter, “almost immediately you start to experience a little fluid shift in your body where fluid is moving from the extremities toward the head and the trunk of the body,” said Reschke. “Your postural response becomes changed significantly.” Most astronauts feel like they’re tumbling and assume a quasi-fetal position: bend in the spine, head thrust forward, knees drawn up.

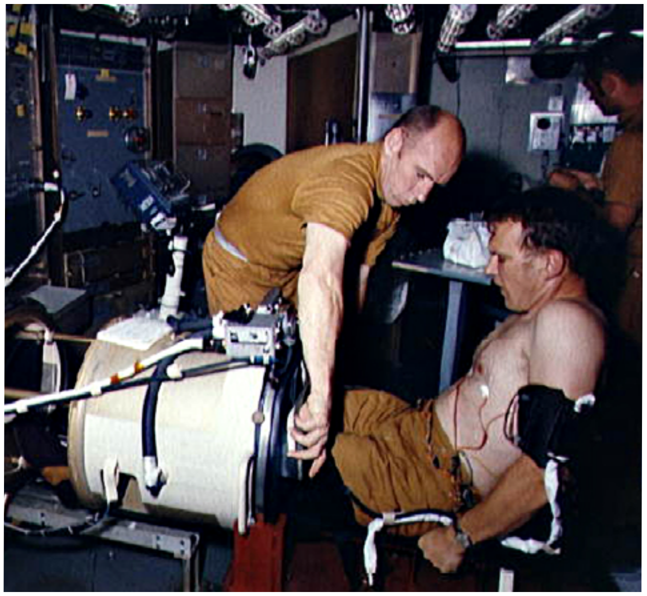
During one mission, Thornton recalls unstrapping himself and floating out of his chair, immediately going about his work with his crewmate. “We moved very, very carefully, making no sudden motions,” he said. “About an hour [later] and both of us were springing a leak [a euphemism for vomit].”

His crewmate was the first to reach for his emesis bag. Thornton’s medical training kicked in. “I grabbed him and started doing a standard routine neurological exam,” he said. There was no pre-indication it was going to happen,

recalled Thornton. No nausea, disorientation, nothing. At this point his neurological exam “was totally normal.” At least it was until Thornton had his crewmate close his eyes and proceeded to tilt him like the hands on a clock.

“He’s one of the nicest men, but when I did that he came up shouting, ‘Don’t do that!’” recalled Thornton. His crewmate had space motion sickness and had become hypersensitive to the tilting motion.

Thirty minutes later, Thornton couldn’t get his emesis bag out fast enough. “Believe you me, globules of vomit floating around in weightlessness is not a pleasant thing.”



During a preview of Skylab medical altitude test experiments, Astronaut Karol J. Bobko is being configured for a test in the Lower Body Negative Pressure experiment while Scientist-Astronaut William E. Thornton assists. Photo Credit: NASA Johnson Space Center

This is only one of several effects microgravity has on the vestibular system. Since the system and the muscles that control eye movements are connected, delays in eye reflexes can also occur. It may take one second or more to fixate on a visual target. When you turn your head to track an object in your visual field, your vestibular system tells the eye muscles that the head is moving and that if they'd like to keep that object in view, they need to move, too. In space, eye-tracking movements can be delayed due to the lack of gravity acting on the vestibular system.

Reprogramming

Once on the ground, readaptation to the earth begins almost immediately. Some systems take longer than others to recover, but within the first six to eight hours, most are returning to normal. Said Reschke, "You're establishing neural connections like crazy at this point. Turning your head to see something after a long mission can take up to several days [to recover]."

An overhead view from the Skylab 4 Command and Service Modules of the Skylab space station cluster in Earth orbit. Photo Credit: NASA Johnson Space Center Embassy in Chile

Head turns can sometimes cause distortion and blurring of the visual field. If the mission lasts longer than six months, it can sometimes take weeks. When astronauts return, they feel very heavy. Said Thornton, "When you walk, you notice that you are unstable." Shut your eyes and you may fall down.

All of a sudden, gravity is tugging on the tiny otoliths in your ear in a way that it hasn't for months.

The Future of Human Factors

Engineers and scientists have addressed most of the immediate problems that arise from long-duration spaceflight: eating, drinking, breathing, sleeping, and going to the bathroom. But invisible changes such as vestibular instability, loss of bone density, and cardiovascular changes will require more innovative solutions and greater collaboration between NASA disciplines.

Although working in different capacities, Reschke and Thornton continue to wrestle with the challenges of sustaining human functions during space-exploration missions. Thornton is writing a handbook for engineers that offers information on how to design space transportation systems of the future with human factors in mind. Reschke looks to continue expanding upon his study of the vestibular system in microgravity at Johnson and through enhanced international collaboration.

"We know that people can live in space for six months without a whole lot of difficulty," said Reschke. "It's those transitions between 0 g and 1 g—the transitions back to Earth or another gravitational environment—where you're going to have a problem." It is those other gravitational environments that are of interest to aerospace engineers and neuroscientists alike.

Gravity on Mars or an asteroid is a fraction of the gravity we feel on Earth. But there won't be a ground crew to lean on during egress on Mars. Without better ways to mitigate the effects of microgravity on human space explorers, one small step might actually be one careful crawl.

The Potential of a New Workplace

By Naoki Ogiwara

Winter 2011, Issue 41

In Europe and Japan, "Future Centers" feature spaces designed to enhance creative thinking.

Organizations—no matter what industry they belong to—are now facing more complex social, technological, political, and environmental challenges than in the past. To tackle such issues, some European and Japanese organizations have created unique physical spaces called "Future Centers." Some of them are producing appreciable results.

Tax and Customs Administration Creativity

At "The Shipyard," a number of officers use the room named "The Brain" when they brainstorm. The room is carefully designed to stimulate users to come up with many wild ideas: walls as whiteboards, lighting patterns, intentionally not-very-comfortable stools (comfortable chairs make people too relaxed for brainstorming, according to them), and an out-of-sight door (doors being points where somebody might intrude and break concentration). A room called "The Silence," in contrast, is serene and hushed, with layers of curtains that shut out any sound and with comfortable cushions—one can even lie on them—and without visible doors or windows. This room is not for discussions but for calm dialogue and reflection.

The Shipyard is owned and operated by the Dutch Tax and Customs Administration. It was built in 2004 by renovating a historic building for the purpose of leveraging the intellectual capital of the agency and enhancing the creativity of its officers. Why is creativity so emphasized at the Tax and Customs Administration? According to Ernst de Lange, founder and innovator of The Shipyard, there is a strong need to leverage officers' brains: "Tax evaders and frauds are very creative. To collect money, or seize assets from them, we simply need to be more creative. Effective education for taxpayers and future taxpayers, utilization of intuition in the revenue office's work—there are so many fields where we need to bring out the potential of our staff's creativity."

A KDI's Future Center. Photo courtesy of Naoki Ogiwara

The Shipyard was built for internal use by the agency, and the more than one hundred topics discussed there in a year are all related to the agency's long-term vision. Over four thousand officers used the center last year, and inspector teams for substantial tax evasions are frequent users, as De Lange suggests. The Shipyard consists of more than a dozen different kinds of rooms for different types of discussions and activities. In addition to The Brain and The Silence,

The Sky Box at ABN AMRO's Dialogues House. Photo courtesy of Naoki Ogiwara

spaces include "The Workshop" for prototyping ideas, "The Harvest" for refining rough ideas, and "The Theater" for developing participants' perspectives and mind-sets. They are all well designed to meet their specific objectives.

Physical space is not everything at The Shipyard, however. Choosing the right topic and designing appropriate processes are keys for success. De Lange and his team are in charge of selecting topics—what will and will not be discussed at The Shipyard—and designing discussion processes: whether there will be just one workshop or a sequence of multiple workshops, who will be invited, which room(s) to use, what methodologies of discussion to use, what type of facilitators to assign. A leading concept of The Shipyard is "license to disturb." Through creative ways of generating, prototyping, and executing ideas of officers, the agency has gained significant economic benefits, including generating more efficient methods of tax collection.

The Shipyard is one example of Future Centers spreading across Europe. A couple of dozen Future Centers have been launched by government agencies, public-sector organizations, and private companies. The centers are basically highly participative working and thinking environments for accelerating innovations via co-creating, prototyping, and building breakthroughs. Although their purposes vary depending on organizations' aims and context, there are common assumptions behind them. All the organizations face issues so complex that they need more creative ways to solve them through the fusion and creation of knowledge by diverse stakeholders.

Choosing the right topic and designing appropriate processes are keys for success.

The World's First Future Center

The first Future Center was built at Skandia Life Insurance in Sweden in 1996. Skandia was already well known as the first company to successfully implement intellectual-capital management. After their efforts to leverage intellectual capital, the company realized they needed special environments with spaces, methodologies, and tools that could maximize the value of those invisible assets. Dr. Leif Edvinsson, one of the key drivers of intellectual-capital management at Skandia, and his team believed the headquarters building or branch offices were not the best places to generate and test wild new ideas for the future. After team discussions and some experiments, the company created the first Future Center by renovating an old lakeside house. A number of teams visited it to think in new ways. They developed many ideas, some of which have resulted in major successes over time.

The Spread of Future Centers

Similar thinking in the United Kingdom led institutions including Royal Mail and the Department of Trade and Industry to open their own centers around the year 2000. Inspired by the success of Skandia's pioneering Future Center, other organizations in Europe began their own initiatives. There are currently more than twenty European Future Centers in both public and private sectors. "Dialogues House" is a Future Center owned and operated by ABN AMRO, one of the largest banks in Europe. It was launched in 2008 by drastically renovating a trading room. Like The Shipyard, Dialogues House has specialized spaces, including "Sky Box," semi-opened mezzanine space for collaboration; "Pressure Cooker," closed space for brainstorming and intensive discussions; and "Forum," for large-scale events with studio features. The bank's purpose in building Dialogues House is to drive

Ceiling of The Silence at the Dutch Tax and Customs Administration's Shipyard. Photo courtesy of Naoki Ogiwara

innovation by incubating ideas related to entrepreneurship, innovation, sustainability, and collaboration. It is also open to outsider social entrepreneurs and nonprofit organizations. Many business ideas have been turned into actual businesses, including, for instance, using the bank's credit management abilities in new areas such as the art trade.

The movement landed in Japan in 2007. KDI (Knowledge Dynamics Initiative), a small consulting unit of Fuji Xerox, launched its Future Center in Tokyo. It is used mainly for holding workshops with Fuji Xerox clients, many of whom visit the center every day. Over 3,500 people visited the Future Center in 2010. KDI has formed a "Future Center Community" with more than forty Japanese organizations to expand the movement

Entering the Pressure Cooker at Dialogues House. Photo courtesy of Naoki Ogiwara

in the country. Some other Japanese organizations have launched their own Future Centers.

Key Elements of a Future Center

Although each Future Center has its own unique features, they have some things in common. All centers are facilitated working and meeting environments that help organizations prepare for the future in a proactive, collaborative, and systematic way. To realize the objectives of creating and applying knowledge, developing practical innovations, bringing citizens in closer contact with government, and connecting end users with industry, they share some key elements:

- Careful design and use of space. Extraordinary settings encourage creative mind-sets and behavior; different modes of discussion require different spaces.
- Facilitation. A skilled facilitator is needed to energize and encourage participants and support the processes.
- Process design. The staff need to be familiar with various styles and methodologies associated with workshops, discussions, and dialogue and be able to choose the appropriate one in a given situation.
- Hospitality and playfulness. Participants are only able to extend their limits when they feel safe and have fun.

There's no magic behind the success of Future Centers; they simply follow the rules of individual and organizational creativity. The key is a holistic approach to bring out that creativity by tapping the power of space, dialogue, and process. Increasing numbers of European and Japanese organizations have started to see the benefits of the creativity inspired by these idea incubators. And the concept is still evolving: the Future Centers of the future will likely be even more effective.

About the Author

As a senior consultant at KDI, Fuji Xerox, Naoki Ogiwara has led several dozen client projects on knowledge management, change management, and Future Centers as well as global benchmarking research for more than a decade.

The Limits of Knowledge

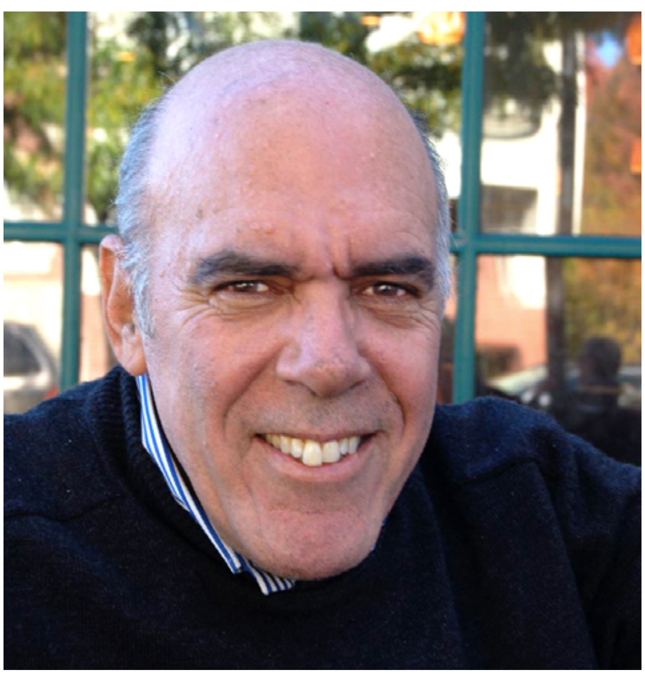
By Laurence Prusak

Winter 2011, Issue 41

Have you thought about why some individuals, institutions, agencies, and even countries seem to exhibit a persistent pattern of bad judgment? There are so many examples to choose from that it may be unfair to single out specific examples, but think, for instance, of the different reactions of Norway and Dubai to the revenues that came from their discoveries of large energy resources. Norway prudently invested its windfall in long-term education and infrastructure and future financial stability, resisting powerful pressures to spend it right away or return it to the taxpayers. Dubai spent much of its wealth on showy projects, building, among other things (and with the help and encouragement of Citicorp), a ski slope in one of the hottest places in the world.

We all could list our favorite examples of flawed judgment. Our recent financial crisis sadly offers enough examples to fill many large volumes. Perhaps it is more useful, though, to try to think about what goes into good judgment. To do that, we need to decide what judgment is. We also want to consider how it differs from knowledge, because being knowledgeable does not guarantee that individuals or institutions will make smart decisions.

Let's look at Wall Street and most of the other financial centers around the world. Who could deny that these firms and their government regulators were filled with knowledgeable people? They recruited the top students of the top business schools, continuously weeded out those who seemed not smart enough and driven enough for their hypercompetitive environment, and continuously poached the most talented brokers and analysts from each other. So how could organizations that possessed so much knowledge and talent make such disastrous mistakes—mistakes grave enough to plunge the world into a recession that destroyed millions of jobs and untold wealth?



Aristotle had an answer for this question that still rings true. He saw knowledge as a tool, a method, a technique that could not arrive at good judgment without virtue. "Virtue" in this case refers to a set of values and dispositions that Aristotle calls "practical wisdom." Practical wisdom is another term—a good one—for what we usually think of as good judgment. Modern researchers have added that judgment can be thought of as the context and background of decision making.

> ***No project or situation exists in isolation, and understanding the context of your work can lead to a wiser choice than a narrow focus on a problem to be solved.***

Probably this distinction between knowledge and judgment does not especially surprise you. We all know people who are highly intelligent and possess extensive knowledge of one or more subjects but who make terrible decisions. They lack practical wisdom. They don't have good judgment.

So should organizations try to hire people who are "virtuous," in Aristotle's sense of the word? Well, organizations sometimes try to choose people who seem to possess practical wisdom, but that quality is not always easy to identify. Besides, it's easy to be so impressed by the knowledge, drive, and confidence of candidates that the question of judgment does not get the attention it deserves.

Certainly (as I discussed at the beginning of this little essay), good judgment is in short supply in many institutions. So here is a very brief list of some ways to try to improve the quality of judgment—your own and that of the people you work with.

Encourage democratic discussion and decision making. The "great man or woman" theory of leadership—the idea that one person has all the answers—is deeply flawed. The odds favor developing sound collective judgment when trust and goodwill are present in a group.

Look to all sources of potential help. Knowledge comes in many flavors and varieties. Make sure your sample size is adequate to your needs.

Think in terms of past and future time. Nothing happens without background or potential consequences. Encourage others to do the same.

Pay attention to context. No project or situation exists in isolation, and understanding the context of your work can lead to a wiser choice than a narrow focus on a problem to be solved.

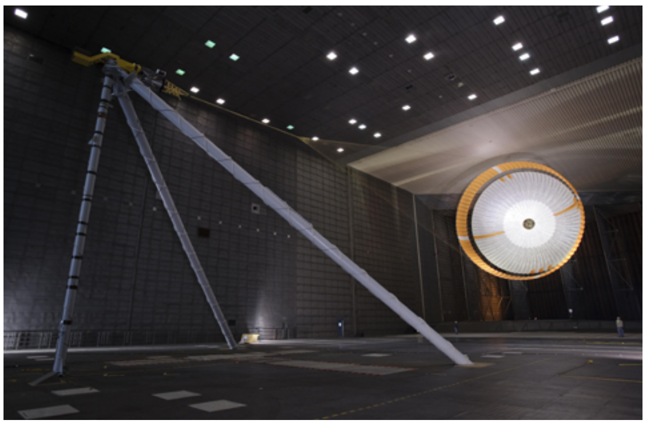
Consult your values as well as your knowledge when making decisions.

Mars Science Lab: The Challenge of Complexity

By Richard Cook

Spring 2011, Issue 42

One of NASA's great strengths over the past fifty years has been our ability to execute complex, one-of-a-kind projects. In some cases, we have literally written the book on how to carry out programs with difficult technological, scientific, or programmatic objectives. It is somewhat surprising, therefore, that we've had significant problems in the past few years with some highly visible, complex projects. I work on one of those projects, the Mars Science Laboratory (MSL).



The parachute for NASA's Mars Science Laboratory (MSL) being tested inside the world's largest wind tunnel at Ames Research Center. An engineer is dwarfed by the parachute, the largest ever built to fly on an extraterrestrial flight.
Photo Credit: NASA/Ames Research Center/JPL

MSL is the next major step forward in NASA's Mars Exploration Program and will address key questions about the past and current habitability of Mars. The project is also developing critical new technology for landing on Mars, acquiring and processing surface samples, and conducting long-duration surface operations. This is probably the most complex planetary mission that NASA has ever attempted. As a result, it has stressed our implementation processes, our technology, our engineering capabilities, and our people. Although the project hasn't launched yet, it has been extraordinarily useful in one regard: demonstrating the challenges of managing complexity on large-scale programs.

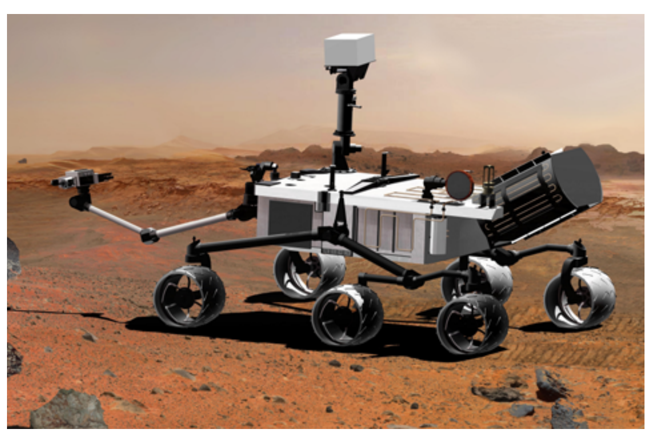
So, what is complexity? The word is frequently thrown around as a sort of synonym for "difficult." But it is more than that. Paraphrasing Webster, "Complexity is the quality of being intricately combined." The characteristic that separates complex projects from merely difficult ones is the number of interconnected elements that are tied either technically or programmatically. Flagship efforts are becoming increasingly difficult and complex. Increased complexity is a primary cause for the challenges we've experienced. The MSL development experience is rich with examples where our ability (or inability) to effectively manage complexity has provided valuable lessons.

At the recent Project Management (PM) Challenge in Long Beach, California, I gave a presentation on those lessons across domains including technology infusion, margin management, schedule planning and oversight, and the role of external reviews. Given space limitations here, I will focus on the connections between system architecture and complexity.

Defining the right system architecture—the top-level structural and behavioral relationships between parts of a system—is critical to managing complexity. So what makes the "right" system architecture? The easiest answer is, the one that is as simple as possible but no simpler; the one with the most "separation" between elements; the one with the simplest interfaces, the most functional independence, the least reliance on those one-size-fits-all solutions that drive custom-interface accommodation. Greater complexity and interaction mean increased potential for problems and increased difficulty in testing to discover them.

Unfortunately, a number of factors frequently undermine system architecture simplicity. Examples include technology limitations and complexity, mass/volume constraints, cost, and the use of heritage hardware. I could mention several examples of MSL handling systems complexity well, but I'll start with one where we didn't.

We inherited several key aspects of the MSL architecture from the Mars Exploration Rover program. One example was having the rover's avionics control the entire mission from launch through landing. This architecture was adopted for MSL despite the fundamentally different functions for launch; cruise; entry, descent, and landing (EDL); and rover operations. The intent was to take advantage of the core elements of the rover avionics (the processor, the power converters) to perform cruise and EDL functions. Adding additional boxes outside the rover required accepting the associated cost, schedule, and mass impacts. The problem with this architecture is that it significantly increased the



Artist's concept of the Mars Science Laboratory in Martian terrain.
Image Credit: NASA/JPL-Caltech

complexity of the design by functionally integrating the rover and cruise/EDL systems. The cruise/EDL system could not be designed and tested independently from the rover because it was an integrated system.

So why was this choice made? We did an early concept study of a "smart" descent stage. The idea was to put enough avionics on the descent stage to control the vehicle during cruise and EDL (the rover would be along for the ride). The primary reason we didn't choose that approach is that we have a tendency in the early phases of a project to base system-design choices on box-level factors. Because the cost, schedule, and design of boxes can be coarsely quantified, it is simpler to factor them into design choices. Less apparent factors like the amount of input/output a box requires, the interface complexity, fault protection implications, and verification challenges—all byproducts of system complexity—are difficult to quantify and factor into system decisions. These items typically don't manifest themselves until later in the development cycle and are frequently the source of significant cost growth. By not adequately factoring this cost-growth risk into the system trade, we ended up with a design with the fewest number of boxes rather than the least complex architecture.

The characteristic that separates complex projects from merely difficult ones is the number of interconnected elements that are tied either technically or programmatically.

Another driver toward functional over-integration is the pervasive impact electronics technology is having on our core systems. Unlike the world of thirty years ago, virtually all electronics we use today come from a commercial sector with different and diverse technology drivers, not just space applications. The increased functionality possible with high-density field-programmable gate arrays (FPGAs), low-voltage parts, and high-speed bus architectures are dramatic and enabling, but they increase complexity enormously. The pressure to have "less" hardware and depend more on software results in highly integrated and highly complex designs.

One associated pitfall is that we don't approach the incorporation of these new devices into our systems with the same degree of rigor we treat other types of technology. That may partly be due to the perceived maturity of the commercial components. We frequently have trouble with parts that have a commercial track record but haven't been through a full flight qualification program. A good success story on MSL was our efforts to "mature" high-density, radiation-tolerant FPGAs.

The Mars Reconnaissance Orbiter and other programs had experienced a series of problems with less dense parts, so MSL adopted an aggressive program to establish acceptable design guidelines, packaging/rework approaches, and thermal control/qualification strategies. The result was that the project did not experience significant FPGA technology issues during the build/test campaign.1

The FPGA challenges we did have were associated with the design complexity caused by functional over-

Spacecraft technicians at the Jet Propulsion Laboratory prepare a space-simulation test of the Mars Science Laboratory cruise stage in a facility that simulates the cold, vacuum environment of space.
Photo Credit: NASA/JPL-Caltech

integration. The large number of logic gates available in modern FPGAs allows many functions to be combined into a single component. This does complicate the design effort, although some parts of the FPGA "code" can be developed by parallel teams. The verification and validation effort, however, grows dramatically because so much functionality is combined. Our test methods don't really support ways of performing rapid, parallel testing of a single, highly integrated element. A long serial-test program is difficult to manage, is brittle to changes and problems, and can be inappropriately curtailed if schedule pressure mounts. A design based on a larger number of simpler elements would permit parallel component testing and (with appropriate interface definition) simpler system testing as well.

Fault tolerance is another system-architecture driver that can significantly affect complexity. Inappropriate evaluation of local-versus-system fault tolerance can dramatically increase complexity without necessarily improving overall reliability. An example from MSL was the incorporation of partial redundancy in the core rover avionics. The mass and volume of the avionics are major drivers on both the rover configuration and the required capabilities of the entry, descent, and landing system. Heavier or larger avionics increase EDL system risk by reducing control-system performance margins or increasing landing velocity and loads.

The pressure to have "less" hardware and depend more on software results in highly integrated and highly complex designs.

Intrinsically, however, avionics fault tolerance is provided by adding redundant boxes with some degree of cross-strapping. (Cross-strapping permits redundant boxes to work with other redundant elements in the system architecture.) On MSL, the project took an intermediate position of incorporating some partial avionics redundancy to mitigate box-level failures while not driving EDL risk adversely. Unfortunately, the resulting system is neither fish nor fowl from a complexity perspective. By having a combination of single-string and redundant elements, the resulting fault-containment architecture is more complex and more difficult to design, analyze, and verify than either a single-string or fully redundant design. The marginal increase in reliability associated with the partial redundancy may not have been worth the increased complexity.

These are just a few examples of the drivers that can push a system architecture toward increased complexity. Potential institutional mitigations could include additional training to increase our systems engineering expertise on both the sources and consequences of architectural choices. Additional efforts can also be made to rigorously review system architecture choices to understand the long-term implications. Upgrading our cost and schedule estimation processes to capture the impact of complexity on cost and schedule risk would also be very useful.

From the perspective of an individual project manager, establishing simplicity as a programmatic goal is both a symbolic and a real step toward managing development risk. This is particularly imperative for projects with profound technical and engineering challenges. Intrinsically difficult missions like MSL are made much more challenging if managing complexity gets inadequate attention. Policy direction advocating simplicity is a useful first step to keeping complexity contained.

About the Author

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Solar Dynamics Observatory Lessons Affirmed

By Brent Robertson and Michael Bay

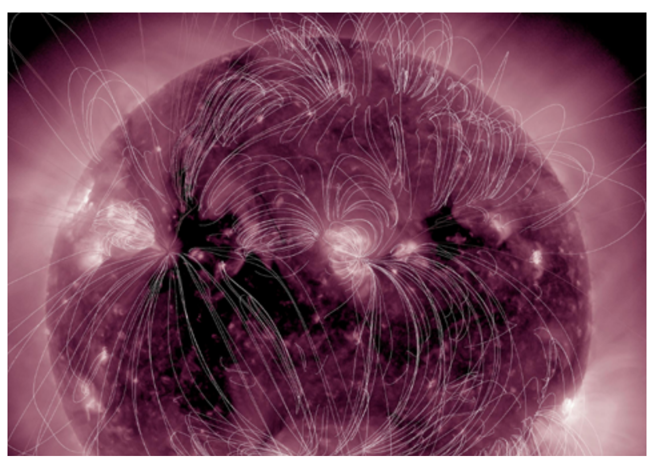
Spring 2011, Issue 42

It is always exciting watching something launch into space. It is even more thrilling when the launch is the culmination of many years of work. Having worked on a large space-science mission at Goddard Space Flight Center, we had the privilege of working with a team of people dedicated to developing a one-of-a-kind scientific satellite that would do things never done before. Watching the Atlas V blast off from the Cape with our satellite onboard was a moment of truth. Would the satellite perform as designed? Had we tested it sufficiently before launch? Did we leave a latent flaw? Had we used our resources wisely to achieve the greatest possible scientific benefit?

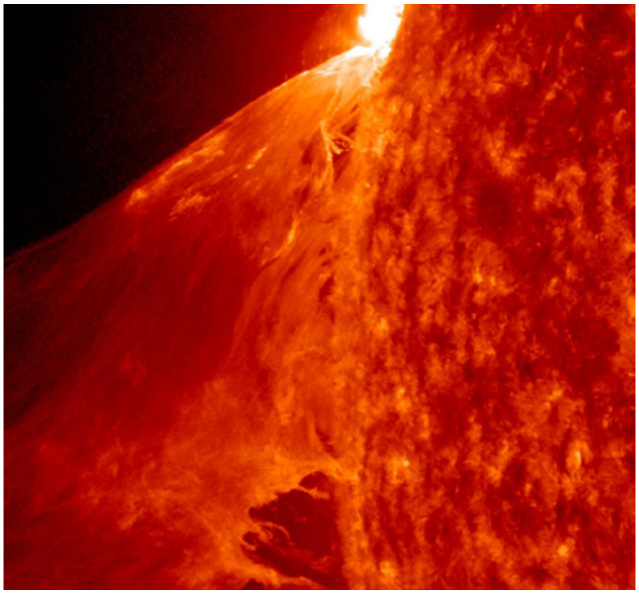
The Solar Dynamics Observatory (SDO) mission is changing our understanding of the dynamic structure of the sun and what drives solar processes and space weather, which affect our lives and society. Goddard led the team who built the spacecraft in house, managed and integrated the instruments, developed the ground system and mission operations, and performed observatory environmental testing. We had a compelling mission, adequate funding, a seasoned project management team, and a strong systems-engineering and quality-assurance staff. The instrument investigations were provided by highly competent and experienced organizations at Stanford University, the Lockheed Martin Solar and Astrophysical Laboratory, and the University of Colorado Laboratory of Atmospheric and Space Physics. It's what we considered a dream team for mission development.

SDO was a technically challenging mission with stringent science requirements necessitating the application of new technology in a severe orbital environment. In order to mitigate potential threats and ensure success, the SDO project instituted a thorough "test like you fly" philosophy at the system level along with a rigorous risk management and problem-tracking approach. A risk identification and mitigation process was put in place for everyone to use early on. As we moved from the design to the build phase, we emphasized stringent problem investigation, tracking, and closeout across the entire project. This process proved to be an effective technique to aggressively identify and track threats to mission success. We found and resolved system-level anomalies that otherwise might have gone unreported or been left open. The result was reflected in the findings of the SDO prelaunch safety and mission success review, where it was noted that there were fewer residual risks than normal.

Like most projects, SDO encountered a number of programmatic and technical issues throughout its



This illustration maps the magnetic field lines emanating from the sun and their interactions superimposed on an extreme ultraviolet image from SDO. Photo Credit: NASA/SDO



A rather large M 3.6–class flare occurred near the edge of the sun on Feb. 24, 2011; it blew out a waving mass of erupting plasma that swirled and twisted for ninety minutes.   Photo Credit: NASA/SDO

development. Looking back at these issues affirms a number of lessons that may be useful for other projects. A budget rescission just after critical design review removed 30 percent of the funding at a critical time during development. The project was forced to slow down instrument development and defer spacecraft procurements. At the time, we gave up some schedule reserve. The launch readiness date slipped by only four months, but we realized in hindsight it was not a wise decision. We later encountered delays in flight-hardware deliveries due to challenges in developing high-speed bus electronics needed for transferring large quantities of data for transmission to Earth. The launch readiness date slipped another four months, which meant SDO lost its launch slot. Due to a backlog of Atlas V launches, a four-month slip ended up costing the project another fourteen months waiting for its turn to launch. We were very worried that we would lose critical people to other jobs during the wait, but in the end almost all the original team supported launch. ***Lesson affirmed: Giving up schedule reserve before starting a flight-build effort is a mistake.***

Looking back at the technical issues encountered by SDO, we can identify some as "high consequence." These were issues that required rework of flight hardware, issues whose resolution held up integration and test efforts, or issues that could not be fully mitigated and resulted in a residual risk at launch. Could these issues have been avoided? Maybe some of them. Unexpected events always happen, especially when building a one-of-a-kind spacecraft. That is why we test. More than half these issues were due to interactive complexity among components that was hard to predict analytically and could only be discovered after system integration. What is worth noting is how these issues were identified and how they manifested themselves.

Some issues were discovered with vendor components after they were delivered to the project. Although the vendor was required to subject components to an environmental test program, component testing did not always uncover all problems. For example, one component had a latent workmanship issue that was not discovered until thermal-vacuum testing. The device experienced anomalous behavior in a narrow temperature range. The problem was caused by an incorrect number of windings on an inductor that was selectable by an operator during the unit's building and testing. The device's functional performance had been verified by the vendor at the plateaus of component-level thermal testing but not during transitions. ***Lesson affirmed: Not all test programs are equal; what matters is having the right test program and, in this case, functional testing as temperatures vary over their full range.***

Another example involved the identification of a shorted diode on a component's redundant power input. Component-level testing verified the power-input functions one at a time but did not specifically test for power-feed isolation between redundant inputs. This short was not discovered until the component was powered by a fully redundant system on the observatory during a test designed to show power bus isolation. Such "negative testing," designed to verify protective functions, had uncovered a problem and was necessary to show the mission could continue in spite of failures. ***Lesson affirmed: Verifying functions may need negative testing at the system level, especially where protective or isolating features are intended.*** Both of these components were de-integrated from the observatory and returned to the vendor for repair, which delayed the completion of system integration and testing. But it was better to find these problems prelaunch instead of on orbit.

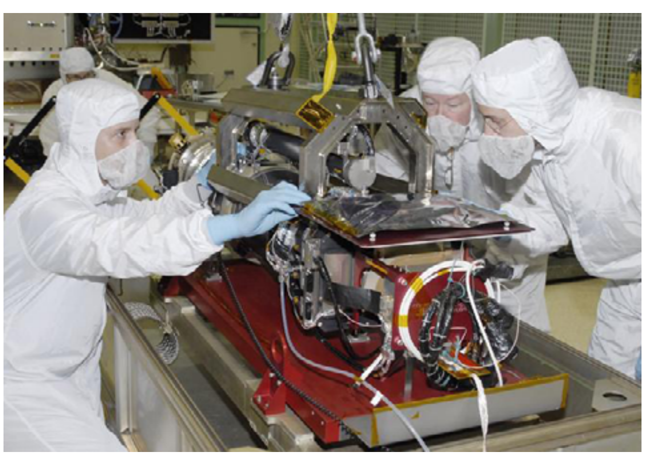
Not all test programs are equal; what matters is having the right test program and, in this case, functional testing as temperatures vary over their full range.

The SDO design used common products in multiple subsystems. This was not only cost efficient but also allowed for the discovery of potential issues through testing a larger number of common units, thereby enabling reliability growth. For instance, a common low-power switch card used in eight locations had a latent flaw that was found during the build of a flight spare unit. A short to ground that had not been uncovered during the testing of other similar cards due to a marginal tolerance was discovered. A possible on-orbit problem potentially induced by launch vibration or extensive thermal cycling was averted by having a design with a common product. Unfortunately, five electronics boxes were affected and all of them were already integrated on the observatory. We decided to de-integrate the boxes and fix the problem. It could have been worse; the observatory had not yet gone through its thermal-vacuum testing. But it was unnerving to find a problem like this so late in the test program. ***Lesson affirmed: The devil is in the details and the details can't be ignored, as Murphy's Law and Mother Nature will show you in flight, sometimes in dramatic fashion.***

Moments after launch, SDO's Atlas V rocket flew past a sundog and, with a rippling flurry of shock waves, destroyed it.
Photo Credit: NASA/Goddard/Anne Koslosky

One issue not due to complexity occurred during a bakeout. Most of SDO's hardware had been baked to remove contaminants; the satellite's high-gain antenna subsystem was one of the last pieces of hardware needing a bake-out. It was just another bake-out; what could go wrong? It turned out that the facility control software for test heaters was left turned off and nobody noticed that the uncontrolled test heaters subjected the hardware to damaging hot temperatures until it was too late. The good news was we had spares on hand to rebuild the subsystem, but this was a problem that could have been avoided. ***Lesson affirmed: Apply product savers1 to protect flight hardware from damaging conditions should test environments run awry, and continuously assess what can go wrong during testing of flight hardware, no matter how often similar tests have been performed.***

SDO used a rigorous "test like you fly" approach at the system level to find issues that might have escaped detection during design, review, and lower-level testing. In today's systems, where interactive complexity can conceal potentially serious issues and impede our ability to foresee failure, it is essential to understand mission-critical functions and work tirelessly to uncover the "unknown unknowns." It was especially critical to apply a "test like you fly" philosophy to increase the chance of finding the latent flaws that matter. Often, seemingly small problems and failures are the tip of an iceberg threatening something bigger. Many loss-of-mission failures are foreshadowed by prelaunch discrepancies. It was not good enough just to make things work. We needed to make sure we identified and understood why they didn't work and then properly obviate or mitigate that cause.

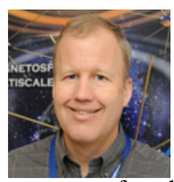


One of the four Atmospheric Imaging Assembly telescopes arrives at Goddard for integration and testing. Photo Credit: NASA

SDO was scheduled for launch on Feb. 11, 2010. But the SDO team was challenged one last time, when a winter "storm of the century" closed much of the Washington, D.C., area, where the Mission Operations Center was located. Undaunted, the entire team made it in to support the launch. It was a spectacular launch, with the rocket flying through a rainbow known as a sun dog, which the rocket's shock wave extinguished. The rocket did its job, placing SDO in a geosynchronous transfer orbit.

Since then, on-orbit science operations continue to exceed requirements and the spacecraft has performed flawlessly. The few residual risks accepted at the time of launch have not come to pass. The use of a rigorous process to uncover potential problems was a success. The technical issues, the wait for a launch, the snowstorm—all these challenges had been met. The years of hard work from many talented people paid off.

About the Authors



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Reflecting on HOPE

By Don Heyer

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In the final days of 2008, the Science Mission Directorate and the Academy of Program/Project and Engineering Leadership released a new opportunity under a fledgling program: the Hands-on Project Experience, or HOPE. It was described as a "training opportunity" and solicited proposals

Recent hires who work for the Jet Propulsion Laboratory successfully launched a sounding rocket carrying the TRaiNED project 75 miles above Earth's surface on Dec. 6, 2010, from the U.S. Army's White Sands Missile Range in New Mexico.
Photo Credit: White Sands Missile Range

for small-scale projects from in-house teams of young engineers and scientists. The philosophy behind HOPE was simple: the most effective way to learn how to do something is to actually do it. Only months earlier, management at the Jet Propulsion Laboratory (JPL) had teamed with a group of young employees to form the Phaeton Program around the idea that smallscale flight projects could be used as a tool to rapidly prepare personnel for larger-scale missions. These parallel ideas met in a shared undertaking in early 2009 when TRaiNED (Terrain-Relative Navigation and Employee Development) was selected to become the first HOPE project. I was selected to be the project manager for that project.

The TRaiNED Concept

The HOPE training opportunity requested proposals for a sounding-rocket project that would have a useful purpose for the Science Mission Directorate. Coincidentally, the JPL Phaeton Program had identified a sounding-rocket-based project to develop a technology called "terrain-relative navigation" (TRN) as one of its first projects.

TRN is a technology that could support precision navigation of future spacecraft. One can refine inertial-measurement-based position estimates using computer-vision technology to identify and track features in ground imagery. The objective of this TRN project was to advance the technology's development by collecting ground imagery, inertial measurement unit data, and GPS data during a sounding-rocket flight and to use that data set to validate TRN through post-flight data processing.

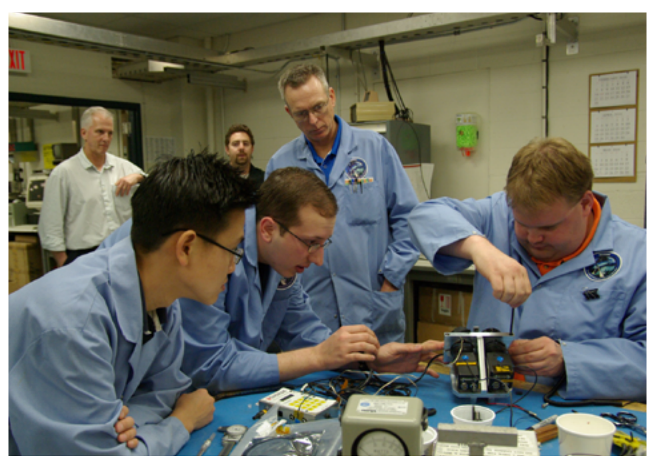
The TRN project presented significant appeal as a training experience. The project would be able to leverage a considerable portion of the technical design from a related sounding-rocket flight flown a few years earlier. The new project would essentially add to and incrementally improve the previous design, keeping the technical scope of the project manageable but challenging. What's more, most members of the project team from the earlier flight were available and many could act as mentors to the new team. Finally, the program would support the developing project team periodically with short classroom-training modules designed to follow the life cycle of the project.

The pieces fit together nicely, but there was one gaping hole: the program hadn't identified a way to get the TRN payload onto a sounding rocket. Project HOPE was the solution, and it quickly became clear that the two programs complemented each other nicely.

Implementing TRaiNED

The TRaiNED project was entirely staffed with early-career hires—employees less than three years out of school. These early-career hires were competitively selected at JPL from a large pool of applicants that wasn't limited to the engineering team: all the project positions were filled with early-career hires. Furthermore, the search for candidates for each position wasn't limited to those who worked in the related area of the institution. A wider search was conducted to give people who were hired out of school in one discipline an opportunity to gain experience in another.

While each member of the project team brought a different background to the table, there were several common learning experiences that we encountered and tackled as one. For example, nobody on the project team had experience writing requirements, yet each individual was responsible for developing the requirements on their own element of the project. There were many different opinions about how to best structure and define these requirements, and these inconsistencies showed through at the project's system requirements review. This review



Project HOPE team members work on the TRaiNED rocket during the assembly and debug processes. Photo Credit: NASA/Berit Bland may not have gone as smoothly as many would have liked, but it served as strong motivation for the team to come together in the following weeks to rework project requirements as a group instead of individually. The result was not only a stronger set of requirements but a more integrated project team.

As TRaiNED was the first HOPE project, there wasn't any clear model to follow to effectively combine the training and technical goals of the project. Rather, the definition of both programs had to take place in step with definition of the project. At times this was a source of frustration: both programmatic training objectives and project technical objectives had to be accommodated, and these two objectives were sometimes in conflict. Working through these struggles became one of the cornerstone learning experiences for the project team, however, as we were forced to negotiate—as any other project would—the scope and expectations of our work with several stakeholders.

Most of the team quickly learned how many stakeholders they actually had as they started work on their work agreements (WAs)—agreements between the project and line management that describes the work that is to be done and the resources that will be available to complete it. We expected to be able to sail through the WA approval process with relative ease but discovered quite the opposite. In some cases, getting a WA approved became a lengthy process of give and take between the project and the line spanning several weeks. While completing the WAs wasn't automatic, the conversations they required helped to bring all the stakeholders together with the same understanding of the project's goals and approach.

In order for the project team to have an authentic hands-on experience, TRaiNED was treated like other flight projects. So, while only a fraction of the size of most flight projects, TRaiNED was planned and structured in the same fashion. Tailoring of the typical processes and requirements was conducted by the project team through normal channels. While there was significant tailoring to reflect TRaiNED's relatively small scale, the project team experienced firsthand all that goes into planning and executing a project from its conceptual stages through its launch.

Launch

Fast-forward to December 2010. The team that started the project nearly two years earlier is still almost completely intact. During the past two years, we have completed and passed the major project life-cycle reviews; have designed, built, and tested our payload; and worked with a team from Wallops Flight Facility (WFF) to integrate the payload into the sounding rocket that sits on the launcher ready to fly. The JPL, WFF, and White Sands Missile Range teams have gathered in the block house or at other posts around the range and are busying themselves with their prescribed prelaunch tasks. We've been here before: once in June when the weather moved in at the last minute and forced the launch to be canceled, and again in September when the weather forecast didn't even hint at cooperating. After all the prelaunch tests check out, December's countdown is also placed into a hold because the skies have clouded over. As the launch window nears its end, most people are beginning to resign themselves to another weather cancellation when, with just a few minutes remaining, Dr. Martin Heyne (the TRaiNED principal investigator) announces that there's been just enough of a clearing in the weather to go for the launch.

If an argument ever had to be made in support of Project HOPE, it was exemplified by the following fifteen minutes. The calm, composed manner in which each member of the project team quickly transitioned from a weather-induced limbo to efficiently executing the final steps of the launch countdown was rewarding to watch and special to be a part of. The collective poise exhibited by the team as the rocket left the rail didn't exist in 2008. It was poise that could not have come from attending classroom lectures or from reading a stack of books. It came from experience.

Lessons Learned and Suggestions for Future Projects

Two more HOPE projects are currently under way, and with any luck their success will mean more to follow. Now that a few months have passed since the TRaiNED launch, I've had a chance to consider what helped make TRaiNED a success. While the following list is in no way comprehensive, I'd like to highlight four factors that I found to be of particular importance.

- **Project Selection.** The selection of an achievable concept is critical. The project has to be challenging enough to be worthwhile, but manageable enough so that the project team can divide their attention between solving technical problems and learning about how a flight project is executed. Learning how to execute a flight project, let alone actually doing it, is time consuming and easy to underestimate.

- **Institutional Support.** JPL provided us with a phenomenal level of support throughout the project. The institutional investment in a program to help direct and shepherd along this project and others like it was invaluable.

- **Review Board Selection.** It is important to convene a standing review board that recognizes the developmental nature of the project, but will still give objective feedback where the project demonstrates weaknesses. The standing review board assembled by Project HOPE for TRaiNED was an asset throughout the project. The TRaiNED standing review board not only helped us identify weaknesses in the project and correct them, but helped coach us so that we were better prepared for the next review.

- **Mentors.** Mentoring was critical to the success of the TRaiNED project. We were fortunate enough to have a team of engaged mentors who routinely took time out of their schedule to help us with whatever problem we happened to be facing that particular day. Most importantly, our mentors were invaluable in identifying upcoming problems that we weren't even aware existed. I lost count of how many times they asked me, "Have you thought about XYZ?" I invariably realized that I hadn't but needed to.

About the Author

Don Heyer is an electrical engineer in the flight communications section at the Jet Propulsion Laboratory. He is currently working on the ExoMars Trace Gas Orbiter project, and he is the project manager for TRaiNED.

Managing in an Unsettled Environment

By Scott J. Cameron

Spring 2011, Issue 42

Government service has historically been associated with a relatively stable work environment, at least when compared with private-sector organizations forced to continually adapt to shifting market forces in the pursuit of survival and profitability. The year 2011 is proving to be an unusually challenging one for NASA and other government agencies, however, replete with change and tumult. Fiscal year 2012 promises to be even more challenging.

The Unsettled Environment

The change and uncertainty are coming from a combination of three main factors: budgets, politics, and an aging workforce.

Budgets

More than half the fiscal year had elapsed before Congress and the president finally came to closure on annual funding on April 8, 2011. Unprecedented debate over how deep budget cuts needed to be this year represented a break in a pattern that goes back at least half a century, which saw presidents typically requesting less money than Congress eventually appropriated.

While the debate over the FY2012 funding level has barely gotten started, House leadership is talking about cuts on the order of $6.2 trillion over the next decade, while the president is also beginning to signal an interest in further reductions after FY2012. Even the Senate is talking about freezing some FY2012 spending at the FY2011 level. Given increased costs due to inflation, even a freeze constitutes a cut in real dollars.

At NASA, these fiscal challenges are compounded by programmatic changes. The Space Shuttle program is coming to an end. Constellation is slowly winding down, using precious financial resources in its last months that could be used productively elsewhere.

Political Environment

The year 2012 will see the return of a presidential election race and its focus on politics and political advantage. Preoccupation with politics will be heightened by the divided party control in Congress, with the Democratically controlled Senate and the Republican-controlled House each looking for ways to score political points. In such situations, sound, public policy-making can be impeded by political considerations, which often lead to stalemate and inaction.

Workforce

For years, federal human-capital management leaders have been warning of an impending retirement flood. The argument is that agencies will experience a massive wave of baby-boomer retirements any time now.

This flood has not yet materialized. The stock market decline in recent years has wreaked havoc with the Thrift Savings Plans balances of many federal employees; like many workers in the private sector, they have been reluctant to retire until their retirement funds regain their pre-financial-crisis strength. At the same time, a historically high unemployment rate has limited federal employee opportunities for post-retirement employment outside government.

But the wave of retirements is coming. Prospective retirees are older now than they were two years ago and, for many people, the attractions of retirement pull all the more strongly as they age. Also, the president and Congress have decided that federal employees will not receive annual cost-of-living adjustments for two years. For many employees, that means their "high-three" compensation years that affect the size of their annuity in retirement are not going to get any higher, so there is little financial incentive to continue in the federal workforce. Finally, potential turnover of political officials, even when an incumbent president is reelected, can create a period of frustration and drift that many senior employees may want to avoid.

Managing Through Uncertainty

Managers can and must do three things to navigate these uncertain times. They must plan for change, support the workforce, and ensure that the organization is capable of performing once most of the change has happened.

Plan for Change

The critical steps in planning are collecting potentially relevant material, with a bias in favor of official sources of information and against tapping into the office rumor mill; analyzing the information collected; and then deciding how to adapt to the anticipated change. In general, do not be swayed by press coverage; editorials; employee blogs; posturing by local, state, or federal elected officials; and interest-group efforts to thwart administration policy. Since purveyors of incorrect or trivial information are often among the loudest communicators, this can be a challenge.

Strive to explain what the organization will look like after the change, so employees can visualize the future and think about their place in it. Without underplaying difficulties, identify and share the positive.

Agency leadership testimony before Congress, official press releases, and approved communications to employees are among the best information sources. Those documents go through a thorough internal clearance process, and, therefore, are most likely to accurately represent the official viewpoint.

Analysis of the information collected needs to be done in the context of understanding how and when the change will likely happen, and who will be instrumental in accomplishing it. Change can be driven by a variety of processes, each with its own timelines and windows of opportunity for influence. It is critical to understand what's driving a particular change, so the interested manager may inject himself or herself into the process in the most effective way at the most opportune moment. Typical change drivers are budget, litigation, acquisition, regulation, executive orders, and congressional action to amend current or create new statutory authority. Agency managers should develop a mental model of what the organization will look like after the change, so appropriate strategies can be defined to get from the "as is" to the "to be."

The process driving the change will typically provide crucial information on when the change will actually begin and when it is expected to be completed. It is important to understand the motivation of those forcing change. Do they want to cut budgets, decrease staff, or simply shift the emphasis of an agency? Unless their motives are understood, there is a real risk that strategies chosen to manage change will be misguided and unsuccessful, since they may not address the "problem" to be solved. Indeed, there is even the possibility that an adaptation strategy chosen without regard to the driver behind the change may exacerbate the perceived problem, and cause the manager to lose credibility.

Support the Workforce

The single best way to support the workforce is through practicing good communication. Communication must be

- **Open.** Keep no secrets from employees unless you have been given information confidentially.

- **Frequent.** If employees don't hear from their manager enough, they will make up their own imaginative—but invariably wrong and often damaging—explanations of what is going on.

- **Honest.** Share what you know and what you don't know; don't try to fake it, because people will notice and you will lose credibility.

- **Respectful.** Recognize that employees will vary a great deal in terms of experience, sophistication, and anxiety, so don't give the impression that any questions are inappropriate.

- **Multimodal.** Don't rely on just one form of communication; people learn differently and not everyone may have ready access to a single mode of communication.

- **Consistent.** Leverage the chain of command to share and exchange information, but make sure that all communicators are "on message."

- **Current.** Stay on top of developments so you can share promptly when conditions change to retain confidence and reduce anxiety.

- **Prudent.** Avoid talking to the press without a handler from your public affairs office to avoid unnecessary pitfalls, since a reporter may be more interested in creating an exciting story than reporting the "truth" as you see it.

Strive to explain what the organization will look like after the change, so employees can visualize the future and think about their place in it. Without underplaying difficulties, identify and share the positive. Adhere to the party line, since nothing is gained by publicly disagreeing with policy decisions. Expect to repeat your message, since not everyone "gets it" the first time, and people will take comfort in constancy in an unsettled environment.

If it looks like your organization is going to have to absorb a significant budget cut, then you need to think strategically, tactically, and humanely.

From a strategic perspective, be active, not passive. Seek to drive change rather than be a victim of it. Discover if the change creates an opening to reshape the organization in ways you wanted to pursue in the past that may have been impractical in a more staid institutional setting. Perform a multisector workforce analysis, taking the opportunity to reconsider the appropriate mix of federal employees, contractors, and other partners in light of the future mission. Envision the federal workforce that you will need to succeed after the change, and conduct all other activities with that end in mind.

Tactically, be willing to make difficult decisions intelligently rather than abdicating control to bureaucratic processes. Make sure you are aware of applicable labor-relations regulations and constraints. Use early-outs and buyouts selectively to reshape the workforce. Working closely with your acquisition office, consider modifying contracts to refocus effort on the highest-value work. Choose not to exercise option years or cancel unnecessary contracts to conserve cash. Manage vacancies thoughtfully, avoiding across-the-board hiring freezes. If all else fails and you find yourself presiding over a reduction in force, find and work closely with an expert in the human resources office who will show you how to use your discretionary powers to shape it. Creatively target the reduction functionally and geographically, to help shape the outcomes as much as possible. Finally, get it over with as soon as possible to control the damage to morale and reduce the flight of your best talent.

Be humane by being honest with people about their futures; don't try to protect them from the truth. If you have not been doing it all along, this is the time to separate senior people who are poor performers; the organization cannot afford to carry them anymore. Work closely with human resources, but get it done. Set up an outplacement process to help capable people who don't have a natural place in the changed organization to find a better niche in other parts of the agency. Pay special attention to your star performers; let them know that you want them around and plan to look after their interests as much as you can.

Preserve the Capability to Perform

Keeping in mind your vision for the "new" organization, be clear with yourself and your team, and human resources, on the competencies your people will need to succeed in the future. Then deliberately hire people who can catalyze the transition to the new organization. Do succession planning, and shape your training program so that it enhances the desired competencies and equips high-performing junior people to handle more-senior positions. Use the individual performance-management system to signal the new skills, knowledge, and competencies that you want in your new organization, and to focus the efforts of your staff on work that will advance the transformation. Work very hard to keep your high-performers engaged, so they will stick with the organization through the transition.

Don't forget to manage your relationships with contractors and other partners so they, too, begin to focus on creating the target organization. As applicable, revise contracts, grant agreements, and cooperative agreements so they are aligned with the new organization.

Resist the temptation to follow the typical but deplorable pattern of responding to budget cuts by eliminating travel, awards, training, and new hires. While this may be a tempting stop-gap strategy to solve a short-term budget problem, it is not a good long-term choice. You and your customers are better off with a relatively smaller organization that is well trained, well rewarded, gets to develop professionally through travel to important events or locations, and can hire new people when they are needed, than with a slightly larger organization that can do none of these things. This implies that initial staff reductions should be deeper than what is necessary to simply "squeak by." Squeaking by is no way to run an organization over the long term.

Finally, in managing an organization in an unsettled environment, do not forget to manage your own needs. Without allowing yourself to take the opportunity to periodically refresh yourself, your own morale and attitude will be less than what you want to project and less than what you need to successfully manage a difficult transition.

About the Author

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Galileo's Rocky Road to Jupiter

By Erik N. Nilsen and P.A. "Trisha" Jansma

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On October 18, 1989, the Galileo spacecraft lifted free from the shuttle cargo bay. This step was the culmination of a development effort spanning eleven years and six major mission redesigns, and the first step on a long, rocky road to Jupiter. Galileo's ultimate success is a tribute to the creativity, hard work, and determination of the many individuals and groups who wrestled with problems that easily could have doomed the mission.

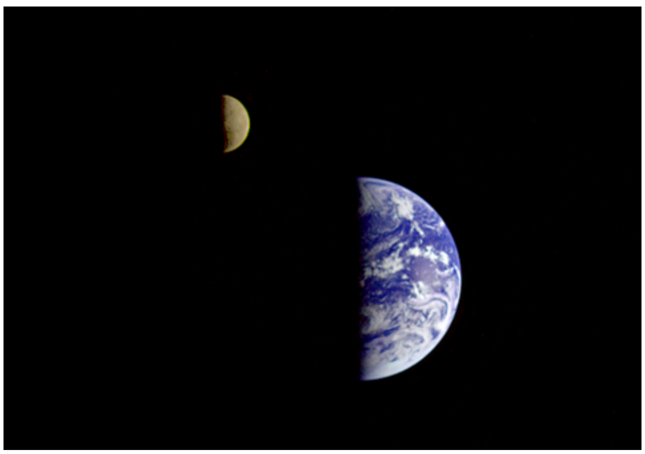
During STS-34, the Galileo spacecraft atop the inertial upper stage is deployed from Atlantis's payload bay. Photo Credit: NASA

Galileo was originally conceived in the late 1960s and received its first development funding in 1978. Planned for launch in 1982, its fate was inextricably intertwined with that of the Space Shuttle, then under development. Galileo was to be one of the first deep-space missions to launch on the shuttle; early slips in the availability and capability of that vehicle directly affected Galileo. They also influenced the design.

Early on, the decision was made to use new technologies previously used only in Earth-orbiting spacecraft. Dual-spin spacecraft design was new to interplanetary craft and new to the Jet Propulsion Laboratory (JPL). The dual-spin design has one section of the spacecraft fixed while the other part spins. Remote-sensing instruments (which desire a stable platform for imaging) could be mounted on the fixed section, and the fields and particles instruments (which desire a complete view of space in all directions) could be mounted on the rotating section. This was an innovative way to meet science requirements, but it presented many design hurdles.

The extended journey required design modifications, including adding several sun shields to project the spacecraft when flying to Venus for its first gravity assist.

The second decision was to use a deployable high-gain antenna (HGA). Constraints on the size of an antenna that could fit within the shuttle cargo bay and a desire to reduce mass—a constant Galileo design issue—led to this choice. But both decisions created difficulties on the way to Jupiter. By far the most serious was the failure of the HGA to deploy.



Eight days after its final encounter with Earth, the Galileo spacecraft looked back and captured this remarkable view of Earth and the moon. Photo Credit: NASA

Political pressures dogged the initially underfunded project as costs began to rise. Slips in capability and delivery of the planned shuttle necessitated several major redesigns, including options to move Galileo to an expendable launch vehicle, and dual launch options, with the spacecraft and the Jupiter probe (an integral part of the mission concept) launched on separate vehicles. Launch slipped from 1982 to 1983, then 1985, and finally to 1986 before the shuttle was successfully completed and flown, and the Galileo design stabilized. The spacecraft and the launch team were at the cape when the Challenger accident occurred on January 28, 1986.

Galileo was shipped back to JPL for storage and continued testing. Ultimately, the spacecraft would make three transcontinental trips, which may have contributed to the antenna failure. While awaiting the shuttle's fate, the Galileo team investigated alternatives. As the Challenger investigation drew to a close and recommended changes were made to shuttle operations, it became clear that Galileo was at a crisis point. To get the energy for a direct trajectory to Jupiter, Galileo planned to use the Centaur liquid-propellant upper stage to boost it on its way after exiting the shuttle. After the Challenger accident, the decision was made to prohibit liquid-propellant upper stages, forcing Galileo to use the much-less-capable inertial upper stage, which used solid propellant. This booster was not capable of sending the spacecraft on a direct course to Jupiter, but by the clever use of gravity assists from Venus and from Earth, a viable mission could be flown, with a much longer flight time to Jupiter.

The extended journey required design modifications, including adding several sun shields to protect the spacecraft when flying to Venus for its first gravity assist. Operational changes were needed also to ensure the systems would survive. One was to delay the deployment of the HGA until the spacecraft was past the first Earth flyby.

The science team had to work long and hard to prioritize science goals, develop new science plans, and, in some cases, plan updates to onboard software in the instruments to increase data efficiency.

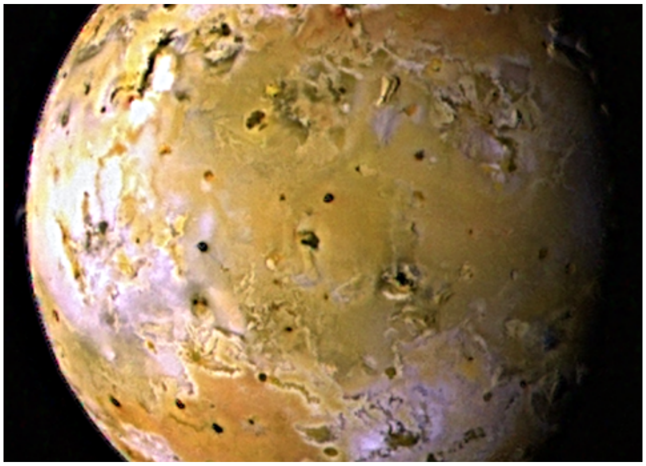
The HGA was made of a metalized mesh attached to a set of ribs, and looked very much like an inverted umbrella. The ribs were held to a central tower by a series of pins and retaining rods. Shortly after launch, the retaining rods were released, but the antenna was held in a closed configuration, protected under the sun shield when the spacecraft was within 1.0 astronomical unit of the sun—the distance from Earth to the sun.

During the first two and a half years of the mission, the operations team communicated with the spacecraft via the first low-gain antenna (LGA), and a second LGA added specifically for communications during the Earth-to-Venus-to-Earth leg of the trajectory. On April 11, 1991, shortly after the first Earth flyby, the operations team at JPL commanded the HGA to open. After twenty minutes of anxiously waiting for the fully deployed signal, the project team realized that something terribly wrong had occurred, and the HGA mission was in jeopardy. An investigation team was quickly organized to determine the state of the antenna and find a way to rectify the problem.

Over the next two years, numerous attempts were made to further deploy the antenna. At the same time, the project commissioned a separate, multidisciplinary study team to investigate ways to continue the mission without the HGA. Radical alternatives such as launching a relay satellite were quickly discarded due to time and budget constraints, so the team concentrated on alternatives using the LGA to support Jovian orbital operations. The project's worst fears were realized. All efforts to fully deploy the antenna were unsuccessful. The HGA was virtually useless.

Emergency Redesign

To support operations using the LGA, we needed to radically redesign the telecommunications link architecture. Without any modifications, the LGA would only support 10 bits per second (bps) at Jupiter, less than one-ten-thousandth of the 134 kilobits per second (Kbps) planned. The task of the team was to recover as much functionality



The images used to create this color composite of Io were acquired by Galileo during its ninth orbit of Jupiter. Photo Credit: NASA/JPL/University of Arizona

as possible, given the capabilities of the communications link. Major modifications to the spacecraft hardware to boost transmit power were not possible, so much of the effort was focused on increasing the receiving capability on Earth and developing a much more efficient data and telecommunications architecture.

Using advanced arraying at the Deep Space Network complexes, the receive aperture available (and thus the data rate) could be increased by a factor of 2.5, and additional changes to the receivers and the telecommunications link parameters increased capability significantly. These changes increased the data downlink rate from 10 bps to approximately 300 bps. More efficient downlink encoding and onboard data compression further increased the effective data rate. Together these efforts could increase the information downlink to approximately 4.5 Kbps, more than four hundred times the initial 10 bps.

But even this improvement was a huge decrease in the expected data-return rate. The science team had to work long and hard to prioritize science goals, develop new science plans, and, in some cases, plan updates to onboard software in the instruments to increase data efficiency. Clear, frank, and frequent communication between the science team and the development team was required to balance science desires with the capabilities of the system.

The most significant resource the Galileo team had was time: approximately four years between the time the HGA anomaly occurred and the spacecraft's arrival at Jupiter. Having that span of time was critical to the redevelopment of the onboard software to do the required data processing and data compression. This was also a time when some other preflight decisions became crucial.

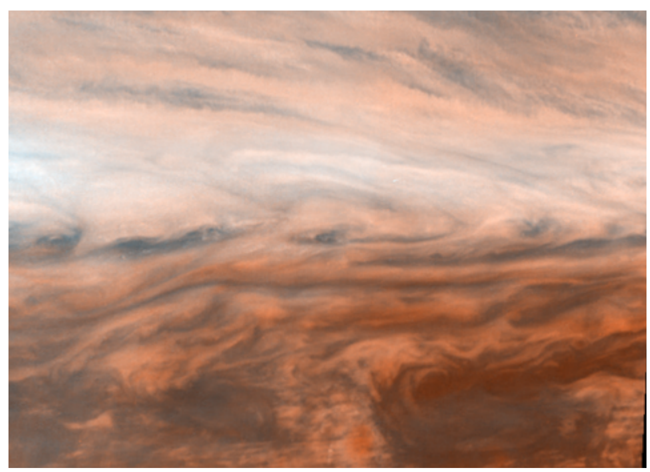
The most significant resource that the Galileo team had was time: approximately four years between the time the HGA anomaly occurred and the spacecraft's arrival at Jupiter.

As a backup to the real-time downlink, an onboard tape recorder (the Data Memory Subsystem, or DMS) had been designed to record data during certain high-activity periods. Since these periods were few, only a single DMS had been included in what was largely a dual, redundant avionics system. In addition, during the delay due to the Challenger accident, the project team investigated a potential solid-state memory failure and decided to double the onboard memory. Both of those resources became critical to the new orbital operations, to buffer high-rate data during the Jovian encounters, and trickle it to Earth over the remainder of the orbit.

Over the next four years, two updates to the onboard software were prepared and extensively tested. The first was a minor update to the software to support the critical probe relay and Jupiter orbit-insertion sequences. The project team wanted to make only those changes necessary to buffer the critical probe data to allow downlink over the LGA. The second update would completely replace the onboard software to implement the changes to the data system.

One More Glitch

The fates were not through with Galileo. On October 11, 1995, as the spacecraft was approaching Jupiter, the mission controllers commanded the Solid-State Imager to record an image of the planet and store it on the DMS. At the conclusion of this activity, the tape recorder was to



Pseudo-true-color mosaic of a belt zone boundary near Jupiter s equator. The images that make up the four quadrants of this mosaic were taken by Galileo within a few minutes of each other. Photo Credit: NASA/JPL Caltech

be rewound and the data played back onto the downlink. When commanded, the DMS began to rewind, but failed to stop at the end of the tape. All indications were that the DMS was broken and would not be available for orbital operations.

The project team immediately began an intensive effort to determine the actual state of the DMS, while initiating a concurrent activity to redesign the LGA orbital-operations software to work without this critical equipment. After two weeks of effort, the flight engineers were able to determine that the DMS was not broken, but that the tape itself had stuck to the erase head and did not rewind. The tape capstan was turning without tape movement, resulting in burnishing a spot on the tape. Subsequent efforts moved the tape forward, and the team decided it was prudent not to run the tape across the damaged area ever again. The burnished area was buried under several wraps of tape on the reel. The Phase 2 flight software was modified to use the tape recorder in a new way, using recorded markers to indicate the end of tape (rather than the tape markers), ensuring the damaged area would remain buried.

The support of the NASA management that made funding and resources available to the project to deal with the anomaly was critical, as were the enormous contributions of the technical community in understanding the system capabilities and design options.

After Jupiter orbit insertion, and successful reception of the critical probe data, the flight team carried out the first complete reload of flight software ever performed on a deep-space mission. Loading the Phase 2 flight software was a major operational undertaking, requiring several weeks. After all the software was loaded, the flight team waited breathlessly as the command was transmitted to turn on the new capabilities. After a brief blackout while the ground system synchronized with the new telemetry stream, data started flowing, and the new system became operational. The team was tremendously relieved, and as the science data flowed, they all celebrated the accomplishment.

Science Success

While the volume of data returned was less than originally planned, the science value of the data is immense.

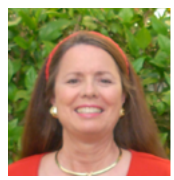
The ability of the Galileo project to face and overcome a debilitating failure in flight was a testament to the creativity and determination of the NASA community. The support of the NASA management that made funding and resources available to the project to deal with the anomaly was critical, as were the enormous contributions of the technical community in understanding the system capabilities and design options. The contributions of the Deep Space Network and the telecommunications community in advancing the state of the art in antenna arraying, low-noise receiver technology, and advanced modulation schemes provided hope that a solution could be found. And the dedication of the Galileo flight team and the software development and test crew proved that the loss of the HGA could be overcome. The HGA anomaly workarounds were truly a team effort involving a system approach that included science, flight, ground, hardware, and software.

In the end, the science return was the clearest testament to Galileo's success. While the volume of data returned was less than originally planned, the science value of the data is immense. The textbooks on Jupiter and its moons have been rewritten, and intriguing new questions have surfaced. One is whether Europa could harbor an immense ocean under its icy surface. It will be up to future missions to build upon the legacy of Galileo and find out.

Note: This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

About the Authors

Erik N. Nilsen joined the Galileo flight team shortly after launch and was integrally involved in the HGA anomaly investigation team and the LGA mission development team. He is currently the Mars Sample Return Advanced Concepts manager, working on the campaign to return surface samples from Mars to Earth for study. He is a registered professional engineer in the state of California and has more than twenty years of experience in space mission analysis and design.



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Rapid Prototyping and Analog Testing for Human Space Exploration

By Douglas Craig

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Humanity's dream of exploring the wonders of space—to look for life on other planets and to better understand our place in the universe—has not diminished over the years. But advances in human space exploration beyond low-Earth orbit have been slow to emerge.

NASA's new human space-exploration enterprise requires a strategy that will enable us to explore new worlds, develop innovative technologies, and foster burgeoning industries, all while increasing our understanding of Earth and our solar system. It will allow us to work on objects in Earth's orbit such as the International Space Station (ISS) and satellites while also exploring objects such as near-Earth asteroids, the moon, Mars, and Mars's moons. But traveling to and living on these destinations will require us to develop cutting-edge technologies and new ways to work in space to help us survive and thrive in these forbidding, faraway places.

As a first step, NASA has implemented two separate but integrated activities: rapid prototyping and using analog test environments. Rapid prototyping creates innovative concepts for exploration by rapidly developing low-cost but functional space-system prototypes using small, dedicated teams drawn from NASA's ten centers. These prototypes are incorporated into terrestrial, analog mission tests that enable an inexpensive, integrated validation of mission concepts in a representative environment. These analog missions include going out into the Arizona desert to perform long-distance traverses over lunar- and Mars-like terrain, using the National Oceanic and Atmospheric Administration's (NOAA) underwater Aquarius habitat to conduct simulated extravehicular activities under differing levels of gravity, using the Nuytco Research Deepworker submersibles to study microbialites in a remote freshwater lake in Canada for traverse planning and science data collection, and using the volcanic environment of Mauna Kea in Hawaii to test systems that extract oxygen from volcanic rocks.

Rapid Prototyping

Using lessons learned from the Department of Defense and the sub-sea industry's rapid-prototyping activities, NASA created a management environment for the rapid development of several prototypes at very low costs. The philosophy was to establish a series of iterative design-build-test projects, built on the principle that NASA is at its best working with a clear, simple, and understandable vision and a limited amount of time to achieve that vision. The projects focus on producing functional prototypes of increasing fidelity so systems integration issues can be understood early through rigorous design, build, and human in-the-loop testing.

The project teams are multi-center, multidisciplinary groups of capable and motivated individuals working together virtually from their home NASA centers. Several systems were developed using this philosophy, including the Space Exploration Vehicle

Space Exploration Vehicle docking with Cabin A for a simulated rescue mission. This simulated mission was part of the 2009 Desert RATS held at Black Point Lava Flow in Arizona. Photo Credit: NASA

NASA Aquanaut crew performing demonstration of incapacitated crewman recovery on the side hatch of the SEV during the NEEMO 14 mission. Photo Credit: NASA/Bill Todd

(previously the Lunar Electric Rover), a habitat demonstration unit, Robonaut 2, a portable communications tower, and an extravehicular activity suit port.

The Space Exploration Vehicle (SEV)

In the past, many people believed the best way to explore the lunar surface would be similar to the Apollo missions: astronauts in space suits using a rover with no enclosed cabin. Others believed a small rover with an enclosed, pressurized cabin that allowed astronauts to function without being in their space suits—but with the ability to quickly put on or take off a space suit—would be more effective. This debate continued for about a year with experts arguing over presentation charts until, at a workshop break, three people came up with a plan to develop a low-cost, low-fidelity version of the rovers needed to test the competing concepts. Nine months later, the concept vehicle now known as SEV was sent out into the desert to pit its performance against an unpressurized rover—and prove that pressurized rovers were 67 percent more effective than unpressurized rovers while providing an environment better suited for long-duration surface exploration missions.

Key to SEV's success was a high-level set of architecture questions to be addressed and a clear vehicle concept. The project manager also had the flexibility to develop a project structure and choose team members. Because of the tight funding and schedule, this team was kept very small, with members having much more responsibility than on larger NASA hardware-development projects. This empowered the task leaders and required them to be creative in their areas of responsibility, instilling a feeling of greater accountability. They also had more agility since the process for making changes involved much less review and paperwork than typical NASA projects.

The SEV project was able to make important design decisions in a thoughtful but cost- and time-efficient manner, due mainly to the small team and the prototype vehicles not being flight vehicles. Quick decisions in the early stages of development—when mistakes are less expensive and less consequential—gave the project team an understanding of how those decisions interact and how they manifest in hardware.

For example, the initial design of the suit port on the SEV consisted of a manual latching mechanism, on the principle of keeping the design as simple as possible. The test at the Desert Research and Technology Studies (Desert RATS) demonstrated that the mechanism design did not perform well in the environment. These results formed the basis for changing the mechanism from the manual mechanical latch to an electrically powered latch. Learning this early on in the design phase allowed the change to be made with minor cost impact.

As missions to other destinations are studied, the SEV concept has been found to be very advantageous for in-space activities such as satellite servicing and exploration of asteroids. As a result, the SEV now has two variants: one for surface exploration and one for in-space exploration.

An astronaut and a geologist don spacesuits to test an unpressurized version of a lunar rover concept that enables them to easily disembark and explore. The test was part of the 2008 Desert RATS held at Black Point Lava Flow in Arizona. Photo Credit: NASA

Analog Testing

Driving a rover around a center's rock yard isn't enough to reveal the true operations and limitations of a vehicle designed for long traverses. It is important to test the systems in an integrated, operational field mission to ensure relevant test results. These extreme environments greatly enhance our ability to analyze concepts in simulated conditions and enable experiments with long-range and long-duration expeditions. Additionally, members from the NASA mission and ground operations team as well as international space agencies, industry, academia, and other government agencies take part in these tests. Each test refines our understanding of the systems and human capabilities needed to successfully explore beyond Earth's orbit while developing the teamwork and methodologies to ensure that future space systems are efficiently built to accomplish their tasks.

NASA has developed a process for these tests of system and operational concepts on Earth and on ISS, known as analog missions. These missions are carried out in representative environments that have features similar to the missions' target destinations. These can include locations underwater, in the arctic, on terrestrial impact craters, in the desert, on volcanic lava flows, and on ISS. Two of the larger missions are the NASA Extreme Environment Mission Operations (NEEMO) and Desert RATS, or D-RATS.

NEEMO

NEEMO uses the only underwater research facility in the world: NOAA's Aquarius habitat. Working in partnership with NOAA, NASA uses the habitat because it provides some of the best conditions for practicing space operations in a harsh environment, giving astronauts a broad knowledge and awareness of risks, issues, and objectives associated with human space-exploration missions. There have also been numerous discoveries made during NEEMO missions on human health, engineering, telemedicine, space operations, education, and public outreach that directly relate to spaceflight needs and are being implemented with each mission.

The NEEMO mission tests are developed with the same rigorous timelines as current shuttle and ISS missions. Upon completion of the latest NEEMO mission, the NEEMO mission commander, Astronaut Chris Hadfield, who has flown on two Space Shuttle flights and was the first Canadian to walk in space, stated that this mission was the closest to a real spaceflight mission as you could get on Earth. This rigor allows us to make informed decisions about design changes before project development begins.

For example, the size of side hatches changed significantly between the first and second SEV designs based on testing configurations at the NEEMO and D-RATS analog field tests. The tests were designed to address the human factors group's belief that a larger hatch was needed for mission operations. Results showed that the astronauts had no issues using the smaller hatch size for standard or emergency operations in a low-gravity environment. This enabled the design to be changed to the smaller hatch size, thereby reducing the overall mass of the architecture vehicles that contain a hatch. This, in turn, reduces the cost of the architecture due to less propellant required throughout the architecture phases. The cost of these tests was minor compared with the cost impact if this information was learned during the flight vehicles' development.

D-RATS

D-RATS field tests have become large missions where multiple prototype systems are tested together to evaluate concepts about integrated operations. Using the Black Point Lava Flow and SP Mountain areas in Arizona—because their terrain, geologic features, size, and dusty environment are similar to what would be encountered on surfaces in space—allows NASA to test prototypes under realistic communications and operational scenarios.

Quick decisions in the early stages of development—when mistakes are less expensive and less consequential—gave the project team an understanding of how those decisions interact and how they manifest in hardware.

The latest D-RATS field test focused on the simultaneous operation of two SEVs, including new ways of performing surface-science operations. Over a fourteen-day period, the astronaut and geologist crew teams performed a science- and exploration-driven course of more than 300 km under different communications and operations scenarios, only egressing to perform simulated extravehicular activities: to collect geological samples or to work in the habitat demonstration unit.

One of the major concerns about the SEV was that its size was relatively small. There were people who did not think it was large enough for a fourteen-day mission; they thought it would be too small for two astronauts to work in the confined space for that period of time due to psychological issues. The ability to perform a fourteen-day mission in an SEV would have a major impact on the mission architecture, reducing the number of heavy-lift launch vehicles needed for a lunar campaign. Upon completion of the test, the crew stated that not only was the size adequate for a fourteen-day mission, but they felt as though it would be suitable for a thirty-day mission. A mission spanning thirty days would allow much more exploration of the lunar surface at a greatly reduced cost.

Inexpensive and Informed Decision Making

Validating rapid prototypes of innovative concepts through analog field tests has greatly advanced NASA's understanding of more effective methods for human space exploration. In addition, the process has provided an example of how future human space-exploration systems can be developed at a greatly reduced cost. Rather than sitting through design reviews and trying to understand how systems would be used, these approaches provide realistic insight into system and operational requirements, guiding design changes early in the development phase and saving the time and cost associated with changing designs and contracts later on.

For more information, please visit the following:

www.nasa.gov/exploration/analogs/index.html

www.youtube.com/NASAanalogTV

www.nasa.gov/multimedia/podcasting/nasa360/nasa360-0214.html

www.nasa.gov/multimedia/podcasting/nasa360/nasa360-0318.html

About the Author

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Taking a Risk to Avoid Risk

By John McManamen

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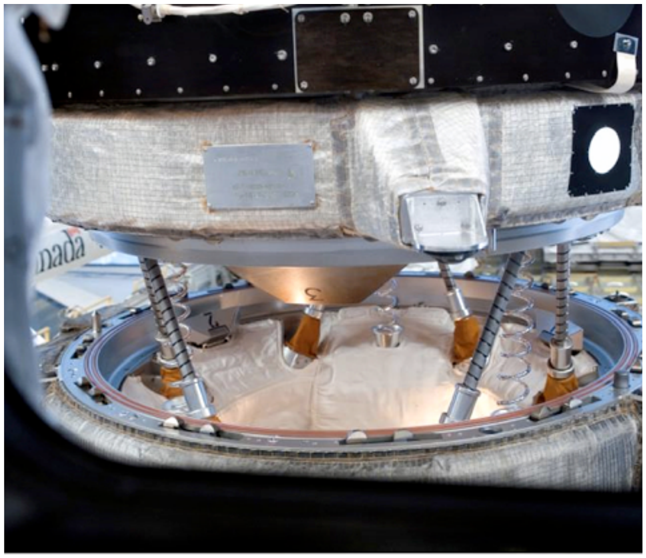
One of the many lessons I've learned during my career is we aren't always as smart as we think we are. When we discovered large oscillations occurring during docking between the Space Shuttle and International Space Station (ISS), I had a chance to learn that lesson again. It's amazing the kinds of problems you can find even in a mature program like the shuttle, which has been operating for thirty years. It teaches us to be vigilant and always stay curious, questioning things that don't look right.

In this instance, what didn't look right was a recurring misalignment during docking retraction: a process that occurs after the shuttle and station have successfully joined (known as "soft capture") but have not yet achieved what we call a "hard mate," when the docking is complete and everything has successfully sealed. Retraction is the process of the ISS docking mechanism slowly pulling in the docking mechanism on the shuttle side. Considering how close these two massive objects get to each other—anywhere between six and fourteen inches—a little wobble can mean a lot of risk: in this case, contact between things not intended to touch.

Docking is one of those highly integrated operations that involves massive spacecraft and many systems, including relative rate and alignment sensors, digital autopilot for attitude-control systems, crew piloting to maintain lateral alignment and translational velocities, and a complex docking mechanism that can deal with residual misalignments and rates. Then consider that, once capture is achieved, both vehicles begin free drift—turning off their thrusters and thus giving up attitude control—and you can begin to imagine the entire process as a very complex dance happening at more than 17,000 mph, and up to 280 miles above Earth.

During the STS-133 docking operation, significant oscillations were experienced between the shuttle and ISS as the retraction was occurring. Reviews and a more detailed post-flight assessment raised numerous concerns about the current docking procedure and posed fundamental questions about whether we were operating within certification limits.



(Top) The shuttle and station docking mechanisms after soft capture and before retraction during STS-121.
(Middle) The shuttle capture ring ready to dock with station during STS-131.
(Bottom) Visitors learn about the docking mechanism that allows the Space Shuttle to dock with the International Space Station.
Photo Credits: NASA

This partial view of the starboard wing of Space Shuttle Discovery was provided by an Expedition 26 crewmember during a survey of the approaching STS-133 vehicle prior to docking with the International Space Station. Photo Credit: NASA

Trajectories and Timelines

When the docking procedure was originally created during the Space Shuttle–Mir missions and early ISS flights, the orbiting stations were much smaller, and the shuttle could approach and dock fairly quickly—usually in less than 20 minutes—along a trajectory much less susceptible to gravity-gradient torques during free drift. The gravity gradient (a greater gravitational pull on the parts of objects closest to Earth) can affect the orientation of satellites in space, inexorably pulling them out of alignment. In the case of shuttle and station, this force can pull hard enough to change their orientation to each other. This usually isn't a problem when the station and shuttle can use thrusters to realign themselves individually. But when they shut off those thrusters and enter free drift, the gravity-gradient torques begin disturbing the operation. The longer the free drift lasts, the worse the wobble becomes. This wasn't a problem when the shuttle–station docking process was completed within the nominal less-than-20-minute timeline, but that timeline had been getting progressively longer over the years—a result of making operational changes to deal with docking-system idiosyncrasies discovered over time.

One such idiosyncrasy occurred when an electromagnetic "brake," the high-energy damper, inadvertently stuck beyond its normal time to disengage. We dealt with this by adding steps to the docking process: extending the docking ring and then retracting it briefly to reverse torques in the system, which allowed the clutch plates holding on to the high-energy damper to release. Adding steps also added time.

As the station grew in size and mass, the gravity-gradient effect became more dominant during shuttle–ISS docking. As this rotation built up over tens of minutes of time, the centrifugal force would create a misalignment during docking, which would slow down the docking procedure. If a sensor indicated a misalignment, the crew would follow procedure by stopping the automatic docking sequence,

Partial view of the nose and crew cabin of Discovery taken from the International Space Station during the shuttle's docking approach. Photo Credit: NASA

which would then disengage "fixers," a design feature meant to limit misalignment during retraction. This would cause more wobble, and the crew would have to wait for alignment to reoccur before starting up the process again—more time.

Everything culminated during the STS-133 mission; the docking took nearly 50 minutes—more than double the nominal time. I had a moment to speak with the commander during a debrief about the mission, and he described what he saw looking out the overhead window: the ISS pressurized mating adapter coming fairly close to the orbiter, and the ISS guide pins looking as though they were going to hit the orbiter docking interface as misalignment grew. When I heard what he was talking about, my jaw dropped. We realized that with the evolution to our current procedure, we had no way of controlling the growing misalignment and no integrated tools to analyze the gravity-gradient implications for the hardware, vehicles, or mission timeline. We needed a solution quickly, and we had just under four weeks to find it: STS-134 was getting ready to launch.

One Line, One Light

> ***Convincing anyone to make a procedural change in under four weeks is no easy task, so we made sure we had our facts straight and our data validated to prove that the resolution was less risky than letting the system proceed as it had been.***

Though we showed that the shuttle and ISS could never actually collide if oscillations happened during the soft-capture phase—though they could get worryingly close, closer than six inches—there were other risks to station that were very severe. Because the timeline had grown from less than 20 minutes to nearly 50 minutes, the station was at risk of losing its power-generation and thermal-heat-protection capabilities due to longeron shadowing; the station's solar arrays could not generate enough power for vital onboard systems. Something had to change to avoid this risk.

We knew there was no time to make any hardware changes, so we looked at what we else could do. Some of our concern was with the earlier procedure changes, which had the fixers operating in a different way than what had been certified. A fixer is just what it sounds like: a small switch that deploys to fix something in place, in this case the gears controlling the orbiter docking-ring rotation. We needed to understand what the fixers were doing in the new procedure. Were they engaging or not? Were they working properly or not? Were they failing or working?

The operations community was very concerned about ensuring the fixers were working; if they weren't, and we had a large gravity-gradient-induced oscillation, we could impact parts of the docking mechanism not intended for contact. We had to come up with a new technique to determine what was happening with the fixers in real time.

The previous procedure included shutting off the automatic sequence if misalignment occurred in order to protect against a fixer failure. Our perception at the time was that the fixers could not structurally handle the stress of gravity-gradient torques. But stopping the sequence stopped the ring retraction and disengaged the fixers, so the fixers never got to do their job: preventing the orbiter capture ring from rotating. What we discovered during testing was the misalignment sensor

The International Space Station and the docked Space Shuttle Endeavour photographed by Expedition 27 crew member Paolo Nespoli from the Soyuz TMA-20 following its undocking on May 23, 2011. Photo Credit: NASA

would actually trip before ever making contact with the fixers. So we had to look creatively at what else was available in the system in terms of more accurate sensors, and we needed to better understand the fixers' structural capacity.

The initial-contact sensor in the docking system is odd because that is all we use it for—it turns on a display-panel light for the crew—but it's actually an unreliable indicator of initial contact. It turns out to be a very good indicator of how

Backdropped by Earth, Discovery approaches the International Space Station during STS-133 rendezvous and docking operations. Already docked to the station is a Russian Progress spacecraft.
Photo Credit: NASA

much the capture ring has rotated, though. We found that the initial-contact-sensor indication always occurred after the fixers engaged. Once we understood that, and were able to demonstrate it on the brassboard docking-mechanism unit we have—a test model which is essentially a flight unit—we knew the sensor was a very good indicator of whether a fixer had failed or not. The only time we should see that sensor light during retraction is if a fixer has failed.

Convincing anyone to make a procedural change in under four weeks is no easy task, so we made sure we had our facts straight and our data validated to prove that the resolution was less risky than letting the system proceed as it had been.

The fixer load capacity was refined based on discussions with our Russian colleagues, who had originally designed, built, and tested the system. We were able to demonstrate through test data that loads applied to the test-unit fixers far exceeded our predicted worst-case gravity-gradient loads. With this information and our new knowledge of a sensor that could accurately indicate a failed fixer, we were confident we could modify the docking procedure to make it safer and more robust.

The procedure change ended up being very small. We altered only one line of code in the auto-sequence programming, and trainers advised the flight crew to ignore the misalignment sensor and instead use the initial-contact sensor to judge misalignment. But that small change had profound consequences for the overall operation. We mitigated huge risks to the docking mechanisms on both the shuttle and ISS, as well as risks to the vehicles themselves. The team worked hard and through long hours to find the simplest, safest solution before the next shuttle mission launched, and we found it in one light and one line of code.

By making those changes, we were able to decrease the delays caused by the automatic stop programmed into the docking procedure, which occurred whenever the first misalignment-sensor indicator lit up. Our hard work and innumerable data were validated once more when STS-134 docked without any of the delays experienced on STS-133. In fact, it achieved the transition from soft capture to hard mate in just 13 minutes and 4 seconds.

Mitigating Potential Problems

Very few anomalies are caused by just one thing. It's usually a number of factors, events, or changes that line up to result in a real problem. In our situation we had a number of things lining up for a potentially bad outcome. Thankfully, our team was able to recognize the signals and mitigate the risk before the potential could become reality. And we learned some very valuable lessons in the process: a thorough assessment is required even for the smallest, simplest procedure change; environments and systems can change, even after thirty years of proven performance, so reevaluate integrated system certification/verification regularly to ensure operations are still valid and safe; and, most importantly, stay hungry, be curious, and question things if they don't look right. If those questions lead to hardware modifications or procedural changes, have a rigorous certification process in place to assess unintended consequences. This will help ensure one risk doesn't unintentionally lead to more.

About the Author

John McManamen began his NASA career at Johnson Space Center in 1987 as an aerospace engineer in the Mechanical Design and Analysis Branch of the Structures and Mechanics Division. In 2000 he became chief engineer of the International Space Station, seeing it through final development and early on-orbit assembly operations. In 2003, he was selected as an inaugural member and Technical Fellow in the newly formed NASA Engineering and Safety Center. He is currently chief engineer for the Space Shuttle program.

Human Spaceflight and Science

By Howard Ross

Fall 2011, Issue 43

Intentionally igniting a fire inside the Space Shuttle might seem like a bad idea, but done safely and correctly, it could answer all sorts of seemingly simple questions, such as, "Would a candle burn in zero gravity?" Several university doctoral programs had asked this very question for years, and nobody—not even microgravity-science experts—could agree on an answer. What we never expected was that the answer would lead to even more answers, and some remarkable scientific discoveries and advancements.

Small Flame, Big Discoveries

What started as a trivial hallway conversation between me and a couple of grad students eventually grew into something

This still capture from a video shows a probe that incorporates light-scattering technology being tested at the National Institutes of Health. Photo Credit: NASA

more concrete. My colleagues, Dr. Daniel Dietrich of Glenn Research Center and Professor James T'ien of Case Western Reserve University, presented the idea as a simple high-school education experiment when, in fact, we didn't know the answer ourselves. The idea sold.

Since the shuttle had flown so few combustion experiments, we had to put the candle inside a nonflammable Lexan box, which was then placed inside a glovebox already installed on the orbiter. We drilled some holes in the candle box (the candle needs oxygen to burn), included a hot-wire igniter for the crew to operate, and away we went.

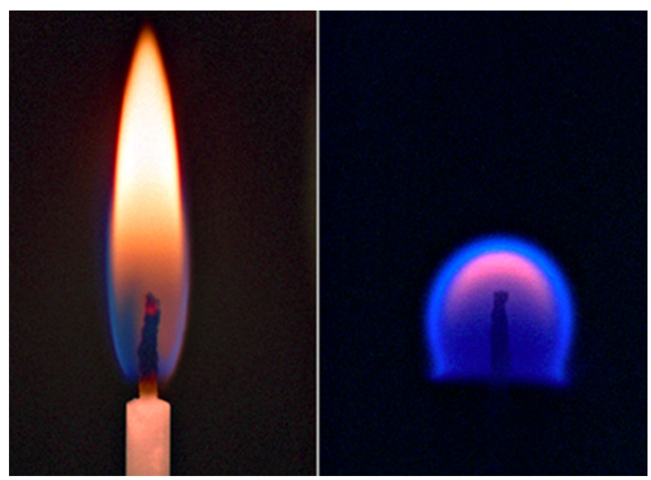
What we discovered was a candle would indeed burn in 0 g: unlike lit candles on Earth, it had a round flame, except near the bottom where the candle wax quenched it. It burned for about 45 seconds (we had a bet going about how long it would burn; I lost—I had 20 seconds, Dan had 40 seconds). But later we realized the time it burned may have been limited by the number of holes in the box, preventing oxygen from the glovebox from easily getting to the flame. Would the candle burn longer if we used a different design? We had also wanted to study two candles facing each other (unlike a birthday cake where the candles stand next to each other in parallel lines, here the candles were on a single line with the wicks facing each other). To our surprise, we learned that once we lit one candle, we couldn't light the other, because the oxygen concentration near the second one was too low—the first candle effectively used up the necessary amount of oxygen.

We were lucky to get a chance to try the experiment again on Mir, and the Russians allowed us to switch from a Lexan box to a wire-mesh one, which was much more open. But they required us to fly oxygen sensors with the experiment if we wanted to get it on board. We used commercial off-the-shelf sensors. They didn't work well in flight, but their mere presence did allow us to get approved and onto Mir.

This time we learned that a candle that burned for about 10 minutes on Earth burned for 45 minutes (not seconds!) in space once we got rid of the Lexan box. The flame was incredibly weak (about 5 watts in space compared with 50 watts here on Earth), but it could survive a very long time.

During the experiment with the wire-mesh box, we asked crewmembers to turn the lights on and off. What we found when we did that is all the candle wax had melted, but it didn't drip off the candle because there was no gravity to pull it down. With the lights off, it was possible to see these incredibly fast, thermal, capillary-driven flows—essentially aerosol spray—inside that wax melt.

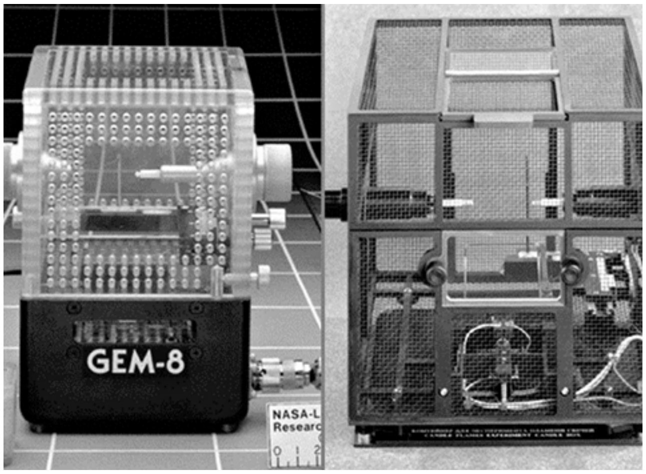
At the end of one of these Mir experiments, Astronaut Shannon Lucid turned on the lights and said, "I see something that looks like a dandelion there, sitting there. I will take a picture of it, as well as make a drawing of what I see, in case the camera fails." This happened right after the flame went out. Now, on Mir, you had 10 minutes of communication ("comm") time followed by 70 minutes of no communication. So right at the end of her comm she said, "Can you tell me what that is?" Suddenly all the lights lit up from Moscow with people (especially those in safety) wanting to know, What is that thing? In the 70 minutes we had, we came to the conclusion it was a fog of condensed water vapor, which we told to Shannon and those in safety, and everyone seemed satisfied. Months later, when we saw the pictures and video, we came to a different conclusion: it was probably a cloud of condensed candle wax. Once the flame went away, the aerosols inside the wax melt condensed into a little round ball of flammable material.



A candle burning on Earth (left) versus in microgravity. Photo Credit: NASA

So you start by wondering, "Will a candle burn in 0 g?" and you end up eighteen years later helping pilots understand their physiological status when flying at high altitude.

Fortunately at the time, when her comm time came around again, we told Shannon to turn on the fan inside the glovebox to blow the cloud of material into a filter in the glovebox. The whole event served as a realistic reminder of the need for careful



A Lexan box (left) from the original candle experiment and a wire-mesh box later used on Mir. Photo Credit: NASA

post-fire cleanup operations. From this we learned that if there ever were a fire on a spacecraft, the crew would need to worry about the safety of their operations even after the fire was out.

Later, there was a chance the agency would let us fly the experiment again. Since the oxygen sensors had not worked, we really wanted to know what the oxygen concentration was while the candle burned. We couldn't find sensors that were minuscule enough to avoid hurting the delicate flame in 0 g that were also reliable over a wide temperature range, so we ended up building our own oxygen sensor. The same was true for the carbon-dioxide concentration: we designed, built, and tested our own non-intrusive sensor to measure the CO_2. We were all set to fly, but the flight opportunity got canceled.

Dan began to wonder what else we could do with what we had created. Somebody said, "Well, you need to know oxygen and carbon dioxide concentrations for metabolic analysis during exercise, and our sensors are really small—could we integrate them into a mask?" So he led a team that did just that. He began talking and working with a doctor at University Hospitals in Cleveland, Ohio. The resulting Portable Unit for Metabolic Analysis, or PUMA, ended up weighing less than two pounds and could collect and transmit data wirelessly in real time.

Fast-forward a number of years and a number of tests—we showed it to flight surgeons, demonstrated it could work at 2 ½ atmospheres underwater during NASA Extreme Environment Mission Operations—and eventually a private company and the U.S. Navy became interested. Today, PUMA has been successfully used for testing oxygen and carbon dioxide concentrations, monitoring metabolic analysis, and testing for hypoxia in pilots flying at high altitudes.

So you start by wondering, "Will a candle burn in 0 g?" and you end up eighteen years later helping pilots understand their physiological status when flying at high altitude. Along the way, our descriptions of this silly little experiment packed the house at combustion-science symposiums where, honestly, much more important research was being discussed.

Scientific American carried a photo of the Mir flame, and references were made to it in the Encyclopedia Britannica's annual updates. Professor T'ien tasked graduate students with modeling what was happening with the 0 g candle flame, and this effort proved far more challenging than anyone imagined.

From Fire to Fluids

Another experiment made possible by the Space Shuttle started by wondering how colloids—the small particles that float around in paints, shampoo, soaps, detergent, milk, etc.—actually aggregate, or condense. On Earth, they tend to sediment over time, so producers of these products need to acquire stabilizers to help keep the colloids in place. But would they exhibit the same behavior in space?

When we flew them on board the shuttle, the colloids created weird, treelike dendritic structures not normally seen on Earth. Some things that had never previously crystallized actually crystallized in space. And when the colloids did separate from each other, they did so under conditions completely contrary to the theory being used at the time. They would segregate under conditions far different from what anybody predicted.

The Portable Unit for Metabolic Analysis. Photo Credit: NASA

During one of those experiments, Rafat Ansari, a project scientist who looked at the light scatterings where we measured particle concentrations, discovered that what he was seeing acted the same way as his father's cataracts. Rafat realized that a cataract is simply a collection of particles that have come together just like the colloids he was seeing in space. He used the measuring technology that we flew in space, miniaturized it, and started applying it to see if he could detect the formation of cataracts very early on. Turns out, he could detect it—ten times sooner than any other device that existed on the market at the time. In 2003, the National Eye Institute featured this device to Congress. And in 2009, it wasn't just the National Eye Institute but the entire National Institutes of Health citing it as one of their top six technology advances in the past year.

Afterward, I asked Rafat why he became a scientist. He told me that when he was a seven-year-old in Pakistan, he saw people walking on the moon, and he said, "That's absolutely amazing. I want to go into science because of that." Human spaceflight touches people in ways we don't expect.

Unexpected Outcomes

These are just a few examples of how scientific curiosity, no matter how trivial it may seem at the beginning, can manifest itself in unexpected ways. This is an important aspect of science in general: what you learn along the way can end up being applied very differently than you ever anticipated. And space also teaches us to think differently, which makes those who work on these experiments a needed commodity even in environments outside space.

If there is any lesson in all of this, it's to not be afraid to ask what seems to be a really simple question; you never know where it will lead. And always look at your own life for motivation to create solutions to common problems.

The Space Shuttle played a big role for thirty years in helping foster scientific discoveries and technological innovations such as these. The International Space Station and countless other missions will help us continue to do so in the future. As long as scientists continue to ask questions, and the space program flies the resulting experiments, big discoveries can come from very small beginnings—and the impact of human spaceflight can continue to surprise us.

Each time we flew it felt like a personal Olympics: years of preparation for a few moments or days when proof would be forthcoming on whether our efforts—and yours—were worthwhile. I can say unequivocally and in every case, yes, they were. I want to thank everyone who played a part in making the shuttle fly so successfully for so long. I will always be grateful to all of you.

About the Author

Howard Ross is currently the chief technologist at Glenn Research Center, as well as the director of the Office of Technology Partnerships and Planning. Among his previous roles, he once served at NASA Headquarters as deputy associate administrator in the Office of Biological and Physical Research and helped select many spaceflight experiments that flew on the Space Shuttle and International Space Station. This assignment was based on his service as a principal investigator and project scientist on many microgravity experiments.

Expecting the Unexpected

By Taralyn Frasqueri-Molina

Fall 2011, Issue 43

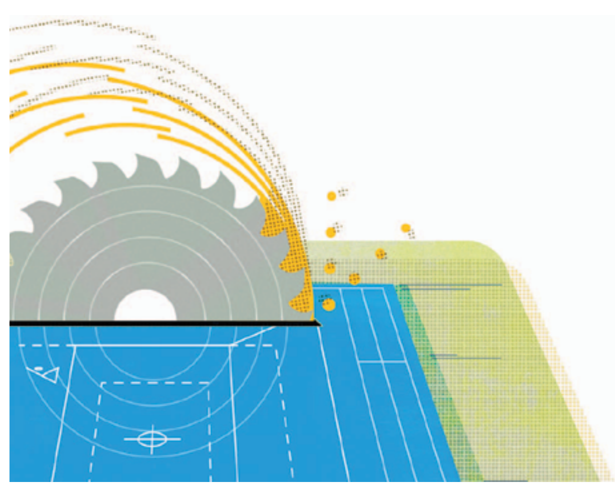
Even a genius team can never anticipate every possible risk that might occur on a project. Before unexpected risks rear their ugly heads, create a mitigation plan for dealing with the risk of not knowing what could happen.

In December of 2009, I had the opportunity to manage a great project. It was a huge renovation and technological upgrade to the main theater at the Walt Disney Animation Studios in Burbank, California. It would be the biggest project in terms of budget, schedule, and crew that I had managed in my Disney career. This project would also be an opportunity to show what serious project management could do and how necessary it was.

Since 2007, I and my media-engineering team had been going through all the phases and processes of a new project management life cycle. Before then, we hadn't had any standardized methodologies. That lack of structure was contributing to project failures. When I was handed the project management reins and tasked with making some big changes, the first thing I did, after wigging out, was create a structure and a methodology that would work for my team and the kinds of projects we delivered.

This large-scale shift didn't occur overnight. I worked diligently to discover what project management meant for us, and to uncover what processes worked and didn't work. Sometimes I'd ask my team for direct feedback about our process. They didn't mince words about the things they didn't like. Sometimes we learned by making mistakes together and realizing a change was necessary. Truthfulness and pinpoint criticism helped me make an honest assessment of my skill level as a project manager, how mature our project management system was, and where it (and I) needed to be. One thing that came from this introspection was a Change Control Board, or CCB. Team members were used to solving problems on their own and not having to make a pit stop, pitch their idea, and wait for someone else's approval. In order to keep a lid on scope creep and gold plating, and to keep track of great ideas we couldn't take advantage of immediately, a CCB was necessary. Our CCB is both formal and informal, structured enough to handle changes in complex projects, but flexible enough to approve changes that can add value right away.

Once the methodology and processes were in place and my colleagues and I started to follow a structured plan, we began to have little project management wins. We started to shrink



how far behind schedule we had been. Then we started to meet our deadlines, which eventually led to us meeting our project schedule as a whole. Completed projects began to cost less. We were still over budget, but less and less. Soon we were meeting all project costs, which eventually led to us coming in under budget for our entire fiscal-year portfolio. Our stakeholders' frowns and grumbles turned to smiles and praise. My team could clearly see the value of project management. Over time I gained their buy-in, a big win for me considering they had been used to running without a project management plan for so long.

From 2007 to 2009, I improved upon and streamlined our early structure, methodology, and processes. When the main theater renovation came around in late 2009, it was a chance to showcase what I had developed and show what media-engineering project management was all about.

Essentially, the intent of the main theater project was to remove all the old stuff and put in new stuff. The space was important; it was our only theater and could not be structurally changed. The schedule was critical; the theater was regularly used to support production and therefore could not be out of commission for more than a few days. It would be a technological powerhouse in a 140-seat space, including a first-of-its-kind dual-powered screen system. The screen system was the crown jewel and the one feature regularly touted as the driving factor behind the project. This system would allow the studio to have, in addition to a 2-D standard screen, a 3-D stereoscopic screen, a key piece of equipment for all technologically advanced movie theaters. And we wanted to get these two types of powered screens to fit in a space originally engineered for one.

Unlike a fixed screen, which is hung on the wall like a giant portrait (this is what you usually see in a commercial movie theater), a powered screen is housed in a massive metal box weighing around 700 lbs. The metal box contains the screen, which is wrapped around a huge roller, and a motor that powers the roller to raise and lower the screen. The box is anchored into the ceiling, in a fly space. The need for two of these boxes in one space created a significant design challenge, but the project delivery team worked it out, and a screen company custom-made what we envisioned. Our biggest hurdle cleared, it seemed we were on our way to project victory. All we had to do was follow the plan.

After months of talking and theorizing, the day of installation arrived. I should have known the day wasn't going to go well when the contracted demolition and install crew showed up with no hauling equipment and maybe two hammers among them.

Once all my crews (demolition, construction, electrical, audio/visual technicians, HVAC, fire safety, clean up) were settled and demolition started, I got a call from building security that my screens had arrived. I stepped outside and saw a massive flat-bed trailer with two long, wooden boxes strapped to it. The whole thing seemed to be as long as two city blocks! The delivery crew hauled the boxes into the lobby and the install crew started breaking everything open. Things seemingly under control, I stepped away from the scene for a moment to take care of paperwork. About thirty minutes later, the install crew lead was at my desk telling me there was a problem with the metal boxes that house the powered screens. Each box measured 30 feet and 10.5 inches long. But the screen wall inside the main theater measured only 30 feet and 7 inches long. Each box was 3.5 inches too big.

The crowning piece of the whole show, the one-of-a-kind, custom-made, initiating force behind the project didn't fit. On the way to project victory, we had taken a major detour into a project nightmare.

The team looks to you, the project manager, for direction in times of trouble. If you are scattered and frantic, their confidence in you and your ability to resolve the problem successfully will greatly be diminished.

While I plan for as many risks as possible with the help of the project delivery team, I know it's impossible to account for every risk. Realizing this early in establishing a project management methodology, I had developed a risk-mitigation plan for unknown risks that would help reestablish order during a time of chaos. The eight-step plan is

- Remain calm.
- Halt the entire project or just the affected work momentarily and let everyone take a break.
- Immediately gather the resolution team, which consists of the project manager and any of the people who can offer solutions; meet privately.
- Assess risk impact.
- Brainstorm solutions.
- Choose a solution.
- Obtain project sponsor approval.
- Communicate the solution to the entire team, resume project, resolve risk.

This process works for the kind of projects I manage. While these specific steps may not work for everyone's projects, some of them should be widely useful. Remaining calm is a good general principle. Panic is not a useful approach to any problem. The team looks to you, the project manager, for direction in times of trouble. If you are scattered and frantic, their confidence in you and your ability to resolve the problem successfully will greatly be diminished. Stopping the affected work is also a valuable rule, since acting before you understand the problem or its solution is likely to make things worse. And quickly identifying and gathering the individuals who can help makes sense in most situations; you need the right people on hand to help make the right decisions. Not everyone needs to be involved in solving the problem. Whatever the details of your plan are, having some kind of plan in place to handle unanticipated risks will always work in your favor.

Following the eight steps, the resolution team and I came up with a solution for handling the problem. When we looked at the two sets of design drawings, we noticed the actual screens were the correct dimensions on both sets. On one set of drawings, however, the box dimensions were incorrect. We pulled open the boxes and found over seven inches of empty space on the motor side. An electrical crewmember grabbed a buzz saw and safely cut off the excess. Now the screen boxes are up in the ceiling of the main theater, nestled into a perfect fit, and they haven't caused any trouble since.

It wasn't until after the solution was being implemented that the manager, the project engineer, and I met to talk about how the trouble originated. We never pointed fingers during project implementation, since there was still a lot of work to be done, and a negative crew is less effective than a happy one. After many discussions and honest assessments of points of failure, we determined that the main cause of the risk were the erroneous sets of drawings the manufacturer gave to the project delivery team. Each drawing showed a different measurement. When I would call the manufacturer with one set of drawings, they'd confirm the measurements I was talking about. But when the engineer called the manufacturers using the other set, the manufacturer would confirm that as well. And because the project delivery team got both drawings from the same manufacturer (who is still a very reputable and trusted source), we assumed they were identical copies and didn't think to compare the sets.

That is the worst part about project management. The smallest detail, one incorrect measurement, a seemingly harmless assumption left unverified, can spell disaster for a project you've been planning for months or years.

I know the old saying is, "measure twice, cut once," but sometimes something (usually a very small thing) slips through the cracks. For those times, having a pre-planned response will help minimize a negative impact or eliminate it altogether.

That's what I learned. That, and always have a buzz saw on hand.

About the Author

Taralyn Frasqueri-Molina is a project manager in media engineering for Walt Disney Animation Studios. She leads projects and project teams focused on developing, retrofitting, and integrating media technologies into existing buildings and system infrastructures. She is a member of the Project Management Institute, Los Angeles chapter; the current virtual headmaster of online resource Gantthead University; and was a speaker at NASA's Project Management Challenge 2011. You can reach her on Twitter, @PML33T.

FAST LEARNING

BY MATTHEW KOHUT

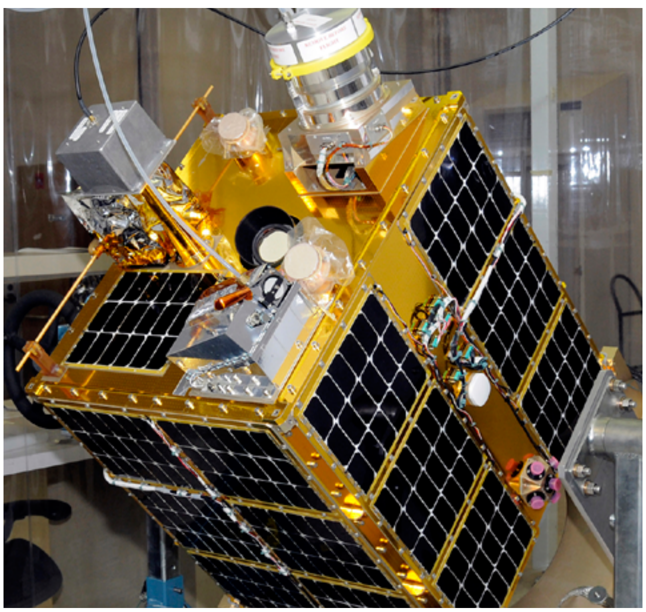
FALL 2011, ISSUE 43

"Fast" is the word that best describes Tom Simon's experience working at Marshall Space Flight Center on the Fast, Affordable, Science and Technology Satellite (FASTSAT), a microsatellite designed to carry six small experiments into space. Having served as a Space Shuttle subsystem engineer and a research and development project chief engineer at Johnson Space Center since 2001, Simon went to a spaceflight project where the whole team could stand around the satellite. Working on a small team with a quick schedule, Simon saw nearly every major production phase while assisting the project's chief engineer in the fabrication and testing of the spacecraft.

Team members prepare to lift FASTSAT from its shipping container at Kodiak Launch Complex on Kodiak Island, Alaska.
Photo Credit: U.S. Air Force/Lou Hernandez

Simon came to FASTSAT as a participant in the Systems Engineering Leadership Development Program (SELDP), which provides opportunities for a small class of high-potential candidates to develop and improve their systems engineering leadership skills and technical capabilities. A core feature of the program is a hands-on developmental assignment away from a participant's home center in a work context that differs significantly from his or her past experience. In Simon's case, FASTSAT fit the bill.

The objective of the FASTSAT project was to demonstrate the capability to design, build, and test a satellite platform that would allow researchers from government, academia, and industry to conduct low-cost scientific and technology experiments on an autonomous satellite in space. The project was in itself an experiment in lean, affordable development. FASTSAT is intended as a multigeneration effort with future launches of the satellite bus with different experiments on board. The first FASTSAT was called HSV-01 (Huntsville-01) and had a mass of approximately 100 kg. (Future FASTSAT satellites can now be produced by NASA's partner, Dynetics.) HSV-01 was launched as a piggyback payload on an Air Force Space Test Program launch vehicle. HSV-01's payloads included Marshall's NanoSail-D, the first-ever solar sail of its size to unfurl in low-Earth orbit. From Simon's perspective, the team learned a lot carrying out the project at a manned spaceflight center.



One of FASTSAT's mission objectives is to demonstrate its ability to eject a nanosatellite from a microsatellite while avoiding re-contact with the FASTSAT satellite bus.
Photo Credit: NASA Marshall Space Flight Center/Doug Stoffer

The difference in scale from the Space Shuttle program Simon had worked on for four years changed his approach to learning. "If I had a question about how we mate to the launch vehicle with the satellite, I knew exactly who to talk to," he said. "The family size of the project allowed the advantages of a co-located R&D [research and development] effort even when we applied it to the development of a spacecraft."

FASTSAT also operated completely differently from the systems he'd encountered earlier in his career. "There were almost no moving parts, and no fluid systems," said Simon, whose previous experience included working on the shuttle's power-reactant storage and distribution system, which stores and supplies the liquid oxygen and liquid hydrogen for the shuttle fuel cells and crew breathing, and R&D systems to produce propellants on other planets. "My rotation had me focusing now on software and electrical engineering, which meant being outside my comfort zone and learning a lot," he explained. He found himself troubleshooting electrical problems and software bugs. "The day-to-day work was in completely different technical disciplines, which forced me to grow."

As the new kid on the block, Simon found that his colleagues were glad to help him get up to speed. "Even though I wasn't coming in on the same page that they were on, I tried to make it very clear that I cared about the success of the program," he said. "As long as that connection is made, folks don't mind helping you catch up—especially if they see you as someone who can help them, too."

The schedule also represented a new way of working for Simon. FASTSAT had a twelve-month project life cycle. Processes were streamlined to where decisions were made in hours, not weeks. "Most of the projects that I've worked on I've had intended launch dates a few or several years away," said Simon. The FASTSAT team charged hard, from a kickoff meeting in January 2009 to an assembled, fully loaded satellite nine months later.
Working under such a fast-paced schedule shifted his approach to projects. "Every project I join now, I'm going to start with [the perspective of], 'What do we need to do?' and not necessarily, 'What have we always done?'" he said. "I'll never be the same again."

To keep pace with the schedule, testing took place nearly every day. "We had to basically get to the test phase earlier than any of us usually get to it, and let the data speak for itself," Simon said. During the thermal-vacuum test, the team was reviewing the output signal from the flight transceiver and noticed a discrepancy that likely would have led to a failure. "One thing I learned from this project is that even if you're trying to do things affordably and quickly, you don't skip these meat-and-potatoes tests," he said. "We could have spent six months analyzing the system, and we never would have found the transceiver issue. Instead, in a few days of testing, we found it."

As the project wrapped up and awaited launch, Simon drafted a lessons-learned document for the team: "I tried to keep it very concise. What was the issue? What did you do to fix it? How did it turn out? And it included a contact name to find out more. Rather than turning it into a giant bound book, I wanted to keep it fairly short." He also organized the lessons by disciplines such as project management and systems engineering to make it user-friendly for readers.

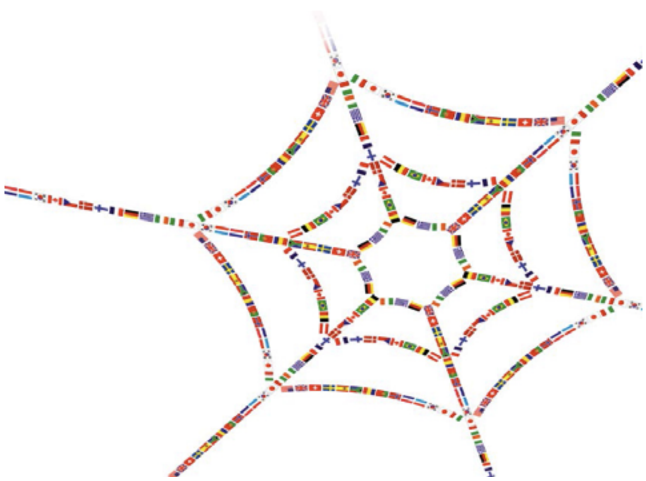
Simon saw the lessons-learned document as a resource for future work at NASA's manned spaceflight centers. "Once the shuttle is retired and the station is complete, there are going to be a lot of people working on systems that need to be approached differently than the way we've worked in the past," he said. Many of the lessons he captured went directly into the draft systems engineering management plan he wrote for potential future FASTSAT satellites, such as HSV-02. "Until you've gone through a build like that," he said, "it would be impossible to predict all the lessons up front."

Working on FASTSAT—a robotic, non-human satellite—helped Simon fill a gap in his experience between working on the shuttle and R&D work earlier in his career in a lab setting. "I don't think they [the SELDP team] could have picked a better assignment, team, or organization for me," he said. "If the first ten years are any sign, I'll be learning every day until I retire."

Weaving a Knowledge Web

By ASK Editorial Staff

Summer 2011, Issue 43



In March 2011, some two dozen representatives from space agencies and related organizations around the world meet in the top-floor conference room of the European Space Agency's (ESA) Paris headquarters. Outside the windows lining one wall, flags representing ESA's nineteen member nations stir in the breeze. A painting of two human figures floating on a background of stars and galactic dust—an image of space exploration—hangs at one end of the room. Space exploration is why the members of the International Project Management Committee (IPMC) have gathered here. The group meets twice a year to develop ways to share the project management expertise that successful space programs depend on.

The space agencies of Germany, France, Italy, Czech Republic, Canada, South Korea, South Africa, and the United States are represented. Committee members from JAXA, the Japanese space agency, have sent their regrets; the aftereffects of the recent devastating tsunami have kept them home. Ed Hoffman, director of NASA's Academy for Program/Project and Engineering Leadership, chairs the meeting.

The committee is just over a year old. Prior to NASA's 2010 Project Management (PM) Challenge in Galveston, Texas, Hoffman asked Lewis Peach to help bring the international space community together. The result was two days of panels at the PM Challenge featuring senior leaders from space agencies around the world and focusing on multinational aerospace projects. Participants in that international track stayed an extra half day to explore the possibility of forming the committee that became the IPMC.

The value of such a committee was clear to Hoffman and the others at that meeting. International collaboration on aerospace projects is increasingly the norm. Most efforts today are multinational, bringing together space agencies, universities, and industries from around the world. And carrying out ambitious and expensive future science and exploration missions will undoubtedly require the resources of many nations. Those missions will demand that all the partners involved possess high-level project management and collaborative skills. An international committee focused on sharing the collective project management knowledge of many space agencies could help make that expertise widely available and build some of the relationships that collaboration depends on.

Bettina Böhm, head of human resources for ESA and now vice-chair of the IPMC, explains ESA's interest in the committee, noting that the need to collaborate with others is becoming more and more important and that, at the time of that first, exploratory meeting, ESA had just carried out a study on new and better ways to prepare people for program and project management. Bringing experienced people together to share practical learning was clearly one valuable approach.

At that initial meeting, the group established some foundational norms, namely, inclusiveness, mutual respect, and the need to show practical benefits.

The IPMC had its first official meeting a month after the 2010 PM Challenge in conjunction with the International Astronautical Federation's (IAF) spring meeting in Paris. It became an IAF Administrative Committee. That official link with IAF's more than two hundred organizations that are active in space in nearly sixty countries gives the committee visibility and the potential for widespread influence. IPMC meetings since have been coordinated with IAF events: the International Astronautical Conference in Prague in the fall of 2010 and now in Paris again, where the IAF was holding its sixtieth-anniversary celebration and planning for the next conference.

The value of such a committee was clear to Hoffman and the others at that meeting. International collaboration on aerospace projects is increasingly the norm. Most efforts today are multinational, bringing together space agencies, universities, and industries from around the world.

Böhm says these early meetings have been mainly—and appropriately—devoted to developing relationships, and creating and maintaining trust and openness. There have been some concrete actions taken, though. The most ambitious so far is the International Project Management course held at Kennedy Space Center in early 2011. Participants in the five-day course included fifteen people from ten IPMC agencies and organizations. At this Paris committee meeting, Andrea Cotellessa, an ESA staff member who attended the course, describes his experience. His review is positive (as were the assessments of other attendees), but he does suggest that some of the sessions were too much from a NASA point of view, with little attention to the different experiences of other agencies. The committee discussed ways of bringing more cases and lessons from other agencies into the curriculum. The second International Project Management course at Kennedy was held in July.

The committee has also recognized the importance of reaching out to young professionals—the engineers, managers, and scientists starting their careers—who will have the privilege of shaping international space-exploration missions over the next several decades and will face the challenges of those ambitious space programs. Young professionals have been invited to the meetings as observers, and the committee is considering a proposal for a young-professionals workshop and young-professional membership.

Emphasizing the need for continuing action, Böhm suggests that at least a couple of hours of every future meeting should focus on an issue in a way that results in specific, useful activity. Her emphasis on concrete action resonates with other members of the committee, who know that the benefits they can bring to their organizations justify their investments of time and travel.

The committee's key challenge, says Hoffman, is to learn how to share the right expertise in the right ways among agencies that differ in size, experience, and how they approach aspects of the work. Continuing activities and conversation among members, like Cotellessa's International Project Management course critique, are helping to develop a fuller understanding of member agencies' practices, which will make effective learning possible at future International Project Management courses and in other settings.

Another challenge is how to keep committee members who are scattered around the globe productively connected, given that they meet formally only twice a year.

That seems to be happening. Relationships formed here are proving to be the foundation for gatherings of small groups to work on issues of specific concern to their agencies. For instance, DLR, the Germany Aerospace Center, brought practitioners of several space agencies together at a small PM Challenge–like event, something unlikely to have happened without DLR's participation in NASA's PM Challenge and connections developed through the IPMC.

The committee will meet next at the International Astronautical Conference in Cape Town in October. It is still very much at the beginning of its efforts. Its contribution to building the knowledge and networks to support twenty-first century space exploration will no doubt take a variety of forms, likely including joint conferences and courses and a range of collaborative initiatives that arise from members' discussions of their shared concerns and challenges. It is not possible to say exactly where its commitment to inclusiveness, respect, and the pursuit of practical benefits will take the IPMC, but it hopes to have a significant role in improving international aerospace learning and cooperation.

Learning to Be an Engineer

By Adam Harding

Summer 2011, Issue 43

A new engineer's career with NASA usually begins by being tossed into the deep end. You are immediately handed real-world engineering challenges and face the overwhelming data, procedures, and calculations needed to solve them. There are mentors and training opportunities along the way to help adjust to the relentless pace of learning to be an engineer at NASA, but there isn't much time during these formative years to pause and reflect on the evolution of your career or formulate potential advice for those about to follow in your footsteps. This is exactly the opportunity afforded me as a member of the "Developing New Engineers at NASA" panel at the 2011 PM Challenge in Long Beach, California. As a panelist, I was to appraise experiences that either promoted or detracted from my development and then share these perspectives.

Airmen of the 23rd Equipment Maintenance Squadron make preparations to inspect for cracks within the wing frame of an A-10C Thunderbolt II, or "Warthog," model. The risk of structural damage to wings of A-10 models was discovered at Hill Air Force Base, Utah. Photo Credit: U.S. Air Force/SrA Javier Cruz

Unlike the four other members of the panel, I didn't begin my career with NASA. That allowed me to provide some comparisons with another government agency that hires and trains many aerospace engineers: the U.S. Air Force.
After graduating with a BS in mechanical engineering from the University of Utah, I accepted a position at Hill Air

Force Base to support the A-10 "Warthog." I spent my first year learning about military aircraft, designing repairs to jets damaged by enemy fire, and learning how to maintain an aging aircraft. Fortunately, I was placed on a team with a good mix of greybeards and newer engineers.

I had many experiences working for the air force that helped me develop as an engineer, including some notable mistakes. Part of becoming successful in a profession is being given the chance to fail. Making mistakes is part of becoming a good engineer. As Niels Bohr said, "An expert is a man who has made all the mistakes which can be made, in a very narrow field." One memorable mistake that helped me better value my own contributions and appreciate the insight of experts occurred when I had been working for only a few months. Being the new guy, I was assigned easier projects like repairs on damaged bolt-holes. While not the epitome of engineering glamour that is dreamed of in college, it was nonetheless critical to airworthiness. I began to notice a pattern of damage in the wing-attach fitting area and decided to compile a summary of all documented repairs for this fitting over the past fifteen years. The end product was a reference table allowing quick turnaround on repair requests for any hole in this critical fitting that held the wing on the aircraft.

Several of the experienced engineers took note of my increased efficiency and started to talk with me about it. I proudly showed them my summary of all the previously approved repairs. Instead of praise for the new guy's accomplishment, they showed concern as they recognized a major flaw with my approach. While any single hole could be enlarged to the respective "clean up" diameter, only one hole in that particular fitting could be enlarged to that degree. If another hole on the same fitting required repair, it could not safely have that maximum diameter due to serious fatigue issues, something I was unaware of.

Finding the flaw in my summary led to a fleet-wide evaluation of these basic repairs. My branch supported about thirty aircraft located at three different air bases at any one time, and there was no cross-check on this repair among the fifteen engineers who carried it out to ensure that multiple

Testing the Orion crew module using air bearings. Photo Credit: NASA

hole repairs weren't being done on the same fittings. Soon this issue was resolved with an updated technical order that included a new summary table of the limits for each hole as they related to other damaged holes on the same fitting. I was not the one who engineered the solution; I was just the engineer who made the biggest mistake and highlighted the problem in the first place.

This experience taught me two principles that have helped me in my career. The first is how important the big picture is, and that I needed to rely on those with enough experience to see the big picture. Sometimes the solution to one problem creates new problems that you won't see if you don't have that broad vision. The second principle is, if an answer comes too easily, ask experienced engineers to evaluate the solution. It's true that the right answer is sometimes the simplest one, but not always, and the simple right answer is not necessarily the easiest to find.

The air force allowed me to return to graduate school to earn a master's degree in engineering after my first year. This additional schooling was very valuable to my development as an engineer. I had spent a year learning from mistakes and interacting with experienced engineers. That gave me a different perspective when I returned to the classroom. I appreciated the fact that most great engineering solutions are not pounded out individually, but through collaboration among team members. I had seen firsthand how things are built, broken, and rebuilt.

Following graduate school, I returned to the maintenance hangar and tried to apply what I had studied in class. Although my job was inherently technical, the greatest challenges for me would be better classified as learning how to apply research skills to understanding the engineering already in place. Essentially, I was fixing problems that required an engineering degree to understand the proper contextual background for established technology but not for direct application for research or new design. The real engineering had already been done. Despite this, I still experienced a high degree of job satisfaction.

In 2007, I accepted an offer to work at NASA's Dryden Flight Research Center. NASA's mission is oriented toward research-based engineering. I was coming from an "end-user" focus on established engineering and, to a degree, felt like I was starting over with a greater technical emphasis. Instead of focusing on A-10 fleet maintenance, I was now working on research and development of the Orion crew module.

My initial assignment was to the structures team. I had responsibility for the mass property testing of the crew module. This involved developing test equipment capable of manipulating the crew module in a variety of positions and attitudes while inducing oscillations and recording precise measurements to determine the center of gravity and moments of inertia (a measure of an object's resistance to changes to its rotation).

These measurements would directly influence the success of the launch. I had not worked on anything like this in my five years with the air force. Fortunately, I had access to seasoned engineers who had information dating back to similar testing done during the Apollo era.

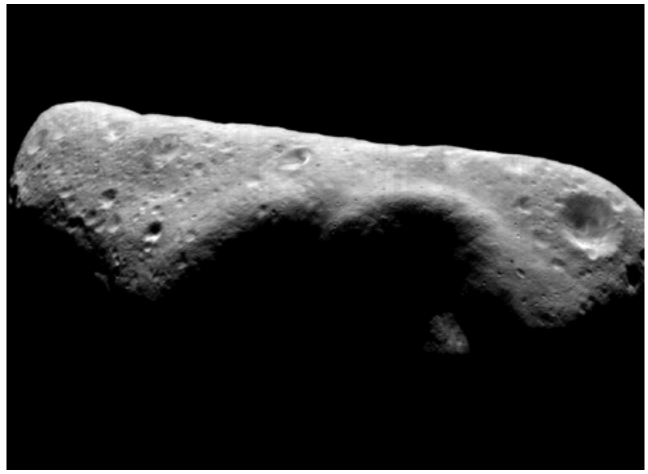
> ***Even though NASA's culture and mission were different from the air force, the principle of learning by trial and error still held true. The simplest of oversights on one of our center-of-gravity tests emphasized a great lesson: always read the owner's manual.***

However, the greatest contributor to the success of these tests was a young engineer named Claudia Herrera, who had only been out of school for a couple of years. She had experience with the mass property testing of airplanes at Dryden, but not space capsules. Claudia tackled the technical and programmatic challenges head-on. As I worked with Claudia, I saw that the few years of hands-on experience at NASA had really given her an edge in continuing her development as an engineer. While I had already experienced some mental atrophy on principles taught in school, Claudia had been able to catapult ahead in her development thanks to the challenges of working at NASA.

Even though NASA's culture and mission were different from the air force, the principle of learning by trial and error still held true. The simplest of oversights on one of our center-of-gravity tests emphasized a great lesson: always read the owner's manual. We were using air bearings to provide a near-frictionless interface for our test fixtures. These allowed us to tilt the crew module to various angles for measurements. We had received on-site training by the manufacturer, who stated that our concrete floors were adequately smooth to interface with the air bearings. However, during our initial testing, the crew module caused the air bearings to drag despite weighing only a fraction of the system's capacity. Due to schedule constraints, we didn't have time to solve the problem and decided to retest when the next window opened in the schedule.

Six months later, as we prepared to retest, we moved to another hangar with smoother concrete. As we began testing we noticed the same dragging problem. Our team was stumped. A mechanic recommended reviewing the owner's manual, which we had previously only skimmed. A careful reading revealed a suggestion to use sheets of aluminum to improve performance. We did this and finally had the results we needed. This time, the answer was easy to find—it was right there in black and white—but our team took a long time to find it.

If asked by a recent engineering graduate whether to accept an offer to work at NASA or the air force, I would recommend NASA. Here's why: NASA engineers are directly responsible for cutting-edge research, testing, and publication of flight data. This makes NASA a premier training ground for new engineers. A new engineer develops best by building, testing, and breaking, and learning from the process. My development as a new engineer has accelerated since joining NASA. The maintenance environment at the air force was purposefully designed to reduce opportunities to make mistakes. That inherently reduced opportunities for growth. Despite this, I still found ways to mess things up there, too.



This image mosaic, taken earlier in the NEAR mission, shows Eros's southern hemisphere, offering a long-distance look at the cratered terrain where the spacecraft touched down. Photo Credit: NASA

My evaluation of what benefited me most as an engineer is that trial and error taught me more than reading and research. Exposure to the technical accomplishments of others is no substitute for experiencing failure yourself. My advice to new engineers is to volunteer for the challenging assignments and don't be afraid of the mistakes that will happen along the way. Keep in mind that these mistakes are necessary steps to success.

About the Author

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Rendezvous with an Asteroid

By Andrew Cheng

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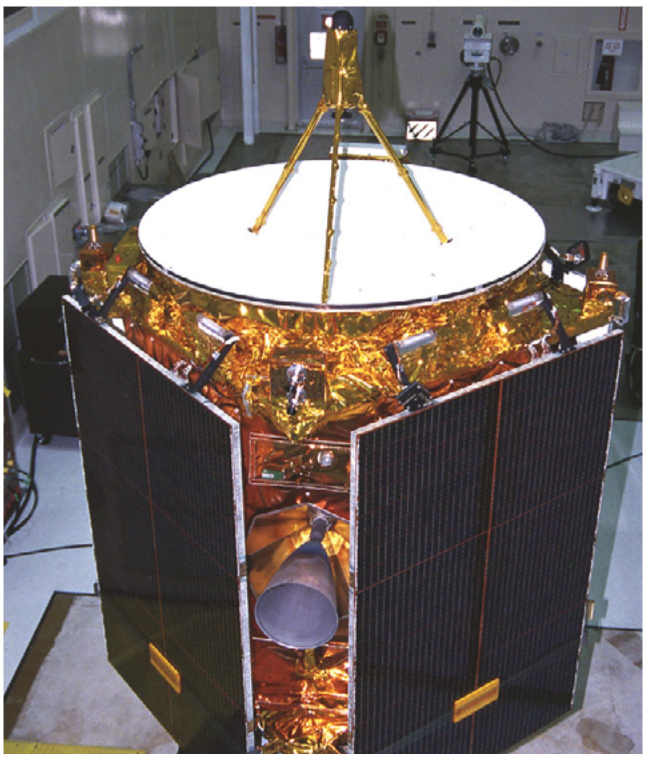
NEAR was the Near-Earth Asteroid Rendezvous, the first launch in NASA's Discovery Program—and the first dedicated asteroid mission. The plan was to insert the vehicle into orbit around Eros, one of the larger near-Earth asteroids. Not everything went according to plan.

NEAR was the first planetary mission by the Johns Hopkins University Applied Physics Laboratory (APL). And NEAR was probably the first NASA mission on which the Internet was widely used. I remember being called in to my management's office and being asked, "How come I don't have a file of all the letters and announcements and schedules that I sent out to my science team?"

And I said, "Oh, I'm not doing that. I'm using e-mail."
"Using e-mail?"

Not that management wasn't aware of e-mail, but, in 1993, it was a bit innovative to rely on it instead of printed paper. NEAR was also the first mission with an open-data policy. Previous missions, like Galileo, had a one-year proprietary data period; investigators owned the data for that year and often were reluctant to let other people use it. We were the first mission that had to agree up front to an open-data policy with no proprietary period. Our scientists—in fact, the whole science community— was not used to that idea. In their view, they were investing years to build the instruments and develop the mission, and then wouldn't receive any reward for the effort.



The NEAR spacecraft undergoing preflight preparation in the Spacecraft Assembly Encapsulation Facility-2 at Kennedy Space Center. Photo Credit: NASA

Without a proprietary period, and with the rapid release of all data, scientists anywhere in the world would be able to glean new scientific results and potentially scoop the mission investigator team. But our experience on NEAR, and subsequently on numerous other missions, alleviated this concern. Mission investigators are familiar with the mission, the instruments, and the science issues, and they have dedicated funding to analyze the data. Given those advantages, they are rarely, if ever, scooped. Science missions with open-data policies are now standard for NASA.

NEAR was also one of the first faster-better-cheaper missions. We advocated for less than thirty-six months' development, and we actually delivered in twenty-seven. We also came in below our cost cap, which was $150 million. One reason for this success is that we were able to work the way we had always done at APL, even though this was a new type of mission. That was a good lesson: you really don't want an implementing institution to completely change the way it does business. Even if nobody knew at the time what we were getting into.

When we started mission implementation in 1993, no one had any idea how to operate a spacecraft around a small body. That was the biggest leap into the unknown for NEAR. Even though we had identified the target asteroid, we didn't know its mass. Because of that, there was no way to simulate orbital operations. Things you take for granted today, in terms of simulating navigational accuracy and showing that you can obtain all the promised measurements, we couldn't do because we had no idea what the orbits were going to be like. It was worse than that, actually, because APL, it turned out, had no idea how to operate a planetary mission. We had to learn on the fly.

Our original plan was to approach the asteroid very slowly and remain at a high altitude—where irregularities in the gravitational field due to the non-spherical shape of the asteroid would be less important—until we gained enough knowledge to orbit at a low altitude, which was required for many of the key measurements we wanted to obtain. Our original plan changed.

There's folklore that says the job of a mission or program manager or project scientist is to just say no—that when requirements are set they're set. Real life is not like that. On NEAR, we had a bunch of things we agreed to that were not in our original plan. Flying by Mathilde—to explore a C-type asteroid (meaning its surface is believed to have a high concentration of carbon) for the first time and obtain great science—was one of them. We had to spend extra fuel to get there and undertake operations we had never tried before. And then we agreed to fly closer to Eros than we'd ever intended to or guaranteed we would, and finally land on the asteroid.

The final mission operations ended up being the Mathilde encounter, Earth flyby, the Eros flyby—which was supposed to be the rendezvous, but we missed—the Eros rendezvous insertion, the asteroid landing, and then the science operations.

Learning from Problems

The changes, and our first miss of the Eros rendezvous, ended up being good news. Since we were learning on the fly, we learned more the longer we flew. After we failed to get into orbit as originally planned, we flew by Eros and made preliminary measurements of its mass and shape. This information allowed us to simulate orbital operations, which we couldn't do before because the information didn't exist. When we returned to Eros in February 2000 and entered orbit, we were able to descend to a low altitude quickly and make all the planned measurements (plus more) as a result.

That first flyby taught us some tough lessons, too. When we started the second burn of the spacecraft's main bipropellant engine, it shut down after one second. This brought back

High-resolution surface images and measurements made by NEAR's Laser Rangefinder have been combined into this visualization based on the derived 3-D model of the asteroid. Photo Credit: NASA

memories of what happened on Mars Observer, which was lost during the second burn of its big bipropellant engine. And we didn't know what had happened on NEAR.

Miraculously, NEAR recovered twenty-seven hours later. The spacecraft contacted Earth and indicated the battery was fully charged. It was in sun-safe mode, but fine. But what actually happened?

We were only able to recover the first forty-something minutes of events that led to the shutdown. After that, we don't really know what happened because low voltage detected on the spacecraft shut off the solid-state recorders, and the data were lost. So we don't know what happened toward the end, but we understood the series of errors leading up to that time—starting with how the spacecraft was fundamentally put together. Its construction had many advantages for the mission, but it also contributed to the shutdown.

The main engine was perpendicular to the main load-bearing structure, so when we fired the engine, the structure flexed just enough to create a false reading of lateral thrust on an accelerometer, and that's what shut us down. The data by which an analyst could have predicted this would happen was actually available but had not been seen or acted on by the right people in order to set the accelerometer's threshold properly.

Once the burn was shut down, an automatic command was supposed to place the spacecraft into an Earth-pointing safe mode. It turned out that the command script programmed this maneuver to be done with thrusters, but the same script also disabled the thrusters. So the command was initiated with thrusters but used momentum wheels when the thrusters were disabled. The wheels didn't have enough torque to stop us in the proper attitude, so we overshot. And because the spacecraft didn't stabilize at the Earth-pointing attitude, it went again to a sun-pointing safe mode. It didn't stabilize immediately in this mode, either, so it began to fire its thrusters again to compensate.

In other words, our preflight testing failed to turn up several errors. APL has a deeply ingrained culture of test as you fly, fly as you test. Nevertheless, at least four errors were not turned up by our testing. The right tests—of the guidance system, the autonomy system, the operations scripts—were not done. That's what caused our problems.

Still, NEAR was designed with enough back-up systems and redundancy that it recovered from the anomalies. We don't know exactly how it recovered, but when it contacted Earth twenty-seven hours later, the battery was fully charged and the spacecraft was in a nominal state.

There were a number of lessons to be learned there: the way the ops team should operate, the way operations scripts are tested, the way the guidance system is tested before launch. We took those lessons to heart because they showed us where we needed to improve. Since then, we routinely perform the tests that would bring out issues like those experienced on NEAR, and we have not had any similar anomalies on subsequent missions.

Success

Many things also went right. Achieving the first landing on an asteroid is one of them. Another was a magnificent science return that exceeded all expectations.

Our second rendezvous burn occurred at the beginning of 2000, only a few months after the losses of the two Mars '98 spacecraft. Things that happen to other projects can have a big effect on you, and that's exactly what happened to us. The Mars '98 missions were lost, and NEAR was about to make its second attempt to get into orbit around Eros, after screwing up the first one. You can imagine the kind of scrutiny we were under, and the interest we got from Headquarters—exactly the kind of interest you don't want. When the time came for us to land NEAR, Headquarters

High These images of Eros were acquired by NEAR on February 12, 2000, during the final approach imaging sequence prior to orbit insertion. Photo Credit: NASA said no, you're not landing the spacecraft. Instead, we were allowed to command the spacecraft to "descend to the surface," because descending to a surface does not necessarily mean a safe, soft landing.

When our ops team announced that the spacecraft was on the surface and we were still in contact with it, it took a while for that news to sink in. There was a stunned silence in the room, with all our VIPs looking around nervously. It succeeded? Yes, it did!

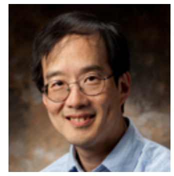
Because it was the first launch of the Discovery Program, everybody needed NEAR to be successful. Obviously, APL needed it because it was our first planetary mission. NASA needed it to enable the Discovery Program to establish that it was a credible, useful, important thing to do with Congress and with the Administration. The community needed it because there was great science to be had.

To help us succeed, we had strong support from Headquarters. At the time, the Discovery Program Office at Marshall Space Flight Center did not exist, so we worked directly with the program executives at Headquarters, and we had a good relationship with them. That relationship was—and is—key to helping missions proceed smoothly.

Getting the team to truly be a team is also important. Science, engineering, and management are separate disciplines, but they all have to be pulling in the same direction or you cannot succeed. Nobody can do the mission by themselves. You need the whole team. There were many instances on NEAR, from getting to launch on time and within budget to overcoming the problems that arose in flight—like the 1998 burn anomaly—where the difference between success and failure was, simply, the team.

And it isn't enough for the leadership team to know what the requirements are; your whole team needs to understand them deeply. Not only what they are literally, but where they come from and how they bear on what the mission is supposed to be doing. The subsystem leads and even the people at lower levels than that should understand them, too, because they make decisions every day. If they don't understand your requirements, they may create a problem you won't find out about for a long time. Or they may have a better solution to offer that fulfills the intent of the requirement. It must be okay to ask questions and bring up issues, even about subjects that may be outside one's discipline.

Many lessons are learned over and over again. It's not that we're stupid and never learn from the past, but when you're going to new places, doing new things, and making discoveries, you often run into old problems in new guises. Technical circumstances, political environment, external environment, and program management are always changing. So when the gremlins show up on your program, they may look different from the ones people saw before, even though they are fundamentally the same. The challenge is to recognize those similarities earlier so you can apply lessons learned to fix them with less pain than your predecessors.



About the Author

Andrew Cheng is the chief scientist for the Space Department at the Johns Hopkins University Applied Physics Laboratory, where he serves as the department's external liaison for space science and provides independent science advice and strategic vision to lab and department leadership. He was the project scientist for the Near-Earth Asteroid Rendezvous mission, which was the first to orbit (and eventually land on) an asteroid.

MANAGING STAKEHOLDER STYLES TO OPTIMIZE DECISION MAKING

BY VANIA NEVES

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We make many decisions every day. Should we wait patiently for the green light to cross the street or risk an accident? Should we buy something we want or save money for the future? We also make decisions with other people. When planning a vacation with friends or family, the group has to decide on destination, route, dates, costs, transportation, hotels, and attractions. Sometimes planning is easy and the result is a pleasurable outing for everyone. At other times, some members of the group take too long to agree about the trip details; in the end, some may decide not to travel together as they realize they have different objectives. The complexity and flexibility of decision making is directly related to the objectives and characteristics of each individual.

Similar situations occur during program and project execution. Project decisions can become especially tough when they involve many people. The individual perspectives and behaviors of various stakeholders can create differences of opinion and may raise political issues and spark conflict between different organizational environments. When a project team is geographically dispersed, these complexities are likely to increase. So what can program and project managers do to avoid or minimize problems in such situations?

There is no simple formula for success, but proper communication and stakeholder management can reduce the negative effects of bad decisions or long, drawn-out decision-making processes. For complex programs and projects, mapping psychological characteristics, including decision-making styles and personal motivators, provides guidance on how and what to communicate to stakeholders.

Stakeholder Analysis

Focusing exclusively on execution rather than paying attention to removing barriers in the project environment may not bring the expected efficient and effective results. Communication gaps are one of those barriers, especially in large projects. As part of project communication planning, it is a good practice to carry out an accurate and systematic stakeholder analysis by identifying and understanding who the people involved in the project are, what their organization positions and project roles are, their contact information, how they feel about the project, what they expect, what their interests are, what their influence levels are, and whether they are internal/external, neutral, resistors, or supporters. Additionally, it is useful to identify how key decision makers are likely to respond in various situations, given their decision styles.

Understanding Stakeholder Decision Styles

Mapping likely reactions to a given situation requires a common-sense understanding on decision style models. A good approach is offered by Rowe and Boulgarides in Managerial Decision Making: A Guide to Successful Business Decisions.

They define decision style as the way in which a person perceives information and mentally processes it to come to a decision. Decision style reflects a person's cognitive complexity and values. Understanding stakeholder decision styles is a valuable part the stakeholder management strategy.

The Decision Style Model

Rowe and Boulgarides identify four styles: directive, analytic, conceptual, and behavioral. Individuals usually exhibit a combination of these styles, though one or more may dominate.

Directive: This individual has a low tolerance for ambiguity and low cognitive complexity. The focus is on technical decisions based on little information, few alternatives, and minimal intuition, resulting in speed and adequate solutions. Generally directive individuals prefer structured and specific information given verbally.

Analytic: This individual has a much greater tolerance for ambiguity than the directive one and also has a more congnitively complex personality that leads to the desire for more information and consideration of many alternatives. This style enjoys problem solving and strives for the maximum that can be achieved in a given situation. Generally, such people are not rapid decision makers; they enjoy variety and prefer written reports. They enjoy challenges and examine every detail in a situation.

Conceptual: This individual has both cognitive complexity and a people orientation and tends to use data from multiple sources and consider many alternatives. Conceptual decision makers have a long-range focus with high organizational commitment. Generally they are creative and can readily understand complex relationships.

Behavioral: Although this individual has low cognitive complexity and uses low data input, he or she has a deep concern for the organization and people. Behavioral decision makers tend to have a short-range focus and use meetings for communicating. They provide counseling, are receptive to suggestions, persuasive, and willing to compromise.

Using stakeholder analysis, the project manager, with the project team's support, can create a stakeholder management strategy for gaining support or reducing obstacles.

Applying the Decision Style Model

Managing a virtual program team to integrate the information technology (IT) infrastructure of two merging companies provided an opportunity to confirm the value of this approach. This IT-integration program included an infrastructure project, a commercial systems project, and a manufacturing systems project. In the planning phase, several integration options were designed to fit business and technical assumptions. A lot of money was required to implement any of the options of full, medium, and minimum IT integration. (Doing nothing was the low-cost option.)

Full integration would replace all the acquired company's systems and infrastructure with the owner company's IT infrastructure. This option would produce merger benefits anticipated by the commercial units of both companies, but it was not aligned with the manufacturing unit's strategy of keeping both companies' manufacturing environments running with minimal changes and investments.

Medium integration would be similar to full integration but with no changes in manufacturing systems. This option would support expected commercial benefits and be consistent with manufacturing strategy. It would, however, mean extra work for a few people due to a lack of some process automation.

Minimum integration would apply mandatory changes to the acquired company's IT infrastructure to meet the new company's standards. It would mean faster implementation and would fit into manufacturing strategy, but it would not support expected commercial benefits.

The decision-making process to select the integration option was as difficult as the program execution. Having these clearly defined steps and requirements was essential to our success:

A robust merge-and-acquisitions framework. This made the team aware of the steps to follow and how to contact subject-matter experts to provide guidance when needed.
Clear definitions of roles and responsibilities. This kept the team committed to and focused on program goals.

Mapping stakeholders' expectations and motivations and identifying the decision makers were critical to support the stakeholder management strategy.

As specified in the communication plan, we held regular team virtual meetings tailored for different audiences.

All required technical and functional specialists were invited to support the design for the integration.

Workshops with business and technical teams from both companies were held for gathering business requirements and identifying key risks for the integration.

Integration options and budgets were submitted to senior management for approval.

Given the program's complexity, the budget required, and the decision's impact on the business of both companies, new stakeholders from higher levels of the organization joined the program approval committee partway through the process. As they were not familiar with the project's history, some of them asked for new integration options based on new assumptions. It became clear that the decision-making process would take longer than expected.

For complex programs and projects, mapping psychological characteristics, including decision-making styles and personal motivators, provides guidance on how and what to communicate to stakeholders.

The program approval process would have been an endless journey if we had not adjusted our communications to respond to these new demands. Using the decision style model, I mapped the potential dominant decision styles and updated the program stakeholder management strategy. Before the final session for program approval, we held individual and group meetings and teleconferences tailored to the stakeholders' interests and influences on the project. To the overall presentation with the integration options and rationale for each of them, we added additional appropriate information and adjusted emphasis to match stakeholder styles. The majority of senior stakeholders had conceptual, analytic, and directive decision styles.

The main concern of the stakeholders with an analytic style was understanding the financial impacts in detail. Our supporting materials were therefore related to on-time costs, ongoing costs, and the net present value of each integration option.

For stakeholders with a directive style, who were concerned about understanding overall integration scenarios in a concise and objective way, we provided a matrix and summary that went straight to the point. We showed integration level, scope, pros and cons, risk impact, and costs for each option.

The stakeholders with a conceptual style were concerned about financial impact as well, but their questions also addressed long-term benefits, risks, and impact on both the organizations and their people. For them, in addition to the big picture provided by the matrix with a summary of integration options, we used supporting material with long-term effects, such as the high risks of implementing a minimum integration or doing nothing. Those options would not give the acquired company the benefits of the owner company network and services, so although low or no investment would be done in the short term, in the medium term they would need additional budget to remediate their IT environment. In addition, the new company's business would not benefit from up-to-date technology.

In the end, senior management approved the medium integration option proposed by the program team. They agreed that the preferred integration strategy was the most cost-effective option and aligned with the owner company's IT target architecture, which would support both commercial requirements and future manufacturing strategies. Like a group that works to decide on a joint plan for a trip, these executives only reached a common decision when the advantages, disadvantages, and risks involved were communicated in ways that matched their decision styles.

In other words, we were successful because we were able to adjust communication channels and messages to match stakeholders' behaviors and interests. We accelerated and improved the decision-making process by giving stakeholders information in the ways they could best process it.

About the Author

Vania Neves is a senior information technology leader for GlaxoSmithKline, where she holds the position of IT director, accountable for supporting commercial business unit demands in Brazil, Argentina, Chile, and Uruguay. Her responsibilities also include the IT division of Phoenix, an Argentinean company, part of the GlaxoSmithKline group.

Government and Academia Study Systems-Thinking Development

By Danielle Wood, Heidi Davidz, Donna Rhodes, and Maria So

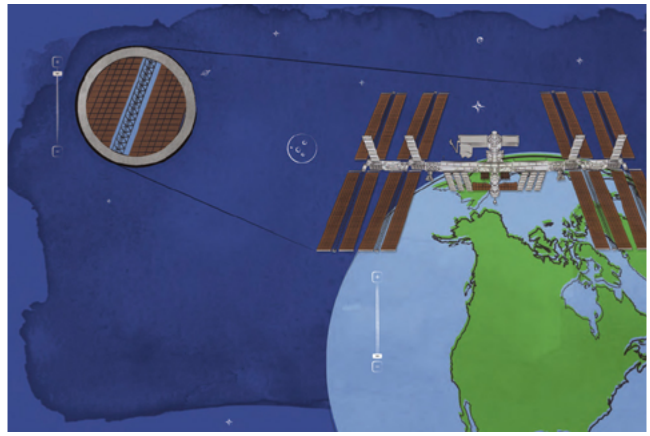
Fall 2011, Issue 44

How do NASA's systems engineers develop the skills they need to think effectively about the complex systems they develop? How do people outside formal systems-engineering roles improve their ability to see connections across subsystem and organizational boundaries? What can NASA management do to facilitate the development of systems thinkers in its workforce? A collaboration between NASA and a university research group addressed these challenging questions.

The questions were tackled as part of the doctoral dissertation of Heidi Davidz while she was a PhD student in the Engineering Systems Division at the Massachusetts Institute of Technology (MIT). Working under Professor Deborah Nightingale, Dr. Donna Rhodes, and other faculty, Davidz devised interview and analysis methods that approach the issue both qualitatively and quantitatively. She interviewed 205 engineers at ten organizations, primarily in the aerospace industry.

Another MIT student, Danielle Wood, used Davidz's methods to explore the development of systems thinking among engineers at NASA's Goddard Space Flight Center. Wood's project was part of a collaboration between Maria So (then chief of the Mission Systems Engineering Branch) and Dr. Rhodes of MIT's Lean Advancement initiative and Systems Engineering Advancement research initiative. As a branch chief and line manager for about fifty senior system engineers at the time, So's responsibilities included caring for the professional development of Goddard's core systems professionals. She was also involved in several NASA activities aimed at improving systems engineering methods, including participating in the NASA Systems Engineering Working Group, shaping a NASA systems-engineering leadership development program, and updating the NASA Systems Engineering Handbook.

So and Rhodes invited Wood to carry out data collection and analysis for a systems-thinking study at Goddard based on the work of Davidz. In early 2007, Wood interviewed thirty-seven Goddard employees in four categories: senior systems engineers, junior systems engineers, senior technical specialists, and expert panelists. The expert panelists were senior leaders in the systems engineering community at Goddard. The core interview questions asked participants to define systems thinking and name enablers or barriers to the development of systems thinking in engineers. The results show that at Goddard, as in other parts of the aerospace industry, the key enablers of systems-thinking development are experiential learning, personal characteristics, and environmental effects.



Experiential Learning

Davidz's doctoral study emphasized the importance of experiential learning in developing systems thinking. Interviewees from Goddard and the broader industry study cited valuable learning from both work and general life experience. A relatively high percentage of respondents (30 percent) at Goddard said that exposure to systems thinking and to the relationships between subsystems helped develop systems thinking. Specifically, they mentioned the opportunity to see other capable engineers successfully implementing systems engineering tasks. As one respondent said, "I got to work on projects where I had senior engineers who were willing to teach and who modeled the behavior that I needed to learn."

One supervisor modeled systems thinking for his team when testing and qualifying equipment. As one interviewee recalled, "He always asked about how their work would affect the whole mission." About 21 percent mentioned that it is valuable to experience a variety of roles. At Goddard, this often means rotating to various subsystems within a satellite mission team. One engineer was thankful for experience in design, testing, and project management—even when the role did not suit him.

He noted, "I tried design and realized I was not a designer." Sometimes a team leader helped engineers find new roles that were opportunities for learning. One engineer reported that her mentor "basically fired [her] off the Hubble Space Telescope project so [she] would get some experience." She eventually saw this as a favor. It was also helpful for one of the engineers to work on three small explorer satellites "in the span of eight years and see three of them launch."

Some members of the Goddard team (27 percent) gave examples of formal systems-engineering training programs, such as Goddard's SEED (Systems Engineering Education Development) and JumpStart initiatives. Engineers in the SEED program benefit from a combination of courses and rotational assignments designed to increase their exposure to the work of the overall satellite team. JumpStart, a program initiated by So, allows senior technical specialists to move directly into a systems role without formal training. Goddard interviewees also found short courses to be helpful.

One person specifically appreciated a course because it took him away from his routine for a week, and another appreciated a course that gave guidance on opportunities to move within his organization. For one interviewee, the key aspect of a training course is working through case studies that expose engineers to areas with which they are unfamiliar "because systems engineering is about constantly running into stuff you know nothing about." Some subsystems—for instance, the on-board computer and attitude control system—naturally interface with many other systems on a satellite. Working on a team that works closely with many other teams can also help enable systems thinking (according to 15 percent of the Goddard respondents).

Recognizing the value of experiential learning to the development of systems thinking will encourage both engineers and their managers to harness opportunities for learning by experience.

Personal Characteristics

Results from the Goddard interviews supported Davidz's conclusion that personal characteristics also influence the development of systems thinking in engineers. Many of the Goddard engineers (42 percent) stressed that systems thinking develops best when a person is not prone to "bench-level" thinking about their specific subsystem or task. Some interviewees (15 percent) proposed that certain people have an innate desire and ability to do systems-level work. This may be seen as a desire to understand how the parts of a system interact (18 percent), a desire to experience new things periodically (12 percent), or a natural tendency toward big-picture thinking (36 percent). One respondent said, "I'm unhappy when I see something and don't understand it."

The Goddard team proposed that systems thinkers may also be good at interacting with people (27 percent), communicating (21 percent), thinking logically (18 percent), and staying open to new ideas (21 percent). All these qualities are facilitated by humility and a willingness to ask questions. One person commented that in transitioning from a role as a subsystem expert to a systems engineer "you have to be willing to lose some depth in order to gain some breadth." Several ideas from the Goddard study were similar to Davidz's results, especially the concept that systems engineers often have an inherent or developed sense of curiosity and a tendency to think of the big picture. One enabler that came out of Davidz's study, not commonly mentioned at Goddard, was a tolerance for uncertainty.

Engineers and managers can use these ideas to foster systems-thinking development in their teams. People who seem to naturally have systems-thinking ability can be moved into positions with systems responsibility. People who may not have some of these innate characteristics but still need to apply systems thinking for their work may be candidates for an intervention via experiential learning. Someone in the study saw a teammate grow in this way. "One of the engineers I worked with … had been an analyst and became a subsystem lead. I would ask him questions that would cause him to go back and revisit his assumptions. Soon, he started to anticipate my questions. This is an example of training via exposure to the bigger picture."

Environmental Effects

According to the Goddard community and Davidz's doctoral results, the environment in which an engineer works also influences the development of systems thinking. Systems thinking can be enhanced by an engineer's relationships with individuals, the immediate organization, and the broader community. Close relationships with mentors and supportive management play an important role (as seen in 21 percent of Goddard responses). Mentors can help people see their own potential for systems thinking, as in the case of the interviewee who said, "The key enabler was a mission systems engineer who said that he thought I would be good as a systems engineer. I said no three times, but I'm happy I said yes." One person was thankful for a mentor who shared lessons from his own experience: "Having somebody who is twenty years more experienced than you sit down for an hour of relaxed conversation … I cannot put a value on what those lessons meant." Twelve percent of the Goddard interviewees mentioned that engineers benefit from managers who explicitly value the development of systems thinking.

Similarly, a narrow interpretation of an engineer's role by their organization discourages systems-thinking development. One interviewee recalled that people discouraged him from thinking creatively when he tried to consider possible implications to changes in his flight software: "People said things like, 'Don't worry about that aspect—that's not your area.'" Another interviewee noted that the role of a systems engineer can be limited to "clerk" if all he does is write requirements and track their completion. Such a concept does not contribute to systems-thinking development.

Systems thinking is also fostered by a surrounding community that has a systems understanding. One example is teams that invited all the subsystem leads to be part of the systems-engineering group. As some Goddard leaders noted, community understanding is aided by the growing recognition of systems engineering as a formal discipline. An organizational culture that values people with diverse experience also contributes to systems engineering skills. For example, people are better able to develop as systems thinkers when the organizational culture makes it possible to rotate among various job activities. A few people from Goddard noted that organizational pressure for engineers to stay in their disciplinary area could hinder that development. Davidz's results uncovered some issues that were not often mentioned by the Goddard team. Schedule and cost constraints and misaligned organizational incentives can be challenges to exercising systems thinking. The Goddard expert panelists gave examples of organizational tactics to foster systems thinking that included encouraging risk taking, giving awards for systems thinking, and providing funding for exploring new ideas.

Follow-Up to the MIT–Goddard Study

The MIT team—Rhodes, Davidz, and Wood—delivered the results of the Goddard interviews to So, the Mission Systems

Engineering Branch, and the director of Engineering via a report and presentation. So's team took some immediate steps to respond to the research. They saw the need to ensure that the mission systems engineers in So's organization had a variety of mission experiences and communicated with each other about their projects. So addressed this by ensuring that systems engineers served on peer-review panels to missions outside their main assignments and by establishing small discussion groups where systems engineers could share knowledge. Goddard also continued to benefit from a monthly systems-engineering seminar in which speakers from inside and outside NASA shared about issues in the field. So continued to be involved with NASA's wider activities to improve systems engineering, helping to develop the Project Management and Systems Engineering Competency Models.[1]

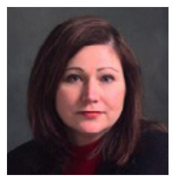
The Goddard–MIT Systems Thinking Study provided great benefits at low cost to the participants. The relationship between Goddard and MIT was mutually beneficial. Goddard's Mission Systems Engineering Branch gained from access to the expertise and research effort of MIT. Rhodes's research group was able to validate their research results by extending the scope of investigation to include government engineers. Wood, as a young master's student, profited from the exposure to NASA and the research training. She went on to follow Davidz's footsteps and pursue a PhD within MIT's Engineering Systems Division. So and Rhodes continued to find ways to work together through student projects. Another MIT student, Caroline Lamb, also worked with So's team for the data collection for her doctoral dissertation (completed in 2009). In her doctoral work, Lamb built on Davidz's definition of systems thinking and explored the dynamics of collaborative systems thinking at the team level. One of Lamb's case studies was the GOES-R satellite team at Goddard. The results of this study were featured in a paper coauthored by NASA and MIT.

As So reflected, this project brought intellectual value to Goddard's systems engineering community. It also stands as a shining example of government collaboration with academia. The government does not always have the financial or personnel resources to do exploratory studies about important issues like the development of systems thinking. Academic organizations bring expertise and effort, and benefit from access to NASA's practitioners. The team hopes that this project will be a model for future useful collaborations.

About the Authors

Danielle Wood is a doctoral candidate at the Massachusetts Institute of Technology (MIT), where she studies aerospace engineering, technology policy, and international development. Her technical focus is on the systems engineering and architecture approaches for satellites and satellite programs.

Heidi Davidz is the chief process engineer for Pratt & Whitney Rocketdyne. She advised the NASA Office of the Chief Engineer's Academy of Program/Project and Engineering Leadership in developing its systems engineering capability. In 2006, she earned her PhD from MIT with her dissertation, Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers.



Donna Rhodes is a senior lecturer and a principal research scientist in the MIT Engineering Systems Division and director of the MIT Systems Engineering Advancement Research Initiative. She is a past president and fellow of the International Council on Systems Engineering (INCOSE), and a member of the Institute of Electrical and Electronics Engineers (IEEE) and American Institute of Aeronautics and Astronautics (AIAA).

Maria So is the deputy director for the Safety and Quality Assurance Directorate at Goddard Space Flight Center. Previously, she was with the Mission Engineering and Systems Analysis Division, first as the senior technologist, then associate branch head of the Earth Science Systems Engineering Branch, branch head of the Mission Systems Engineering Branch, and associate division chief. She is a member of the AIAA Space Systems Technical Committee, INCOSE, and IEEE.

1. See www.nasa.gov/offices/oce/appel/pm-development/pm_se_competency_framework.html.

Chapter 4

Case Studies

Weathering the Storm: Lessons from Hurricane Ike

When the performance of one of NASA's centers is hindered, mission success is at risk. Natural occurrences such as wild fires, earthquakes, snow storms, and hurricanes are usually not the first performance-threatening obstacles that come to mind at NASA—budgets and technical problems are more frequent show-stoppers. As Kennedy Space Center Emergency Manager Wayne Kee said at the 2010 PM Challenge, "When you're dealing with emergency management, if the winds are not howling, and the rains are not blowing, and the earth's not shaking, it's out of sight, out of mind."

Every center at NASA faces some threat of natural disturbance or disaster. Any number of natural disasters can shut down a center, threaten the well-being of NASA employees, and put missions behind schedule. Each center has emergency response plans in place, but the chance to execute and learn from these plans are far and few between—which can be both a blessing and a curse.

Picture of Hurricane Ike taken by the crew of the International Space Station flying 220 statute miles above Earth. Credt: NASA

In August 2008, NASA astronaut Greg Chamitoff was aboard the International Space Station (ISS) with two cosmonauts from the Russian Federal Space Agency. A series of Progress and Soyuz spacecraft were set to dock and undock from the ISS between September and October. STS-125 was slated to launch October 8, 2008 for the final servicing mission of the Hubble Space Telescope. Mission Control at Johnson Space Center (JSC) was busy with operations and preparations for ongoing and future missions. From August to October, JSC would also endure three tropical storms—one of which would devastate the Gulf Coast of Texas and earn the title of third costliest hurricane to hit the United States. The JSC community had to be ready to persevere.

Download PDF Case Study.

http://www.nasa.gov/offices/oce/appel/knowledge/publications/weathering_ike.html

The Deepwater Horizon Accident – Lessons for NASA

On April 20, 2010, the Deepwater Horizon rig was finishing up a drilling job at the Macondo lease site, a plot in the Gulf of Mexico 49 miles off the coast of Louisiana. At the time, the job was 43 days over schedule and $21 million over budget due to additional leasing fees. At 9:49 p.m., the rig exploded, leading to 11 deaths and the worst oil spill in U.S. history.

The lessons from this tragedy are potent reminders of the pitfalls that can plague complex programs and projects in any industry, even (perhaps especially) those with long track records of success. Prior to the accident, Deepwater Horizon was one of the best-performing deepwater rigs in BP's fleet. In September 2009, it had drilled to a world-record total depth of 35,055 feet. As of April 2010, it had not had a single "lost-time incident" in seven years of drilling. The deficiencies that set the stage for this tragedy—government

Vessels combat the fire on the Deepwater Horizon while the United States Coast Guard searches for missing crew. Photo Credit: US Coast Guard.

oversight, disregard for data, testing, changes to processes and procedures, safety culture, and communications—are common to other high-stakes, high-visibility accidents and failures.

Download the PDF Case Study.

http://www.nasa.gov/offices/oce/appel/knowledge/publications/deepwater_horizon.html

Columbia's Last Mission

The Space Shuttle *Columbia* thundered skyward at 10:39 AM on January 16, 2003 from Kennedy Space Center. Little more than a minute later, a chunk of insulating foam tore away from the external fuel tank and splintered against *Columbia's* left wing. The incident did not disrupt *Columbia's* planned path to orbit; indeed, nobody on the ground or in the orbiter even noticed it. It would be another day before routine reviews of launch photos revealed the foam strike.

Engineers were concerned about the apparent momentum of the strike, and the fact that none of the imagery from 12 ground-based camera sites showed a clear image of the impact or potential damage to the Orbiter. While foam debris had been a common occurrence on prior Shuttle missions, no one had ever seen such a large debris strike so late in ascent. Once the strike was confirmed, engineers and managers from across the Shuttle Program began discussing and assessing its significance in order to determine what, if anything should be done about it.

Download the PDF Case Study.

http://www.nasa.gov/offices/oce/appel/knowledge/publications/columbias_last_mission.html

A close-up camera view shows Space Shuttle Columbia as it lifts off from Launch Pad 39A on mission STS-107. Photo Credit: NASA

Chapter 5

Interviews

Jon Verville
The NASA Wiki Space

ASK the Academy May 10, 2011 — Vol. 4, Issue 3

If you ever feel like a mad scientist who can produce game-changing inventions, but can't seem to find your wallet, a wiki may help you get things in order.

Jon Verville, an information-based software engineer and lead for the Applied Engineering and Technology Directorate (AETD) Wiki at Goddard Space Flight Center, is on a mission to find clever ways to push NASA's capability through sharing knowledge, data, and ideas across the organization. Prior to his wiki work, he was involved in the RF communication systems for LADEE, the SCaN Test Bed (CoNNeCT), the South Pole TDRSS Relay (SPTR), and served as the deputy communication systems lead on the Magnetosphere MultiScale mission.

Home page for the AETD Wiki at NASA's Goddard Space Flight Center. Image courtesy of Jon Verville.

ASK the Academy: You weren't always the Goddard "wiki guy." What sparked your interest in creating a wiki and knowledge management systems?

Jon Verville: That's a good question. Basically, I had some level of frustration with the information resources that were available when I was just starting my engineering career at Goddard. My first mentor, Dave Israel, was both a great mentor and a world-class communication systems engineer. My work and the challenges I faced were equally world-class in difficulty, and to find solutions to these challenges required very specialized data, information, and knowledge. One of the challenges was getting to relevant pre-existing paper and digital materials, which had been produced by Dave and the rest of my fellow communication systems engineers at Goddard, at the time when they were needed. Much of this useful information and knowledge was locked away in each engineer's own paper or digital file cabinet, or in an archived email, often buried very deeply. Specific things within this material weren't very easy to find, even for the engineer themselves! You pretty much go hunt for it on your own. However, as an early engineer at Goddard, I didn't even know what questions to ask or the context that would even be necessary to ask a question. That was a frustration for me. I don't think that this is unique to Goddard or NASA, but is something that is a problem for any large organization. The trick is organizations that address this problem in a unique way have an advantage. I saw this as an opportunity.

In a small attempt to address this, I started a wiki as a side project, just by installing the free software that powers Wikipedia. I began experimenting with it, slowly telling a few people about it here and there. Eventually, I really saw how it could work for us just by testing some simple ideas out and experimenting. One of the first things I did with this new wiki site was put together a table of all the spacecraft that our branch, the Microwave and Communication Systems Branch, had worked on, and included the technical specifications for each mission. Now this certainly did not require the use of a wiki, but the nice thing was that it now was in a central, discoverable place on our intranet and anyone in our group could update it. The table had columns such as: the radio manufacturer, antenna details, and the communication data rate of the spacecraft. Just creating this table and putting a point of contact for the communications engineer on that particular mission actually was a very quick and easy win. Since then it has expanded to over 500 technical wiki pages.

ATA: How did you gain leadership support to pursue this wiki initiative?

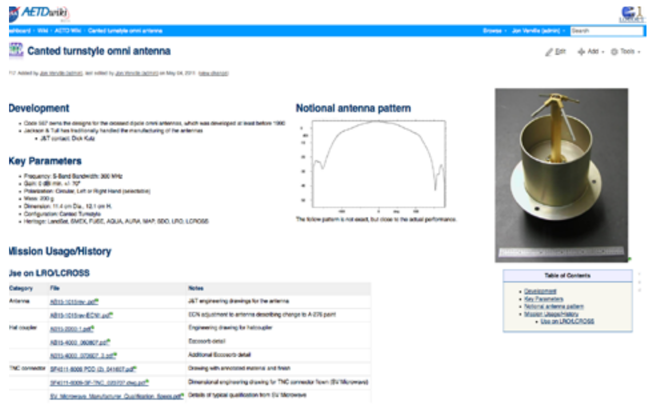
Verville: I've been very fortunate, actually, because at some level, I have been in the right place at the right time and had support from the right people. Back in 2009, I was on a committee that was tasked with giving our perspective of life within our engineering directorate at Goddard as it pertained to early career employees. We were asked for suggestions and advice, which we delivered to our Director of Engineering, who at the time was Orlando Figueroa, and his next level of management. We had a series of meetings with the directorate, and through the course of those meetings one of the things that came up as a topic was how we address knowledge transfer and knowledge capture for engineers within Goddard's engineering directorate.

Basically, I spoke up during the meeting and said, "Hey, I'm kind of working on this wiki as a side project and am trying to address that very problem. Is that something you guys would be interested in hearing about?" And they said, "Sure, let's do it." So I went and collected my thoughts on what I had learned from my wiki experiment and the other early career folks also on this committee and I organized the material and flushed out how that vision would look before I presented it.

I also took the time to meet with Orlando ahead of time to see what he was looking for. Essentially, I wanted my enthusiasm – our enthusiasm – to match up with the needs of the organization. I crafted the presentation and after all of that legwork, it was very well received. The director polled all of his direct reports and he asked them what they thought about the idea, and they jumped at it.

ATA: Tell us about the biggest challenge you face in trying to increase collaboration with a tool like this?

Verville: The biggest challenge by far is not technical. It's most definitely cultural. Just the simple idea of somebody being able to live edit something someone had created previously is such a foreign concept. We have this culture whereby you do what your boss tells you and you're graded against how well you did on what your boss told you to do. This kind of breaks that paradigm in a sense because it's really a proactive paradigm with each person finding a way to uniquely invest in the organization. In the end, that's what this is all about, everyone helping to invest in the organization so that when new engineers and scientists are coming into the organization they have that resource that I was looking for, but didn't have in my early career. I think that's a big challenge because you have to help the knowledge workers



Screenshot of the canted turn style omni antenna wiki page housed within the AETD Wiki at NASA's Goddard Space Flight Center..

in your organization to get past that because there's no direct model for it at some level. In NASA, we're used to working in a very document and email-centric world where someone owns a document from cradle to grave and people share updates and answers to questions through email to only who needs to know. New collaborative websites, such as wikis, have the potential to change this. It's not one person investing in an organization's knowledge, its democratizing it so that everyone has an easy way to contribute to that organization's knowledge. In a sense, we're asking, "How can you pay it forward?"

I found that a solution for this challenge is literally meeting people face to face and talking them through it. I do a lot of going out and talking, sharing what it is I'm doing and why I'm doing it, and teaching tutorials and such. This helps people dip their toe in the water, and from there it's easy to take the second step.

ATA: What are some examples of groups or organizations who have succeeded in using a wiki?

Verville: The majority of my examples are grassroots projects, which is telling of the way these things work. It's really hard to make these initiatives top-down and not bottom-up. There's one group here at Goddard that built an instrument that flew on STS-125. It was called the **Relative Navigation System**. This team based out of Goddard had to coordinate individuals at Glenn and Johnson. Since they were geographically dispersed, they used a wiki to document their system because it was very experimental. It was an experiment that was essentially trying to improve the state-of-the-art for robotic docking. The team used it for day to day operations and documenting their systems and the nuances, quirks, strengths, and limitations that they didn't know about previously. This team used it in a way that was really beneficial. It was only open to a small, closed group, but again, they didn't have support or even see the need to share outside of their group. But this is where I see the great use of a wiki and where they can be successful.

I have heard about or read about dozens of organizations where wikis have come and gone. These failures were because there wasn't a clear purpose. So, number one, have a clear purpose. Number two, communicate that purpose. Number three, weave that purpose into the organization's mission and figure out how the wiki can fit the ways the organization does business. Those are definitely three things that I spend a lot of my time doing.

Another example comes from before I even really got into wikis seriously, I was attending a conference and I bumped into Chris Rasmussen and some others who worked on Intellipedia, which is part of the system that the intelligence community put together. User adoption was very grassroots. They use it as an institutional resource. The wiki was added, I think, six years ago, and the system has thousands of active users and I think it has over a million edits.

They also have an award called "The Golden Spade," which is awarded to people who have contributed to the wiki significantly. It is a little, gold spray-painted shovel that is given to the individual or their supervisor and is used as a sort of incentive to reward that kind of behavior. (The spade is representative of wiki "gardening.")

ATA: You have an upcoming paper on the state of wiki practices at NASA. Can you give us a preview of what to expect?

Verville: There are many more stories beyond what I have told that I have discovered in my travels around the agency talking about these topics. In the paper we are going to be highlighting different wikis that have been used successful at NASA. They are sort of mini-case studies. They tell you some of the background, typical specs for what they have created, and then how they are encouraging adoption. We'll also touch on some of the reasoning and motivation behind collaborative engineering systems in general.

My collaborator, Dr. Patricia Jones from Ames and I are approaching this paper to spread the story of early wiki adopters across the agency. In the words of Tim O'Reilly, "The future is here. It's just not evenly distributed yet." We are just trying to distribute that future among folks so that if they get their hands on this paper they can have some insight into this organization and then maybe it'll give them a place to start.

Interview with Jeffrey Hoffman

By Don Cohen

ASK Magazine Fall 2011, Issue 44

Currently a professor in the Department of Aeronautics and Astronautics at MIT, the Massachusetts Institute of Technology, Jeffrey Hoffman flew on five shuttle missions as a NASA astronaut, including the first Hubble repair mission. He also served as NASA's European representative for four years. Don Cohen spoke with him at his office at MIT.

Cohen: You were a scientist first and then an astronaut. How did that come about?

Hoffman: I've been interested in space since I was a little kid. When the first astronauts began to fly, I was excited by the idea of flying in space, but I had no desire to be a military test pilot. I took an astronomy course in college, found that I liked it, and went on for a PhD in astrophysics. I was most interested in high-energy aspects of physics for two reasons. I liked the space connection, the fact that you had to go above the atmosphere. And, because we were looking at these wavelengths for the first time, you were almost guaranteed to make interesting discoveries. I was involved in the discovery and elucidation of the nature of X-ray bursts, work I did with Walter Lewin.

Cohen: And you need to get above the atmosphere to study those wavelengths?

Hoffman: Absolutely. For my PhD thesis, we flew gamma-ray detectors in balloons. That was before we realized that you can't do gamma-ray astronomy from balloons: you need more exposure time. Now we do it from satellites, of course. Here at MIT we had our own SAS-3—small university-class satellite—we operated out of the control room at MIT. The commands went to Goddard to send up to the satellite, but it was our satellite, and we determined what commands should be sent. I was also project scientist for the high-energy X-ray experiment on the first high-energy astrophysical laboratory, HEOA-1. I've always followed the space program. When I read that NASA was going to need quite a few new astronauts for the shuttle and that they were looking for scientists, engineers, and doctors, not just for test pilots, I figured, "Why not have a go?" I put in my application and was fortunate enough to be selected in the first round. I was in the first group of shuttle astronauts that showed up for work in 1978.

Cohen: Did being in space live up to your expectations?

Hoffman: Yes, both the physical and psychological experience and the interesting work that I got to do up there. I was very fortunate in having a lot of different and interesting

missions to work on. My career coincided with the heyday of the Space Shuttle as a multipurpose vehicle. I was on missions that launched satellites, did medical experiments, did tethered satellites, materials sciences, and, of course, the Hubble rescue mission.

Cohen: What are the benefits of having a scientist in space?

> ***There are many scientists designing space experiments who really don't appreciate the limitations and also some of the special opportunities they would have.***

Hoffman: I think the most valuable thing was the work I did with scientists on the ground preparing experiments to go into space, being able to use my understanding of the environment of the shuttle in space to help them plan experiments. I worked with scientists in many different fields. Every time I got involved in a new project, it was like being a graduate student all over again, trying to understand what they were doing. I've always felt comfortable having a foot in both the science and engineering worlds, even when I was working with sounding rockets and satellites. Being able to work in both disciplines is important. There are many scientists designing space experiments who really don't appreciate the limitations and also some of the special opportunities they would have. When you're doing laboratory science in space, the deeper your understanding of the experiment, the more likely you are to be able to recognize unusual results and take advantage of the serendipity that is a part of most laboratory science. That was very difficult in a Space-lab type mission because everything was so tightly programmed. You had to do what you were supposed to do and then shut down that experiment and go on to the next one. We didn't have the luxury of turning people loose in the laboratory. NASA is very good at running missions: organizing an EVA [extravehicular activity] or planning for the visit of one of the supply ships. But a laboratory has to be run with flexibility, with rapid response. You need procedures, but you need the flexibility to know when to change things. That's something I hope some day we'll be able to get to in the space station.

Cohen: How did your astronaut experience help scientists who had never flown?

Hoffman: I was not the only one who felt it was important to get the astronaut perspective to scientists. There were a number of us—Franklin Chang-Diaz, Bonnie Dunbar, Rhea Seddon—who formed what was called the Science Support Group. We produced a movie where we went through some of the problems that people don't understand—simple things like handling fluids, for example, because people didn't plan on the unusual types of fluid behavior. Experiments can go awry because of that. And thermal control. Particularly in the early days, we lost a lot of locker experiments because of thermal problems. There is no density-driven convective cooling in weightlessness. Also things involving cabling could cause problems. Cables have a life of their own in space. You need to design systems so you can set them up and take them down without spending hours controlling all these things that are floating around. Little parts floating away can ruin your day. There are things you can do to avoid that, but you have to think of them beforehand.

Cohen: So, for various reasons, good communication between scientists and astronauts is important.

Hoffman: Right now, the system places as many barriers as possible between the scientists and the crew. During some of the older Russian missions—I think they still do it this way—it was a requirement that the scientists be there to talk with the crew. At least, that is what some of the Russian scientists told me. We don't allow that. A scientist has to put in a request to get something to the crew, and that has to be sent to the PAYCOM [payload command], and the PAYCOM, who is not a scientist and may not have a deep understanding of the science, has to transmit that up to the crew. It's not the way laboratories should work.

Cohen: Like a game of telephone, where you lose the message in translation.

Hoffman: You got it. People guard the air-to-ground loops very carefully. They don't want people getting on who don't have proper protocols. But frankly it's easier to teach a scientist how to talk over the air-to-ground loops than it is to teach a contractor or someone working at the PAYCOM console to be a scientist. Verbal communication is part of it. The training is much more important. The amount of time the crew can spend getting to know the scientists and understand the science that is supposed to be done is far more critical than the conversation back and forth.

Cohen: Do you think we're getting better at using the space station for research?

Hoffman: A lot of people are working very hard to increase the efficiency of research operations on the station. We're only just starting the operations phase of the space station. It took years before we really learned how to operate the shuttle efficiently. We're pushing in the right direction, but it takes time. There are cultural gaps that have to be bridged. I hope we can do it successfully. At the moment the crews are still overscheduled. I think that maybe the biggest challenge that faces the space station program, at least from the scientific point of view, is transforming the station from a construction project into a flexible, working, scientific laboratory.

Cohen: The construction is essentially finished …

Hoffman: Yes, but the crew is still incredibly busy taking care of the station. People are trying to figure out how to get more crew time available, and not just time on orbit. When crews trained for Spacelab missions, they spent a lot of time with the scientists. In many cases, they were personally invested in the experiments, because they had spent time in the laboratories, they knew what the scientists were trying to achieve. I think that made a big difference in the success of many Spacelab experiments. Crews are so overwhelmed with training responsibilities now—just the basic stuff you've got to do in Russia, plus learning the European module, the Japanese module, robotics training, EVA training. The crew has basically been pulled out of the kind of science training that was a part of Spacelab missions, to the detriment of space station science.

Cohen: The tradition of astronauts working closely with scientists goes back to geologists training Apollo astronauts.

Hoffman: And that made a huge difference. You don't get it by magic. It requires training time.

Cohen: What are the potential advantages of science in space?

Hoffman: In many cases, weightlessness improves the precision with which you're able to make measurements. I remember an experiment where one of the limitations in the lab was the pressure gradient in a fluid caused by gravity. In space, you have no pressure gradient so you can get an order of magnitude improvement in the precision of the measurement. I think there are planned experiments for atomic clocks up in orbit. Because you don't have atoms falling out of the field of view of the exciting lasers because of gravity, you can observe them for a much longer time and that gives you better precision. The hope is that we'll get maybe an order of magnitude improvement in our ability to measure time. Whenever we make an improvement in our ability to measure time, it ends up having technological spinoffs, GPS being the most obvious example. In other cases, you're trying to look at phenomena which flat-out don't exist on the ground. That's probably where serendipity is going to be even more important.

Cohen: What kinds experiments would you personally like to see happen at the space station?

Hoffman: Telling time better is probably at the top of the list for me, if only because there have been so many benefits from telling time better in the past. Demonstrating the efficacy of the station as a useful investment for our country is probably going to come from biotechnology. I was in Houston last weekend at the International Space Medicine Summit. They announced that they are reactivating the bioreactor program, which I think has a tremendous potential for health. If it turns out that this bioreactor research in orbit can lead to better vaccines and medicines and treatments, that's the sort of thing that the public will really respond to. What goes on in laboratories doesn't make the news, except when they make major discoveries. We hope there are going to be some significant discoveries from the space station.

Cohen: And the advantage of having a bioreactor on the space station is what?

Hoffman: Suppose you have a bit of liver tissue. It starts to grow. As it gets bigger, it sinks toward the bottom. So you rotate the bioreactor so it's at the top again. It's continually falling through the liquid and it continues to grow. The problem is, as it gets bigger and bigger you have to rotate faster and faster to counteract the settling forces. Eventually you build up shear forces, which will rip the material apart. So there's a limit. In space, where you don't have the settling, these three-dimensional tissue cultures can be grown much bigger. That's been demonstrated. The original work was done up on the Mir station. They've actually seen vascularizaton of tissues; they've grown knee cartilage, liver cells, cancer cells. You can then use these to test drugs. If you can get good three-dimensional human tissue to test on, you could save one or two years in the development of a drug. At $100 million a year—my understanding is drug development can cost that much—that's enough to finance experiments up in space. Assuming that we can do them quickly. That's part of the other challenge I mentioned before: turning the station into a working laboratory. If the pharmaceutical company or a research university comes up with something they'd like to test and they've got to wait three years in the queue, you've lost it.

> ***I think that maybe the biggest challenge that faces the space program, at least from the scientific point of view, is transforming the station from a construction project into a flexible, working, scientific laboratory.***

Cohen: Do you think the station has a role to play in future space exploration?

Hoffman: I very much believe in the space station as preparation for long-duration spaceflight, and I hope we will take up that mantle again.

Cohen: And fly to Mars some day?

Hoffman: The more we learn about Mars the more fascinating a place it is in terms of geological history, potential for biology, and resources. For long-term activities on Mars, we need to be able to do ISRU, in situ resource utilization. All explorers have lived off the land. The first time we go there, we'll take everything we need, just like the first time we went to the moon, but for longer-term exploration we need to learn how to use the local resources. That's absolutely critical. It makes a huge difference in terms of the ultimate cost as well, if you can make your own oxygen and rocket fuel. We need to do that first on the moon. There are differences between the moon and Mars, but would we really rely on surface operations that we've never tested out on another heavenly body the first time we go to Mars? I don't think there needs to be a permanently manned moon base; I don't want to see us build another space station there. Let's remember that we can operate equipment on the moon telerobotically from the earth. The Mars rovers have to be pretty much autonomous, and when they run into problems, they have to shut down and wait for advice, whereas we can keep things running 24-7 if we want to on the moon, and periodically visit to set them up, make repairs, do whatever you have to do for operations while they're building up supplies. We need to do that before we are ready to go to Mars. We also need to develop and demonstrate the capabilities for deep-space travel. That's where visits to asteroids come in, because you don't have to land on them. We don't now have the technological capability to do entry, descent, and landing on Mars with human-class vehicles. I think we can develop at least the entry capability with experiments in the upper reaches of the earth's atmosphere, which I know NASA is thinking about, but we've never had successful demonstrations. So there's a lot that has to be done before we go to Mars.

Exit Interview with Bryan O'Connor

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On his last day in the office, Bryan O'Connor, Chief of Safety and Mission Assurance, spoke with ASK the Academy.

Bryan O'Connor retired as Chief of Safety and Mission Assurance on August 31, 2011, after serving nearly a decade as NASA's top safety and mission assurance official. O'Connor is a former Marine Corps test pilot and aeronautical engineer, with more than 5,000 hours of flying time in over 40 types of aircraft. He joined the NASA astronaut program in 1980 and flew two space shuttle missions, serving as pilot on STS-61B in 1985 and commander of STS-40 in 1991.

ASK the Academy: You were a test pilot and a shuttle astronaut before becoming Chief of Safety and Mission Assurance, and your successor Terry Willcutt followed a similar career trajectory. Can you talk about how being a test pilot is good preparation for leading in safety and mission assurance?

Bryan O'Connor: As you mentioned, both of us have test pilot backgrounds, for about the same amount of time and from the same place. Different airplanes, but we came from Patuxent River Naval Air Test Center backgrounds. I think we learned there that you have to have a great deal of respect for the potential and kinetic energy of these things we strap on to ourselves. We spent an awful lot of time in planning for the flights we did. Operationally, there was always obviously planning for a mission. We were operational pilots. But when

Astronauts Mary L. Cleve and Bryan D. O'Connor look toward the camera during an integrated simulation for the STS-6 mission. The two are at the spacecraft communicator (CAPCOM) console in the mission operations control room (MOCR) of the JSC mission control center. Photo Credit: NASA/JSC

Official portrait of Bryan D. O'Connor, United States Marine Corps (USMC) Colonel, member of Astronaut Class 9 (1980), and space shuttle commander. O'Connor wears a launch and entry suit (LES) with his helmet displayed on table in front of him. Photo Credit: NASA

we went into the test world, the planning took a different slant to it. It was more about the test objectives. The actual airplane itself is the test objective, not delivering a weapon to a target.

There's an obvious safety piece that was a little different than what we had as operational pilots. We learned the difference between hard rules that you just cannot violate and rules that are the kind you challenge. An operational pilot knows that you're supposed to stay within the flight envelope of the aircraft. Don't go faster or higher than the aircraft is cleared for. But we were creating the envelope as test pilots, so we gained a great deal of respect for the idea of expanding an envelope, and all the test preparation and understanding of the aerodynamics and the engineering and the systems stuff that we had to know in order to go and rewrite, challenge, or change things that in the past had been inviolable rules. I think it was that learning that helped us appreciate the safety aspects of what we were doing when we came to NASA.

ATA: What changes have you seen in the safety culture during your time at NASA?

BOC: Before the Challenger accident, the safety and mission assurance community and the safety culture in human spaceflight were what we'd inherited from the Apollo days. There was a substantial operational flavor to it. For those of us in the crew office, I remember one of the first lectures we heard as brand-newbies down there in Houston was the Apollo 13 story. Gene Krantz himself gathered us all around and spent about three hours talking about that flight, and what it meant to the human spaceflight community to have experienced the failure of the hardware and bringing back the crew alive, and how Apollo 13 was considered by folks in the Mission Operations world as right up there almost at the same level of success as Apollo 11 itself. The safety culture was just very much a piece of that story.

In later years I read about the British explorer Ernest Shackleton, who failed in his mission to explore the South Pole and Antarctica, but he got all 27 of his people back. He spent two years down there after his ship got stuck in the ice and then was crushed and sunk, and his men were standing on ice floes for all that time before they could finally get them back to England. It's the fact that he saved everybody that makes that story very compelling and unusual, and it has a special place in the hearts and minds of British people when they talk about their heroes. That was the same flavor of the Apollo 13 story. It really suggested that we like doing high-risk things, but we really like bringing the crew back alive afterward. So that was what I was introduced to in Houston.

The developmental aspects of systems safety engineering were there, but in retrospect they were not very well founded. They weren't accepted too much by the engineering community, and even thought there were safety, reliability, and quality engineers involved in the design, development, and test flying, it was almost as if they were checks in the box: "Did somebody remember to call them?" Their value statement was not as high as it subsequently became.

It was the learning from both the Challenger and the Columbia accidents that really helped to solidify the need for a capable and credible SR&QA (safety, reliability and quality assurance) workforce to help from Day 1 in the development activities of a new system. I hope that's the legacy of those mishaps, because there were strong words in both of those mishap reports about the safety organization. Where is it? What is it doing? Is it relevant? Do the things that the safety people do mean anything to the developers? I think today that as a (SR&QA) community, we're much more appreciated. They're (engineers and designers) actually asking for us to show up for their meetings because they don't want to start them without us. That's been a big change.

ATA: Along that same line, a couple years ago at an event at Goddard on organizational silence, you said that there has to be an institutional system in place that ensures that people speak up and bring relevant information forward. Do you think NASA has arrived at that point today?

BOC: There has been a lot of work done after Columbia accident investigation. The checks and balances were one of the big root cause discussions. There was a need to improve the standing of both the engineering and the SR&QA organization in the decision-making when there's residual risk, or safety matters especially. So, we explicitly wrote into our policy the requirement that all these people have a seat at the table, that they have mandatory votes where their authority calls for it. We've also instituted and put in writing for the first time the role of the risk-taker when we're talking about residual risk, and that's been very important.

I think of it as the four-legged stool: the technical authority owns the requirements, the safety and mission assurance authority decides whether the risk is acceptable or not, the risk-taker must volunteer to take the risk, and then and only then, when those three things have been done, can the program or project manager accept that risk. Those four roles have been stated in the highest documents for governance in the agency. It's flowing down — and in some places it was already there — for the decision-making for the high-risk work that we do, especially when there's safety involved.

Now having said that, I keep telling my people and the Center Directors around the agency that instituting that governance model in a set of words with a "shall" statement — "You shall have so and so governance model" — does not make it work. The only way it works is if you have good, credible, respected people with whom you have populated the various legs of that stool. You shouldn't just hire enough crewmembers to fly the space station missions and no more. You must have experienced crewmembers who are not currently flying but who are available to the next development activity as part of the development team, so that you can get the crew's look at residual risk areas, and have them in tune and involved enough so they understand what the risks are and can represent "The crew volunteers to take the risk" model that I talked about. I say this because there are people questioning how many crewmembers NASA needs, and why you need any more than what you're flying. This is an R&D activity, it's not just about flying.

When Terry (Willcutt) and I were at Pax (Patuxent) River, we spent a heck of a lot more time planning and participating in the development of the next aircraft or the next major mod to an aircraft with the designers and the developers than we did in the cockpit. We spent a tremendous amount of time in simulators and design sessions, and looking over hazard analysis reports, and giving the crew's input to the development as part of being a test pilot. That same thing applies here at NASA, and sometimes people forget that.

The same goes on the safety and mission assurance side. In the past we sometimes were criticized for not having capable people in our workforce, and folks might show up at a meeting and not be prepared or not understand the issue. Maybe we'd send a propulsion person from the safety organization when the subject was aerodynamics, and they weren't much help, and they didn't bother to go and ask for help because their staffing was very low in the home office. These are all problems that cannot be fixed by simply saying, "You have to have the safety office represented in the meeting." You have to fix these by having good, capable, credible people in those organizations with responsive home offices to back them up. This is the job of the Center Directors, by and large, and I credit them for putting really good people in our safety and mission assurance organizations over the years. In my opinion, NASA SMA is populated today with the best group that we've ever had at NASA.

ATA: You mentioned the legacy of the Challenger and Columbia accidents. What do you think is the most memorable contribution you've made in your time as Chief Safety Officer?

STS-40 Mission Specialist (MS) M. Rhea Seddon (left) and Commander Bryan D. O'Connor review the text and graphics system (TAGS) 15 ft long printout on the middeck of Columbia, Orbiter Vehicle (OV) 102. Photo Credit: NASA/JSC

BOC: I don't know that I've personally made any contributions, because I tend to steal from other (smarter) people. (Laughs.) I am not very good at inventing things or coming out of nowhere with creative ideas, but I know a good one when I see it, and I'll steal it and benchmark and ask my guys to do something like it if we think it makes sense. Coaching and prodding is the mode that I've been using. The real work that's been done is by the folks in the trenches.

The requirements work that it takes to do this job at Headquarters is continuous. We often are criticized for having too many "shall" statements, and then the very next day we're criticized by others for not being standardized enough across the agency, which begs for more "shall" statements. Trying to drive that mission support function that we own in SR&QA down the middle of that road is tricky. We're not a bunch of Chicken Littles waving red flags every five minutes, and yet we're credible enough that when we do speak up, people will listen because they trust us. And that's the car I've been trying to drive, but I'm just steering. The folks who are in our divisions here and at the Safety Center and at the IV&V facility, and the safety and mission assurance directors at the centers with their people are the ones who get the credit for these changes over time.

ATA: What do you see as the biggest challenge on the horizon for safety and mission assurance?

BOC: Fighting complacency. I commonly tell our folks that there are two modes of mishap prevention. One mode is reacting to the last big accident, and the other mode is fighting complacency. Just about everything we do in the SR&QA world can fit into one of those two buckets. For example, the Launch Services Program has seen a couple of failures with the commercial Taurus XL rockets that they buy. They're reeling right now and trying to figure out how to prevent that in the future. Complacency is not anywhere to be seen in that community. They're reacting to the last mishap, and everything they're doing is to try to understand what happened and put things in place that will prevent similar failures in the future. That basically defines their entire workday, whereas in the human spaceflight world, we haven't had any failures in quite a while. Right now we've got a logistics issue with Russian rocket problems, but by and large since the Columbia accident there hasn't been a real human safety failure to speak of.

There's a tendency — not necessarily of the people in the trenches — but we Washingtonians sometimes tend to forget the lessons because we haven't thought about them in a while, and we sometimes forget the tremendous amounts of energy involved, and the challenges posed by the environment and the human elements to our designs. Those things become a little bit past history, and unfortunately, what that feeds sometimes is complacency, and it shows up at all levels, including our stakeholders outside the agency. If it's been a while since our last failure, people who are looking to us to do great things sometimes forget how hard this work is to do. We start talking more about affordability than safety, and about getting the NASA oversight and insight down to very low levels because it's so expensive, without mentioning in the same sentence how important oversight and insight are to preventing mishaps. We even hear our astronauts being referred to as simply "biological cargo" by people who should know better. These are signs that we look for that we're in complacency mode, and of course it's natural for that environment to creep up on us. It's a real challenge for our community to fight that, and to remind each other that just because we haven't had a recent accident doesn't make this stuff easy.

ATA: What are your thoughts about the safety and mission assurance challenge ahead regarding the transition to commercial crew?

BOC: The S&MA challenge for commercial crew is trying to figure out where we fit in best, how to support the program in ensuring and assuring that when we do finally decide to put our people on top of these rockets, that we're not taking unnecessary risk. These are not NASA developments, per se. The concept designs are coming from the commercial people. We're experimenting with new ways to oversee that work with as few people as we can manage in order to meet the affordability goals. It's quite a big management experiment for us, and our folks are not comfortable with it, just as nobody is comfortable when they're getting into unknown territory. I think the big challenge that I hand off to Terry is, "Make sure that we're not doing something inappropriate here in pulling back or not having the visibility we need, or by not setting the table properly for our decision-makers to accept risk and to put our people on these rockets when they're relatively new and haven't been tested yet."

ATA: What advice do you have for young professionals entering the aerospace profession fresh out of college?

BOC: I'd tell them that when we hire a fresh-out, we do it because we like their technical potential, their education, and their energy, and we want them to help us go to the next levels in the agency. Because of that, when they see something they don't understand or that doesn't pass a sanity check in terms of a communication they're witnessing, it's OK for them to raise their hand and say something about it. This goes back to that concept of organizational silence. Sometimes our new people are intimated a little bit and they don't speak up, even when something doesn't smell right. We should encourage them to go ahead and do that. You don't want to overdo it of course, and have people being disruptive or educating themselves at the expense of everyone else who's trying to get something done. I know that can be overdone. But when I first showed up at the Johnson Space Center, they had a plaque over the wall in the Mission Ops control room that said something to the effect of, "In God We Trust — All Others Bring Data." That was quite intimidating to a new person, because between the lines it suggested that, "We not interested in your opinion on things. If you have data, we'll listen, but your opinion is not requested here."

A lot of us came to NASA after years of doing flight testing and R&D work and so on. After the Challenger accident, I really beat myself up for being too silent in the first few years that I was there, and I said to myself, "This agency isn't as smart as it thinks it is," to quote Tommy Holloway.

The idea of asking if you don't understand something — even if you want to go out in the hall and do it so you're not disruptive — that's fine. We hire good people to help us move forward, and asking questions is just part of that.

Chapter 6

ASK the Academy

The SELDP Year from Three Perspectives

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There's no clear path to become a top systems engineer, but as three engineers experienced, learning on the job is an important part of the process.

The **Systems Engineering Leadership Development Program (SELDP)** provides opportunities for a small class of high-potential candidates to develop and improve their systems engineering leadership skills and technical capabilities. A core feature of this yearlong program is a hands-on developmental assignment. These experiences, which take place away from a participant's home center, lead to a broader understanding of NASA and expand his or her systems engineering experience.

The FASTSAT-HSV01 spacecraft designed to carry multiple experiments to low-Earth orbit. Photo Credit: NASA

ASK the Academy tracked three members of the 2009-2010 SELDP class throughout the year as they adapted to the challenge of working and learning in a new setting.

Learning Every Day

"Fast" is the word that best describes Tom Simon's SELDP experience working at Marshall Space Flight Center (MSFC) on the **Fast, Affordable, Science and Technology SATellite (FASTSAT)**, a microsatellite designed to carry six small experiments into space. Having served as a subsystems engineer at Johnson Space Center since 2001, Simon went from a program with thousands of employees to a project so small that everyone on the team could stand around the satellite.

Coming from eight years in the space shuttle program, the difference in scale was a learning experience. "If I had a question about how we mate to the launch vehicle with the satellite, I know exactly who to talk to," he said. "The family size of the project allowed the advantages of a co-located R&D effort even when we applied it to the development of a spacecraft."

FASTSAT also operated completely differently than the systems that Simon was accustomed to working with. "There were almost no moving parts, and no fluid systems," said Simon, who spent most of his career working on mechanical and fluid systems. He found himself troubleshooting electrical problems and software bugs. "The day-to-day work was in technical disciplines, which forced me to grow." As the new kid on the block, Simon found that his colleagues were glad to help him get up to speed. "Even though I wasn't coming in on the same page that they were on, I tried to make it very clear that I cared about the success of the program," he said. "As long as that connection is made, folks don't mind helping you catch up--especially if they see you as someone who can help them too."

The schedule also represented a new way of working for Simon. FASTSAT had a 12-month project lifecycle. Processes were streamlined to where decisions were made in weeks, not months. "Most of the projects that I've worked on I've had intended launch dates a few or several years away," said Simon.

Working under such a fast-paced schedule shifted his approach to projects. "Every project I join now I'm going to start with the perspective of 'What do we need to do?' and not necessarily 'What have we always done?'" he said. "I'll never be the same again."

To keep pace with the schedule, testing took place nearly every day. "We had to basically get to the test phase earlier than any of us usually get to [it], and let the data speak for itself," Simon said. During the thermal vacuum test, the team was reviewing the output signal from the flight transceiver when they noticed a discrepancy that likely would have led to a failure. "One thing I learned from this project is that even if you're trying to do things affordably and quickly, you don't skip these meat-and-potatoes tests," he said. "We could have spent six months analyzing the system, and we never would have found the transceiver issue. Instead, in a few days of testing, we found it."

As the project wrapped up and awaited launch, Simon authored a lessons learned document for the team. He saw it as a resource for future work at NASA's manned spaceflight centers. "Once the Shuttle is retired and the Station is complete, there are going to be a lot of people working on systems that need to be approached differently than the way we've worked in the past," he said.

Working on FASTSAT helped Simon fill a gap in his experience between working on the Shuttle and R&D work earlier in his career in a lab setting. "I don't think they (the SELDP team) could have picked a better assignment, team, or organization for me," he said. "If the first 10 years are any sign, I'll be learning every day until I retire."

Leading from the Middle

Cynthia Hernandez knew the SELDP year demanded that she remained focused on meeting the goals she'd set for herself in the program. As a software engineer from Johnson Space Center, she enjoyed the challenge of working on an aeronautics flight project when she became the Deputy Chief Engineer of the **F-18 research program** at Dryden Flight Research Center. "Coming from a human space flight program, it's very rare that you actually get to see the hardware you're working on," she said. The F-18 project met her SELDP job assignment goals, but it did not address her leadership goal, which called for her to lead a team.
Hernandez sought the guidance of her SELDP support team, and ultimately reached a decision to seek a new assignment. Stephen Jensen, the SELDP Advocate at Dryden and Chief Engineer of the **Stratospheric Observatory For Infrared Astronomy (SOFIA)**, an aircraft-based observatory, and he identified a need within his own project that would enable Hernandez to meet her goal.

In March 2010, she joined SOFIA as it approached its final stages of integration and testing before its first test flight. Hernandez's job was to lead the Observatory Validation and Verification (V&V) Working Group, a 10-person team with responsibility for developing the V&V test procedures and executing the tests properly. "It was my responsibility to organize and develop the team, help them work together, and help each other out to accomplish our tasks," she said.

"I have a lot to learn in such a short period of time" said Hernandez at the beginning of her work on SOFIA. In addition to having never formed or led a team before, she had to bring together a diverse group, including senior engineers and scientists from Ames Research Center, the Germany Aerospace Center (DLR), Deutsches SOFIA Institute (DSI), University Space Research Association, and Dryden, to agree on test procedures. She also had to coordinate the writing of procedures, another new experience, which meant finding someone with the necessary expertise even though she had a very limited network at Dryden. In short, she faced the challenge of learning to lead from the middle--the team was her responsibility, yet she had very little formal authority.

"They were each so busy trying to meet their own milestones," she said. "Initially it proved difficult to find people to write test procedures." She happened to read a test procedure from another group that she found particularly well written, and she asked her boss, the Chief Engineer of SOFIA, if he knew its author, Cathy Davis. When he indicated that he did know her, Hernandez said she wanted her on the team. "She really played a key role in pulling the procedures together." Hernandez, Davis, and a small core team made sure that the right procedures were in place and that the team didn't waste time on unnecessary ones.

The SOFIA airborne observatory's 2.5-meter infrared telescope peers out from its cavity in the SOFIA rear fuselage during nighttime line operations testing. Photo Credit: NASA

Hernandez ultimately led the team through a four-day observatory checkout process before scientists came aboard to do their own tests of the instruments. She then began work on the test plan for the 003-level (the highest level) of integration testing for the overall observatory. Shortly after her assignment ended, SOFIA achieved "first light" -- the observatory was successfully activated in flight.

Looking back on her assignment, Hernandez learned a great deal from the process of working across organizational and cultural boundaries. "Working with different cultures and different organizations gave me the opportunity to broaden my way of thinking and approach to solving problems," she said. As NASA's missions increasingly involve international partners in critical path activities, that lesson is likely to pay dividends many times over.

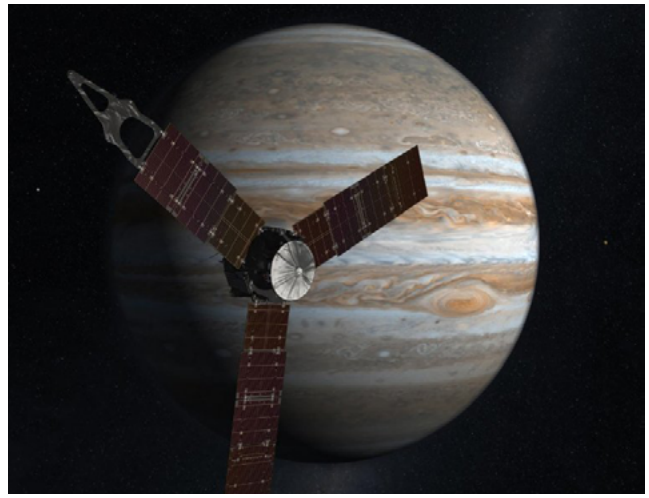
The Value of Constructive Paranoia

Going from aeronautics research at Langley Research Center to a large spaceflight project at the Jet Propulsion Laboratory (JPL), Michael Lightfoot felt like he had travelled to another planet. At JPL, the lexicon everyone used sounded familiar, only it carried a different meaning. Team members seemed to intuitively know what to do, like bees in a hive. "You don't know how they know what they're doing or what they're supposed to be doing, but it happens," he said.

His SELDP assignment brought him to the **Jupiter Uranus Neptune Outreach (Juno)** mission, a billion dollar international project. From the beginning, he took care to watch the people around the center to uncover the source of the invisible "playbook" that seemed to be ingrained in the team. "I've come to the conclusion that the processes, the rules, and the requirements serenade a point from which discussion can begin," he said, "but the real glue that holds it all together is the people."

Lightfoot, who spent a large portion of his assignment working on verification and validation (V&V), saw the value of "constructive paranoia," which kept the team on its toes. "No one wants a failure to happen while they're on deck, or at any time, so people are constantly looking for avenues to make improvements that actually aid the confidence that the spacecraft's going to do what they expect it to do." Certain people within the team picked up on concerns or issues, evaluated them, and generated detailed solutions or scenarios to determine how they would affect mission success--that is, focusing on the value of the science that would be collected.

For instance, the team realized that it could decrease ground control costs by putting the spacecraft into hibernation mode at times when it would not be collecting data. At the same time, they recognized that while this offered a savings in cost, it also posed the risk that the spacecraft might not awaken from its sleep mode. Solutions included developing a "phone home" capability if Juno ran into trouble, and also prompted debate concerning how such changes would affect the design of the spacecraft. Thinking about cost in this way, "forces people to think differently to come up with good alternative engineering solutions," he said. Lightfoot,



Artist concept of Juno spacecraft in front of Jupiter. With its suite of science instruments, Juno will map Jupiter's intense magnetic field, investigate the existence of a solid planetary core, measure the amount of water and ammonia in the deep atmosphere and observe the planet's auroras. Image Credit: NASA/Jet Propulsion Laboratory

who prior to this assignment was accustomed to developing an instrument that was then shipped off for installation elsewhere, appreciated the opportunity to participate in the system-level evaluation of a mission.

Lightfoot's overall understanding of systems engineering changed during his rotational assignment. "I thought I knew what it was when I went away," he said. "I got a more complex picture of what it could be at JPL." His key insight related to the high level of integration on most NASA projects today. "Some of the things we're taking on now are so highly coupled that if you try to decompose them and ship work off to traditional engineering disciplines, you run the possibility of locking in a design too early, and shooting yourself in the foot without knowing it."

His SELDP experience added another challenge to his day-to-day work as an evolving systems engineer. "It's hard to put the genie back in the bottle," he said about learning to work at the systems level. "I've seen a lot and there's an awful lot I want to share." He aims to share his experiences with his Langley and other agency coworkers to "make sure we put some things in place that enable us to sustain ourselves."

Academy Bookshelf: *The Ambiguities of Experience*

January 31, 2011 — Vol. 4, Issue 1

Experience is the best teacher, right? Not so fast, says James March of Stanford University.

An organization such as NASA exists in an ever-changing context. To take a simple example, the management practices that enabled the agency to thrive during the design and development of the Apollo systems could not be superimposed directly onto the design and development of the Space Transportation System (the space shuttle). The organization's mission had changed. The programs' requirements had vast differences. Technologies had matured. The social context in which the agency operated also had shifted in ways ranging from the political environment to the composition of the workforce. As a result of these factors (among others), some management practices from Apollo were clearly still applicable, while others were no longer instructive.

How do organizations learn intelligently from their accumulated experience? In ***The Ambiguities of Experience***, James March of Stanford University examines the evidence and the folklore about learning from experience. March begins by noting that, "... although individuals and organizations are eager to derive intelligence from experience, the inferences stemming from that eagerness are often misguided." The problems, he says, "lie partly in correctable errors in human inference forming, but they lie even more in properties of experience that confound learning from it." In other words, experience itself can limit the ability to learn and adapt.

So what's an organization or an individual to do? In short, the best approach is to recognize the limitations of learning from experience. According to March, "Experience is likely to generate confidence more reliably than it generates competence and to stop experimentation too soon. As a result, there is a persistent disparity between the assurance with which advice is provided by experienced people and the quality of the advice."

Reflections on *Challenger* by Bryan O'Connor

January 31, 2011 — Vol. 4, Issue 1

On the 25th anniversary of the *Challenger* accident, a story by Bryan O'Connor offers a powerful reflection on the dangers of organizational silence.

[Editor's note: The following is a transcript of a talk by Bryan O'Connor, NASA Chief Safety and Mission Assurance Officer, at Goddard Space Flight Center on July 30, 2009. O'Connor delivered his remarks at an event hosted by Goddard Chief Knowledge Officer Dr. Ed Rogers on the subject of organizational silence.]

When I first heard about this topic [of organizational silence], the very first memory that came to me was the flood of emotions after the *Challenger* accident. I lost some good friends in that accident. It had happened just two missions after I had flown my first spaceflight, so it touched me quite a bit there. I was already assigned to another mission, and that mission got delayed indefinitely and then later canceled as we went through post-flight/return to flight activities. Now I had lost friends before in aircraft accidents, but I had never had the same kind of feelings after those as I did after *Challenger*. And it wasn't just because I lost friends. There was another thing that entered the picture, and that was in spite of the fact that I didn't really have a job at NASA that put me in the accountability chain of command for safety on space shuttle, the fact is that I didn't know, like everybody else, I was responsible to some degree for safety—to the extent that I had any authority, to the extent that I had knowledge. I certainly had a responsibility to speak up if I didn't understand something. I kind of knew all of those things and I felt a little bit guilty. In fact, I felt very guilty. That was an overwhelming feeling that I had that I hadn't had in previous cases.

The reason I felt guilty, I believe—and I've thought about it a lot since then—was that I could remember times when I was sitting in a meeting listening to a discussion in an all-pilot's meeting, maybe even over in a programmatic meeting, a change board or something—where I was sitting in the audience, where I thought and sometimes claimed to know that two people were talking past each other. And I didn't say anything about it. I just kind of let it happen. I thought, "Well, these people know what they're doing. The Space Shuttle Program comes from all this learning from Apollo. These folks can't really make mistakes because they have already done that, they learn from them and...this thing is being developed as something that will be pretty much an airline-like operation very soon here."

There were things about that whole concept that I didn't really get, I didn't understand. I remember having a

The U.S. flag in front of JSC's project management building flies at half-mast in memory of the STS 51-L crewmembers who lost their lives in the Challenger accident. Photo Credit: NASA/Johnson Space Center discussion with T.K. Mattingly, who was training for STS-4, which as you remember, was going to be the last "test flight" for space shuttle and after that we were going to be "operational". STS-5 and beyond was operational. So operational, in fact, that they were going to put the pins in the ejection seats so that the crew couldn't use them on STS-5. And they weren't going to have ejection seats after that.

This, to me, was a huge leap of faith from my prior experience. I had come from an acquisition background where it took a couple thousand flights to get something to where it was IOC (initial operating capability), and then maybe another several hundred to full operational capability. And in DOD (Department of Defense) terms, IOC and FOC mean it's time to give it to the ultimate operator: we're done with all the testing, and it's time to go into the "operational phase" and give it to the operator to go use in the field. That's what those terms meant to me.

I saw us using terms like "we're going to be operational on Flight Five" on what looked like to me like a more complicated machine and operation than anything I'd ever been dealing with. And I asked Mattingly about it, and he said, "Don't worry about all that stuff, that's just rhetoric up in Washington. This thing will be in a test mode for a hundred flights." He told me that before STS-4. That was a little bit more comfortable to me because I thought, OK, I got it. I'm now in an area where there is a political and public affairs activity that goes on that I can't allow to interfere with my engineering and technical job. Yeah, I know they're taking the seats out, and I know we're going to put four or five people in these things, and there's people talking about flying reporters, book writers, teachers, and people who are not professional test-folks in a test environment, but I've got to treat that last part as just more rhetoric and that probably won't happen. Our people really understand the risks here.

Above: Crew members of mission STS-51-L stand in the White Room at Pad 39B following the end of the Terminal Countdown Demonstration Test. From left to right they are: Teacher in Space participant Christa McAuliffe, Payload Specialist Gregory Jarvis, Mission Specialist Judy Resnik, Commander Dick Scobee, Mission Specialist Ronald McNair, Pilot Michael Smith, and Mission Specialist Ellison Onizuka.
Photo Credit: NASA

Of course, there was a big awakening for all of us after *Challenger*. Those were thoughts that I had, and I didn't talk a whole lot about them. They just were just a way for me of rationalizing what was going on. But we didn't really talk much about that. We went the first twenty-some-odd flights—and this conversation between Mattingly and me was quite rare. It was almost as if we all know that but...let's just press on and do our business. When the *Challenger* accident happened, the accident board beat us up, the public wrote articles about how we were fooling ourselves about how operational we were, [and] we had totally under-estimated the risk of this operation. All those things that I had sensed at some point early on were now being blasted at us by the public. The same public that was buying our discussion about how safe this was, was now beating us up for how we had fooled ourselves. That was part of why I was feeling different after this accident.

In previous accidents, we weren't kidding ourselves about the risks, in any environment I had ever operated in. Flight test environment, training for combat, whatever, we kind of knew where we were, what the risks were, and yeah, bad things happen, that's too bad and we've got to learn from it. But we didn't come out of that thinking, "Wow, we really underestimated the risk there," like we did after *Challenger*. That, I think, was part of why I felt so bad. And how this feeling bad sort of registered was [the realization that] I'm never going to sit in a meeting and allow two people to talk past each other and not say something myself. Or at least talk to them in a hallway afterward. I just can't do that anymore. I don't have the right to do that. That was something I carried with me from then on.

There's a dilemma that goes with that, though, because that's an intimidating environment. When do you speak up and say, "I think you guys missed the point here?" I'm sitting in the peanut gallery and I'm not even cognizant of the technical issue here, it's just a matter of...trying to follow the logic and it doesn't make sense to me. I may not really know the details of the engineering discussion, but I can tell when two people are thinking they are agreeing on something and they didn't say the same thing. At least I know that. To that extent I am accountable because at least I know that, and I can say something about that. And I hadn't for five years. I sat and listened to that and I thought, 'Wow, sounds like those guys talked past each other, but I guess that's OK." It's not OK.

This was the big awakening for me after *Challenger*. I don't have the right to be quiet when I think something is wrong.

Now, what do you do about that? You could rapidly become a pain in the butt if you operated on every instinct. Even if you batted as well as Ted Williams and got four out of ten things right, six times out of ten you're a nuisance by speaking up and interrupting the flow of discussion and slowing things down and so on. That's real life. You have to take that into account. We can all say we all ought to speak up if we feel bad about something, walk out of here, and say, "Right, I'm going to do that." But in real life you've got to think about the environment you're really in. Do we really need to slow this thing down on this count? How badly do I actually feel about this? Is this something I can talk one-on-one in the hallway with? You've got to think about those things too, and that makes it more difficult sometimes.

Part of that awakening registered itself about three years after *Challenger*, when I was involved in the simulations out at Ames Research Center where they have this big vertical motion machine....It can get up about 80 feet above the ground and 60 or 70 feet left and right, 6 degrees of motion. We used it for landing simulations so we could try out new gains on the flight control system for landing and rollout, nose-wheel steering algorithms that we were trying to change to make it so that the space shuttle would be able to survive a blown tire on landing. [That was] one of the many things we were doing after Return to Flight. I was involved in that. I came back [to Washington] and I was sitting in a meeting where this was a topic of discussion, and Arnie Aldrich was program manager and he was in charge of this meeting. It was at a change board, and when this particular issue had come up, I was the guy they sent from the crew office to go sit and represent the crew office. I was sitting in there, but I'm sitting behind the chairman, not at the table. He went through everything, and they were talking about how they needed to make a change, and it was probably going to cost some money, and this will be to the benefit of the safety for the program. Arnie, somehow, was aware that I had walked in—I don't know how because I didn't say anything—but he turned around and said, "Now you just came back from Ames, right and flew the simulator?"

"Yes sir, I did."

"I want you to tell us about that."

I never would have volunteered what I had learned in that simulator in that meeting. I didn't have the nerve to break in, but I certainly had relevant information. The fact that the institution was such that they pulled something from me helped me with part of my dilemma about speaking up. It suggested that sometimes speaking up is not something that you can just tell every person that they have that right or that responsibility. It's something that you have to put into your organizational construct. You have to have a system that actually pulls a little bit. If you don't do that, you're going to miss a lot. Speaking up is not just about proactively interrupting meetings or raising your hand or throwing down the red flag. Those all have their place, but it's also about having a system in place that draws out relevant information, that gives people permission to speak, that points at folks and says, "What do you think?" When Arnie Aldrich did that, I thought, "That is tremendous leadership he just showed here," because I did have some relevant information that probably would not have gotten into this meeting had he not asked for it.

It showed two things to me. One, I'm still not there yet on when to volunteer. But two, it's really important to have an institutional component to this business of speaking up.

Orbiting Carbon Observatory-2—Unfinished Business

May 10, 2011 — Vol. 4, Issue 3

OCO-2 demonstrates that there is a way to bounce back from failure and forge ahead with the mission.

On Tuesday, February 24, 2009, the **Orbiting Carbon Observatory (OCO)** launched into the sky aboard a Taurus XL rocket. Its mission was to measure carbon dioxide in the atmosphere globally. Ultimately it would provide a better understanding of Earth's carbon dioxide emitters and sinks. But the mission did not go according to plan when OCO left the ground.

"It was there one moment and then gone the next," said Ralph Basilio, then OCO deputy project manager. "We didn't have anything." OCO had missed its insertion orbit due to a mishap with a faulty launch vehicle payload fairing. The hardware that didn't burn up in the atmosphere splashed down in the Pacific Ocean near Antarctica. The next day, the OCO team returned to the Jet Propulsion Laboratory in Pasadena, California. "By the end of the day Friday [three days after launch], we had put together initial study results [for a replacement mission] and sent it off to NASA Headquarters," said Basilio.

There was no time to grieve. The OCO team shook it off and got to work. "We went from emotional shock to we need to roll up our sleeves and get the work done," said Basilio. The mission was that important.

Sleeves Up

In the six months that followed, the OCO team needed to formally establish the "why" and "how" of and Orbiting Carbon Observatory-2 (OCO-2) mission. Basilio, now the project manager of the proposed OCO-2 mission, and his team took a step back. An OCO science team established the "why": the scientific community simply cannot wait for a future mission. OCO's measurements were fundamental

NASA's Orbiting Carbon Observatory is on the launch pad at Vandenberg Air Force Base in California. Credit: Randy Beaudoin to future missions laid out in the **NASA's Earth Science Decadal Survey** designed to inform global climate change science and policy.

A team of engineers worked the "how." Options included: a direct rebuild of the original OCO; rebuild and improve on OCO; co-manifest an OCO-like instrument on another planned mission; put an OCO instrument on the International Space Station; or rebuild and co-manifest an OCO observatory on a shared launch vehicle. The team decided that a direct rebuild with necessary improvements was the best option given the mission risk profile and tight schedule.

In September 2009, NASA presented an almost "carbon copy" OCO-2 mission plan to the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB). By early 2010, the OCO-2 team received Authority to Proceed (ATP). NASA assigned project management to JPL. Orbital Sciences Corporation was selected to rebuild the spacecraft and provide the Taurus-XL launch vehicle. OCO-2 has a 28-month development cycle from the ATP received at Key Decision Point C (KDP-C) to launch.

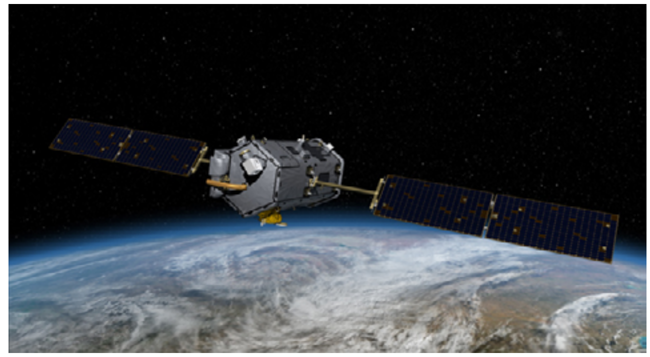
Challenges

One of the most daunting challenges for the OCO-2 team is the compressed schedule. OCO's original project lifecycle was 36 months long. OCO-2 has 28 months. Currently in Phase C, the team is building, assembling, and testing hardware. Getting to this point hasn't been easy.

OCO-2 went through a tailored formulation phase. Since OCO-2 is a near-replica of OCO, the project team was permitted to skip key decision points (KDP) A and B, and several other technical reviews. As a result, the formulation phase was only eight months long, rather than a more typical 21 months. They completed their Critical Design Review (CDR) in a single day in August 2010. "People said it couldn't be done," said Basilio. The OCO-2 team walked away with two action items, both of which were closed out on the second day during a splinter session. KDP-C followed a month later. Basilio, who worked on missions like Mars Pathfinder and Deep-Space 1, said that "a lot of those 'faster, better, cheaper' experiences that I had back then are helping me on OCO-2."

Schedule aside, the OCO-2 team also has had to face the reality of parts obsolescence. The original OCO design incorporated a few now obsolete instrument components, including a memory chip on the RAD6000 flight computer. The team also has had to account for long-lead parts, redesign certain components, or find certain components elsewhere. In the case of OCO's instrument cryocooler assembly, there wasn't a spare, and the team worked with the GOES-R project to acquire one.

Heading into the summer, Basilio has identified one critical path item: an optical bench assembly. Described as "the heart of the instrument," the team has instituted corrective actions to catch the team back up over the next few weeks. Time remains the big driver. "We need to make sure that the product is correct and that we work only as quickly as proper caution permits," said Basilio. "Our big challenge is to make sure that we get to the launch site as scheduled."



Artist's concept of the Orbiting Carbon Observatory. Credit: NASA/JPL

OCO-2 is scheduled to launch in 2013, though the recent mishap with Glory, which bears similarities to the original OCO mission, has introduced new uncertainties.

On Learning

With a second chance to fly, the OCO-2 team is has a unique opportunity. "Instead of documenting lessons learned for potential incorporation into a future endeavor," said Basilio, "we have this opportunity to actually go ahead and employ those lessons learned." Ultimately, the OCO-2 team hopes to be able to measures how successful these lessons were to the success of the OCO-2 mission.

OCO-2's lessons are already making their way elsewhere. The Jason-3 project team sits four floors below the OCO-2 project team at JPL. "We have an opportunity to talk to each other once in a while," said Basilio, who also worked with the mission's project manager on Jason-2. "I try to provide him [the Jason-3 project manager] with as much information as I can to help him along." Basilio believes that this type of knowledge sharing is beneficial not only to the OCO-2 project, JPL, and NASA, but also to the American taxpayer in the long run.

The lessons and knowledge gained from OCO-2 will also be employed for a possible OCO-3 mission of opportunity and inform the Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS) mission. ASCENDS is a movement away from OCO's passive measurement system to an active measurement system. OCO's instrument looks at the spectra of reflected sunlight, ASCENDS is envisioned as an active laser system. "You can actually look at the carbon dioxide on the dark side [of Earth]," explained Basilio.

OCO, OCO-2, and the OCO-3 mission of opportunity are the evolutionary steps needed to get to ASCENDS. "We're hoping to use the experience that we've gained using a passive system to help us figure out how to enact an active laser system that will provide more precision, more accuracy in the future."

On People

After the failure of the first OCO mission, "coming to work every day was a little bit of a struggle, at least for me personally, because of the unknown," said Basilio. "A lot of us just couldn't wait until NASA Headquarters made the official decision to say 'OK, you guys are real, hit the ground running. Here are the resources that you need and make it happen. If you need any help, we're here to facilitate.'"

"One of the key strengths that we have is that we have a very, very good team," he added. "Not just here at JPL, not just internal to the project and with our industry partner, but the program office and NASA Headquarters." Managing relationships with all of the project stakeholders has been vital to OCO-2's promising progress.

"We lost OCO because of something we couldn't control," said Basilio. Now, taking on OCO-2 and its compressed schedule, Basilio said the stress is worth it. "For me, getting ready for launch and getting ready for mission operations has always been a high point." Basilio and his team take pride in giving the nation's decision-makers and public the information that they need so they can make informed decisions. "How could you want to avoid something like that?"

"We don't just come to work and punch a clock and walk away from it. If you really look at the folks at NASA, people are really dedicated to doing a good job – not just for the sake of the job, but because they believe in that endeavor." Basilio is proud to lead his 100-plus member team. "People are the critical component in any endeavor that we have at NASA," he said. "People are willing to work together for a common cause and that's really the thing that's going to carry us through."

Academy Bookshelf: *Willful Blindness*

May 10, 2011 — Vol. 4, Issue 3

Our unwillingness to see the reality surrounding us can have devastating consequences, according to Margaret Heffernan.

In the years leading up to the financial meltdown of 2008, there were clear signs that something was seriously amiss with the U.S. real estate and housing markets. At the height of the boom, homes in some communities sold the day they hit the market for significantly more than the asking prices. Homeowners borrowed against the newly inflated values of their houses, confident that the upward trend would continue. Even people without jobs, incomes, or assets could get so-called NINJA mortgages (no income, no job or assets) and purchase homes costing hundreds of thousands of dollars for no money down. Industry veterans knew there was a problem, but many said nothing, eager to profit or, at the very least, not be left behind. "When the music stops, in terms of liquidity, things will be complicated. But as long as the music is playing, you've got to get up and dance," the former chief executive of Citigroup told the Financial Times in 2007.

In *Willful Blindness: Why We Ignore the Obvious at our Peril*, Margaret Heffernan examines this phenomenon in detail. Drawing on research about organizations, neurobiology, human behavior, and cultures, Heffernan explores the powerful forces that conspire to keep us from seeing what is plainly obvious to others. Our willful blindness originates, she writes, "in the innate human desire for familiarity, for likeness, that is fundamental to the ways our minds work." We are attracted to people who see the world the same way we do, and we seek confirmation of our ideas and beliefs in everything from the people we choose as friends to the news we consume.

Heffernan is careful to point out that willful blindness does not begin as a conscious choice:

> "We don't sense our perspective closing in and most would prefer that it stay broad and rich. But our blindness grows out of the small, daily decisions that we make, which embed us more snugly inside our affirming thoughts and values. And what's most frightening about this process is that as we see less and less, we feel more comfort and greater certainty. We think we see more——even as the landscape shrinks."

Organizations like NASA face unique challenges because of the complexity of their contracting arrangements, which Heffernan refers to as "the disaggregation of work." She recounts the network of organizations involved in the Challenger accident, noting the distance among the manufacturers of the O-rings, the suppliers of the plastic for the O-rings, and the decision-makers at NASA's centers who had a direct stake in the decision to launch the shuttle. The trend toward outsourcing has not always yielded the benefits that its proponents have championed. "In reality, the disaggregation of work has made it harder than ever to connect all the pieces; in fact, you need huge swaths of management to oversee outsourcing, competitive bidding, partnerships, and contractors," she writes.

One manifestation of the willful blindness Heffernan describes is a behavior that Goddard Space Flight Center Chief Knowledge Office Dr. Ed Rogers calls organizational silence. This refers to the reluctance of individuals to speak up either when they don't understand something or they know something is wrong. Heffernan cites a study by Elizabeth Morrison and Frances Milliken of New York University's Stern School of Business, which found that fully 85 percent of executives interviewed in a cross-section of industries felt at some point unable to raise an issue or concern with their bosses. The consequence of this silence, Heffernan concludes, is that "the blind lead the blind."

Mouse Management: Taralyn Frasqueri-Molina

June 14, 2011 — Vol. 4, Issue 4

At the request of her manager, Taralyn Frasqueri-Molina opened the first page of the PMBOK™, holding a highlighter and pencil. She was going to change how her group did work.

Taralyn Frasqueri-Molina is a project manager at the Walt Disney Animation Studios in Burbank, California. Photo courtesy of Taralyn Frasqueri-Molina

Taralyn Frasqueri-Molina, or "TL" as she is often called, is a young project manager at the Walt Disney Animation Studios in Burbank, California. She oversees media technology projects that shape and optimize work environments for Disney animators. Ask her about project management today and she'll explain its importance in a way that takes you on an adventure. Five years ago, she might have given you a blank stare.

When she arrived at Disney in 2005, the Media Engineering Department was fun, but disorganized. Schedules slipped and costs increased. Her manager, Ron Gillen, was almost a year into his new position and determined to fix the problem. He asked Frasqueri-Molina to "tame the chaos" of the scheduling department. As lead of the two-person scheduling crew, she reshaped the process so rooms were no longer double-booked, equipment showed up when it was supposed to, and support crew was available as needed. Frasqueri-Molina succeeded to the point where she engineered herself out of the job.

But even with scheduling on track, it didn't seem to fix the department's problem.

Gillen gave her a new job: media resource supervisor. If the problem wasn't the scheduling, perhaps it was the people and the equipment. She managed the distribution of media equipment (televisions, microphones, and other audiovisual gear) and the people responsible for setting it up. The staff seemed to work well. Yet, even with things going smoothly, the department's problems still persisted.

"We had these initiatives that had a specific start and end date, and we couldn't seem to get them done," said Frasqueri-Molina. This led her group to conclude that a lack of project focus might be the heart of their problem. Gillen approached Frasqueri-Molina a third time. "I hand you something and you seem to fix it. I hand you something else and you seem to fix it. So here's the PMBOK™. Fix it," Frasqueri-Molina recalled him saying.

"It was the end of 2006 when he handed me this big, strange book with words I'd never heard before," she said. It was the Project Management Institute's Project Management Body of Knowledge (PMBOK™). She read each line of the 450 or so pages of the PMBOK™, and she did everything it told her to do. "It was like throwing a giant net to catch a minnow," she said. "Over time you think, 'OK, that was unnecessary—not useless, but perhaps too much.' We didn't really need to be that robust, but we needed to start standardizing projects." As time went on, Frasqueri-Molina honed the management process. What worked for individuals? What worked for the team? What did they like? What didn't they like? Once she and her colleagues figured that out, things started to work really well. Sometimes this meant slowing the process down a bit, which didn't sit well with everyone in her department. She learned the value of taking the time to explain the method behind the perceived madness. "This is what was happening in the past, and it didn't work, this is why we're doing it this way now," Frasqueri-Molina would tell colleagues. "What do we have to lose?" She didn't intend to squash enthusiasm, creativity, or energy; she just wanted to get the job done right.

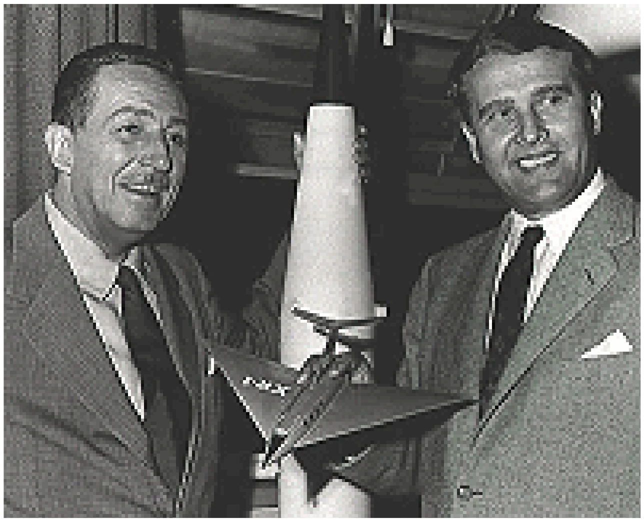
Frasqueri-Molina and her department found a way to see not only how their individual work fit into the bigger picture, but how their technology group collectively fit into the rest of the animation company. Along the way, she evolved into a project management enthusiast. "I've come from this sort of primordial, chaotic ooze."

Telling the PM Story

At a company powered by imagination, creativity, and a dash of pixie dust, infusing project management into its work might seem anathema to the Disney way. Not so. The company's famous "blue sky" thinking lets its artists and engineers explore every curiosity, every possibility, and improbability, before project managers get involved. While this might be viewed as stifling, project management serves to streamline the creative process into a deliverable product. It brings order to a chaotic process.

"There have been people in history who have built amazing things, most likely using some sort of process," explained Frasqueri-Molina, listing off marvels like the Parthenon, Colosseum, the Hanging Gardens of Babylon, and the

With Cinderella's castle in the background, the seven STS-118 crew members march down Main Street at Walt Disney World's Magic Kingdom theme park. Photo credit: NASA/George Shelton



Wernher von Braun (right) poses next to Walt Disney (left).
Photo credit: NASA

Pyramids of Giza. “I don’t think they used Agile, but if they did they didn’t call it Agile,” she said. “These amazing feats of engineering were created by somebody who was running the show and had to deal with workers, risks, and bring in the money, perhaps from a rich patron.”

Frasqueri-Molina has created a first-of-their-kind workshop to tell this side of the story of project management to the Disney workforce. “Humans have been doing project management for thousands of years without a PMBOK™, Scrum, Agile, or RUP,” said Frasqueri-Molina. “The idea is to get people comfortable with the basic, universal concepts that they already naturally understand. Everyone understands that in some cases, something must be done before something else can happen. In project management, we call that ‘task precedence,’ which helps create network diagrams. Those are just the technical terms for what you already do every day.”

The idea for the workshop grew out of Frasqueri-Molina’s experience during Disney’s 2010 “Summer of Creativity and Innovation.” The event was designed to get employees to network, try something different, and spark conversation and innovation. In the midst of her own department’s transformation, Frasqueri-Molina had hoped to encounter something related to project management. She mentioned the absence of a project management outlet to Dan Davidson within the Learning and Development Department. The concept lingered until the following year.

When Molina presented at the **2011 NASA PM Challenge** in Long Beach, California, the response she got from the attendees brought the workshop idea back to the surface. “There seemed to be interest around being able to learn more about the good basic practices of project management,” she said. She revisited the Learning and Development Department. The time was finally ripe for both parties to put the concept in motion.

She proposed the workshop, which is scheduled to pilot this fall, as a modest first step in a larger process toward creating a gateway into the world of the project management that would encourage the workforce to advance their management education. “What you’re doing is starting to think about the skills you learn in the class and apply them to a larger scale,” said Frasqueri-Molina. The workshop is not meant to prepare someone to walk up to NASA and declare they will manage the next Pluto mission. “You would be able to understand the language of someone in project management and what they’re trying to accomplish. You’ll see if project management is right for you.”

“In essence, it comes down to understanding the fundamentals of project management and the structures,” she explained. “Do you want your structure to be in the shape of a triangle? Do you want it to be in the shape of a square? Then you figure out what that means, what processes make up the inside. The structure should be somewhat custom made. Only you and your colleagues will know what is best for your projects.”

For Frasqueri-Molina, fifty percent of being a good project manager is having the right attitude. “No structure, no fundamental understanding of the project management concepts, are going to help you if you don’t have the right attitude,” said Frasqueri-Molina. “Nobody’s going to want to work for you, regardless of how amazing you are when it comes to concepts and structures of project management, if you’re an unpleasant person. Your relationships to your stakeholders, how you interact with them, and how you understand them, that’s the linchpin.”

The Whippersnapper Cycle

Frasqueri-Molina was born into Generation X, but grew up with the Millennials. “I was all about cable television, microwave ovens, video games, and how technology was going to shape my future,” she explained, noting that her coming-of-age moment was the late 1980s. “Michael Jackson was still walking around with the glove and red jacket. ET and Return of the Jedi were on the big screen.” This notion of being on a generational “cusp” has made Frasqueri-Molina highly observant of generational differences in the workplace.

“Facebook might not draw somebody who was born in 1922. Whereas a place like Disney, that’s been around for 90 years, has a very long history and will probably have those traditionalists because it’s a long-time, stable, family company,” Frasqueri-Molina said. While Facebook might not appeal to a traditionalist today, it may in the future. After all, Disney was once a “young, whippersnapping, upstart company,” she pointed out.

Uniting generations through mutual understanding is central to organizational progress. “Millennials are just on fire,” said Frasqueri-Molina. “They have to save the world and do everything right now.” The energy and drive of Millennials is critical to progress, she stressed. “You cannot create the amazing things that really push our country and our generation to the next level without that whippersnapping generation. You need that next generation that will create that unexpected, unimaginable thing. That's their job, to create that unexpected, unimaginable thing because nobody else can do it. Only they can."

In her experience, inserting generational "cusp" people into a multigenerational group helps alleviate stark differences. Cusp people speak the language of two generations: the one they were born in and the one they grew up in. Frasqueri-Molina finds she has the ability to build a bridge between a Twitter-centric 26-year-old and a "phone-call-is-enough" 47-year-old. Everyone appreciates having his or her intelligence and genius recognized, explained Frasqueri-Molina. "That taps into something innate in everyone: the need to be a part of something, to be recognized. That, I think, is cross-generational. I've found that if I approach people that way— with a humble attitude that respects their contributions regardless of generation—it usually works out really well."

Extraordinary Lessons

June 14, 2011 — Vol. 4, Issue 4

Shot down, tied up, and imprisoned somewhere in China, two CIA operatives were told by their captors, "Your future is very dark."

On a clear winter night, November 29, 1952, Central Intelligence Agency (CIA) operatives Richard Fecteau, 25, and John Downey, 22, boarded a plane to retrieve an informant in Chinese territory. During a second pass over the pick-up site, heavy fire from the ground brought the plane down. Their informant had been "flipped"—he had shared information with the Chinese about their mission. Shocked and confused, Fecteau and Downey, the only survivors, were immediately taken away for interrogation and imprisonment. It would be twenty years before either man would return home.

A half-century passed before the Downey-Fecteau story could be told in full. Before institutional memory could fade, the CIA captured lessons from this incredible story: the communication shortfalls that preceded the ambush; the extraordinary psychological stamina that sustained both

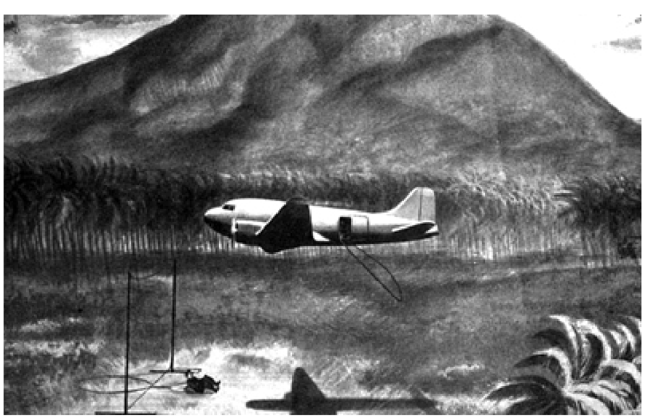


Illustration of the snatch pickup, from 1944 U.S. Army Air Forces manual Image Credit: Central Intelligence Agency.

Downey and Fecteau with captured B-29 crew in a Chinese propaganda photo. (Fecteau is standing to the right of the table, reaching down for a meal. Downey stands in the center of the photo, up against the wall.) Photo Credit: Central Intelligence Agency

agents; and the creative, dedicated maneuverings of the agency to provide for the men and their families during their absence and ultimately bring them home.

At CIA Headquarters, a painting of the Downey-Fecteau nighttime ambush hangs on a wall shared by images of other intelligence heroes like Virginia Hall, a World War II spy who received the Distinguished Service Cross, and Drew Dix, who singlehandedly assembled a small team and liberated the city of Chau Phu from Vietcong forces in 1968. Employees regularly stop and gaze. Not too far away stands the Memorial Wall, its 102 stars chiseled into the marble, commemorating lives lost in the line of duty. Among them is a star for Downey and Fecteau's pilot from that November night. More than fifty years since their story began, it finally can be told—and taught.

Tale of Two Agencies

The CIA, like NASA, is an organization defined by extraordinary individuals with extraordinary stories. And intelligence, like aerospace, is a tough business. Complexity and expectations rise without commensurate increases in resources. Successes usually go unheralded, while failure is subject to heavy scrutiny. And, to a certain extent, this is rightly so. Lives are on the line.

Congress created the Central Intelligence Agency with the passage of the National Security Act of 1947. Eleven years later, the Space Act led to the establishment of NASA. Both agencies grew up in the context of the Cold War competition with the Soviet Union and the perceived threat of global communism.

Both have also had their share of public failures over the last half-century. This year marks the tenth anniversary of 9/11 and the twenty-fifth anniversary of the *Challenger* accident—watershed events for these agencies and the nation.

Within the last decade, the intelligence and aerospace communities have had to respond and adapt to a dynamic world where information flows freely, technology is a

Christa McAuliffe received a preview of microgravity during a special flight aboard NASA's KC-135 "zero gravity" aircraft. She represented the Teacher in Space Project aboard the STS-51L/Challenger mission. Photo Credit: Central Intelligence Agency

blessing and a curse, smart networks define success, and transparency rules. While instinct may tell organizations to restrict and regulate information, taking this reality as a challenge to adapt and use the elements of the new environment to its advantage might be more effective.

Today, both agencies also face the challenges of resolving a "grey-green" generation gap. When NASA went to the moon, the average age in mission control was 26, whereas today it's closer to 50. At CIA, over half of the workforce entered the agency after 9/11. Passing on institutional knowledge is essential.

Center for the Studies in Intelligence

Knowledge sharing is particularly challenging in an agency of silos fortified by untold layers of security and secrecy. The Lessons Learned Program at the CIA is an initiative that started in 1974 with the establishment of the Center for the Study of Intelligence (CSI). Getting to its current form today took time. In an elite, unforgiving profession, admitting, much less embracing, the possibility of failure is not easy.
"A program explicitly designed to improve human performance implies that human performance needs improving," wrote Dr. Rob Johnston, director of the CIA's Lessons Learned Program, in his work *Analytic Culture in the U.S. Intelligence Community: An Ethnographic Study*. By gaining the support of agency leadership, Johnston was able to establish a resourceful knowledge sharing outfit. The CIA Lessons Learned Program produces case studies, oral histories, training, knowledge sharing events, and manages internal communities of practice. In a "failure-is-not-an-option" environment, having respected leaders share stories about past failures and successes stimulates learning and growth.

"It is important…that there be a voice in favor of openness to counterbalance the many voices whose sole or primary responsibility is the advocacy and maintenance of secrecy," Johnson wrote in Analytic Culture. This balance between restriction and freedom would optimize personal efficacy. In an increasingly transparent world, where organizations are sometimes forced to learn in public, one could argue that this type of organizational evolution is necessary.

To Be Better and Do Better

Supporting organizational knowledge sharing is a way to address big questions in pursuit of mission success. How did we get those guys home? How did we respond when all hell broke loose? What did we do when we got it really right? Initiatives like the CIA Lessons Learned Program preserve valuable experience and knowledge within the institution before it walks out the door.

The Challenger and 9/11 tragedies are reminders of the necessity for organizational learning and knowledge sharing. So are the stories of Downey and Fecteau; Jim Lovell, Jack Sweigert and Fred Haise; Gus Grissom, Ed White, and Roger Chaffee; and countless others who made extraordinary sacrifices. Their stories provide fundamental lessons for current and future generations of practitioners.

Working Outside the Box at Johnson Space Center

July 20, 2011 — Vol. 4, Issue 5

What impact does a room really have on your work?

Ask someone where to find "the sp.ace" at Johnson Space Center (JSC) and they might look at you as though you've queried the location of Platform 9 ¾ or a wardrobe leading to Narnia. Between Buildings 34 and 585 at JSC sits Building 29. It once housed the Apollo astronaut centrifuge, and later the Weightless Environment Training Facility (WETF)—a precursor to the Neutral Buoyancy Laboratory—which trained astronauts for Hubble repair missions. Today Building 29 supports another mission: collaboration.

Inside one of the high bays overlooking the former home of the WETF is a work area available to everyone at the center. The decor is simple and functional: whiteboard tables, colorful rolling chairs, mobile desks and whiteboard walls. Have an idea? Write it on the table or a wall. Share it on a screen. Need a bit of privacy? Go to the neighboring room ("the fishbowl") and work there.

Open, light, and flat, the sp.ace is an environment where people and ideas can connect, collide, and coalesce. It is a place where the traditional workforce meets the increasingly transient one. As project teams become more geographically dispersed and the demand for cross-disciplinary innovation continues to grow, some organizations are creating work environments that foster disruptive ideas and unexpected solutions.

Beyond Cubism

Collaborative spaces are not new. Early coffeehouses from the 1600's were hotbeds of social interaction and collaboration. Walk into any on-campus college café and you'll see writing on the walls and hear lively conversation. While the

The sp.ace in Building 29 at Johnson Space Center.
Photo Credit: NASA JSC/ Christopher Gerty

fundamentals of human collaboration have not changed since the Enlightenment, the amount of information and knowledge available through technological advances has. The challenge facing organizations is to standardize the technology used to collaborate and connect, not the location of the worker.

Until the mid-1960s, typical office spaces consisted of open areas lined with orderly rows of desks. Paperwork was filed in cabinets or neatly piled in stacks on desktops. As the amount of information passing through organizations increased, something had to give.

In 1968, Robert Propst invented the cubicle, which drastically altered the office work environment. While the original intention of the cubicle was to liberate workers from piles of paperwork and give them the opportunity to spread out, visualize information differently, and establish a sense of identity at the office, Propst's invention took another path. Now a symbol of compartmentalization, the workplace is undergoing a shift away from "cube farms" toward more collaborative working spaces.

Organizations like SpaceX have open, flat work environments designed to reflect their flat organizational structure. **Fuji Xerox** has rooms in Europe and Japan that are designed to elicit certain types of thinking – a sort of "cognitive ergonomics," a term used by researchers at large office furniture companies like Steelcase and Herman Miller. Companies from Google to Capital One have made open, transparent, collaborative work spaces available to their employees.

Work real estate is at a premium. Projects are increasingly interagency and international. Employees don't always utilize an office—they're getting the job done elsewhere. IBM, for example, has done away with office space for tens of thousands of its employees. Practices such as "hotelling," where employees are given unassigned spaces in a work environment, are being used to meet the needs of nomadic workers. This way of working is making its way to government.

In December 2010, President Obama signed the Telework Enhancement Act "to improve teleworking in executive agencies by developing a telework program that allows employees to telework at least 20 percent of the hours worked in every two administrative work weeks, and for other purposes." This June, executive agencies passed the first milestone of informing employees who meet the teleworking criteria that they are eligible for a new way to work. The next steps include acquiring technologies to allow for incorporation of telework into agency operations and policies in order to decrease real-estate costs. Collaborative workspaces allow organizations to optimize the use of their work real estate, and workspace is no longer defined by one function or set of walls. It becomes adaptable, flexible; anything the organization wants it or needs it to be.

The Sp.ace, the Sandbox, and Fab Labs

NASA is accustomed to collaboration on many levels. Collaborative spaces exist at Ames Research Center and the Jet Propulsion Laboratory, connected by hyperwalls—large multi-screen displays—to collaborate on projects such as high-resolution image analysis from Mars. The pixel resolution allows for scientists separated by nearly 400 miles to collaborate and plan out a rover's path. The JSC sp.ace is a modest beginning to something that hopes to grow. It's a place for people to congregate and spur imagination, creativity, and curiosity. But it's only a start.

Plans for another collaborative working space at JSC are afoot. The "Sandbox" will draw on the global success of the MIT Fabrication Laboratories ("Fab Labs") which started gaining recognition in 2002. Fab Labs were founded on the premise of giving people tools to create things rather than consume them. The Sandbox, used to be warehouse that held old boxes of this and that and then acquired a variety of electronics, welding, and machining equipment in addition to an open meeting area. It is the hardware/prototyping equivalent of the sp.ace in Building 29 and will be virtually connected to other collaborative working spaces. As this new space evolves, a sort of collaborative space "cookbook" with information about standardizing connections (e.g., HDMI inputs), bandwidth requirements, audio and video

Collaborative work taking place in the sp.ace at Building 29 at Johnson Space Center. Photo Credit: NASA JSC/ Christopher Gerty SFC

The "Sandbox" at Johnson Space Center.
Photo Credit: NASA JSC/ Christopher Gerty

connections and positioning, and power needs (e.g., easily accessible power strips) will be made available for others to create other collaborative spaces capable of connecting with established ones.

While the creation of collaborative spaces at JSC is continuing to evolve, the JSC "sp.ace" has already had success with a designated coworking week. Anyone from flight controllers, to administrative assistants, to project teams utilized the space to meet their needs or simply check it out. Throughout the week, as new faces trickled in and familiar ones returned for another visit, it was apparent that an entirely different wave of information and knowledge sharing driven by increased technological capability is upon us. Traditional offices aren't supporting workforces like they have in the past, and organizations are starting to adapt.

Aaron Cohen on Project Management

July 20, 2011 — Vol. 4, Issue 5

A pioneer of human spaceflight projects offered five rules for avoiding project management pitfalls.

[Editor's note: As the space shuttle moves from the launch pad into the history books, it seems appropriate to revisit the wisdom of Aaron Cohen about successful project management. Cohen joined NASA in 1962 and served in key leadership roles critical to the success of the flights and lunar landings of the Apollo Program. From 1969 to 1972, Cohen was the manager for the Apollo Command and Service Modules. He oversaw the design, development, production, and test flights of the space shuttles as manager of NASA's Space Shuttle Orbiter Project Office from 1972 to 1982. After serving as Director of Engineering at Johnson for several years, he was named director of the center in 1986, serving in that post until 1993.

The text below is an excerpt from "Project Management: JSC's Heritage and Challenge," which was originally published in 1988 in the anthology "Issues in NASA Program and Project Management" (NASA SP-6101).]

Whatever priorities are dictated by the environment, a project manager can never equally satisfy all elements of project management. There is no exact project management formula or equation for making performance-cost-schedule trades. But the lessons I have learned from people like Robert Gilruth, Max Faget, Chris Kraft and George Low—and from my own experience—tell me that there are several important principles in maximizing the probability of success. Those factors sometimes contradict one another and they must be applied on a case-by-case basis, but they are nonetheless valuable.

First, you must fearlessly base your decisions on the best information available. As a project manager you will have many different considerations with regard to each programmatic issue. Simply by making a decision, you ensure that you probably will be right more than half the time.

Many times during the life of a project, a project manager will be faced with decisions that need to be made in a timely fashion, and either all the data is not available or it will not become available in time. In other words, the time and effort spent in trying to obtain additional information may not be worthwhile. A specific example of this occurred during the early design phase of the Orbiter. The avionics system was being formulated and a microwave scanning beam landing

Aaron Cohen served as NASA Acting Deputy Administrator from February 19, 1992 to November 1, 1992. Mr. Cohen started at NASA's Johnson Space Center in 1962 working on the Apollo program. After Apollo he served as Manager of the Space Shuttle orbiter, directing the development and testing of the orbiter. In 1986 h`e assumed the position of Johnson Space Center Director. Photo Credit: NASA system (MSBLS) was being considered as a navigation aid. At the time, the MSBLS was pushing the state-of-the-art. The question before me: Should I use current, proven technology or should I try to push the state of the art and wait for such an advancement in the technology? I based my decision to push for the new technology on the data I had and the desire of my team to use the system. We made a decision, and it proved to be correct.

Second, you must make decisions in a timely manner. If you are decisive early and are wrong, you can still correct your error. During the Orbiter design, development, test and evaluation phase, I was forced to make many trades in terms of performance, cost and schedule. On one particular occasion, I was reviewing thermal system structural test requirements that contained a number of articles such as parts of wings, parts of the mid and forward fuselage and their thermal protection systems. The technical team needed to test all of the articles, but they were too large to test all at once, and I had a limited budget. After spending a full Saturday in review of all the test articles, I eliminated several despite the extreme concern of several of the technical experts I had supporting me. Weeks later they came back and argued their point of concern again. This time, their point struck home and I reversed myself and put the test articles back into the program. By making a timely decision, I had given myself a chance to correct a potential error.

Third, if you can fix a problem by making a decision, do it. During the checkout of Apollo 11, the Inertial Measurement Unit (IMU) of the lunar module was slightly out of specifications in gyro drift. The analysis showed that you could accept a little more degradation and still perform the mission. The questions before management: Do we understand the reason for the gyro drift, and could this lead to a greater degradation and threaten the success of the mission? Changing an IMU out of the lunar module on the pad was not an easy task, and we would be risking major damage to the fragile structure of the lunar module if one of the heavy instruments were dropped during a pad change-out. A group of us discussed this problem with George Low, then Apollo program manager. We strongly recommended to him that we should not change out the IMU. His comment was: "If you can fix a problem by making a timely decision, do it." We replaced the IMU.

Fourth, always remember that better is the enemy of the good. You can never solve all of the problems. If you have obtained an acceptable level of system performance, any "improvements" run the risk of becoming detriments. Right now, we are struggling with this very situation [in the Shuttle program] as we try to improve the design of the solid rocket motors and add emergency egress systems to the Orbiter. Each improvement brings with it a price in terms of weight. Each additional pound reduces the margin we have in the amount of thrust available to reach orbit. We have had to ask ourselves, "At what point do these new safety features become liabilities?"

Fifth, don't forget how important good business and contract management are to the successful operation of a contract. Project managers must realize that when they manage a contract they should do their best to be fair to both the government and the contractor. In order to do this, they need strong project controls on budget, schedule and configuration. The project manager must be sure the changes that are made are negotiated promptly and equitably for the government and contractor. Fairness in dealing with the contractor is the most productive way to do business. You want to penalize when appropriate, but you also want to reward when appropriate. To establish what is appropriate, you must set the ground rules early. The first signs of project management failure are budget overruns and schedule slips. This can be understood and potentially avoided or minimized by good project control and contract management

Last, and most important, you must be people-oriented. It is through people that projects get done. Dealing with people is extremely difficult for many project managers who have an engineering background and more comfortable working with an algorithm than explaining how to use one. Good project managers surround themselves with talented people who will speak up when they believe they are right. They make themselves available to their bosses and to the people who support them. They listen when people express their concerns, and make people want to express their concerns by explaining decisions that contradict the advice given. They accept criticism without being defensive and are able to reverse their decisions when they are wrong.

One of the most vivid and memorable experiences I've had in this regard happened during the preparation for Apollo 8 in early December 1968. The preparations had been going very smoothly without any big issues needing to be worked for several weeks. Then it happened. About two weeks before the flight I was told by the contractor, North American Aviation, and JSC propulsion subsystem managers that we had a potentially serious problem with the service propulsion system (SPS). We had just finished some tests in the configuration that we were going to use for lunar orbit insertion.

The Major General J.A. Abrahamson, right, talks to JSC Director Christopher C. Kraft, Jr., (seated left) and Space Shuttle Program Manager Glynn S. Lunney on the back row of consoles in the mission operations control room (MOCR) in the Johnson Space Center mission control center. Abrahamson, second right, talks to JSC's Aaron Cohen, right, as Kraft (seated left) and Lunney listen in mission control. Photo Credit: NASA

Apollo 8 was going to place the CSM on a free-return trajectory, which meant that if we did not perform an SPS burn behind the Moon the spacecraft would automatically return to Earth. The SPS fuel injector was fed by a pair of redundant systems. We wanted both of them to be active during the lunar orbit insertion burn so that if one feeder line malfunctioned, the other would get propellant to the SPS. The tests we had just finished were in this configuration, but it was the first time they had been used and both lines had been dry before the test. The tests showed that if we started the burn with both lines dry, a pressure spike occurred that could cause a catastrophic failure in the SPS. If both lines were wetted, however, the pressure spike would not occur.

I got very upset when I was told this, but the test engineers stood their ground. They told me very firmly that the problem had to be addressed, and they presented a good solution. By firing the SPS on a single system out-of-plane burn during coast—which would not disturb the translunar free-return trajectory—we would have both systems wetted by the time we needed to use them together and, hence, avert the high-pressure spike.

Now it was my job to call my boss and let him know what I knew and how to fix the problem. I had no qualms about doing this because my boss, George Low, had taught me several important things by his actions and words: get out and touch the real hardware; when things go wrong, look for innovations, the unusual solutions, or try to meet your commitments no matter what; and have great respect for your fellow human beings.

Shuttle Trackers

September 28, 2011 — Vol. 4, Issue 7

A team of thirty-five trackers worked together to provide the photographic story of a space shuttle launch.

When a piece of foam the size of a briefcase hit the leading edge of *Columbia's* left wing 81.7 seconds into the launch of STS-107 on January 16, 2003, no one saw. It wasn't until the following day that images from cameras on the ground revealed the strike and triggered a series of conversations about what to do. The story of Columbia is just one example of the impact that imagery can have. Getting the right image is a story in itself.

Approximately 400 ground-based cameras recorded every shuttle launch after *Columbia*, an increase from previous missions that was recommended by the Columbia Accident Investigation Board Report. The report identified other upgrades to Kennedy Space Center's ground camera ascent imagery assets such as obtaining higher quality optics and higher image resolution. For each shuttle launch these assets were precisely calibrated to capture the data needed to make decisions about the progression of the mission.

Most stories about shuttle launch photography focus on the cameras and the massive tracking equipment. As with all NASA projects, though, it is the people behind the cameras and machines who make the visual story of a launch come to life.

Cameras inside of explosion-proof enclosures near Launch Pad 39-A. Photo Credit: NASA APPEL

A Mad Scientist Machine Shop

"Want to hear 400 frames per second?" asked Adam Nehr, instrumentation specialist. He flipped a switch and the camera chugged its way through a full magazine of film in less than a minute. The camera resembled many others sitting in a storage room across the hall. Inside there are rows of racks containing cameras, film, and tripods and at least one cabinet dedicated to the famous Hasselblad cameras used to capture lunar imagery during the Apollo Program. "This is what we have in terms of the smaller equipment," said Mark Olszewski, photo and media services manager. "These are the little toys."

The Photo and Media Services Center is home to a team of 35 men and women dedicated to seeing the shuttle launch story unfold amid the chaos of fire, gas, and debris during launch. Some took a winding path through various technical school curricula, while others transitioned to NASA from jobs ranging from shooting high-speed commercial imagery for locomotive companies to photographing autopsies.

"All of us here are construction technicians, welders, [or] machinists who are able to fabricate all kinds of stuff," said Nehr. "We can make anything in metal, wood, plastic." The team can design, build, and repair optical equipment as well as maintain and calibrate high-speed motion picture equipment. The team prepped the cameras (the film was installed by feel in total darkness) and placed them in explosion-proof boxes around the pad." Generally accustomed to flying below the radar and getting the job done right, "we become pretty important 11 milliseconds after something goes wrong," said Nehr.

The Lesser Known PADD

Each camera for a launch has a specific job to do. For shuttle, there were hydrogen burnout cameras on the launch pad to capture the diamond shockwave that comes out of the engines. There were cameras inside the Tail Service Mast (TSM) recorded the human-sized carrier plates as they were pulled back and shut into the TSM enclosure. There were cameras set up to capture the gimballing and ignition of the engines, the release of the explosive bolts holding the shuttle up, and to record the movement of the twang. "There's a camera for every mechanical function that we need to quantify," said Nehr.

Each camera is prepared according to the type of image it will capture. "We need to set up our equipment to acquire that image precisely," said Nehr. Specific calculations for each camera are documented in the Photographic Acquisition Disposition Document (PADD). Derived from the Program Requirements Document for the shuttle, the PADD defines the imagery requirements according to what the imagery analysis team needs to do its job after a vehicle launches.

"The PADD specifies what the intent of the image is," explained Nehr. Shutter angle, shutter speed, and frame rate, are calculated for every single camera, in addition to the shuttle's path and gas velocities so that the photographers know how fast something might be moving through a frame. "They have to be calculated so that any credible event that we would see is kept sharp," explained Olszewski. A blur streaking through an image can render it useless.

There were cameras calibrated for short-, mid-, and long-range imagery. Some sat on the pad, next to the pad, around the perimeter of the pad, or even many miles away. Perhaps the best-known cameras sat on a tracking device called a Kineto Tracking Mount (KTM). It looks like something straight out of a *Star Wars* film. One side of the KTM carried a film camera packing 1,000 feet of film, and the other housed a HD-quality video camera. A manned tracker used a spherical joystick to follow the shuttle skyward. Unmanned KTMs were remotely controlled and sat as close as two miles from the pad.

For every shuttle launch, a total of 14 KTMs were deployed to stations from Cocoa Beach to Daytona. "We set them up here in the hanger, put all of the cameras and lenses on them, make sure they're balanced and everything works just right, and then we tow them out to the field," Ken Allen, chief electronic technician, who has been with the team for over 23 years.

Allen started his career with NASA working telemetry for STS-1 on an island in the Caribbean. He later transferred

Camera inside of an explosion-proof enclosure pointed towards Endeavour one week before it launched on STS-134. Photo Credit: NASA APPEL

Operator Kenny Allen works on the recently acquired Contraves-Goerz Kineto Tracking Mount (KTM). Trailer-mounted with a center console/seat and electric drive tracking mount, the KTM includes a two-camera, camera control unit that will be used during launches. Photo Credit: NASA

to KSC during the days of the KTM predecessor, a tracking mount called the Intermediate Focal Length Optical Tracker (IFLOT), which used World War II anti-aircraft gun mounts retrofitted with cameras instead of artillery. They have been used to capture imagery for launches from the late 1950s to shuttle. Not quite fast enough to track the faster rockets of today, NASA started using KTMs, which were more capable, in conjunction with the IFLOTs in the late 1980s.

"I actually took these (the KTMs) off the truck when they showed up," said Allen. The KTMs were computer controlled and modern and Allen took to them immediately. "The old-timers that were here back then didn't want anything to do with them," he laughed. "That's how I ended up in this section. I knew the electronics and could take care of them."

Not Your Average Photostream

Just before rollback of the Rotating Servicing Structure, Nehr would carry a heavy bag of equipment up to the shuttle stack. He meticulously photographed the tiles and the forward reaction control system, documenting everything he saw. Of the 2,000 plus images he took, bird droppings were a common item he took care to note. "To the laser range finder on the end of the robotic arm they used for tile inspection [in space], bird droppings look exactly like tile damage," Nehr explained. Tile damage can be cause for a spacewalk, an unwanted risk and waste of valuable time if the tiles aren't really compromised. "I've had thousands of published pictures," said Nehr, "but I tell people some of the most important pictures I've ever taken are of bird poo."

Another set of photographs he was responsible for were of tiny pieces of tape placed where the external tank connected to the belly of the shuttle. Once the tank was jettisoned, the doors closed in a specific way. "We position the tape so that it shows just a little bit [when this happens]," he explained. "When we examine the photographs, if there's more tape showing than there should be, we know the doors didn't shut properly."

Operators Rick Wetherington (left) and Kenny Allen work on two of the Contraves-Goerz Kineto Tracking Mounts (KTM). There are 10 KTMs certified for use on the Eastern Range. The KTM, which is trailer-mounted with a center console/seat and electric drive tracking mount, includes a two-camera, camera control unit that will be used during launches. The KTM is designed for remotely controlled operations and offers a combination of film, shuttered and high-speed digital video, and FLIR cameras configured with 20-inch to 150-inch focal length lenses. The KTMs are generally placed in the field and checked out the day before a launch and manned 3 hours prior to liftoff..
Photo Credit: NASA

After a launch, the team put together what is called a 'quick review' or 'quick video' within an hour or two after liftoff. This is the HD video of the launch that is sent to the image analysis team called the Intercenter Photo Working Group. "While that's happening we're gathering film from each of the cameras and getting it together to have it processed." They had approximately twenty-four hours to deliver.

A Thousand Words

Being able to answer the simple question "Did you see that?" is important to mission success. From the camera boxes that were embedded into the Apollo launch ring stands to the place where periscopes used to peer out of bunkers to watch Mercury spacecraft launch ("That's how they watched it back then in the days before easily usable video cameras," explained Nehr.), being able to actually see what's happening during liftoff is critical.

"A picture is worth a thousand words," said Olszewski. "It's that simple. Try to describe it verbally or try to write it down exactly as you've seen, it takes too much time. Sometimes you don't have the right words. Sometimes you know how to describe it. But if you take an image, you're looking at it. You don't have another person's perception of what they thought they saw."

When an anomaly or a failure occurs, often it happens so fast that the human eye misses it, perception distorts it, and memory fades. Said Nehr. "The only thing you've got left is imagery."

Something to Shout About: Bloodhound Supersonic Car

October 28, 2011 — Vol. 4, Issue 8

The Bloodhound Supersonic Car aims to set a new land speed record and a new standard for openness in projects.

Project Director Richard Noble and his team are building a car that will go zero to 1,050 miles per hour (mph) in 40 seconds. Named after Britain's 1950s Bloodhound Missile Project, the Bloodhound Supersonic Car (SSC) car is 12.8 meters long, weighs 6.4 tons, and cruises on high grade aluminum wheels, which will experience radial stresses of up to 50,000 times the force of gravity at full speed.

The project is risky, dangerous, and unprecedented. Focused on building the safest car possible, Noble's Bloodhound team intends to overthrow the current FIA World Land Speed Record by 30 percent. "It's such a huge leap, of course we're going to get into trouble," said Noble. "We're going to learn an awful lot as we develop it."

World records aside, the team wants to capture the attention of students and inspire a new generation of engineers.

Genesis

In 1898, French driver Gaston de Chasseloup-Laubat set the world land speed record at 39 miles per hour (mph). Fast-forward to 1970, when after decades of battle between the Americans and British, an American-built car called Blue Flame set a new record of 630 mph. "We in Britain were very keen to get it back again," said Noble. "Or, at least, I was," he laughed.

Noble assembled a team to build a new car, Thrust2. With Noble literally in the driver's seat, Thrust2 set a new record of 634 mph in 1983, sparking a race for the sound barrier.

Building and modeling cars intended to travel upwards of 600 mph was difficult, dangerous, and nearly impossible. Noble had pushed the limits with Thrust2. "The [aerodynamic] data was varied and not reliable," said Noble. What designers needed was a transonic wind tunnel with a sort of car treadmill capable of speeds up to 900 mph, he explained. This didn't exist.

With competitors already at work, Noble decided to throw his hat into the Mach 1 race with Thrust SSC. This time around, Chief Aerodynamicist Ron Ayers insisted on modeling the car. Software programs in the early 1990s facilitated new ways of using computational fluid aerodynamics (CFD) to model Thrust SSC, but Ayers wanted to qualify their results. The team went to a long rocket test track, normally used for accelerating warheads up to Mach 3 and slamming them into slabs of concrete, and used a modified rocket sled to confirm their results. They ran 13 tests of their car and compared it to their CFD data. "Amazingly, we found there was just a 4 percent variation in the data," said Noble. This proved that the car was safe and viable.

In 1997, Thrust SSC went supersonic five times in the Black Rock Desert of Nevada. Fifteen miles away in the town of Gerlach, the sonic boom knocked the covers off the classroom sprinkler system. "We all said that we would never, ever do this again," said Noble. Little did they know they weren't done—with building supersonic cars or rattling educational establishments.

Meeting with the Minister

After Thrust SSC's run, the late Steve Fossett, a world-renowned aviator and sailor, expressed an interest in overtaking the new speed record. If they waited, Noble and his team would spend five years studying how Fossett bested them, and then another six years building a defender. "We all looked at each other, got slightly grey-haired, and decided eleven years was too long," said Noble. "We'd better do it now."

The new car, the Bloodhound SSC, would shoot for 1,000 mph. Two jet engines on the car brought about too many design difficulties. A combination of one jet engine and one rocket motor was more feasible. Lightweight, small, and fuel-efficient, the Eurofighter-Typhoon EJ200 jet engine would be a perfect fit. However, there was only one place to get the engine: Britain's Ministry of Defence.

Driver Andy Green arranged a meeting with then-U.K. Science Minister Lord Paul Drayson, who formerly held a post in the Ministry of Defence. Drayson also happened to race cars. "The meeting remained very friendly until I asked him for the jet engine," Noble chuckled. Sensing they had failed dismally, they started to retreat from the room.

The BLOODHOUND SSC Show Car outside Coutts Bank in The Strand, London. 17th October 2010. Project Director, Richard Noble OBE. Photo Credit: Sarah Haselwood

"Then Drayson said something that changed all of our lives," said Noble. "He said, 'Look, there's something you could do for us.' I said, 'Of course, Minister, what can we do for you?'" Drayson explained that the Ministry of Defense was having a problem with recruiting engineers. There didn't seem to be any in Britain anymore. During the 1960s, there had been a new airplane every year, which got kids excited and motivated them to become engineers. Drayson told Noble and Green that was the goal: they could have their engine if they agreed to start an education program with their project.

Noble agreed and shook Drayson's hand. "We walked out of his office intent on setting up an enormous education program, which we knew nothing about."

Engineering: A Dead Subject?

Noble's team went to work researching the state of education in Britain. "We found all sorts of terrible things were happening," he said. Britain's skilled workforce was on the decline, its students were sliding in international rankings, and the country's information technology sector was dismal. They needed to create an Apollo-effect—to inspire people to change their lives because of this project.

With their posters and a model of the car, the Bloodhound team attended education exhibitions across the country, talking to as many STEM (science, technology, engineering, and mathematics) teachers as they could. Their conversations went something like this:

"What's it like teaching STEM?"

"Absolutely awful. It's an absolute nightmare. The kids aren't interested. They are very arrogant. All they think they need to know how to do is add, subtract, and work percentages."

"Sounds pretty bad."

"It's like teaching ancient Latin or Greek. You know, dead subjects."

Their conversations proved enlightening. "We needed to do something exciting," said Noble, "but above all, we had to be able to share the information." If they were going to educate Britain, teachers needed to be able to understand the charts, models, and drawings so they could make new lesson plans and explain it to their students. Every aspect of the project had to be entirely accessible.

This lack of secrecy initially worried the Bloodhound team. Then they realized that their fears were unnecessary. The only rules for the land speed record are that the car must have at least four wheels and be controlled by the driver. "All of the cars and all of the challengers are completely different," said Noble. "The technology simply won't transfer from one

The Bloodhound SSC Show Car at the Bloodhound Technical Centre. September 2010. Photo Credit: Flow Images

competitor to another. We realized that we could make all of the data available. Absolutely everything."

Nitrous: Not Quite So Funny.

The Bloodhound team is blazing a new trail. They still have many challenges to overcome, but have learned a great deal so far. One particular lesson came from choosing the oxidizer for their hybrid rocket motor. The team thought it had an easy answer: nitrous oxide (N_2O). Safe, reliable, and easily accessible, N_2O seemed a sensible choice. Not so, warned one of Noble's peers—N_2O is not to be trifled with.

Noble investigated the claim. After scouring the Web, his team found a paper from 1936 that explained how pressurizing N_2O beyond 13 bar could cause an explosion. "Whole plants had been taken out by nitrous oxide explosions," explained Noble. Nitrous was also the culprit in a 2007 Scaled Composites explosion that killed three people. The Bloodhound team was shocked.

They selected high-test peroxide (HTP) as an alternative that is less likely to set off an N_2O -like explosion. Testing with smaller rockets has been successful, with the rocket motor running at 98 percent catalyst efficiency. The team is currently doing testing on the full-scale motor.

The Team: Grey to Green

Chief Rocket Engineer Daniel Jubb worked the N_2O problem. He joined the Bloodhound team in 2005 when he got a call from Noble for a meeting. Highly recommended by several seasoned rocket engineers, Noble drove out to Manchester to meet Jubb. "I discovered that I was face to face with a guy who was twenty-three," said Noble.

From Jubb to Ayers (who is in his eighties), Noble respects the importance of having a generationally diverse team. Typically, young engineers only see one part of a project. Rarely do they see the whole lifecycle. "Getting the overview perspective is very, very important," said Noble. The project is demanding, but offers young engineers (the youngest is 18) the opportunity for gaining tremendous experience and acts as a stepping stone to a future career.

"It's very important from our point of view to use as many young people as we possibly can," said Noble. He finds the younger generation's rapport with technology enormously useful. "But, of course, they've got to be able to contribute to the project." The flat structure of the Bloodhound organization facilitates this. Everyone has their own set of responsibilities and the authorizations, and everyone in the organization is empowered. "Anyone can go fail the project if they wanted to," said Noble. "One would think this is some sort of undisciplined rabble, but it's certainly not."

"You end up with a very, very fast moving, highly motivated organization and therefore can do [great things] on very small sums of money," said Noble. (Thrust SSC was completed for £2.4 million, 12 percent of what their competitors budgeted.)

Something Incredibly Wonderful Will Happen

Partway through the project, Noble and his team realized there was a flaw in their openness plan. "If we were going to put up all of the operational data after each run on the web, we'd have to be very clever about the way we actually presented it," said Noble. "Unless people were given the

The Bloodhound SSC Team after the unveiling. (July 19th, 2010. Farnborough) Photo Credit: Nick Chapman

Richard Noble and Andy Green with a model of Bloodhound SSC. Photo Credit: Bloodhound SSC

appropriate education, they wouldn't understand the data. It would just be numbers to them and they wouldn't really be able to take part in the program."

Taking the lead from the highly successful Khan Academy, Noble partnered with Southampton University to develop educational tools the public will need to engage with the Bloodhound SSC data flow. Today there are 4,600 schools in Britain and 207 countries worldwide participating in the Bloodhound engineering adventure, as the team preps for their 2013 run in South Africa. Via the Bloodhound SSC website, anyone can be a part of the project through **games**, **videos**, **pictures**, **explanations of the car elements**, drawings, or **blog posts from Noble**. Just months ago, the team posted a suite of **40 computer-aided design (CAD) drawings** online to help people understand how the car was designed and built. There have been approximately 2,500 downloads of the drawings.

"It might well be that someone makes a [copy], which would be brilliant," chuckled Noble. "We could race!"

Young Professional Brief: Jennifer Keyes

January 31, 2011 — Vol. 4, Issue 1

An offhand response landed Jennifer Keyes a chance to work at NASA, leading to ten years of unexpected opportunities.

"I want to be an astronaut."

Jennifer Keyes, a systems analyst and engineer at NASA Langley Research Center, showed all the signs of having an engineer's mind at an early age. She took water measurements and surveyed plots of land with her father, a hydrologist. She drew out detailed assembly instructions for family campsites on vacations. She dismantled and re-assembled everything that captured her interest.

A trip to Space Camp during her senior year of high school opened her mind to the possibility of becoming an astronaut if she studied engineering. The next fall she started as a freshman at Rensselaer Polytechnic Institute (RPI), majoring in Aeronautical and Mec hanical Engineering. That spring a career development counselor asked her what she wanted to be when she grew up. "Being a smart-aleck freshman," recalled Keyes with a laugh, "I said I wanted to be an astronaut, but meanwhile, working for NASA would be cool."

To her horror, the counselor made a few calls to contacts at NASA's Langley Research Center. A few weeks later, she had the opportunity to apply for an internship, and wound up with her first position at NASA.

A Four-Year Interview

For her summer internship, Keyes coded for lidar data that had come back from the STS-64 Space Shuttle *Discovery* **Lidar In-space Technology Experiment (LITE)**. She was given the chance create plots from data that had never been made before, "which was tremendously cool to me," she says.

Within a matter of weeks after she finished her internship, Keyes returned for what would be the first of four co-operative (co-op) positions at Langley. During the first, she interviewed with project leads to determine which project suited her best. She chose to work on data analysis of a temperature-sensitive paint wind tunnel test with an aeronautical engineer named Ken Jones. "I started out

Systems analyst and systems engineer Jennifer Keyes. Photo Credit: NASA

The Lidar In-space Technology Experiment (LITE) in the foreground on STS-64 Space Shuttle Discovery. Photo Credit: NASA/Johnson Space Center

in subsonic aerodynamics, looking at the flow of air over the airplane wings," she says. Jones challenged her with material she had yet to learn in her aeronautics engineering classes and took the time to explain to her how the material would apply to her schoolwork.

Her co-op experiences led her into a number of fields. "There was something new and exciting to do every day," she says. She worked in atmospheric science for a while and wrote data analysis code for an A-band spectrometer, performed systems analysis where she reviewed proposals for small spacecraft, designed "Tumbleweed" rovers for Mars, and wrote flight code for a successfully launched sounding rocket that blew off a nose cone so that the instrument could see into space.

As she neared graduation from college, a job opening at Langley in systems analysis became available. She jumped at the chance. A year earlier or a year later, she said, she might not have gotten the job. But her experience paid off. "I happened to be in the right place at the right time," she said. "I had a four-year interview."

Mentors and Shadowing

Always the engineer, Keyes initially thought finding a mentor would be a data-driven process. With three prospective mentors to interview, she approached each armed with intelligent questions designed to elicit interesting answers that would guide her towards a mentor-mentee match. "That was going to be my deciding moment."

But it wasn't. "It was completely a gut feel," Keyes says. Sitting in the office, of Laura O'Connor, technical assistant to the center director, she observed a different kind of data output than she had expected. "I was just sitting in her office and it just felt really natural to talk to her." Some people want mentors who hold positions they aspire to have one day, but not everyone needs that in a mentor. "I wanted to be able to talk out hard situations." O'Connor fit that role.

O'Connor's mentorship led to an opportunity for Keyes to shadow Langley Center Director Lesa Roe. "I was completely amazed at her ability to have a conversation with everyone," says Keyes. One minute Roe would be talking political strategy with a project manager, and then she'd seamlessly switch gears to have a technical discussion with a scientist. If Roe didn't know someone, she made a point to get to know them, added Keyes. "You can tell she's storing the information away so she knows who you are, where you came from, and how you got to where you are."

Listen, Try Everything, and HOPE

After 10 years at NASA, Keyes has two pieces of advice for young professionals: listen and try everything. She readily admits she's terrible with date memorization (much to the dismay of an earlier mentor, her U.S. History teacher Mr. Thomas Madson), but she appreciates learning the story behind a place, a people, and a culture.

"[History] builds the foundation for the advances in aeronautics, exploration and science that will come in later years," Keyes once wrote in an online forum. She takes every opportunity to learn more about her center and the agency through everything from tours to participation in an archeological excavation at Langley during a construction project. But it's the stories people share that she finds fascinating. She remembers listening to one of her colleagues talking about how cool Alan Shepard's car was. Suddenly it dawned on her: "Holy smokes, this guy actually knew Al Shepard!"

The 14 x 22 Subsonic Wind Tunnel at Langley Research Center. Photo Credit: NASA/Sean Smith Credit: NASA

"I try to listen as much as I can," she says. "I wish I could do a brain download on some of these guys because they're going to leave someday, and I don't want that [knowledge] walking out the gate with them. I don't want it to leave in their heads and never have gotten captured."

Trying everything leads to unexpected pieces of information or contacts that will help later on, says Keyes. A recent task involved extensive work with the international community, and now she wants to learn more about the financial side of things. "It (NASA) all runs on money, and it sure doesn't make sense to me sometimes." She hopes to gain a better understanding of the process of mission support and procurement to further her own experience and knowledge.

Currently, Keyes works as a systems analyst in the Constellation of Earth Observing Satellites (CEOS) office at Langley. She is also the systems engineer for DEVOTE, a project designed to develop instruments and modify two Langley research aircraft for future science missions. DEVOTE is part of **Project HOPE (Hands-On Project Experience)**, a collaboration between the Science Mission Directorate and the Academy of Program/Project & Engineering Leadership that gives a project team the opportunity to propose, design, develop, build, and launch a suborbital flight project over the course of a year. Her team is currently finalizing its Level One requirements and success criteria for DEVOTE.

Keyes wears many hats. She tries to take advantage of every opportunity that comes her way, knowing in advance that not every one will be a perfect fit. "Some of them are a lot of work and I've realized they really were not the right thing for me," says Keyes. Even with those that end up being less than enjoyable, "it's just as important to learn that as it is to learn what you love." Keyes also aims to strike a balance between work and life by setting realistic goals and expectations. "I'll probably work on that for the rest of my life."

Luck and Preparation

Keyes's ten years at Langley happened through a series of fortunate events, from her last-minute change in college application strategy to getting a career counselor who had a connection at Langley. "I have been in the right place at the right time and surrounded by the right people ever since the very beginning," she says.

It hasn't been all luck. Keyes continuously prepares herself, both by trying new things and reading as much as she can. She also has developed a practice of self-reflection through journaling. A habit instilled in her during her year in NASA FIRST, she regularly writes three pages reflecting on how her day has gone.

"You can't get to the third page without having to deal with whatever issue is going on in your head." This ranges from finding a better way to work with someone, repairing a working relationship, or simply trying to understand fluctuations in her energy level at work.

Moving Forward

At 30 years old, Keyes hopes to have a long career ahead of her. Her initial dream of becoming an astronaut has not faded entirely. Ultimately, she wants to make a positive impact through learning from others and teaching those who come next. "I'm not sure what my path will be between here and there. I don't know what projects or activities I'll work on," she says. "I like to leave my options open since I've already had so many opportunities, most of which I never could have planned for or guessed would happen."

Young Professional Brief: Lealem Mulugeta

May 10, 2011 — Vol. 4, Issue 3

Lealem Mulugeta's journey from Ethiopia to NASA has led him to reimagine the future of space exploration as one in which anyone can participate.

Ethiopia to Canada

Born in Ethiopia, Lealem Mulugeta, was always picking things up and handling objects. "There was this side of me that was very creative and needed to build stuff," he said. Growing up, he used to watch his father, an electrician and mechanic in the navy, work around the house and imitate what he did. His father hoped he would become a doctor, but his true passion was flight. "That was the one thing that always fascinated me," said Lealem.

Lealem and his family moved to Canada when he was eleven years old. He planned to study medicine, but found he couldn't shake the allure of flight. "I started reading about spaceflight and different kinds of aerospace projects," said Lealem. "I found that aerospace engineering was the [field] that combined all of my talents into a nice package," said Lealem. He enrolled in the newly formed mechanical-aerospace engineering program at the University of Manitoba. While studying engineering, he trained as a competitive gymnast and worked as a research assistant in a metallurgy laboratory where he helped conduct research related to material processing in microgravity.

During this time he also got involved in Mars analogue research with the Mars Society of Canada. He "flew" two missions, one of which he commanded, another where he was an engineer. "When I went through all of that I discovered I was really interested in engineering, but I also had this fascination on the human aspect of it."

Lealem Mulugeta standing in front of Yuri Gagarin's capsule in Moscow, Russia. Photo courtesy of Lealem Mulugeta

Lealem Mulugeta performing an EVA at the Mars Desert Research Station in Utah. Photo courtesy of Lealem Mulugeta.

This led Lealem to pursue an interest in spacesuit design. The field offered many challenges related to materials technology and had the added bonus that his medical interests were applicable. "That's really where I merged my engineering background and my interest for space life sciences together."

Canada to France

Lealem wanted to work in human spaceflight, but his path was unclear. He considered a master's in metallurgical engineering, but decided his heart wasn't in it. Instead, he started working on mechanical design for a local aerospace company that developed satellite and aircraft hardware. He gained experience as a lead engineer on a small project with the satellite division and transitioned over to aircraft work, but it wasn't spacesuits. "Everything I did there, I focused all of my design experience towards how I could transfer it to spacesuit design," said Lealem. After a while, Lealem decided that he wanted more and left for France.

He went through the one-year master's program at the International Space University in Strasbourg, France. The program supplemented his technical knowledge while also fostering the ability to follow his curiosity about space life sciences. "The internship was a gateway for me to access experiences that I would have otherwise not had access to." This included multidisciplinary work, cross-cultural experiences, and an internship opportunity with the EVA Physiology, Systems and Performance Group at Johnson Space Center in Houston, Texas, where he gained experience and expanded his network.

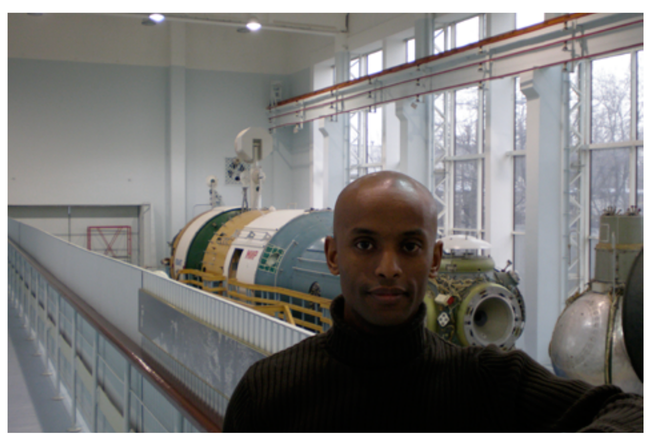
After his coursework and internship were complete, Lealem returned to Canada for eight months to perform independent research. He took it upon himself to publish as much as he could, which turned out to be five papers within that timeframe. The time also allowed him to reconnect with people he had met in Houston. It was only a short time before they invited him to come down and work.

Moore's Law

Lealem achieved what he had wanted since he was a boy: space, engineering, and life sciences all in one job. He currently works for Universities Space Research Association (USRA) as the project scientist for the **NASA Digital Astronaut Project (DAP)**. The DAP develops and implements computational physiology models to beneficially augment research to predict, assess, and mitigate potential hazards to astronaut health during spaceflight. His work has also sparked another interest: free data. "My passion for open data is an activity that I've taken on outside of my cool job," he laughed.

Mooer's Law (not to be confused with Moore's Law) states that information will be used in direct proportion to how easy it is to obtain. Lealem has observed this phenomenon within space research and hopes to bring about change. "If people don't know that the data exists, they aren't going to ask for it," said Lealem. "It gets locked away, nobody talks about it, people forget about it, and nobody requests it."

The process to obtain space data is not impossible, but it is challenging. Currently the process to acquire raw data is complex and lengthy. The primary concern about releasing medical data in a timely fashion has to do with confidentiality. While this concern is justified, he hopes to help modify the research process by incorporating "open" data requirements to make the data more widely available. "For example, if there's data that is not sensitive, you can



Lealem Mulugeta standing near the MIR Mockup in Moscow, Russia. Photo courtesy of Lealem Mulugeta.

talk to your subjects about it," he explained. "If they agree, then you release the data instead of locking it away and expecting people to look for it."

According to Lealem, there is a large community of researchers who would love to have more readily available access to NASA life sciences data to discover innovative medical treatments that can be used here on Earth as well as in space. "They might be able to do things with it that we might not have thought of," he said.

Global Impact

Lealem would love the opportunity to be an astronaut, but for now he hopes to contribute to shape sustainable, participatory space exploration. "I have this dream of having an impact at the global level," he explained. His ultimate vision includes a large-scale project that utilizes data or expertise that is freely available in a totally collaborative form.

A citizen scientist project called Zooniverse serves as one source of inspiration for this vision. Lealem explains that the "genius" in what they have accomplished is because of their ability to "leverage the common person to help them do things they just don't have the time to do." Lealem would like to see space agencies around the world take advantage of the public's common curiosity. "They are winning the support of citizens around the world with the work they are doing."

"The amount of innovation that is required to advance us to the next level cannot be achieved by any one nation. It's going to be multiple nations," he said.

Young Professional Brief: Philip Harris

June 14, 2011 — Vol. 4, Issue 4

Two weeks on the job, Philip Harris walked into an office looking for something to do and walked out a project manager.

He Asked for It

"It was absolutely terrifying," Philip Harris, aerospace technologist for Mission Operations Integration in Johnson Space Center's Mission Operations Directorate, said about his new project management position. "I was expecting to be the worker bee on some project," he said, "expecting somebody else to be managing me." The next thing Harris knew, he joined the project management team for Johnson Space Center's ISS Live!, a large-scale, public outreach project scheduled to launch in the fall 2011.

"I didn't feel like I was ready for it at the time," recalled Harris. He'd managed small-scale projects in college, but nothing like this. Faced with unfamiliar technical work, schedules, deadlines, and cost, Harris was worried about what he didn't understand. Fortunately, he had support in place. Jennifer Price, the group lead who assigned him the job, was (and still is) available to answer questions, talk about the project, and help keep the team on track, explained Harris.

Feeling comfortable with asking why things are done certain ways and getting good answers has also been helpful to Harris. "People actually take the time and have a discussion with me about why they do it this way versus the way you're thinking," he said. "There's been a lot of help along the way in just being able to understand the process not only at the technical level, but at the project management level."

From a Route Less Taken

Harris has an uncommon background for someone within the Mission Operations Directorate (MOD). He graduated from the University of Denver with a degree in Computer Science (CS), and he also studied Russian and Geographic Information Science. "I am headed in a different direction than most CS students for my career, and that is by design,"

said Harris. "I think that is one reason CS really brought me in—every discipline needs CS people, from humanities to engineers to lawyers to healthcare. It provides me with two great opportunities: I can work in a field that interests me and I also have the opportunity to engage in learning about a lot of disciplines to learn my job."

His path to NASA was even more uncommon.

The Role of Serendipity

Watching space shuttle launches at age three and having an astronaut visit his elementary school classroom sparked his enthusiasm for space exploration at a young age. That enthusiasm waned and then reemerged during his freshman year in college at the University of Denver, when he was working as part of the university's theater technical crew. Upon returning from a competition in Fargo, North Dakota, Harris spotted a man in an airport wearing a jacket with the NASA meatball on it. "I walked up to the guy and started talking to him about opportunities at NASA," said Harris.

Philip Harris in the Mission Control Center at Johnson Space Center. Photo courtesy of Philip Harris.

Philip Harris in Neutral Buoyancy Tank at Johnson Space Center. Photo courtesy of Philip Harris.

The man with the NASA jacket, an engineer from Dryden Flight Research Center, gave Harris his card and told him to look into the NASA coop program. He returned to school and did just that. "I called pretty much every week for a long time until they got back to me, applied to each of the different centers, and got selected to go out to Dryden just before Thanksgiving of my sophomore year." In nine months, Harris went from Denver to his first NASA coop position in Edwards, California.

From Dryden to Johnson

With his sights set on joining mission control one day, Harris made the most of his coop opportunities. During his first coop experience at Dryden in January 2007, he worked with the range engineering group on the **Western Aeronautical Test Range (WATR)**; acted as an interface between the operations team and the test teams; and assisted with the integration testing for the Phoenix missile adapter for the F-15.

An opportunity arose halfway through his Dryden coop. He got a call from Johnson Space Center (JSC), where he had applied earlier. He interviewed, got the coop position, and transferred during the summer of 2007. He started working with the IT group on mobile workstations, encryption of flash drives, and setting up twelve-character passwords. ("It was good to work there because I understand the reason behind those now," added Harris.) During his second coop, he gained experience working on the onboard global interfaces and networks, and maintaining encryption systems for ISS. He got command certified and then moved onto work at the Neutral Buoyancy Lab, where he built configuration checklists for training events.

During his third coop at JSC he worked as an International Operations Liaison, interfacing with the Russian Federal Space Agency, Japanese Aerospace Exploration Agency, the European Space Agency, and other international partners to help ensure alignment of ISS operations, programs, and projects within the ISS. This experience complemented an undergraduate study abroad experience in Moscow during his senior year. Fascinated by the differences across cultures, these experiences sparked a desire to expand his understanding of program and project management at the international level.

Professional Development

At age 24, Harris has grand plans for his career. "One of my ultimate career goals is to get one of the permanent change of station positions over in Russia," he said. In the meantime, he's taking every opportunity to learn and experience as much as he can.
Last April, Harris went through space station "boot camp," a six-week training event for new flight controllers that provides a generic overview of all the station's systems. Ultimately, when Harris goes into his specific discipline, this experience will provide foundational learning about how everything fits together.

He also has personal development objectives ranging from attending the Academy's "**Foundations of Aerospace at NASA**" course to completing a Master's degree in aeronautical engineering and participating in his center's leadership development program. He is currently at work on an online master's degree from the University of North Dakota's Space Studies Program, where he is focusing on international space policy.

Philip Harris standing in front of the Crew Compartment Trainer at Johnson Space Center. Photo courtesy of Philip Harris.

Harris aims to maintain an interdisciplinary view throughout his career. "You can have all the technical knowledge in the world, but if you don't know how to write, analyze and understand other disciplines in other areas of the world, it's just not going to work out very well," he said.

Young Professional Brief: Stacey Bagg

July 20, 2011 — Vol. 4, Issue 5

Stacey Bagg had her sights set on the slopes of Colorado when an opportunity to work at NASA changed her plans.

Stacey Bagg, aerospace engineer at Glenn Research Center.Photo Credit: NASA

In the months leading up to her graduation from the University of Colorado at Boulder, Stacey Bagg, aerospace engineer at Glenn Research Center, handed out a few resumes to a handful of friends to circulate. She wasn't expecting to settle into a full-time job right away. "I was planning on being a ski bum," she joked.

She happened to hand a resume to a friend who passed it to the wife of a NASA contractor. "I got a call out of the blue the summer after I graduated from a manager up at Glenn Research Center," she said. The phone interview led to an onsite interview, which led to a job offer. She accepted. "NASA and Ohio were both a fluke," she said.

The Cutting Edge

Bagg started out as a test engineer at the Creek Road Cryogenic Facility. She did testing on liquid oxygen and nitrogen for liquid acquisition in propulsion systems. "In space you don't know where your fuel is," explained Bagg. "You can't always rely on it being at the bottom of the tank because you don't have gravity to put it there. Liquid acquisition is basically finding the liquid and making sure that only liquid goes into your engine when you turn it on."

She also participated in mass gauging tests. "Again," explained Bagg, "in space, if you don't know where your liquid is, how do you tell how much you have?"

She worked for a contractor at the cryogenic facility for about a year before she had the opportunity to take a civil servant position. She's currently working on the Advanced Stirling Radioisotope Generator (ASRG). The engine is an electric power generator that runs on naturally decaying radioisotope fuel. The ASRG uses a quarter of the Pu-238 required for the older generation of radioisotope thermoelectric generators (RTG) that have flown on Viking, Cassini, Voyager, and other nuclear-powered missions. Like the RTG, the ASRG is ideal for long-duration missions in deep space – "anywhere where it's not going to be practical to use another power source like batteries or solar cells," Bagg said. "It's revolutionary technology compared to the current way of doing nuclear power."

Bagg's initial interest in aerospace was in the emerging commercial sector. "I didn't think I was going to work for NASA because of all the bureaucracy, but here I am," she said. While the bureaucracy is present, it's the work that keeps her around. Private industry is focused on the quickest, cheapest answer to solve current problems in the field, she explained. NASA is looking at the long-term, "out-there" ideas. "We're good at the cutting-edge stuff. The people in industry just don't have the time or the money to spend on these technologies," said Bagg. "We do the stuff that no one else can do. My current project is one of those. No one else can do this."

Bagg's excitement about her work is also fueled by what comes next. "We're trying to get new technologies into the field," she said. While she appreciates the tried and true technologies of the past, she looks forward to pushing the limits of today's capabilities with new, innovative products to move into the next era of exploration.

Starting out at Glenn

"When I moved halfway across the country, I knew absolutely no one in Ohio," said Bagg. However, during her onsite interview, she did have the opportunity to connect with the Glenn Developing Professionals Club (DPC), a group that connects young professionals at Glenn through community service, professional development, and social networking. Similar to a college visit, a DPC representative showed Bagg around the center, and she had the chance to hang out with the group at one of their events.

"I met people very quickly through the club. I really liked what it did for me as a starting employee. When you get into your first job, you don't really have a lot of younger engineers around you." With the agency's average age hovering around 47, it's sometimes challenging to connect with coworkers who might have spouses, kids, or other

Stacey Bagg (front and center) and the 501st at Yuri's Night 2010. Photo Credit: Cleveland Yuri's Night commitments. "It's hard to develop that group up front when you haven't grown up here, and you don't know anyone when you're coming in."

Bagg also started the Cleveland Yuri's Night - an annual, global celebration named for the first man in space, Russian cosmonaut Yuri Gagarin. Bagg attended Yuri's Night for three years in college and was surprised when she learned that there wasn't an event in Cleveland. "My first year at NASA, I started asking around about it. I figured, 'It's a NASA center, everybody should be way into this.'" Since then she has hosted three Yuri's Night parties in Cleveland, all of which drew crowds of 300 people.

Developing the Next Generation

"NASA has a lot of great programs right now, but we need more," said Bagg. "It's a shame to have people that really crave development opportunities be excluded from them." While there are development options, most are highly competitive and limited to a small number of slots. "What do you do with the rest of the people?" she asked.

In addition to leadership development and technical skills, policy and program/project management are also important to Bagg. She wants to understand the rationale behind key programmatic decisions, and she's concerned that valuable knowledge may be already walking out the door before next generation has exposure to it. "It's knowledge. Not just getting professional skills, but professional knowledge. That's what I want to see passed down."

Stacey Bagg working on the Advanced Stirling Convertor (ASC) hardware. Photo Credit:NASA/ Glenn Research Center

She has had some extraordinary opportunities through the DPC, which she now chairs. Ray Lugo, who was deputy center director at Glenn when Bagg first joined, used to attend DPC book club meetings. "He would choose books for us that were along the lines of professional development such as influence or leadership," she explained. "When we discussed these topics with him, we would also discuss applications to the center or our own development, which was very cool."

DPC "work-area discussions," which resembled brown-bag lunches, gave Bagg an opportunity to see what else was going on around the center. "I could see across the lab what was going on in other areas, which is great because a lot of the groups don't interface intentionally."

Making the Connection

In addition to the DPC, Bagg is a member of NASA Forward. Prior to NASA Forward, her exposure to other young professionals across the agency was limited. "Forward is the first time that we've really had interaction between the very new professionals with other centers. Usually the first time you get that interaction is through NASA FIRST."

While NASA Forward is not yet as robust as programs like FIRST, it is a place for networking that has been challenging to do in the past. "It's hard to communicate between different groups," she said. "You just typically don't do it because you don't know a lot of people."

She hopes that opportunities to interact, network, and connect with others across the agency will increase. Having these opportunities not only helps integrate the next generation of NASA, but also helps Bagg tap the expertise of her colleagues. Not too long ago, if she had a question about a particular piece of unfamiliar software, she wouldn't know where to find an answer. Now, with a growing network across the agency, she's able to reach out and ask someone, "Have you done this before?"

Young Professional Brief: Darius Yaghoubi

August 30, 2011 — Vol. 4, Issue 6

In a time of transition at NASA, Darius Yaghoubi wants to learn as much as he can.

In the world according to television, if you work at NASA, you regularly don a white lab coat (horn-rimmed glasses optional) and pace around an office consisting of a chalkboard covered with complex equations and diagrams.

A large rocket probably sits on a test stand dangerously close to your window.

"People think it's either that, or I go up to the rocket with a wrench and tighten bolts or something," said Darius Yaghoubi, in an accent that betrayed his British roots. He also regularly gets asked if he is an astronaut. Neither a technician nor a crewmember, Yaghoubi, a twenty-seven-year-old launch vehicle control systems engineer at Marshall Space Flight Center, is a self-described "desk monkey." Together with his team, he performs control and systems design analysis. This involves running computer simulations of launch vehicle trajectories and vibrational modes, making sure that the vehicles perform properly.

For the first three years of his NASA career, Yaghoubi worked on the Ares I Program. Since the cancellation of the Constellation Program, Yaghoubi has been working on projects related to the Space Launch System (SLS). He is part of a development team that is creating a FORTRAN-based simulation tool that will analyze the liftoff and separation dynamics of the rocket, and he is leading a team to modify an existing heavy launch vehicle model analysis tool. Even with all of the uncertainty surrounding the agency, "I'm happy to be doing some worthwhile work," said Yaghoubi.

Connecting across Generations, Borders, and Centers

Connecting with his peers, communicating with more experienced colleagues, and learning from other disciplines is important to Yaghoubi. Seeking out and making connections with other young professionals – especially at a center with such an experienced workforce – has played an important role in his career and added to his sense of belonging to a community.

Darius Yaghoubi flying in his Cessna. Image courtesy of Darius Yaghoubi.

Darius Yaghoubi testing out an astronaut zero-g sleeping bag. Image courtesy of Darius Yaghoubi.

Last April, Yaghoubi attended the Academy's **Masters Forum 20** in Melbourne, Florida. He appreciated the opportunity to step out of his world of rocketry and ponder **Howard Ross's question** of whether a match would burn in microgravity, and learn about the **activities of international partners** such as Centre National d'Etudes Spatiales (CNES), the Indian Space Research Organization (ISRO), the German Aerospace Center (DLR), and the Japanese Aerospace Exploration Agency (JAXA). He also had the chance to network with young professionals from other centers.

"Prior to the forum, I didn't really know too many people at the different centers. Since then, I know people at Dryden, Johnson, Ames, Kennedy, Goddard, and Headquarters," he said. "I know a lot more people throughout the agency and I've been talking to them a lot more. At most centers I have at least one person I know if I need information."

Yaghoubi observed that regardless of which centers the young professionals were from, they all enjoyed having the opportunity to make connections with one another at the forum. "We all had a great time in just being part of NASA," he said. "We were all one NASA, and that's all we really cared about."

Sharing the Story

Yaghoubi is part of a young professional group at Marshall called 'Marshall Next.' Started in November 2010, group members regularly meet on their own time to achieve

Darius Yaghoubi in a crew capsule at the U.S. Space & Rocket Center in Huntsville, AL. Image courtesy of Darius Yaghoubi.

a number of goals, including community outreach, connecting with early-career hires, making Marshall an attractive place for future employees, and professional development.

One of Yaghoubi's Marshall Next outreach adventures this past March took him to a Woodland Elementary School kindergarten class in Lafayette, Indiana. The wide-eyed, attentive four- and five-year-olds were ready to learn. "It was really interesting because I'm used to teaching college students, and here I am teaching these kindergartners about space, and they're asking me, 'What's the moon?'" explained Yaghoubi. After he quickly simplified his lesson for the day, the students made rockets out of straws and launched them with air pumps. They loved it. "It was really great to see that much passion in children wanting to learn about space, even if they are really young," he said. "It was awesome."

Sharing the NASA story extends beyond the kindergarten level, said Yaghoubi. This is another goal of Marshall Next. "If you work for NASA, you don't realize how little the general public knows about space," added Yaghoubi. "Most people think that the space shuttle goes to the moon." Effectively communicating what NASA does to a number of audiences is important – and often more challenging that most realize. "We're trying to help people understand what we do."

Learning Curve

In his fourth year at NASA, Yaghoubi is learning all he can from the rocketry giants at Marshall. Recalling the challenge of simplifying his explanations for kindergarteners, Yaghoubi said, "It's like I'm on the other end of that."

He has experienced a learning curve. "Lots of times you're just given a whole bunch of stuff to do and you don't have too much experience with it," he explained. "It can be good and bad—good in that it's probably the best way to learn things, bad in that it can take a long time to figure something out."

In the spirit of learning on the fly, he spends a lot of time on self-directed learning, mostly plowing through manuals and reading tutorials. He's had small whiteboard sessions during which he's learned more in two hours than in an entire semester. If he hits a wall, he talks to somebody for added guidance. "You have to have your own initiative to dive in and work through the problem yourself," he said. "There are people here who are smarter than I'll ever hope to be," he said. "They've always been really good whenever I have questions about things."

What Comes Next

"I intend to stay here (at NASA) as long as I can," said Yaghoubi. "It doesn't really get much cooler than dealing with the high performance technology that we work with here," said Yaghoubi. He enjoys working on cutting-edge technology and contributing to society in a meaningful way. Yaghoubi looks forward to the day when he becomes an expert in something and can share it with the next generation. "There are people who are still very interested in NASA and people still working towards the advancement of our space programs, even if they are fresh out of school and haven't been working here for years," said Yaghoubi. "We've got lots still to do."

Young Professional Brief: Jennifer Franzo

September 28, 2011 — Vol. 4, Issue 7

Mother of two, 27-year-old Jennifer Franzo loves a good rocket engine test.

Fire, Smoke, and Family

"Anytime we test an engine out here I think it's cool," said Jennifer Franzo. "Fire, smoke, even the science behind testing the engine is cool." Franzo, who just took part in a recent test in July on a J-2X engine, is a systems safety engineer at Stennis Space Center (SSC). Originally from Hattiesburg, Mississippi, Franzo works on fault tree and hazard analysis for the facilities at Stennis and the tests they will be used for.

"We look at any possible way that any failure could occur that would cause loss of mission or data, damage to the facility or test article, or injury to personnel." She looks at different types of failures and their causes. They range from a valve malfunction to an explosion to human error. With her team, she generates a hazard report for a particular test. "We come up with the controls and the verifications based on the requirements for the different causes and then rank those risks," she explained.

Now a mother of two (she just had her second child in August), Franzo was influenced by her career-oriented mother who instilled in her the determination to balance both work and family. "I have a wonderful support system," she said, referring to the support her husband and family provide her. "I never had a doubt in my mind that I could have kids, work full-time, and have a good job."

Jennifer Franzo at the STS-133 launch with her husband Drew Franzo and son Henry. Photo courtesy of Jennifer Franzo.

Mentors

Immediately after graduating from Mississippi State University, Franzo got a job at Michoud Assembly Facility with Lockheed Martin. "I came fresh out of school with this aerospace degree, didn't know what I was doing," said Franzo. Starting in 2007, her job was working on the External Tank. "That's all I wanted to do. I didn't really know what I was going to be doing, but I would be working on the shuttle program. That's what mattered."

Her supervisor and eventual mentor, Greg Lain, Senior Manager of Safety and Health, put her right into the deep end. Any angst or anxiety about working at NASA was quelled by one simple act. "He (Greg) believed in me," said Franzo. "That was one of the big things for me. He took me under his wing, showed me around, talked to me," said Franzo. "And then threw me to the wolves," she laughed.

Assigned to work on the Thermal Protection System Report (TPS), Franzo knew the gravity her assignment had on the program. "The Loss of ET Thermal Protection System" report is revised and edited after every flight of shuttle, Franzo explained. All inflight anomalies for the External Tanks were documented in the report and could potentially change the risk profile. After Columbia in 2003, these TPS reports increased in visibility.

"When I was given that report, Greg said, 'Here you go, you can do it. I have complete faith in you.' I remember thinking, 'This is a big thing. Don't you have a smaller one that you can give me? I don't know what I'm doing yet.' But he had complete faith in me and guided me."

Transition

During a recent opportunity to participate in a Masters Forum in Melbourne, FL, Franzo had the opportunity to hear the stories of seasoned practitioners from around the world about their experiences working on previous programs. "I enjoyed listening to the people who had been there from the very beginning of shuttle," said Franzo. In particular, she found the stories about transitioning from Apollo to shuttle particularly interesting.

During Apollo, the mission was clear: get to the moon. Wernher von Braun once explained, "Everybody knows what the Moon is, everybody knows what this decade is, and everybody can tell a live astronaut who returned from the Moon from one who didn't." Things have since changed. "People see the end of the shuttle program and they say, 'What are you going to do now?'" said Franzo. She often finds it hard to communicate to her family and friends what is happening during this time of transition. "You know things are happening. You know we're moving towards something, but we don't have a clear defined direction yet," she said. "It's the end of [the shuttle] program, but it's not the end of human spaceflight."

Future Development

Stennis is the smallest NASA center. With roughly 250 civil servants onsite, Franzo sees the center's size as an advantage to her development goals. "You have no choice but to work with upper management because you're probably the only one who does the job that you do," she explained. "They know who you are and you know who they are. It allows you to get that face time, that one-on-one time."

Franzo's direct lead and mentor, Amy Rice, safety engineer for SMA, has been instrumental in her career development. "She has helped me mold myself into being more than just a systems safety engineer working on hazard analysis, which is what I came out here to start doing. My group here has given me the opportunity to expand and do other things."

When she finds a class or training relevant to her career development, her department is supportive of its people learning as much as they can. She has been involved in STEP, a program sponsored by the NASA Safety Center, which allows engineers to gain added depth in their field. "You can choose whether you want to go into systems safety, quality, or reliability assurance." Franzo is also the

A 1.9-second ignition test of the J-2X rocket engine is conducted on the A-2 Test Stand at NASA's Stennis Space Center. Photo Credit: NASA/SSC.

point of contact for the Incident Reporting Information System (IRIS), an agency-wide reporting system that is used any time there is a mishap (e.g. explosion, fire, or someone gets injured).

One of her most memorable opportunities came about during STS-134. She was asked to sit in for her SMA director as the safety point of contact in the Launch Control Center at Kennedy Space Center. “It was always one of those things that would be so cool if you ever got the opportunity to do and how could you ever pass it up,” she said. “It’s just one of those things that makes you smile.”

Networking the Next Generation

During the Masters Forum in Florida, Franzo had the opportunity to connect with other young professionals around the agency. “It made me feel like I’m not the only young person sitting here,” Franzo explained. “It opened my eyes that there are a lot of young people who share my passion.” Formerly part of a young professionals group at Lockheed dedicated to professional development, Franzo is looking to catalyze a similar movement at Stennis. She sees the importance of connecting with her peers at her center and around the agency.

“Everybody should have an opportunity to go see every NASA center they can because each one of them has something different to offer,” she said. She has visited

A remote camera captures a close-up view of a Space Shuttle Main Engine during a test firing at the John C. Stennis Space Center in Hancock County, Mississippi. Photo Credit: NASA/SSC

Johnson, Kennedy, and Marshall, which has helped her to see the bigger picture. “They all put the story together perfectly. From one center to the next you can actually see how all of the puzzle pieces fit together to make NASA what it is.”

In addition to experiencing the culture each center offers, Franzo also believes that the next generation will unify under a common mission. “We are all engineers deep down. We need some sort of documentation that we are moving in a direction,” she said. Talk is one thing, but to see things actually happening makes it real, makes it powerful. “I think there are a lot of young professionals who are willing to wait for a little while, but to keep us moving forward, we need to see things coming to fruition. We can’t wait around forever.”

Young Profesional Brief: Maciej Zborowski

October 28, 2011 — Vol. 4, Issue 8

Maciej “Mac” Zborowski is restoring the fuselage of a XFV-12A plane found in the middle of a vacant field so he can share its story with the public.

Mac Zborowski, 33, is an industrial design contractor at Glenn Research Center, who has worked on various projects since 2003. He moved to Ohio in 1986 from Warsaw, Poland. His background in industrial design and engineering has afforded him the opportunity to do everything from working on planes, developing fuel-cell powered cars, to working as a photographer in Chicago. Currently he is working at Glenn’s Power Systems Facility on a power beaming project. In his spare time, he has been dusting off a bit of history and share the story.

ASK The Academy: You’ve been volunteering your time with a cadre of others on a restoration project with the fuselage of a XFV-12A. What is it and how did you get started on it?

Maciej Zborowski: The XFV-12A is an aircraft that was developed here in Ohio by Rockwell International to take off vertically and fly at supersonic speeds. It was developed off a U.S. Navy contract in the ‘70s and early ‘80s. It was cancelled in ‘81 and somehow, part of the fuselage—the cockpit—was found by a friend of mine in the middle of a field at Plum Brook Station in Sandusky, Ohio, which is part of NASA Glenn Research Center. My buddy was working out there and he sent me a text message with a picture of this mysterious thing. Within two days we figured out that there was only one of these in the world and we have it. The director out at Plum Brook Station, General David L. Stringer, signed it over from scrap status into artifact status. So we got our Indiana Jones whips and hats, and we’ve been restoring it so we can show off Ohio’s cool aviation research history.

Even though the XFV-12A was not a successful program, it shows you that just because you fail does not mean that you’re failing at research. If you want to paraphrase Edison,

XFV-12A fuselage on a dolly out at Plum Brook Station Image courtesy of Maciej Zborowski

it's not that you've failed 2000 times at making a light bulb, but you were successful at finding out that there's 2,000 ways of how not to make a light bulb, and just one to make one work!

It's a pretty neat little artifact to have in your portfolio, whether it's Ohio or the United States or NASA. The restoration is a great project. Sometimes research can be very nebulous to nontechnical people. It's one way of introducing someone to what research is and how it works. ATA: Where is the plane fuselage now?

Zborowski: Right now it is in the old carpenter shop, basically in a small shack out in the middle of a field at Plum Brook Station. We've been ripping stuff out of it and making it kid friendly—removing sharp objects and sprucing it up. I've been taking a scrub brush to it and cleaning it. As soon as it gets painted, it will be sent to a museum or to other facility as an interactive exhibit. We're all doing this on a volunteer basis. To kids and people with some imagination, it's going to be the best thing they've ever sat in.

ATA: Your portfolio of experience is broad. As a practiced problem solver, how do you typically approach a new challenge or experience?

Zborowski: With a sketchbook! One of my favorite things to do is draw. When you get down to it, drawing to me is imaging the problem. Imaging the solution is fine, but remembering that solution or putting that solution into some kind of coordinate system, whether it is on a piece of paper or on a computer, that is where the magic happens. So I start out with a sketchbook, pencil, paper and lots of tea or coffee. When I have a new challenge given to me, I try to learn from it as much as possible to gain as much knowledge and experiences as I can.

Throughout the process of working on the XFV-12A I've learned a lot about different types of paints and surface treatments, and how different metals age. I've also learned that you shouldn't put your face next to a hydraulic hose that potentially has hydraulic fluid still in it from thirty years ago! I've also talked to some of the guys who were involved with the testing of the plane at Langley Research Center. Some of the modeling and dynamics research was done here at Glenn, and then they shipped the XFV-12A off to Langley to test it on a big A-frame to see if it would hover. They also studied the dynamics of the Coandă effect.

ATA: What is the Coandă effect?

Zborowski: Pretend that you are in a car and you stick your hand out the window with all of your fingers pointing towards the front of the car, like an airplane kind of waving your hand up and down out the window. Just like an airplane wing, but with your fingertips pointing towards the front of the car. The air rushing over the top of your hand naturally creates a low-pressure area above. If you start pointing your fingertips up, so that they're perpendicular to the road, there are eddies that come off your fingertips, and basically your hand stalls. It's the same thing that happens to an airplane if it stalls.

In the Coandă effect, the air going over the top of your hand would stick to your hand, essentially pulling it upwards. So no matter what angle you position your hand, it would not stall.

This was what made the XFV-12A special. It used moveable flaps in the wings and canard, to direct engine exhaust though the flaps and thereby causing the surrounding air to be directed in a different direction, all the while not separating or stalling from the surface of the flap. This thing looks like something from Battlestar Galactica. It does not look like a regular airplane you've seen. There's no vertical surface. It's a pretty weird looking airplane, especially for the 1970's. Fast-forward to today, the F-35 Lighting II is an airplane being developed by Lockheed Martin for the U.S. Air Force, the U.S. Marines, and the U.S. Navy. One of the F-35 models will take off vertically and also be supersonic. Imagine the fact that they were trying to do this in the '70s. They were barking up the right tree, they just didn't know of the ducting losses and airflow issues they would encounter. We're just getting around to solving that problem.

ATA: Why is it important to restore something like the XFV-12A?


Maciej Zborowski, an industrial design contractor at Glenn Research Center, stands in front of the fuselage of a XFV-12A plane that he is restoring. Image courtesy of Maciej Zborowski

XFV-12A on ramp at NAA in Columbus, Ohio Photo Credit: North American Aviation

Zborowski: I think that it's a prerequisite for working at NASA. Not only are we the best of the best, but we should take every opportunity that's sensible for us to interact with the public. If there's an opportunity that presents itself, we should be cognizant of that, run with it, and see where it goes. When I found out about this fuselage being out in the middle of a field, waiting to be scrapped, and finding out that it's a prototype that is basically the definition of research, that's when a couple of us grabbed it by the horns and decided to go do something with it.

I will admit that it's been hard work. Plum Brook Station is about an hour away from Glenn. During the summer it was like an oven in the shop and certain parts are hard to come by. It's been tough work, but I think the end goal is pretty well worth it.

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