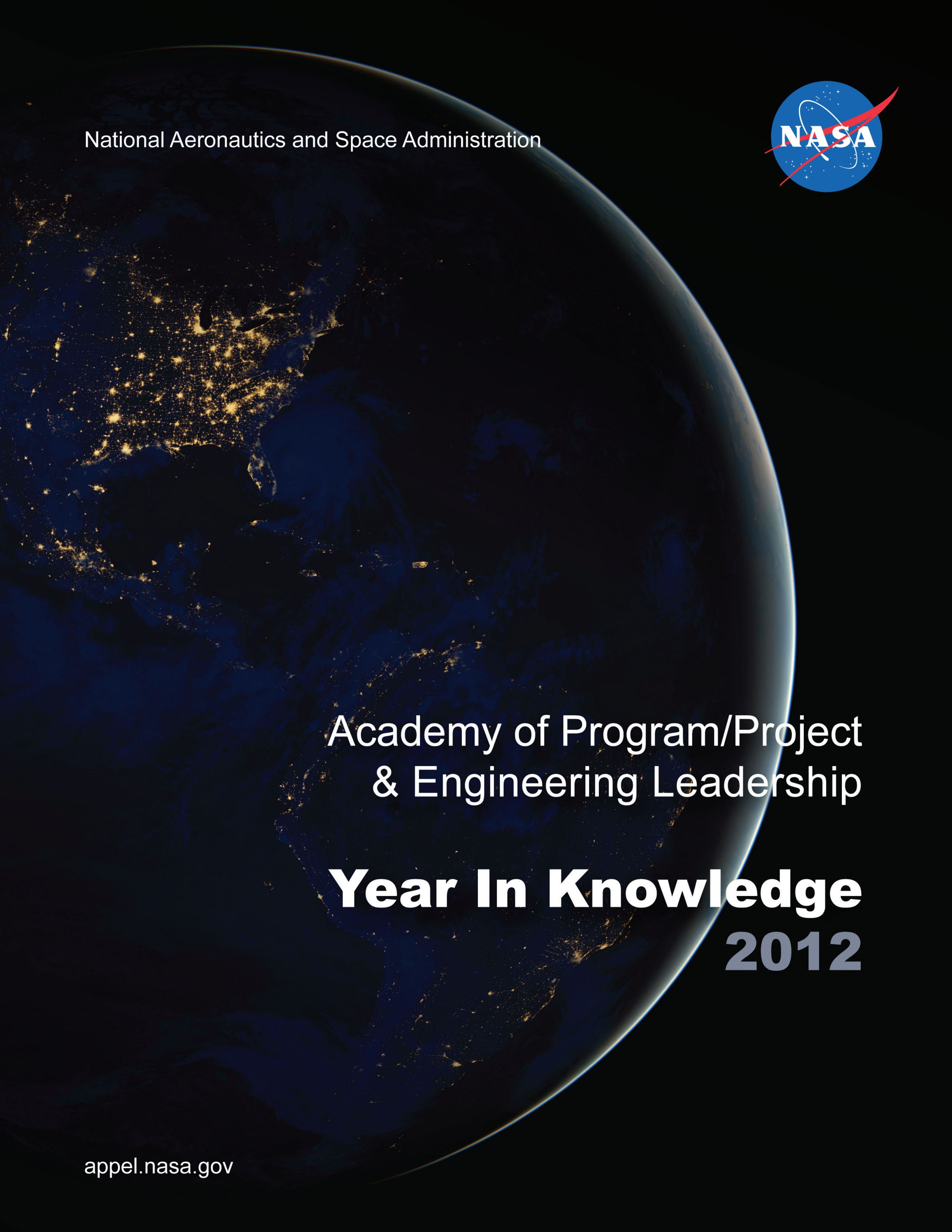

National Aeronautics and Space Administration

Academy of Program/Project & Engineering Leadership

Year In Knowledge 2012

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Foreword: NASA's Knowledge Imperative

Like all large, knowledge-intensive organizations, NASA faces continuous challenges identifying, capturing, and sharing what it knows.

Knowledge is the coin of the realm at NASA. Need to understand something about engine cutoff sensors, the physiological impact of extended stays in low-Earth orbit, or how to drive a rover on Mars? That kind of specialized expertise resides within NASA, and often nowhere else in the world.

At the same time, to paraphrase science fiction writer William Gibson, NASA's knowledge is not evenly distributed, and much of it is at risk of walking out the door. NASA is approaching a significant demographic shift: over half the workforce is retirement-eligible, and there's a high likelihood that many senior employees will leave within five years.

The knowledge challenge also extends to NASA's failures. Our mishaps, accidents, and anomalies yield hard-won lessons that are critical to understand. We use rigorous investigation methodologies such as root cause analysis to ensure that we determine why we made mistakes. Yet our track record of learning from these incidents has been unevenly distributed; we've done better in some instances than others.

Developing more consistent knowledge capability across the agency was part of what motivated the Aerospace Safety Advisory Panel (ASAP), a Congressionally established advisory group, to recommend that NASA "establish a single focal point (a Chief Knowledge Officer) within the Agency to develop the policy and requirements necessary to integrate knowledge capture across programs, projects, and Centers." ASAP acknowledged good work in this area at Johnson Space Center and Goddard Space Flight Center, and also recommended that all centers and mission directorates consider establishing CKOs to "ensure standardization."

In response to the ASAP recommendation, I was appointed NASA's Chief Knowledge Officer. In February 2012 I convened a meeting of the agency's knowledge community, and we took inventory of all the different knowledge services and activities taking place at various centers and mission directorates. Frankly, I was not fully aware of the quantity or quality of knowledge work going on across the agency.

I remain the director of the Academy of Program/Project & Engineering Leadership as I assume the responsibilities of serving as NASA's first CKO. This is a logical extension of the knowledge services that the Academy began providing as an agency-wide resource over a decade ago.

This anthology represents the latest chapter in the Academy's efforts to share knowledge and promote a culture at NASA that values reflection and the power of learning through stories. Hannah Arendt wrote that, "Storytelling reveals meaning without committing the error of defining it." I hope these stories reveal new insights and ideas for you.

As always, I welcome your feedback.

Edward J Hoffman

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NASA Chief Knowledge Officer
Director, NASA Academy of Program/Project & Engineering Leadership

Messages from the Director

Is Strategy a Fool's Errand?

***ASK the Academy*, January 26, 2012 — Vol. 5, Issue 1**

Given the complexity of projects today, the limits of hindsight, and the human inability to predict the future, is strategy a waste of time?

In an organization like NASA, the role of strategy is to provide a critical link between policy and execution. The White House, in consultation with Congress, establishes a direction for NASA: "These are the nation's priorities for our civil space program. Go do these things. Here's the money you can spend." A simplification, for sure, but those are the very basic contours in which NASA operates as a government agency. Strategy is the game plan to make things happen.

That's the blueprint for how it's supposed to work. The reality is always less straightforward. National priorities change, sometimes rapidly. Programs get cut or canceled. Our partners and suppliers also operate in their own dynamic political contexts, which can add to the complexity of our programs and projects. Technology development is a double-edged sword: either our technologies are not sufficiently mature when we begin a project, or occasionally they leapfrog a generation between proposal and launch, creating a different kind of havoc.

On top of all these risks and uncertainties, we humans are notoriously bad at predicting the future. The sudden end of the Cold War in 1989 surprised an entire generation of analysts who studied geopolitics. The same has proven true with financial markets time and again; over time, the vast majority of successful professional investors are lucky, not good. (See Daniel Kahneman's *Thinking, Fast and Slow,* featured in last month's Academy Bookshelf, to learn more about the science behind this.) We also reason by historical analogy, which leads to the tendency to plan for the last war.

The International Space Station can be seen as a small object in upper left of this image of the moon in the early evening Jan. 4 in the skies over the Houston area flying at an altitude of 390.8 kilometers (242.8 miles). Credit: NASA / Lauren Harnett

So since our environment is so complex and our ability to comprehend it is so limited, can we really achieve anything through strategy?

NASA has had different strategies at different times in its history. The most storied, of course, is the one to deal with sending a man to the moon and back within a decade. Consider just some of the moving parts that had to be elaborately sequenced: a series of increasingly complex Mercury and Gemini missions; decisions on how to reach the moon and which vehicles could get the job done (See "A Strategic Decision: Lunar-Orbit Rendezvous"); the Ranger and Surveyor missions that had to be flown to understand the lunar environment; and of course the design and development of the Apollo capsule (with two modules, as it turned out) and life support systems necessary for the astronauts.

Coming at the end of the Cold War as budgets were contracting across the federal government, the "Faster, Better, Cheaper" approach represented another kind of game plan. Significant advances in computing power, electronics, and off-the-shelf technologies offered new efficiencies that could be incorporated into mission design and development. In a departure from the agency's previous focus on expensive flagship missions like the Hubble Space Telescope, Administrator Dan Goldin saw an opportunity for NASA to fly a greater number of smaller, cheaper missions by accepting more risk. There was an open acknowledgement that some missions might fail in the process, but the overall result would be a more efficient agency. There have been lots of debates about the pros and cons of the "Faster Better Cheaper" strategy, but whatever its merits, it represented a clear shift in strategy for the agency in a time of transition.

Our strategy for human space exploration in the post-Shuttle era represents a similar point of departure from past practices. We've embraced a transition to new forms of collaboration with international and commercial partners to reach low-Earth orbit while undertaking the development of a heavy launch vehicle that will carry humans deeper into space. We're still in the early days of implementing that strategy; its effectiveness will not be known with certainty for years. One thing is for certain, though: operating without a strategy is the real fool's errand.

Moscow appears at the center of this nighttime image photographed by the Expedition 30 crew aboard the International Space Station, flying at an altitude of approximately 240 miles on March 28, 2012. A solar array panel for the space station is on the left side of the frame. The view is to the north-northwest from a nadir of approximately 49.4 degrees north latitude and 42.1 degrees east longitude, about 100 miles west-northwest of Volgograd. The Aurora Borealis, airglow and daybreak frame the horizon. Photo Credit: NASA

Hidden Risks

***ASK the Academy*, April 30, 2012 — Vol. 5, Issue 4**

The risks associated with space exploration are not purely technical.

In the mid-1960s one of NASA's visionary leaders, George Mueller, saw great promise and value for the nation in the Apollo Applications Program. Among other things, this program would ensure that all the hardware developed for Apollo would be put to use on missions following the lunar landing. Mueller's plan called for both extended-duration manned missions as well as a wide array of space science missions.

Mueller's proposal for the Apollo Applications Program did not survive contact with political reality. In 1966, with the Vietnam War demanding an increasing share of the federal budget, Congress significantly slashed the program's budget for the coming year. By 1970 it was renamed the Skylab Program, much narrower in scope than the grand plans Mueller had envisioned five years earlier.

The Apollo Applications Program serves as a healthy reminder that even in NASA's so-called "golden age," the agency's programs faced significant political risk. Over time the importance of the political dimension increased, as veterans of the transition from Apollo to Shuttle can attest. This was not unique to NASA. "Because the relationship between a project and its political environment are so important to project success, greater demands are placed on the skills of project managers," wrote Edwin Merrow in a 1988 RAND study of megaprojects. These demands on project managers have only increased in the years since Merrow's study.

I have written in the past about political and social risks. Borrowing from a definition of political risk by analysts Ian Bremmer and Preston Keat, we can understand it as the probability that a political action will produce changes in program or project outcomes.* While the complexities of the budgeting process can make it hard to quantify the political risk to a specific program or project as a numeric probability, it is still valuable to consider the likelihood and consequences. We most often think about political risks in relation to funding decisions, and for good reason: budgets are a clear manifestation of political decision-making. But in an era where the vast majority of our projects include international partners, there can also be geopolitical risks related to events having nothing to do with space exploration.

Social risk in a project context is best thought of in terms of the likelihood that social effects can lead to a negative outcome for a program or project. This can manifest itself either through common biases such as anchoring (becoming overly attached to a first estimate as a point of reference), or through group dynamics such as groupthink or organizational silence. Social risk is even more difficult to quantify than political risk because it is deeply tied to an organization's culture. It poses fewer problems in organizations that empower people to ask questions and challenge assumptions, but it is always present because we are all susceptible to biases in our own thinking. When our mishap and anomaly reports emphasize the crucial role of communications in avoiding the same mistakes in the future, they are talking about mitigating these social risks.

We have known about political and social risks for quite a while, but we have a long way to go in terms of systematically tracking and mitigating them. They require different training and tools than technical risks, but that does not mean they should be treated as secondary. Mission success depends on our ability to manage them.

Projects Built Around People and Networks

***ASK the Academy*, May 30, 2012 — Vol. 5, Issue 5**

What is the greatest risk to a project? What is the most likely culprit to a failed societal grand challenge? How do we understand and address the increasing complexity of missions?

Based on observation and reading, one would guess that project risk is captured within the boundaries of technology, cost, and time. Certainly this is how the professional project manager is schooled. Project management defines itself as a profession that equips its practitioners with the competence to rationally manage critical risks within the technical, schedule, and cost domains. Our bodies of knowledge focus extensive coverage on these areas, as does the typical training devoted to project management.

Yet it seems increasingly obvious **that the most likely cause for project death is the social dimension**.

Let us look into the complexities that a project will encounter. **Technical complexity** points to the significant interdependencies among technologies and the rapid developments that result from innovation. Project teams have a relatively sophisticated set of tools and training to deal with this. **Organizational complexity** is about the interaction and performance of the larger project team – this includes partners and suppliers throughout the chain. **Strategic complexity** resides in the area of socio-political context, primarily concerning stakeholders and funding. It is in these latter two areas where the world of projects has seen the greatest change. Today there are many people in a variety of positions who determine whether a program lives or dies. However, **the field of project management largely ignores all but the technical and cost factors.**

Several critical items related to NASA's next-generation James Webb Space Telescope currently are being tested in the thermal vacuum test chamber at NASA's Goddard Space Flight Center, Greenbelt, Md. This image shows the Optical Telescope Element Simulator, or OSIM, wrapped in a silver blanket on a platform, being lowered into the Space Environment Simulator vacuum chamber via crane to be tested to withstand the cold temperatures of space. Photo Credit: NASA/Chris Gunn

Today projects experience dramatic and constant change due to social and political demands – compromised cost estimates resulting from the need to win buy-in, complicated partnerships, challenges with external budgetary and political stakeholders, and changes in popular support.

Steven Weinberg warns of the demise of big science projects largely due to these factors.[1] He points to the increasing challenges of large programs such as the Superconducting Super Collider, James Webb Space Telescope, International Space Station and concludes that "Big Science" is entering a period of crisis. These challenges go far beyond science however; they impact any large project that relies on public and political support that lasts over decades.

It seems that we have entered a world that will place premium competence on the skills of social, strategic, and political sophistication. It is not enough to sell a project and assume it will survive to maturity. It is also not enough to only address with competence issues of technical, cost, and schedule implementation.

Instead **projects**—it will not matter whether they are science, human exploration, construction, or the Olympic Games as long as they need sustained political and societal support—**will need to be built around people**. Grand challenges will need to have a strong social **network of people committed** to the conception, design, development, implementation and conclusion. What will really be needed for complex, grand projects to succeed will be people who will not allow an agreed-upon project to fail.

Organizations, leaders and teams that are in the business of creating and delivering large-scale projects will need to recognize that social risk has become the biggest risk to project success. The social risks point to the need for generating and maintaining a large community of people who follow and like a mission. The social risks include the need to find knowledge and expertise that is distributed around the world and is multidisciplinary in composition. The social risks also include the need for effective communications to inform and educate a diverse stakeholder community. This will call for a widespread effort to transform projects from linear and limited communities to networks of advocates involving internal team members and broader audiences of external stakeholders.

The importance of social risk will lead to the need for project managers to have competency in social media. In my next column I will continue this conversation, with a focus on social media and the project manager.

[1] *"The Crisis of Big Science," New York Review of Books, May 10, 2012.*

Social Media and the Project Manager

***ASK the Academy*, June 29, 2012 — Vol. 5, Issue 6**

Should project managers be required to have training in social media?

Last month I wrote that a successful complex project today depends on a strong network of people committed to its conception, design, development, implementation and conclusion. So what does this have to do with social media?

The audience waits for Astronaut Ron Garan to appear at a NASA Headquarters Tweetup in on February 15, 2012. Photo Credit: NASA/Maggie Masetti

NASA's largest projects require sustained political and societal support over a series of years. A project's development often stretches from one presidential administration to the next. The General Accountability Office (GAO) recently did its annual assessment of selected large-scale NASA projects, and the average age of the projects surveyed in 2012 was eight years. Even the Apollo program spanned three administrations between JFK's speech to the joint session of Congress in 1961 and the first moon landing. What this tells us is that the stakeholder base for projects has to be broad.

In the past, there were few ways to broaden that base to NASA's ultimate stakeholder, the American public. Projects proceeded more or less out of sight until launch. That no longer has to be the case, nor should it.

Any question about the uses of social media will likely generate predictable answers from two dominant camps: people who think it represents a revolution in human communication unparalleled since Gutenberg, and those who have concluded it is mostly a waste of time. There is another way to think about it. In a world of constrained budgets, social media provide a quick, easy, and cheap way to increase openness and transparency about how work gets done at NASA, and to offer short updates about a project that will bring value to society.

The objections are easy to anticipate. NASA project managers have more important things to do than spend their time on Twitter or some other social media platform. They should be more concerned about making sure their teams can meet cost, schedule and performance parameters. Those responsibilities remain the project manager's primary job. The question is, what else do project managers have to do today to be successful in the current environment? The simple truth is that they need to own the story of their projects.

Bill Gerstenmaier, Associate Administrator for Human Exploration and Operations, put it like this at PM Challenge 2011:

"That's another thing that has really changed dramatically is not just the newspaper headlines, but…the blogosphere or the instant comments out there. Boy, how do you control those? And my point is I don't think you can control those. I will tell you that in the shuttle/station program, [I] used to get offended. I would I do a Flight Readiness Review, and the report would be written on what occurred during the review [before we even go out]. That made me feel kind of bad. So then I thought, well maybe I'll tell everybody, I am going to break your arms if you send any text messages or you call anyone during this review. We're going to have total silence and then we will go talk to the press afterwards. That wasn't going to work either. Then what I decided to do is now I have PAO sit in the back of the room and they Twitter. So now I have my PAOs putting out the message during this Flight Readiness Review kind of the way I wanted. I was still on the edge a little bit. At least it is still kind of the NASA story as a review is going on, and I'm actually now beating the blogs to the web. And so the message there is: instead of trying to slow down communication, again, recognize communication is diverse and fast. How can you now participate in that and use that to your advantage?

My other story that I will tell you is that I had one of my program managers whose son didn't really follow the program very much, gets an email from his son: "I see you're getting ready to go do your presentation, good luck at the FRR." So this guy comes up to me [and says], "How the heck did my son know that I am getting ready to go present at the Flight Readiness Review?" Then he finds out that his son was following the Flight Readiness Review on Twitter and found out his dad was there. So now I connected him and his son through Twitter in the Flight Readiness Review.

So the message there is use these things to our advantage."

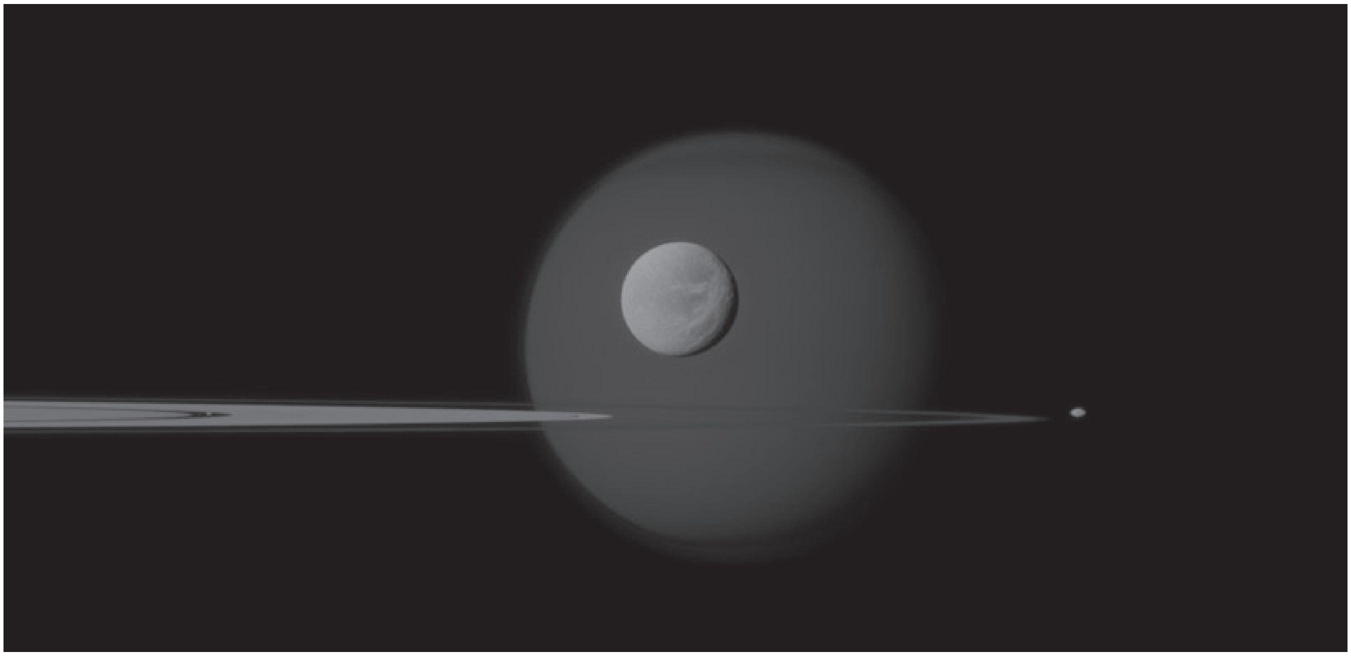
The point is not that social media is a substitute for sound project management practices—it's that the project manager cannot afford to neglect or outsource responsibility for the project's story. As Gerstenmaier's story illustrates, the project manager does not have to send the tweets, just as he or she does not input changes to the master schedule. But ownership of the story begins and ends with the project manager, and the task of telling it is a continuous process that is made easier through social media. In a time where keeping a project "sold" is more critical than ever, social media is a tool that project managers cannot afford to ignore.

'Casino Mission' Royale

***ASK the Academy*, July 31, 2012 — Vol. 5, Issue 7**

The year was 1993—and something wasn't right.

Each time I revisit the story of the Cassini project, I am impressed by their success. With 260 scientists from 17 countries spanning 10 time zones on the science team, 4 years, and $200 million to design and fly the spacecraft and its 18 instruments, project scientist Dennis Matson had quite a challenge. As a flagship mission, the team was hyper-aware of increased resource demand and runaway cost and lacked confidence in the cost reserves paradigm to manage them. Any false move could cancel the project.



Saturn's largest moon, Titan, is in the background of the image, and the moon's north polar hood is clearly visible. See PIA08137 to learn more about that feature on Titan (3,200 miles, or 5,150 kilometers across). Next, the wispy terrain on the trailing hemisphere of Dione (698 miles, or 1,123 kilometers across) can be seen on that moon which appears just above the rings at the center of the image. See PIA10560 and PIA06163 to learn more about Dione's wisps. Saturn's small moon Pandora (50 miles, or 81 kilometers across) orbits beyond the rings on the right of the image. Finally, Pan (17 miles, or 28 kilometers across) can be seen in the Encke Gap of the A ring on the left of the image. The image was taken in visible blue light with the Cassini spacecraft narrow-angle camera on Sept. 17, 2011. Photo Credit: NASA/JPL-Caltech/ Space Science Institute

Instead, the instrument team adopted a market-based approach they called the Cassini Resource Exchange, where they could trade data rate, budget, mass, and power among themselves using an online system. The "Casino Mission" as it came to be known, used a free-market mechanism to deliver all 18 planned instruments successfully.

The system was an innovative and risky move for the Cassini team that paid off with an overall increase in the science payload cost of less than one percent and a decrease in science payload mass by seven percent. As two Cassini team members once wrote in an *ASK Magazine* story, "It's amazing what you can do when you don't have a choice."

The Cassini team had no choice but to adopt a different approach.

In the fifteen years since its launch, I have asked John Casani, who worked on Cassini, why the 'casino' methodology has been used rarely, if ever, on other projects. He replied, "Ed, project managers don't want to give up control." I haven't known how to respond except with a knowing nod.

Now the year is 2012, and something still doesn't feel quite right. Casani's response still gnaws at me. Today's project world is increasingly defined by transparency, sustainability, flexibility, and collaboration— all elements that decentralize control. Some industries and organizations have embraced this. Others see them as threatening and continue to implement tired practices incongruent with the working world today. I've seen young professionals attend training and return to their stations ready to use their newly learned skills, only to have managers tell them that's not how things are done around here. I've seen studies report recurrent findings and recommendations, but core problems don't seem to go away. What are we missing?

I suspect we're in need of a seemingly subtle shift that will be challenging to implement. Parading around and touting management principles like those mentioned above means nothing if they aren't practiced. More importantly, we cease to grow as an organization when we don't keep up with changes in the way the broader world around us does business. Either we innovate or we become irrelevant.

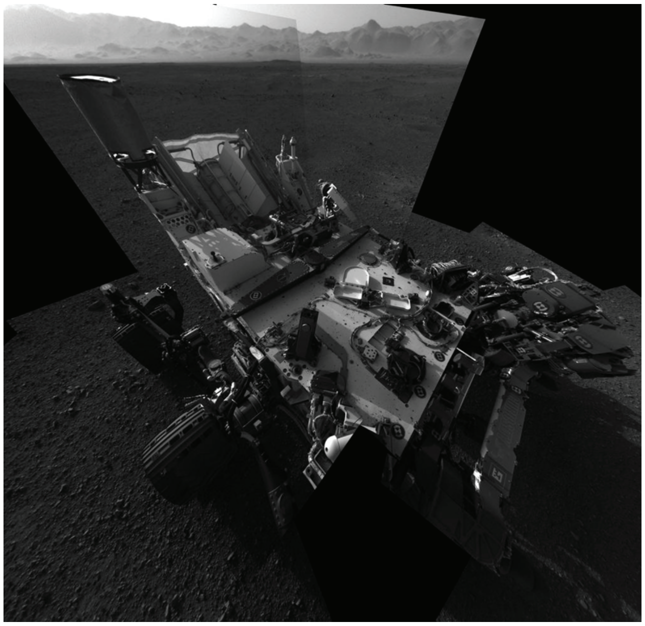
As one NASA young professional recently said to me, "Good ideas don't change the world—implementing them does."

A Strategy for Knowledge

***ASK the Academy*, August 30, 2012 — Vol. 5, Issue 8**

Knowledge is all around us at NASA. So why do we need a knowledge strategy?

The successful landing of the Curiosity rover represented a signal triumph for NASA's Mars Exploration Program. The entry, descent, and landing (EDL) challenge for this car-sized vehicle required a different approach than had been used for previous Mars missions. As *ASK Magazine* Managing Editor Don Cohen noted in "The Sky Crane Solution" (Issue 47), the



This full-resolution self-portrait shows the deck of NASA's Curiosity rover from the rover's Navigation camera. The back of the rover can be seen at the top left of the image, and two of the rover's right side wheels can be seen on the left. The undulating rim of Gale Crater forms the lighter color strip in the background. Bits of gravel, about 0.4 inches (1 centimeter) in size, are visible on the deck of the rover. Photo Credit: NASA/JPL-Caltech

team drew on everything from Apollo data to the expertise of a Sikorsky helicopter pilot in order to design a system that would meet the mission's requirements. Engineers looked back to the Viking program, reviewing documentation where available (much was not), talking to veterans of the program, reverse-engineering some existing hardware, and even retrieving a film of a Viking parachute test from a NASA retiree's attic.

So what does this recent success have to do with the need for a knowledge strategy?

Curiosity is a great story with a happy ending. NASA's Mars program has a deep bench of experienced engineers who represent a living body of knowledge about EDL. If you want to know how to land a vehicle the size of Curiosity on the surface of Mars successfully, these are the only people who have done it. As this team moves on to other projects, its knowledge will disperse, as surely as the knowledge that went into the Viking program did.

As NASA faces constrained budgets for the foreseeable future, the opportunities to put this knowledge into action are likely to be few and far between. There is a precedent for this gap. After the success of Viking in 1976, NASA didn't launch another Mars lander mission until Pathfinder in 1997. Getting to Mars has always been expensive, and it will remain so for the foreseeable future.

Curiosity is far from the only mission to face this kind of knowledge challenge. The team that worked on the Robotic Lunar Explorer Program at Ames Research Center looked back to the Surveyor and Ranger programs of the 1960s and encountered the same kinds of gaps. "One of our Surveyor mission reports came from a consultant who happened to know a project manager from Surveyor, who gave him one of the few remaining hard copies of a document," Butler Hine and Mark Turner told *ASK Magazine* in "A New Design Approach: Modular Spacecraft" (Issue 33).

That's why a knowledge strategy is important. NASA practitioners need access to critical knowledge that can help them achieve mission success—now and in the future. That requires planning. The gaps in knowledge available from the Viking program didn't threaten mission success for the highly seasoned Curiosity team. But it is possible to imagine a different outcome.

As NASA's chief knowledge officer (CKO), I am heading up the establishment of an agency knowledge strategy in close collaboration with CKOs and knowledge leads at the centers and mission directorates. While the details of the strategy are still being developed, some of its core principles are already clear. It will integrate knowledge policy and requirements with those for program/project management; knowledge is inseparable from project success and should not be treated as a stand-alone discipline. It will focus on establishing both systems that make knowledge accessible and a culture that values learning and knowledge. Finally, it will respect existing knowledge practices and local customs while setting agency-wide norms for knowledge identification, capture, and dissemination.

Aware of the importance of capturing its own knowledge, the Curiosity team that performed the EDL sequence made sure to document its own work for future generations of Mars explorers. Their job is more or less done. The rest of us have work to do.

In Search of Answers

***ASK the Academy*, September 27, 2012 — Vol. 5, Issue 9**

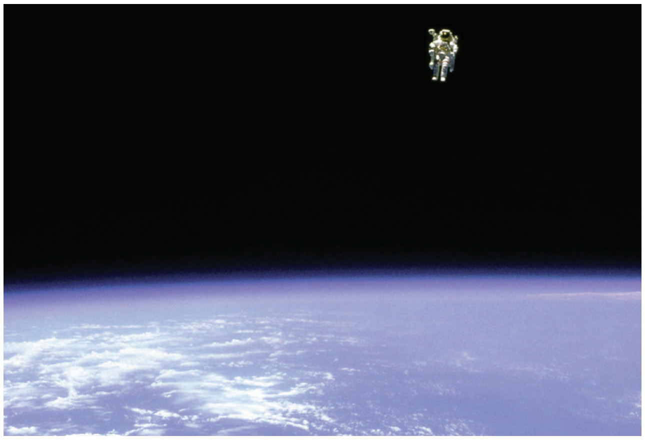
Where do you go to find what you don't know?

Seven months ago, a member of my organization started an ad hoc series of interviews with various people across the agency that asked one simple question: Where do you go to find what you don't know?

Intended as an evolving experiment, she shared her findings with me, noting that each interview progressed almost the same way every time. After a pause, her interviewees would respond: networks and online search. Answers varied from there—books, shared drives, libraries—but almost consistently, the responses followed the same pattern.

"The…structure of knowledge at NASA seems very fractured," one interviewee said. "It presents and behaves more like a bunch of little fiefdoms rather than a coherent presence." This remark struck me.

While the interviewees all talked about knowledge in very similar terms, they all also spoke about the importance of people-to-



On Feb. 12, 1984, astronaut Bruce McCandless, ventured further away from the confines and safety of his ship than any previous astronaut had ever been. This space first was made possible by a nitrogen jet propelled backpack, previously known at NASA as the Manned Manuevering Unit or MMU. After a series of test maneuvers inside and above Challenger's payload bay, McCandless went "free-flying" to a distance of 320 feet away from the Orbiter. This stunning orbital panorama view shows McCandless out there amongst the black and blue of Earth and space. Photo Credit: NASA

people interactions—of walking down a hallway and asking a question, picking up a phone, or even sending an email. Having a network is essential, as is having the capacity to grow that network. Face-to-face integration, impromptu or serendipitous meetings, and exploratory conversations are invaluable and irreplaceable.

On the subject of search, many referred to the almighty Google to characterize what they don't know and where they go in search of answers. Few responded positively to the online services offered by the agency. Their responses followed suit with a variation on Mooer's Law: knowledge that is hard to find is knowledge hardly found.

Currently, there are efforts underway to bring to light all of the knowledge efforts across the agency. Since assuming my new role as Chief Knowledge Officer at the beginning of the year, I've been impressed by the efforts and offerings at the centers and mission directorates. My organization is collaborating with all the centers and mission directorates to develop a map of the knowledge work currently being done across the agency.

Managing knowledge is not an easy task. As one interviewee remarked, "Rarely can you find a cookbook answer for a vexing problem." In collaboration with partners across the agency, the federal government, and industry, we are working toward a new level of integration of NASA's knowledge resources so that our workforce has a better shot at knowing where to go to find what they don't know, and our project teams have the knowledge they need when they need it.

In the meantime, we continue to collect data to better inform the development of our agency knowledge strategy. I will close with a simple question: Where do you go to find what you don't know?

An Ear to the Ground, A Foot in the Game

***ASK the Academy*, October 30, 2012 — Vol. 5, Issue 10**

Knowledge can be found at your fingertips—if you're willing to look for it.

I remember when an earthquake shook the offices at NASA Headquarters and the surrounding DC/Virginia area last year. What I didn't know at the time was that tweets about the earthquake travelled faster than the actual seismic waves. That same year, NASA Astronaut Ron Garan received a tweet asking what the temperature outside the space station was. @Astro_Ron sent back his answer #fromspace while onboard the International Space Station. I am amazed by how social media not only facilitates quick communication to large audiences, but also enables access to sources of knowledge that might otherwise be out of reach.

For quite some time, I have been experimenting with a number of social media platforms, but only recently have I started to pay closer attention to the way I use them. For instance, Twitter I use for browsing and serendipitous snippets I find of interest tweeted out by anyone from Tom Hanks to Steve Martin to the NASA History Office, or the Project Management Institute. I never really know what I'm going to find. On Google+, I prefer to have more focused and often asynchronous conversations with my various communities ranging from the students I teach to my professional colleagues from around the world.

I've written in the past that as a project manager, social media is one way to communicate a project's story to stakeholders in a timely and cost effective manner in order to keep a project "sold." For all reflective practitioners, social media is a way to discover knowledge in unlikely places or gain access to sources and experts when travel budgets, schedule conflicts, or enrollment get in the way.

NASA astronaut Tracy Caldwell Dyson, Expedition 24 flight engineer, looks through a window in the Cupola of the International Space Station. A blue and white part of Earth and the blackness of space are visible through the windows. The image was a self-portrait using natural light. Photo Credit: NASA

A digital learning revolution is shifting the ground beneath our feet. Tools and platforms as varied as Quora, Reddit, the Khan Academy, and even APPEL's newly released iBook point toward a larger trend, the democratization of knowledge, which Steve Denning summarizes as simply, "Anyone can know anything." This is coming closer to reality every day. Learning, conversations, and knowledge transfer no longer happens only when people gather together in the same room. It can take place anywhere: a desktop, laptop, or in your hand.

While there is something irreplaceable about face-to-face interaction, there is something that is irreplaceable about being networked through these connections. As Richard Branson, founder of the Virgin Group, recently blogged, "Anyone who thinks new technology isn't going to keep changing the world has got their head in the sand…. Embracing social media isn't just a bit of fun, it is a vital way to communicate, keep your ear to the ground and improve your business."

While I sometimes feel like I'm pushing out a message to the ether à la Voyager, and asking 'Does someone have an answer for me?' or 'Is there anybody listening out there?', more often than not, in the case of social media, somebody usually is. And the true accomplishment is when a dialogue is initiated as a result.

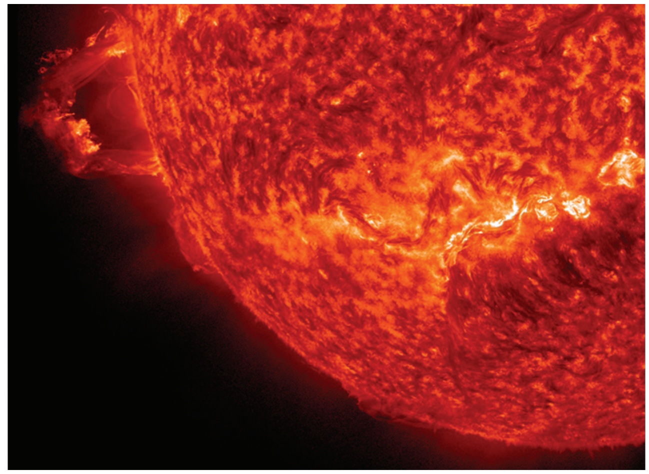
Just as email kick-started an uncomfortable transition into a new way of sending messages, social media is changing the way we network, engage, and discover who we don't know, what we don't know, and even challenging what we know. Our new reality, especially in the project world, is that we can't keep trying to put everything into a box when we exist in a world that is increasingly open and connected.

The Half-Life of Knowledge

***ASK the Academy*, November 29, 2012 — Vol. 5, Issue 11**

Unlike physical elements, it is hard to guess the half-life of knowledge in advance.

Pythagoras has had a pretty good run with his theorem for right triangles. Most knowledge does not endure the test of time, but $a^2+b^2=c^2$ has been with us for about 2,500 years. Math is unique in this sense. Pythagoras did not need complex instruments to make measurements in order to arrive at his conclusion. Ancient physicists and astronomers were handicapped by the limits of what they could observe, and their work survives now primarily as a historical curiosity.



The Sun erupted with two prominence eruptions, one after the other over a four-hour period on Nov. 16, 2012. The action was captured in the 304 Angstrom wavelength of extreme ultraviolet light. It seems possible that the disruption to the Sun's magnetic field might have triggered the second event since they were in relatively close proximity to each other. The expanding particle clouds heading into space do not appear to be Earth-directed. Photo Credit: NASA/SDO/Steele Hill

In the present, it can be difficult to gauge whether a new idea represents a significant breakthrough or a momentary blip, soon to be eclipsed by a greater development. This is true regardless of whether the knowledge in question is fundamental science, a new technology, or even a work process. Just as geometry is incomplete without Pythagoras, we cannot imagine modern manufacturing without Henry Ford's assembly line, even if some of the workers are now robots.

The challenge of managing knowledge at NASA is that we do not know with any degree of certainty what will be useful to future practitioners. As I mentioned a few months ago, the team working on the Robotic Lunar Explorer Program at Ames Research Center looked back to the Surveyor and Ranger programs of the 1960s to develop a new lunar lander. They even translated Russian technical manuals for Lunokhod, a lunar rover from the same era.

We have an obligation to each other and to tomorrow's practitioners to capture and share whatever we can, because we cannot anticipate the value someone else will find in our knowledge. Failures and mishaps serve as cautionary reminders of how little we understand at any point in time: "If only we had known." We can forgive ourselves for failing to anticipate the unknown. Forgiveness is far more difficult when the refrain is: "If only we hadn't forgotten."

Learning at NASA: The Four A's

Learning at NASA: The Four A's

[The following is an excerpt from *NASA's Journey to Project Management Excellence* by APPEL Director Dr. Ed Hoffman and APPEL Communications Lead Matt Kohut. Download a PDF version of the book or find it on APPEL's iTunes U site.]

In the spring of 2007, we asked 70 expert practitioners attending Masters Forum 14 to answer the question, *"How do you learn to do your job?"* Participants discussed the question in small groups of six to eight, recorded their responses on flip charts, and then shared their reflections with the larger group. The responses from that session yielded so much valuable information that we repeated the activity with participants at Masters Forums in April 2008, October 2008, and May 2009. 21 The qualitative data gathered from these small and large group discussions with roughly 275 experienced practitioners have enabled us to draw some conclusions about how successful individuals learn to do their jobs at NASA, including the identification of four key dimensions of effective-ness. (See Figure 3-1.)

In her 1977 book *Men and Women of the Corporation*, Rosabeth Moss Kanter identified activities and alliances as avenues to power, which for the purposes of her study she defined as "closer to 'mastery' or 'autonomy' than to domination or control over others." While we examined a different question than Kanter did, two of the dimensions that emerged in our research, assignments and alliances, corresponded roughly with Kanter's findings. The other two, ability and attitude, reflect the nature of NASA as a project-based organization that demands high levels of technical expertise as well as teamwork.

Ability is a combination of natural aptitude, skill level (which increases with practice), and the capability to assimilate new knowledge and learn from experience. While innate talent is certainly part of the equation—just as very few people possess the right attributes to become concert pianists or Olympic athletes, very few are also likely to succeed as NASA scientists or engineers—continuous improvement and learning is a critical element of skill development. In the context of NASA, this includes being able to learn from errors and failures and identify causes and patterns that can lead to future successes. Ability also refers to systems thinking and "seeing the big picture." In an organization where many projects are best understood as systems of systems, the importance of being able to conceptualize large, integrated systems increases as an individual progresses through his or her career.

Attitude is closely related to the development of ability. Motivation and intellectual curiosity are pre-requisites for success at NASA: expert practitioners never stop asking questions or wanting to know more. They possess a relentless

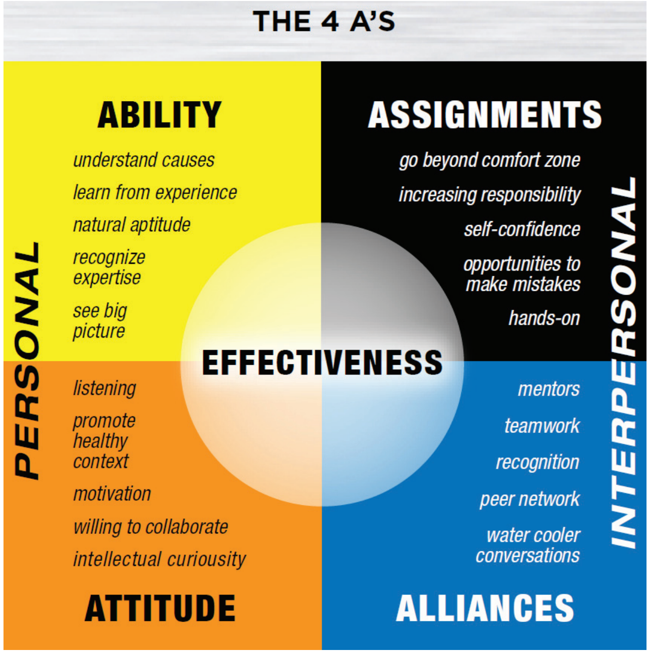


Figure 3-1. There are four dimensions to personal effectiveness at NASA.

focus and a passion for their subject that drives them to work hard for the sake of learning more about their subject area. This passion translates into going beyond expectations to ensure success. In a project-based organization, attitude also encompasses the willingness to work successfully as a member of a team. Since all work at NASA takes place in team settings, it is impossible to overstate the importance of mastering the attitudes and behaviors that enable optimal teamwork. This calls for developing skills such as empathy, listening, and self-awareness.

Assignments are the core learning experiences that lead to the development of personal expertise. When aligned properly with an individual's career level, assignments represent opportunities to develop specialized knowledge, learn from mistakes, build self-confidence, and take on increasing responsibility. Assignments move in two directions: experts seek assignments that will enable them to pursue their areas of interest, and difficult situations demand experts who possess specialized knowledge. Individuals who have gained recognition for their expertise are rewarded with high profile, challenging assignments that are meaningful and valuable to the organization. Work assignments are the proving ground for effectiveness, whether an individual's expertise is technical or managerial, and success leads to a positive feedback loop of more progressively difficult assignments.

Alliances are relationships that enable an individual to succeed within an organization. Mentors and peers are critical for exchanging ideas, sharing experiences, and soliciting advice or opinions. Alliances also play a role in obtaining assignments: professional networks and recognition by superiors can open doors for challenging or high profile work. Expert practitioners create alliances as they progress through their careers, and their success in turn attracts others seeking alliances. Perceptions are central to alliances—a reputation for being a good person to work with is critical to the successful cultivation of constructive relationships. Given the growing importance of "smart networks" that enable project teams to leverage expertise from around the world (see chapter 6), alliances are becoming more critical by the day.

Ability and attitude are intrinsically personal qualities—nobody can give another person a better attitude or a greater ability to do a job. Alliances and assignments, on the other hand, are interpersonal by definition. In an organization like NASA, cultivation of both the personal and interpersonal dimensions is necessary to be effective, though the balance differs for each individual and area of expertise.

The Academy promotes individual professional development that addresses these "4 A's" through multiple channels, including:

- Identifying a career development framework and an integrated competency model for project management and systems engineering.
- Offering a curriculum that includes both core and in-depth courses in areas ranging from Mars mission design to green engineering.
- Sponsoring developmental assignments and hands-on opportunities to help individual practitioners develop their skills.

"Experience may possibly be the best teacher, but it is not a particularly good teacher." — James March, The Ambiguity of Experience

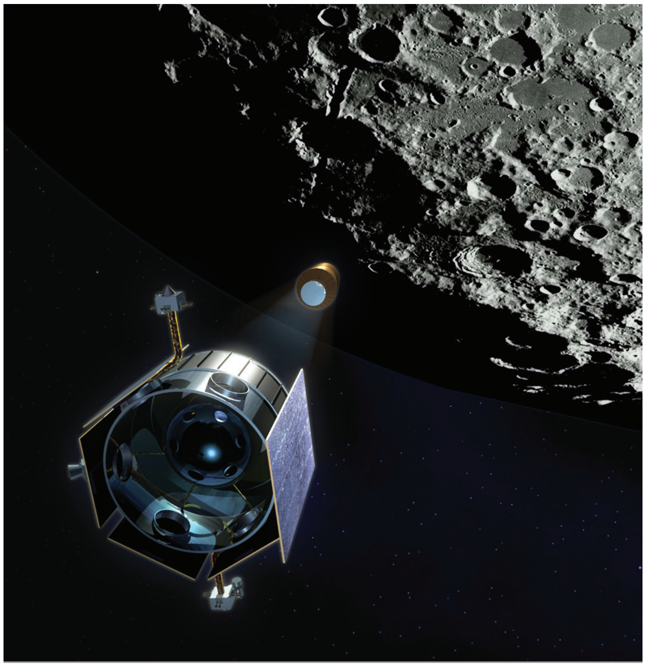
ASK Magazine

Project Stories

Managing the Bad Day

By Daniel Andrews
Fall 2011, Issue 44

It's 3:30 a.m. on Saturday, August 22, 2009. My cell phone rings. As the project manager for the Lunar Crater Observation and Sensing Satellite (LCROSS), I was used to sleeping with the phone near my bed ever since launch. The LCROSS operations team was preparing to do a spacecraft orientation maneuver, turning the cold side of the spacecraft to the sun to burn off any residual ice remaining on the Centaur upper stage—what we called a "cold-side bake." I was planning to go in and observe the activities later that morning. The phone had never rung this early before.



Artist's rendition of LCROSS separating from the Centaur upper stage. Image Credit: NASA Ames Research Center

"Project, this is Mission," the LCROSS mission ops manager (MOM) stated.

"Go, Mission," I replied.

MOM indicated the team had just gotten "acquisition of signal," which means the operations crew had reestablished communication with the spacecraft after a planned period of no communication. MOM told me that once spacecraft telemetry began flowing, the ops team discovered that a very large amount of propellant had been mysteriously consumed while the spacecraft was out of view of the ground stations.

MOM explained, "When we acquired the spacecraft, we discovered that the thrusters were firing almost continuously and believe a substantial amount of propellant was consumed." I asked if we knew if we had enough propellant remaining. "We do not yet know if we have enough propellant to finish the mission—working it now," replied MOM. "The thrusters are still firing, and we are trying to get that stopped."

It was clear that if we hadn't scheduled an early-morning activity when we did, we would have consumed all the propellant and lost the mission. Furthermore, if we didn't get it stopped immediately, we'd lose the mission anyhow.

This was LCROSS's bad day.

I got dressed and headed in to the mission ops control room at Ames Research Center and learned the thruster firing had stopped after a commanded power-cycling of the spacecraft's inertial reference unit, or IRU. The IRU is standard spacecraft equipment used to measure the spacecraft's velocities so its

LCROSS and LRO are installed inside their fairing.
Photo Credit: NASA/Jack Pfaller

attitude can be controlled. The ops team discovered that an IRU fault flag was set. After some consideration, the team issued a reset command, which cleared the fault and halted the thruster firings, returning the spacecraft to its normal condition.

Later analysis revealed that when the IRU fault occurred, the autonomy and fault management system appropriately kicked in, no longer trusting the IRU for velocity feedback and switching to the star tracker's velocity feedback. For (then) unexplained reasons, this changeover drove the attitude control system to fire the spacecraft thrusters at an extraordinary rate. The spacecraft ultimately consumed some 140 kg of propellant, leaving a mere 60 kg to finish the mission.

It eventually turned out that two root causes led to this event and our subsequent challenges:

1. IRU configuration error: A spurious, short-lived error on the IRU was interpreted as a more serious fault by the spacecraft fault-management system because the IRU fault-flag update rate and the autonomy and fault management sampling rate were not properly synced, leading the autonomy and fault management system to believe a persistent error was present and to subsequently switch to the star tracker for velocity measurements. This issue alone wouldn't have been a problem.

2. Star tracker velocity noise: Since star-tracker measurements compute velocity from the spacecraft position relative to the stars, the computations can be noisy, or jittery, which is why IRUs are employed for velocity measurements. The noise levels were within manufacturing specifications, but our high-performance spacecraft attitude-control system was sufficiently sensitive to think the noise was velocity error and tried to control it when it should have ignored it. This led to the excessive thruster firings and propellant consumption.

LCROSS formally declared a spacecraft emergency with NASA's Deep Space Network, given the spacecraft's precarious condition. With this declaration, all missions using the Deep Space Network have an understanding to yield their communications pass time to a mission in danger. This enabled LCROSS to have near-continuous communication with the ground, limited only by geometric constraints of the spacecraft's position relative to ground stations on Earth.

As it turned out, one of those outages was again coming, so we needed to put some protections in place just ten hours after discovering the anomaly. Our plan was to update the persistency with which the IRU fault was monitored so a spurious fault would not throw us into another costly propellant-consumption situation. Then we went dark again and crossed our fingers.

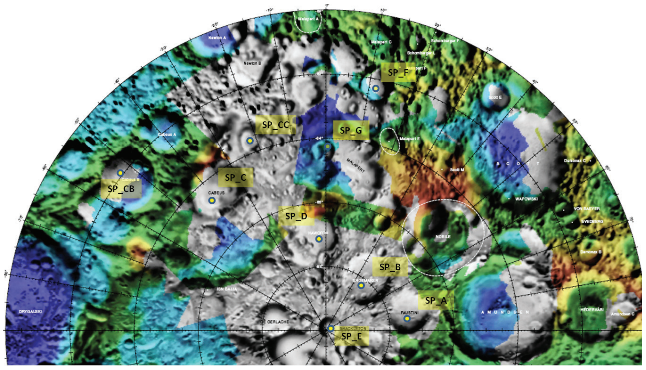
From Anomaly to Recovery

When communications were reestablished, we discovered there had been no further incident. We had made it through, but this was the beginning of a new operational environment for LCROSS as we moved from anomaly to recovery. This required serious triage. Here were the steps we took:

1. Stop the bleeding. The mission is over if you cannot stop the elevated rate of consumption of a finite resource like propellant. Electrical power can be renewed through solar arrays, but there is no mid-air refueling of spacecraft propellant. We needed to stop the propellant consumption ASAP.

2. Make it through the night. We needed to survive upcoming known communication outages caused by orbital geometries. We needed a way for the spacecraft to monitor when excessive firing occurred and prevent further consumption *automatically*.

3. Ensure long-term health. Once you are out of imminent danger, how do you ensure finishing the mission? What are the tasks remaining and the risks of executing them? How far do you go with



LCROSS candidate impact craters. Image Credit: NASA Ames Research Center

analysis, simulations, and other risk-mitigation means? At what point does the risk of human error become greater than the technical risk associated with the spacecraft?

4. Address the root cause (if you can). Discover the specific cause for the incident. Is there anything that can be done to prevent this in the future? Is there a way to fix it, or only ways to avoid the circumstances that led to it?

The Project Manager's Role

Along with this triage process, the operations team's most important job, the project manager takes on a new series of responsibilities when a mission has a "bad day."

Inform and Manage the Stakeholders

Understandably, stakeholders get very engaged after an anomaly. They want to help ensure the mission. The morning of the anomaly, I followed established procedures to call the various stakeholders and inform them of what had happened. Shortly after those notifications went out, the Ames center director and most of his directors arrived at the ops control room with bags of breakfast food and drinks, a gesture much appreciated by the team. And we were grateful that leadership understood the team needed to be given room to work.

I provided frequent stakeholder updates on findings and progress, in person and via e-mail for the broader agency audience, with a brief daily status teleconference by the MOM. E-mail updates were nearly hourly in the beginning, dropping to updates at shift changes near the end of our emergency. My deputy project manager and I tag teamed to cover shifts in the mission ops control room, writing a summary and publishing it to the stakeholders at shift changes, keeping the stakeholders informed and comfortable.

Protect the Team from External Distraction

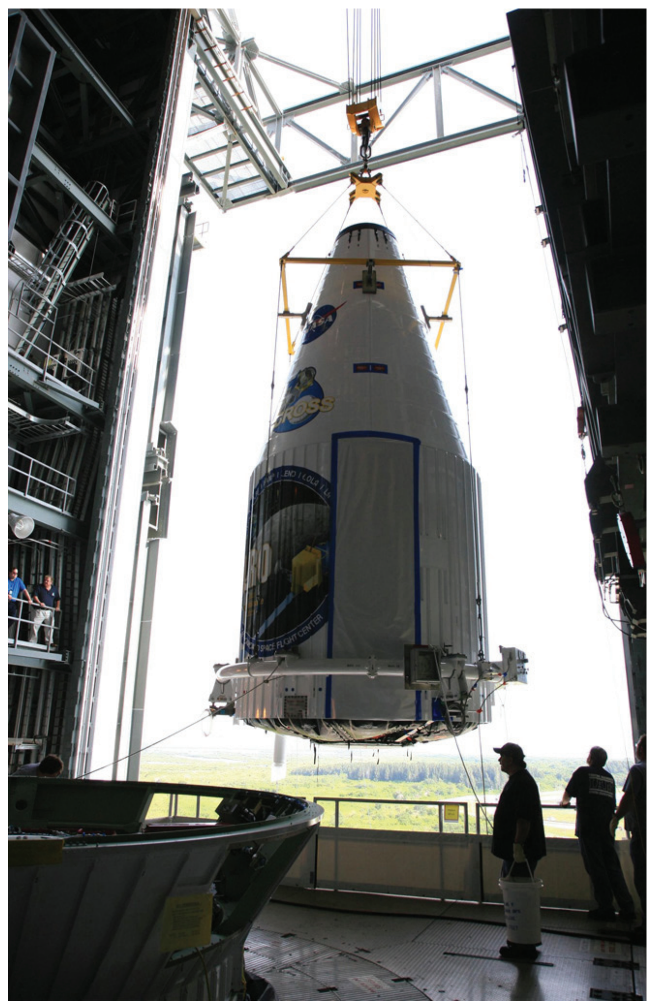
The LCROSS team was of course attempting to get back to more normal operations as soon as feasible after the anomaly. Center management demanded that additional controls be put in place to protect the remainder of the spacecraft's propellant; however, this challenged the team at a time when they were stressed and fatigued—our staffing plan was not designed to support 24-7 operations. It is the project manager's job to try to manage stakeholders to a consistent level of risk tolerance, despite the strong drive to eliminate future risk, which is not possible. This mission had grown to be very important to many, but reason and balance needed to prevail.

Steer Parties Away from Hunting for the Guilty

Once you stop the bleeding, questions naturally begin to surface about why the anomaly occurred. These queries, while important to understanding your continuing risk, should not distract the team from focusing their attention on continuing the mission. I had to push back on this questioning to prevent the team from getting frustrated or distracted.

Handle the Press

When a spacecraft experiences an anomaly, you have to be available to the press. The traditional media want to know



On Launch Complex 41, the Lunar Reconnaissance Orbiter and LCROSS are moved into the mobile service tower. Photo Credit: NASA/Dimitri Gerondidakis

(Left to right) John Marmie, Jack Boyd, Lewis Braxton III, Tina Panontin (standing), Pete Worden, and Chuck Duff celebrate LCROSS's separation from the Centaur upper stage. Photo Credit: NASA/Eric James

all the details and can turn against you if they suspect you are holding back; openness is important. The blogosphere is different in that their "facts" come from unknown sources and their conclusions are sometimes based on personal agendas. We handled the press with frequent phone interviews and updates to the project web page. I conducted about ten phone interviews in two days.

Watch for Things Getting Complicated

After the anomaly, engineers worked through the data and invented responses, but engineers (like me) are predisposed to solving problems and have a tendency to create complex, multilayer solutions to stomp out the risk of reoccurrence. Discussions would work their way from one incremental fix to another, arriving at complex fixes and patches that would move the team far from its operations training and might not be testable. This complexity growth actually *grows risk* that the system will become so sophisticated it will be prone to operator error or create unforeseen interactions. In the heat of battle, there needs to be someone who keeps an eye on the risk of the solution. There were a couple of times when I would ask, "Do we need to go that far, or can we live with just the first corrective measure?" We would usually agree we could accept the residual risk after addressing the principal problem. Missions have been lost because smart people did well-intended things that made problems worse.

Watch Operations Console Staffing

Because the LCROSS team was small, we had the project systems engineer staff the systems engineering console station. The project systems engineer would take one shift, and his deputy would staff the other shift. The idea seemed sensible—why not put your most competent systems engineer right in the middle of the action? I later realized that having your project systems engineer on the console removes him from his normal responsibilities—that you still need. Yes, you benefit from having your lead systems engineer monitoring the spacecraft, but he needs to sleep as well and is less able to participate in important assessment and planning activities, making him unavailable to advise you with his technical assessments and recommendations. I would not organize staff this way again.

Watch for Crew Fatigue

Hardworking, dedicated people get tired. Our cost-capped mission was not designed for post-anomaly staffing demands. A small number of people were covering an extraordinary number of hours. Their work was impressive, but fatigue inevitably sets in. You need to balance attacking technical problems with the growing operational risks associated with fatigue. I saw heads bobbing while on console as people fought back sleep; I saw people struggle to complete thoughts during shift-handover discussions. There was also growing stress at home for many who were working difficult hours. It was essential to remediate the problem as soon as possible.

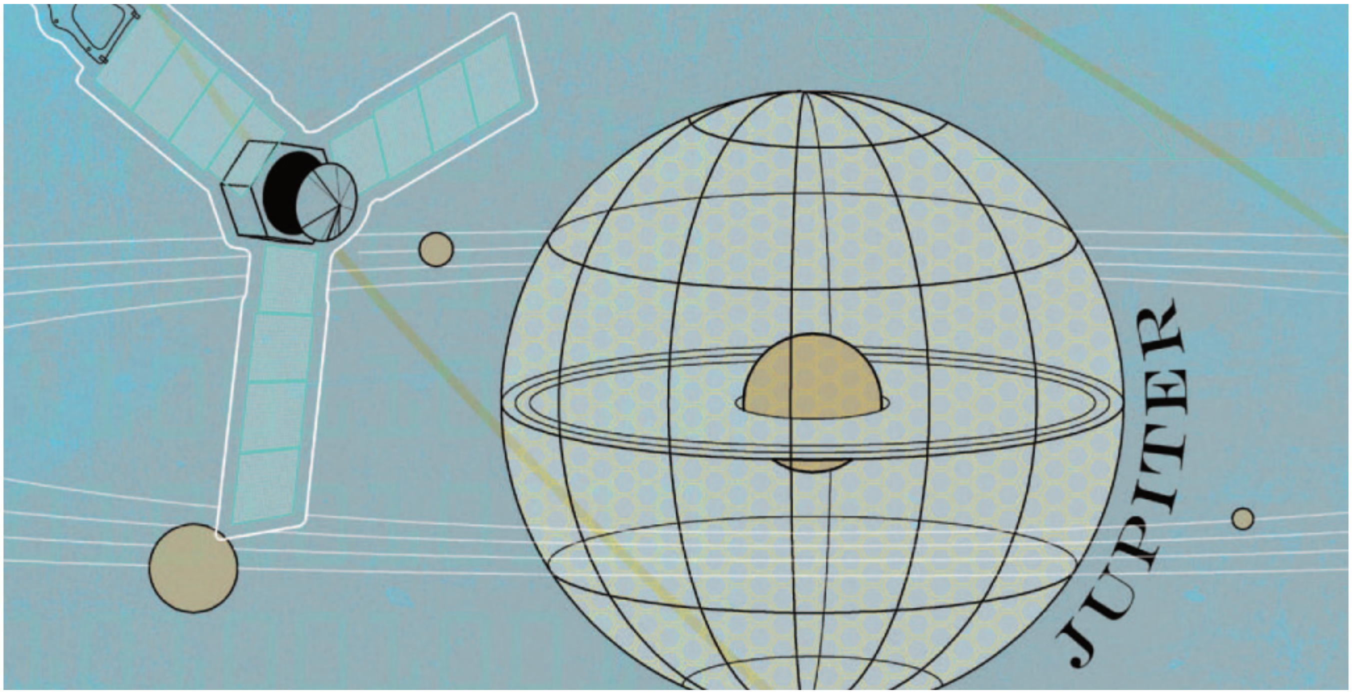
Meeting the Challenge of the Bad Day

The LCROSS team behaved remarkably through its bad day. The triage process was exactly the right mix of urgency and focus, which comes from many, many operational rehearsals where the team trains for what is supposed to happen and even what is not supposed to happen. Of course, you cannot afford to spend unending money training for a low-cost mission, which means you need to focus not on the specifics of what could go wrong, but on your behavior and process when something goes wrong.

The project manager has many responsibilities when a bad day happens. You will depend on individual and team capabilities, training, and roles in ways that are hard to describe. You know that you must trust the team's abilities and judgment, but also watch for signs, both within the team and outside, of good intentions yielding problematic results. You must be reasonable and evenhanded, understanding that you cannot eliminate risk. The bad day is a time when a mission team shows what it is really made of. The LCROSS team earned its stripes on its bad day and through the end of what became an amazingly successful mission, redefining mankind's understanding of the moon—at a bargain price.

About the Author

Daniel Andrews has managed diverse and eclectic projects at NASA for twenty-four years, including the risk-tolerant pathfinder, LCROSS. Favorite motto: "Take calculated risks. Be willing to change course. Keep moving."



Juno: A Look Back at Successful Development

By Jan Chodas
Winter 2012, Issue 45

Dr. Scott Bolton, Juno's principal investigator from the Southwest Research Institute, and the Juno team had been working toward this milestone for several years. A mission of this length and complexity required careful planning and testing to increase its chances of success. Everyone felt a great sense of accomplishment when, shortly after separating from the Centaur upper stage, the spacecraft deployed its large solar arrays as planned and began its journey to Jupiter.

The second mission in NASA's New Frontiers Program, Juno experienced an unusually long definition and planning phase—described by Juno's first project manager, Rick Grammier, in *ASK Magazine*'s Spring 2008 issue—that gave us several advantages, including "more time to talk." This proved beneficial for a distributed team that included members from the Jet Propulsion Laboratory (JPL), Lockheed Martin, Goddard Space Flight Center, Southwest Research Institute, the Applied Physics Laboratory, University of Iowa, Malin Space Science Systems, the Italian Space Agency (ASI), and others. We were able to establish strong working relationships and excellent communication by having regular status telecons, workshops, and frequent in-person meetings.

These relationships helped tremendously during our risk-mitigation planning efforts, which included integrating instruments early on; working through issues such as the impact the L'Aquila, Italy, earthquake had on the Ka-band translator development; developing fallback options for Juno's system-level environmental tests; and using an innovative tool to track our schedule margin.

Integrating Instruments Early

Early in the implementation phase, the Juno team performed interface tests at the Lockheed Martin facility between the engineering models (early versions of hardware) of each instrument's electronics and the spacecraft's flight-like hardware. These early integrations helped find and fix hardware and software bugs in the interfaces, increasing the likelihood that flight-instrument integrations would proceed more smoothly.

Concerned about the possible late deliveries of the avionics and solar arrays, we also prepared a set of fallback options that gave us some flexibility for completing the tests successfully.

The first set of tests in spring 2009 between the instruments' engineering models and the Data, Telemetry, and Command Interface (DTCI) Engineering Development Unit (EDU) board focused on confirming the compatibility of the commanding, engineering telemetry, low-speed science data, and high-speed science data hardware interfaces. These tests uncovered some issues early—such as the clock polarity coming out of the DTCI being inverted—and gave us confidence to move forward with the spacecraft and instrument flight builds. A side benefit was the establishment of an excellent working relationship between the instrument teams and the Lockheed Martin software, simulation, and instrument-integration team members, which was helpful throughout the implementation phase.

During the first part of 2010, instrument engineering models were sent to the Lockheed Martin facility's System Test Lab for a second round of tests that focused on confirming higher-level functionality in the flight-software interface. Greg Bollendonk, the flight software lead, accelerated the development of the instrument-interface portions of the spacecraft flight software in order to deliver beta versions for these tests. Another goal was to flow data to each instrument's ground-support equipment—as would be done during the assembly, test, and launch operations (ATLO) phase—to enable the instrument teams to become familiar with the data formats and ATLO processes. At the time, the spacecraft field-programmable gate arrays that controlled the instrument interfaces were not yet mature, so they benefited from this early testing as well.

More issues were uncovered and corrected, including significant ones in the high-speed data interface that required several months to resolve. One issue in this interface involved the spacecraft's memory-management software. This spacecraft flight software wasn't saving the highest-quality data for the ultraviolet spectrograph (UVS) instrument. The flight software team took advantage of the UVS engineering model in the System Test Lab to iterate code changes with remote support from the instrument team (located at Southwest Research Institute) until the problem was resolved. All in all, this risk mitigation program paid off in smoother flight-instrument integrations during ATLO.

Recovering from a Natural Disaster

ASI contributed two instruments to Juno's payload: the Jovian infrared auroral mapper (JIRAM) and the Ka-band translator for the gravity science investigation. These contributions, added during the definition and planning phase, were not part of the original mission proposal. The ASI contribution gave us an alternate supplier for the Ka-band translator in the original proposal while the JIRAM instrument was completely new. One key feature of this arrangement was that neither of these contributions were required in order for Juno to satisfy its mission success criteria.

This decoupling helped when a magnitude 5.8 earthquake in L'Aquila, Italy, in April 2009 severely damaged the Thales Alenia Space plant where the Ka-band translator's engineering model was being built. This natural disaster threw its development into disarray. Initially, the team had no idea what the impact would be on the model's delivery, scheduled to happen by June 2009, or on the flight unit's delivery scheduled for December 2009.

Rick Nybakken, Juno's deputy project manager and the prime project interface with ASI, led the development of a recovery plan that upgraded the engineering model to a flight quality unit (called the flyable engineering model, or FEM), enabling one unit to meet both delivery requirements. This higher-risk approach was acceptable because full performance from the Ka-band translator was not required for Juno to meet its success criteria. A flight unit would still be built and tested, and if it became available soon enough, we would consider it for flight. The FEM was delivered and installed in April 2010. When the flight unit became available in August 2010, we replaced the FEM with the flight unit due to its higher reliability and because we could still accommodate a swap at that late date.

Working through this difficult situation was helped by the excellent rapport that Scott, Rick, Dorothy Lewis (Ka-band translator cognizant engineer), and the project team had with ASI and Thales Alenia Space. Quarterly meetings helped foster this relationship. Rick had seen this model used successfully on the Cassini mission and set up a rotation of a core set of Juno personnel, both management and technical, that would travel to Italy every three months for management and technical discussions. The ASI/Thales Alenia team traveled to JPL occasionally for the same purpose.

The relationships established proved to be very useful when we worked with ASI and Thales Alenia to recover from the earthquake. The team worked closely with Roberto Formaro, ASI program manager for Juno, to align the project and ASI strategies for revised delivery requirements and tactical

New Frontiers Program Office Insight and Participation

By Brian Key

Juno benefited greatly from an extended definition and planning phase that gave the project team "more time to talk." This additional time also allowed the New Frontiers Program office to become more familiar with the mission definition and to independently assess the project's planning activities. Understanding schedule and technical risks prior to confirmation also allowed the program office to develop a representative cost risk that could be carried as an unallocated future expense (UFE) by the Science Mission Directorate (SMD), and could be included in the overall life-cycle cost for the project at confirmation. This cost risk was established not only through understanding risks but also by examining previous mission performance histories to determine the soundness of the mission cost and schedule profiles.

Upon confirmation, NASA established a principal investigator cost cap and an overall project cost cap. Throughout implementation, the principal investigator (PI) and project manager managed to the tighter PI cost cap. allocations from the SMD-held UFE were controlled through a process established by the program office, which required the project to formally request a UFE allocation and provide a rationale for the request. The program office would evaluate this request and provide the Planetary Science Division (PSD) New Frontiers program executive with an assessment and recommendation.

Essential to this process was the well-established communication among the project, program office, and PSD. Open and candid communication and information flow between the project and program office mission manager gave all levels of NASA management a good understanding of the project's status. This communication and information came in many forms, from monthly status meetings to weekly tag-ups to daily test status e-mails, intertwined with frequent, impromptu teleconferences.

As the project developed and implemented early risk mitigations, worked around impacts from natural disasters, and developed and executed alternate test flows and configurations due to component, instrument, or subsystem delays, these developments were communicated effectively and efficiently to the program office mission manager and PSD New Frontiers program executive.

interactions with Thales Alenia. All Thales Alenia customers who had been affected by the earthquake were claiming priority in the recovery planning, but Juno's only option to receive a flyable Ka-band translator in time for launch was to develop and implement a coordinated strategy among Juno, ASI, and Thales Alenia. Establishing a successful path forward might not have been possible without the meetings and resulting relationships established during the early part of development.

Having Preapproved Fallback Options

The system-level environmental test suite is a major test activity every spacecraft experiences during the ATLO phase. Its purpose is to subject the spacecraft to the environments it will experience during its mission. These environments include the vibration of launch (simulated by an acoustic test), the shock of separation from the launch vehicle, the spacecraft's electromagnetic self-compatibility at launch and during science-data gathering, and the temperature in the vacuum of deep space that the spacecraft will experience on its trajectory to Jupiter. The Juno team planned a traditional set of tests involving the flight hardware and flight software and presented that baseline at the environmental test readiness review (ETRR).

Concerned about possible late deliveries of the avionics and solar arrays, we also prepared a set of fallback options that gave us some flexibility for completing the tests successfully. These options outlined the minimum set of hardware required for each test, including the required pedigree (flight or non-flight). For example, flight-like engineering models could be used for the self-compatibility tests if the flight avionics were not available, and the solar-array qualification model could be used for the shock test if the solar arrays had not yet been delivered. We also outlined specific vibration-level and thermal-cycle tests that would need to be executed to ensure the complete environmental qualification of the spacecraft if a flight-hardware component had to be reworked post-test. Preparing these fallback options ahead of time helped clarify and align our thinking for these anomalous situations.

These options were also presented at the ETRR and discussed openly with the review board. This up-front review minimized the management coordination the project needed later on when some of the options had to be implemented to complete the environmental tests within schedule.

"Stay in the Corridor"

Tim Halbrook, the Lockheed Martin ATLO manager, used typical schedule tools to track Juno's progress: a sixteen-month ATLO flow updated monthly, a thirty-day Gantt chart updated weekly, and a seven-day Gantt chart updated daily. To plan and track the use of Juno's sixty days of ATLO schedule margin, however, Tim also developed a Corridor plot (see figure at top of page). On the Corridor plot, the curve of schedule margin burndown—the rate at which margin is used up—corresponded with the margin days sprinkled strategically throughout the ATLO flow. Tim also included a second curve on the plot that was offset by 20 percent below the nominal curve. Juno's actual schedule margin use was plotted weekly on the same figure.

If our actual margin burndown remained between these two curves, we did not need to take action. But if it dropped below the 20 percent margin erosion curve, Tim would schedule second shifts and/or weekend shifts to bring the actual burndown back within the corridor. Shortly after ATLO started, unplanned troubleshooting and rework with both the avionics and telecom hardware dropped the schedule margin close to the 20 percent margin erosion curve. We recovered schedule margin by using additional shifts once the issues had been worked through successfully.

This graphic became a handy visual tool for the whole team to monitor the schedule margin and to make decisions regarding resource control. It also enabled Juno managers and external managers to tell at a glance how ATLO was progressing.

An Excellent Beginning

Throughout Juno's implementation phase, management teams at all levels looked for ways to help development proceed more smoothly and with lower risk, and the team as a whole worked through many challenges successfully. This was possible due to our strong working relationships and excellent communication, enhanced by the close communicative style of our project leaders. The result meant completing Juno on time and on budget, and its excellent flight performance so far shows the benefits of our efforts.

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. © California Institute of Technology. Government sponsorship acknowledged.

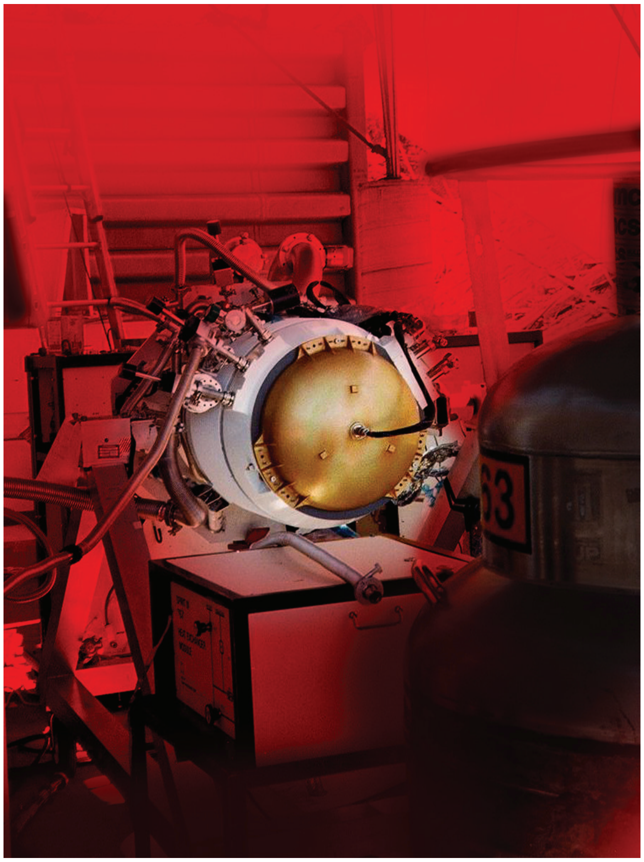
About the Author

Jan Chodas is currently the project manager for the Juno mission in the New Frontiers Program. Prior to this position, she served at the Jet Propulsion Laboratory in numerous roles, including manager of the Systems and Software Division, assistant flight system manager for the Mars Exploration Rover project, flight system manager for the Space Interferometry Mission, project element manager for the Cassini attitude and articulation control subsystem, and technical manager for the Galileo attitude and articulation control subsystem.

WIRE: Learning from Failure

By Bryan Fafaul and Kerry Ellis
Winter 2012, Issue 45

In 1999, the Wide-field Infrared Explorer (WIRE) lost its primary mission thirty-six hours after launch. Those who worked on WIRE, which was the fifth of the Explorer Program's Small Explorer–class missions, thought they had done what they needed to achieve success. But a mishap investigation and a 2002 Government Accountability



Closeup of the cryostat during hydrogen testing at Lockheed-Martin's Santa Cruz facility in July 1997. Photo Credit: NASA/Lockheed Martin

Office report on NASA's lessons learned highlighted poor communication and incomplete testing as contributors to this and other NASA failures. The team's informal motto, "insight, not oversight," also helped WIRE's issues stay hidden.

The motto was meant to respect the professionalism and expertise of each organization involved in the mission. WIRE had a complex organizational structure, with mission management at Goddard Space Flight Center, instrument development at the Jet Propulsion Laboratory (JPL), and instrument implementation at a contractor's location with supervision by JPL. This arrangement was meant to capitalize on the strengths of each organization. By guiding team interactions with "insight, not oversight," the goal was to avoid perceptions of distrust or micromanagement and facilitate a smooth working arrangement that could proceed without the hang-ups of too much oversight. This approach, however, had unintended consequences.

WIRE's sensitive infrared telescope was the most visibly affected by the limited oversight. Meant to study how galaxies formed and evolved, the telescope's infrared detectors required an extremely cold, 7 kelvin environment in order to operate with precision and without interference from the heat of the telescope itself. To achieve this, the telescope was protected inside a frozen-hydrogen-filled dewar, or cryostat. The plan was to keep the telescope safely covered inside the cryostat until WIRE made it into the deep cold of space. Then the cryostat cover would be ejected and the telescope would begin operations.

"We spent three years ensuring that cover would come off, and probably only a handful of hours making sure that it would stay on," said Bryan Fafaul, who was the mission manager for WIRE.

Soon after launch—too soon—the cover ejected.

Communication Breakdown

During development, delivery of the pyro box that would eject the cover had been delayed. As a result, the box wasn't adequately included in a scheduled peer review of WIRE's electronics. A change of management, and the failure to communicate to the new management that the peer review was inadequate, resulted in no additional review of the design.

"We as engineers and scientists do a very good job addressing technical anomalies. We do a great job diagnosing the problem, making the appropriate corrections, and performing the necessary regression testing to ensure success," said Fafaul. "Management anomalies are just as important but are more difficult to address. They take a long time to recognize, after effects are unclear, and regression testing is difficult. For WIRE, we had an issue: we weren't communicating anymore. Ultimately, we had some personnel change out, and that made a significant difference in our communication. But the thing we didn't know how to do was analyze what damage had been done as a result. We made a change, but we didn't know how to go back and verify [regression test] what we caught and what we missed. We just didn't know how to do that."

The result was a chain reaction of miscommunication that led to a lack of insight.

Jim Watzin, who was the Small Explorer project manager at the time, described the communication difficulties as a matter of misconceived ownership and distrust of outside opinions. "These folks feared oversight and criticism and hid behind the organizational boundaries in order to ensure their privacy," he wrote in response to a case study on the mission. "They lost the opportunity for thorough peer review (the first opportunity to catch the design defect) and in doing so they lost the entire mission."

"Everyone was being told to back off and let the implementing organization do its thing with only minimal interference," added Bill Townsend, who was Goddard's deputy director at the time, in his own response. "… This guidance was sometimes interpreted in a way that ignored many of the tenets of good management. Sometimes the interpretation of this was to do nothing …. Secondly, WIRE had two NASA centers working on it, one [JPL] reporting to the other [Goddard]. Given that either center could have adequately done any of the jobs, professional courtesy dictated neither get in the way of the other. While this was a noble gesture, it did create considerable confusion as to who was in charge of what."

As a result, the contractor was able to proceed with the pyro box development without the peer review oversight needed to ensure success. Crucial details about the box design were not complete, others had little documentation, some were included in notes but left off data sheets. No one had a complete view of all the circuitry involved in the pyro box, and an indication that something might be amiss wasn't fully analyzed during integration testing.

Test as You Fly, Fly as You Test

One of the undocumented pieces of information was the startup characteristics of the pyro box—namely how long the instrument took to power up and the effects other current signals would have on the box's field-programmable gate array (FPGA) during its startup. This detail was overlooked due to delays in the box's design delivery that prevented it from being included in subsystem peer review and the mission system design review.

Without the cryostat's protection, the infrared detectors would misinterpret the telescope's own heat as signal noise, which effectively ended WIRE's primary mission.

Testing of the pyro box was challenging because of the cryostat. "It was a hydrogen dewar. You can't just load it up with hydrogen and take it into any building and test it," explained Fafaul. "So we had to adapt and make provisions to do things a little bit differently."

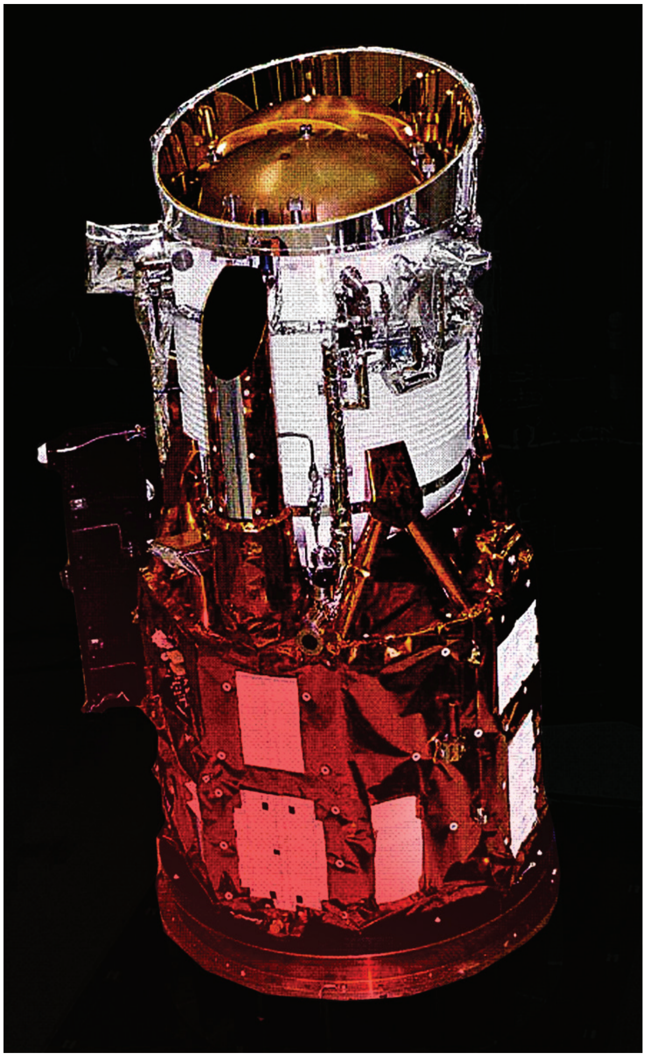
Since the cryostat itself could not be tested with the actual pyro box while filled with frozen hydrogen—otherwise known as being in its nominal, or ideal, state—the team used a pyrotechnic test unit to simulate the pyro event. The test unit had been successfully used in testing for previous Small Explorer–class missions, and was well known for being a bit finicky about false triggers. This knowledge, and a contractor's documented explanation of a similar event, would be the foundation for dismissing a valid early-trigger event that made itself evident during spacecraft testing.

Before WIRE launched, the pyro box on the cryostat had been powered off for nearly two weeks, allowing any residual charge in the circuitry to bleed off. Residual charge turned out to be the key to maintaining a valid test configuration for the pyro box during spacecraft testing, which was occurring almost daily. When the team sent a signal to power up the system after launch, the pyro box powered on in an indeterminate state and the spacecraft immediately fired all pyro devices. The cryostat cover blew off, exposing the frozen hydrogen to the heat of the sun. It boiled off violently, sending the spacecraft into a 60-rpm spin. Without the cryostat's protection, the infrared detectors would misinterpret the telescope's own heat as signal noise, which effectively ended WIRE's primary mission.

Taking Tough Lessons to Heart

"For every shortcoming we had on WIRE, you'll find nearly an identical shortcoming in every successful mission. Like it or not, you're close to failure all the time," said Fafaul.

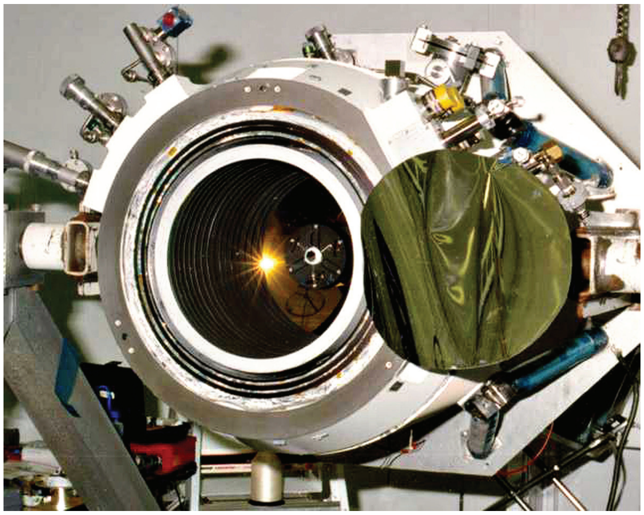
"I've had seven or eight different offices since my WIRE days, and directly across from my desk you will always find my picture of WIRE," he continued. "There are important lessons there that I want to be reminded of every day as I move through life."



The Wide-field Infrared Explorer. Photo Credit: NASA

Among the tough lessons learned during WIRE, Fafaul took six especially to heart:

- Test and re-test to ensure proper application of FPGAs.
- Peer reviews are a vital part of mission design and development.
- Effective closed-loop tracking of actions helps keep everyone informed of progress or delays.
- Managing across organizational boundaries is always challenging. Don't let respect for partnering institutions prevent insight.
- Extra vigilance is required when deviating from full-system, end-to-end testing.
- System design must consider both nominal and off-nominal scenarios—and must take the time to understand and communicate anything that doesn't look right.



The WIRE telescope inside the cryostat assembly. Photo Credit: NASA

"I remind everybody constantly that we are all systems engineers," explained Fafaul. "I expect everybody, down to the administrative staff, to say something if they see or hear anything that doesn't seem right. Remember, you need to be a team to be an A team."

Despite the loss of its primary mission, the team managed to recover WIRE from its high-speed spin and a scientist developed a very successful secondary mission using the spacecraft's star tracker. WIRE began to study the oscillations in stars, releasing data that led to new scientific discoveries. WIRE continued to operate until the summer of 2011, when it returned to Earth.

About the Author

Bryan Fafaul has worked at the Goddard Space Flight Center since 1986 in a variety of technical and management positions. He has served as the mission manager for the Wide-field Infrared Explorer; instrument systems manager Hubble Space Telescope Servicing Missions 3A, 3B, and 4; deputy project managers for the National Polar-orbiting Operational Environmental Satellite System preparatory project; and project manager for Glory prior to his current position as the project manager for the Joint Polar Satellite System flight project.

GALEX: Managing the Unexpected

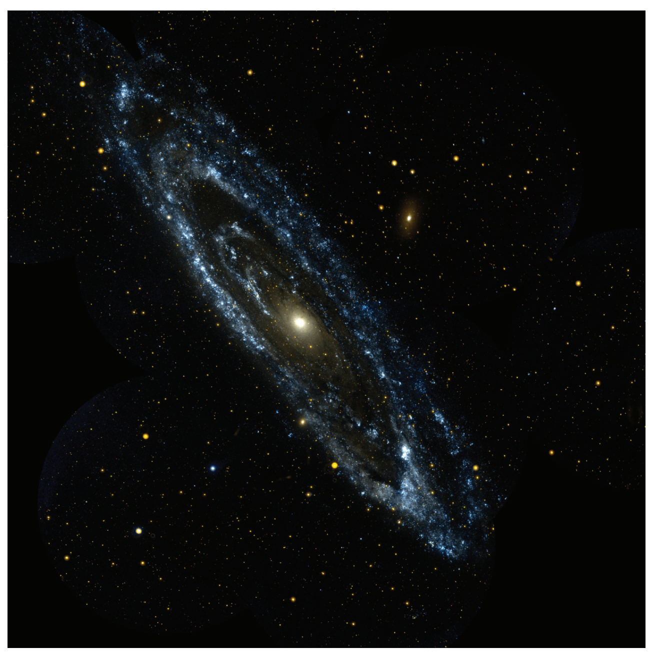
By James Fanson
Spring 2012, Issue 46

They say that good things come in small packages, and this has certainly been true for NASA's Explorer Program. Explorers are among the lowest-cost missions flown by NASA, but they can pack a big scientific punch. Such is the case with the Galaxy Evolution Explorer, or GALEX, a mission designed to map the history of star formation over 80 percent of the age of the universe. Since its launch nearly nine years ago, GALEX has transformed our understanding of how and when galaxies formed over time. Along the way, as the team anticipated, several unexpected and intriguing scientific discoveries have been made. What we did not anticipate was the gauntlet of technical and programmatic challenges that had to be overcome to get GALEX into orbit.

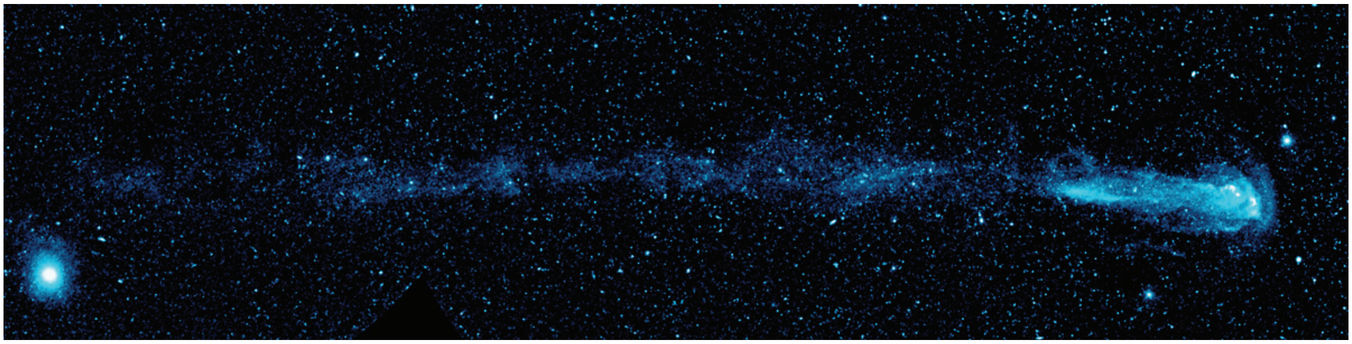
There's a widely held belief that smaller projects are easier projects. In reality, the difficulty of a project is measured by the ratio of available resources to the challenges being faced. Explorer missions by necessity have small budgets, so it's critically important to assemble the strongest possible team and ruthlessly constrain the magnitude of the challenges. This is easier said than done. Take staffing for example. Smaller missions have fewer team members, so each is more crucial. One needs the sharpest individuals with unusually broad skills. It can be difficult to recruit such people in organizations where importance is measured by the size of the budget managed or the number of direct reports.

In reality, the difficulty of a project is measured by the ratio of available resources to the challenges being faced.

Similarly, smaller missions have fewer instruments and components, but each element therefore tends to be mission critical. GALEX is a single-string, single-instrument design with very limited redundancy. This has two immediate implications: each element must have high reliability, and virtually no component can be eliminated. One of the most important tools available to the manager is the ability to "descope" items



The Andromeda Galaxy, or M31, is our Milky Way's largest galactic neighbor. The entire galaxy spans 260,000 light-years across—a distance so large, it took ten GALEX images stitched together to produce this view of the galaxy next door. Photo Credit: NASA/JPL-Caltech



An ultraviolet mosaic from NASA's Galaxy Evolution Explorer shows a speeding star that is leaving an enormous, 13-light-year-long trail. The star, named Mira (pronounced my-rah), appears as a small white dot in the bulb-shaped structure at right, and is moving from left to right in this view. Photo Credit: NASA/JPL-Caltech/C. Martin (Caltech)/M. Seibert (OCIW)

in order to contain cost. When each element is mission critical, the descope tool is limited to accepting lower performance from an element rather than eliminating it outright.

Recognizing these facts, GALEX's principal investigator, Chris Martin of Caltech, proposed a mission that was simple in concept and built around a team of experienced individuals and institutions. NASA selected the mission for implementation in late 1997. Thus set sail a hardy band of explorers into what would turn out to be an unusually stormy sea.

Keeping It Simple

The idea for GALEX was to fly a 0.5-meter-aperture telescope with a wide field of view together with two photon-counting detectors, one optimized for the near ultraviolet and one for the far ultraviolet. The detectors would simultaneously image a region of the heavens 1.5° in diameter via a dichroic beam splitter. A filter wheel would enable a grism—a combination of a prism and grating—to be rotated into the beam to produce spectra that could also be imaged on the detectors. The spacecraft would point the telescope at the desired location during the night side of each orbit and orient the solar panels to recharge the battery during the day side. Over a period of twenty-eight months, virtually the entire sky would be imaged. In practice there were some complications, such as not imaging stars bright enough to damage the detectors, but in general the mission design and architecture were quite simple.

We also felt that the mission required no new technology, but we were to learn otherwise. To achieve the required ultraviolet sensitivity, we needed photon-counting microchannel plate detectors. These make use of specially prepared, thin, porous glass plates supported at their edges, stacked and held at an electrical potential of several thousand volts. An individual photon of light striking the front surface of the detector produces a shower of electrons at the back. The location of the electron shower is measured by timing the arrival of electrical pulses with an array of very high-speed electrical circuits. While these techniques had been used in earlier detectors, they had not been implemented individually or in combination on detectors of the size required for GALEX.

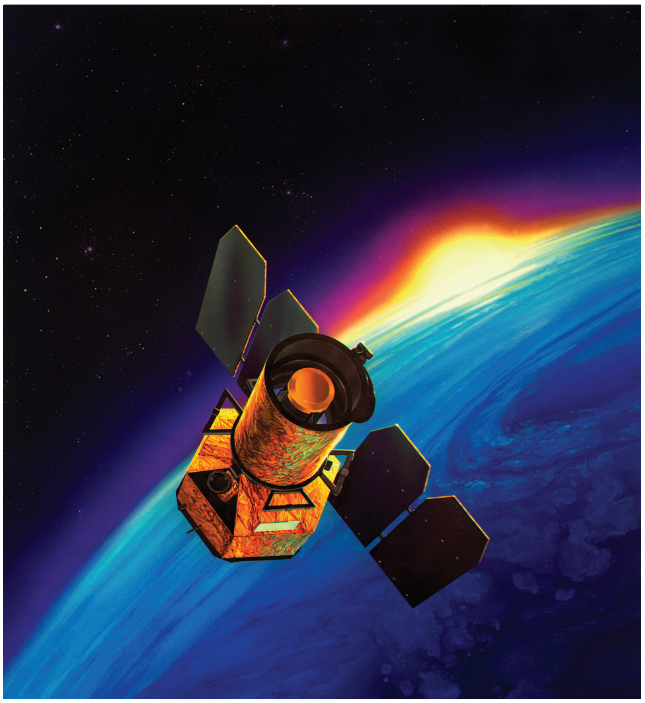
In the end the detectors proved very difficult to manufacture, even by the group at University of California–Berkeley, considered the best in the business at this type of device. By the time we collectively recognized this fact, it was too late to reduce the size of the detectors, so we persevered and accepted delivery many months behind schedule. We learned an important lesson: scaling technology is sometimes as difficult as maturing the basic technology in the first place.

Paradigm Shift

GALEX began implementation during the height of NASA's faster-better-cheaper era, a period characterized by the desire to find innovative approaches to reduce development cost, even if it meant tolerating and managing increased risk. In keeping with this paradigm, the GALEX implementation plan featured many cost-saving aspects, some of which involved cost and schedule risk. Interestingly, GALEX was confirmed with what today would be considered an absurdly low level of cost reserves: 10 percent, or about $5 million in total.

What we did not see coming was the dramatic change in risk acceptance following the loss of the Mars '98 and other smaller missions around this time. These mission failures sent a shock wave through NASA, which responded by overhauling the underlying implementation processes to be followed by every mission under development. By 2000, the paradigm had firmly shifted from "faster better cheaper" to "mission success first."

Many of the cost-cutting approaches taken by GALEX were no longer considered acceptable. The team came under major scrutiny by outside groups of reviewers trying to reduce mission risk. NASA attempted to compensate the team for the cost of these changes, but it was difficult to estimate what the budget ramifications of the new processes would be. In particular, we knew that buying risk down after the fact would be difficult, as key design decisions and part selection had already been made and implemented. It was an unpleasant transition for all concerned.



Artist's concept of the Galaxy Evolution Explorer. Its mission is to study the shape, brightness, size, and distance of galaxies across 10 billion years of cosmic history. The 19.7-inch telescope onboard sweeps the skies in search of ultraviolet-light sources.
Photo Credit: NASA/JPL-Caltech

Manage What You Can

Since we did not have the resources to oversee the detailed design of every subsystem or component independently, we relied on the expertise of the team members to identify where difficulties required additional attention or assistance. This worked well in most instances, but we dropped the ball in one important area—the detector readout electronics. While the Berkeley team was busy solving how best to build the photon-counting detector assemblies, the detector readout electronics were being designed and prototyped by a single design engineer. There were clear indications that he was overloaded, so the Berkeley team's solution was to isolate him from outside distractions. Being close to Silicon Valley during the dot-com boom, it was difficult for them to hire qualified electronics engineers at university pay scales, and they didn't want to lose their one key designer. Efforts to carry out peer review of his work or bring in outside help were resisted on the grounds that they would slow down the effort. We left the engineer alone. It was a mistake.

Another important lesson was learned: when faced with the dilemma of shoring up a flagging effort with new help at the expense of an added delay to bring that help up to speed, the right answer is nearly always to bite the bullet and bring in the additional help.

Close to the time the flight electronics were due to be delivered, the engineer suddenly resigned and left the university. When we looked at the state of the electronics, we discovered why: an important portion of the readout electronics didn't work and contained serious design flaws. The designer had been misleading us and his management about the status of the development. It took a crash program working with Southwest Research Institute to develop a replacement element. Another important lesson was learned: when faced with the dilemma of shoring up a flagging effort with new help at the expense of an added delay to bring that help up to speed, the right answer is nearly always to bite the bullet and bring in the additional help.

Survive Bolts from the Blue

Every project faces unknown unknowns, things that can't be anticipated. These events call upon the resilience and creativity of the team to overcome. GALEX faced an unusually large number of "bolts from the blue." One event on our mission particularly illustrates how extensive the consequences can be.

Our ITAR-Baby

In order to reduce cost, the spacecraft bus supplier, Orbital Sciences Corporation, selected radio equipment manufactured by a company in Britain. The S-band receivers and transmitter were delivered successfully, but the X-band transmitter was more challenging and took a bit longer to complete. Within weeks of the scheduled delivery, Orbital received a phone call from the company stating that they had declared bankruptcy and were being liquidated. If we wanted the incomplete X-band transmitter, we should show up with a final payment and take delivery at their loading dock.

We dispatched a contingent to pick up the hardware and as much design documentation as possible, and returned it to the United States. We approached the radio experts at the Jet Propulsion Laboratory, who explained that what remained to be completed was the staking and tuning of the circuitry, something that could only be done by someone intimately familiar with the design—in other words, they couldn't do it without the engineer who had designed it.

By this time the design engineer was employed with another company in Britain. We explored shipping the unit over to

The GALEX spacecraft before its launch in 2003. Photo Credit: JPL him but discovered that our export license was only for the company that had gone bankrupt; we could bring the radio into the United States, but we couldn't legally ship it back out. The next best thing was to bring the designer to the United States.

This is when we discovered that the designer was a dual British/Iranian citizen. Export-control regulations prohibit providing technical assistance to non-U.S. persons. Orbital explored the possibility of obtaining a Technology Assistance Agreement from the State Department to work with the designer but given his Iranian citizenship, they were encouraged not even to apply.

The last option was to bring the designer to the United States, set him up in an empty lab with a soldering iron and oscilloscope, and let him complete the staking and tuning. At the end of this exercise, we inspected his workmanship and concluded that the unit had been rendered unusable.

Being very short on time to find a replacement X-band transmitter, Orbital identified a potential replacement unit on another NASA spacecraft in their clean room. Several weeks of negotiation produced permission for us to cannibalize this hardware. The only problem was that it operated at a different frequency than our National Telecommunications and Information Administration license specified, and it used a different modulation scheme. One would think relicensing to another frequency would be straightforward, but it turned out that the new radio transmitted in a part of the X-band spectrum reserved for "downward"-looking vehicles (toward Earth) while GALEX was an "upward"-looking vehicle. We eventually got a special non-interference-based waiver approved. This left only the modulation problem—the way GALEX's data was packaged for transmission—which was solved by a crash program to build new demodulators for the ground stations located in Australia and Hawaii so the data could be "unpackaged" correctly.

Make It Work

The team found creative ways to survive various other bolts from the blue during GALEX: a vacuum-chamber failure that back-streamed diffusion-pump oil and contaminated the spacecraft bus; another mission's in-flight failure of the gyro we had selected, forcing the crash refurbishment of a replacement gyro we found; the sudden loss of liquid-nitrogen supplies on the eve of instrument thermal-vacuum testing because the Enron-driven electricity crisis in California shut down the liquid-air production plant.

Once every development challenge had been successfully overcome, we launched GALEX in April 2003 aboard a Pegasus XL rocket. The scientific return has surpassed our expectations. Looking back on the experience, I appreciate the tremendous training value of the GALEX development; just about every type of problem that could arise did arise. It taught me many lessons I've applied to missions that followed, and gave me a true appreciation that small projects can be just as difficult as the big ones.

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. © 2012 California Institute of Technology. Government sponsorship acknowledged.

About the Author

James Fanson's twenty-five-year career at the Jet Propulsion Laboratory has spanned technology development, instrument development, and flight project implementation. He was part of the team that repaired the Hubble Space Telescope; let the team that produced the preliminary design of the Spitzer Space Telescope; and, as project manager, led two telescope missions (GALEX and Kepler) to launch and early science operations.

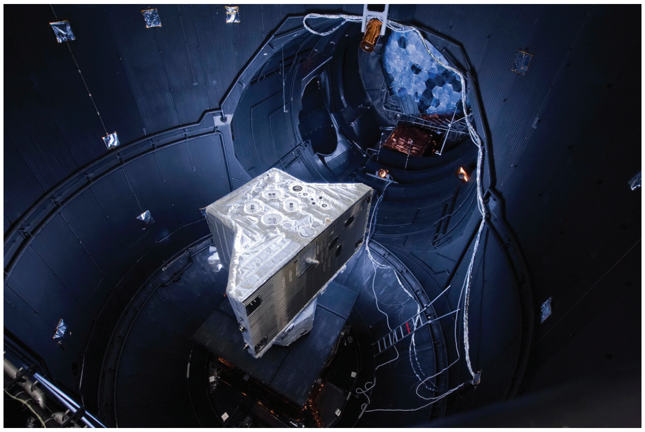
International Collaboration on BepiColombo

By Elsa Montagnon
Spring 2012, Issue 46

BepiColombo is a collaborative mission to Mercury between the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA) due to launch in August 2015. The mission is named after Giuseppe (Bepi) Colombo (1920–1984), an Italian scientist who studied Mercury's orbital motion in detail.

Dedicated to the detailed study of Mercury and its magnetosphere, the mission consists of two spacecraft, the Mercury Planetary

Artist's view of BepiColombo at Mercury. Image Credit: EADS Astrium



The structural and thermal model of the BepiColombo Mercury Planetary Orbiter in the Large Space Simulator at ESA's Test Centre in Noordwijk, the Netherlands, ready for a dry run in preparation for thermal-balance testing. Photo Credit: ESA

Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO). Both will be launched as a single composite spacecraft that also includes a dedicated propulsion module and a sunshield for the MMO. ESA is providing the MPO spacecraft, the MMO propulsion module and sunshield, the launch, the operation of the composite spacecraft until delivery of the MMO in its operational orbit around Mercury, and the operations of the MPO around Mercury. JAXA is providing the MMO spacecraft and its operations around Mercury.

This is the first time that ESA and JAXA have collaborated to such a large extent. I will try to address the questions of how the collaboration has been established and how it is working (including the effects and management of cultural differences) from my perspective as the BepiColombo spacecraft operations manager. My team and I are located at ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany. It is from there that we will control the composite spacecraft from its separation from the launcher until the MPO completes its scientific mission at Mercury, about eight years later.

THE MISSION

The scientific mission objectives of BepiColombo include exploration of Mercury's unknown hemisphere, investigation of the geological evolution of the planet, analysis of the planet's internal structure, investigation on the origin of Mercury's magnetic field and its interaction with solar wind, and characterization of the composition of the planet's surface. To accomplish these and other objectives, the MPO has a payload of eleven instrument packages, and the MMO payload complement includes five instrument packages designed to study fields, waves, and particles.

Launch is planned for August 2015 by an Ariane 5 from Kourou, French Guiana. The long cruise phase will include a combination of electric propulsion and gravity-assist maneuvers (once by Earth, twice by Venus, and four times by Mercury). Arrival at Mercury is currently planned for January 2022. After delivery of the MMO to its operational orbit and jettisoning of its sunshield, the MPO will finally reach its target orbit and start its scientific mission, which will last one Earth year, and may be extended by another Earth year.

My team and I are responsible for conducting composite spacecraft operations from the BepiColombo Mission Operations Centre (BMOC), located at ESOC. For communications with the spacecraft, we will use the ESA network of Deep Space Antennas and JAXA's Usuda and Uchinoura ground stations. After delivery of the two scientific spacecraft to their final orbits, we will remain responsible for operations of the MPO. In Japan, an operations team located at Sagamihara will be responsible for MMO operations. This team will interface with us until separation of the MMO from the composite spacecraft. Science ground segments in Europe and Japan will support the operations centers in the planning of scientific operations and archiving of scientific data. Finally, instrument operations will be supported by teams typically located at an instrument's home institution.

DEFINING THE COLLABORATION

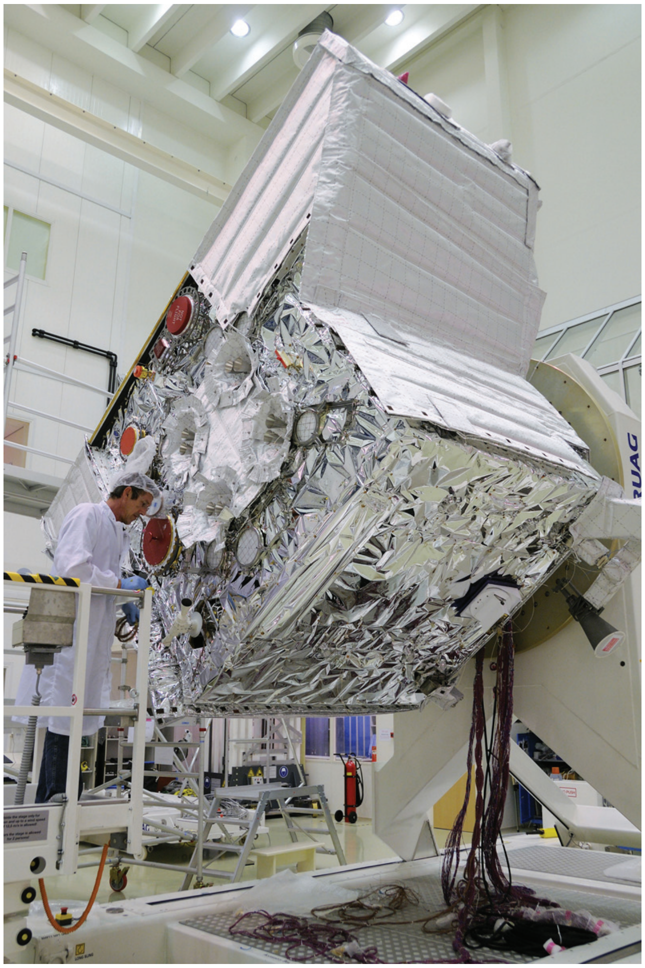
The collaborative mission was selected by ESA in 2000. Like all missions selected as part of ESA's mandatory science program, it underwent studies, first within ESA, then supported by the two main industrial prime contractors in Europe. Finally, at the beginning of 2007, a contract was placed with Astrium Germany to implement the European space-segment contribution.

The collaboration with JAXA on this mission was formalized in a memorandum of understanding signed in April 2007 by the ESA director general and the JAXA president. A slim document of fourteen pages, it establishes the framework of this collaboration in terms of responsibilities, management, handling of reviews, transfer of goods and data, access to scientific data, intellectual property rights, and release of public information. It was complemented shortly after by a program plan working out the principles outlined in the memorandum in more detail.

THE FIRST MEETING

Our first meeting with JAXA took place in October 2006 at ESOC. As the popular saying goes, "You never get two chances to make a good first impression." This meeting was therefore very important, as it would set the tone for the entire collaboration.

At ESA, we are used to handling international collaboration. We interact with colleagues from our nineteen member states as part of our daily work; our contractors may come from additional countries outside the member states. We work daily with industrial representatives and scientists from member states, as well as from long-standing partners such as the United States or Russia. These culturally challenging interactions are facilitated by an important though easily forgotten fact: most of these partners are familiar with the ESA environment. They normally know how we are organized, who does what, and what stands behind the job titles. When we met with our JAXA colleagues for the first time, all this was new to most of them, as their ways were to us.



The BepiColombo Mercury Planetary Orbiter structural and thermal model on its ground-handling trolley with the high-temperature thermal blankets (white) partially installed. The conventional thermal blankets (silver) are visible where the high-temperature insulation has yet to be fitted. Photo Credit: ESA

We therefore took care when defining the meeting agenda to dedicate time to background information on our centers and organizations. On the ESOC side, the meeting was chaired by my boss, the BepiColombo ground segment manager. At the beginning of the meeting, his boss, the head of the Mission Operations Department, which is responsible for spacecraft and ground-station operations at ESOC, joined to introduce himself personally to our Japanese colleagues and present the ESA organization, top-down, as well as a comprehensive overview of the missions being operated at ESOC.

We did not talk about how we would later work together, but focused on trying to understand each other's ways of doing business.

We then spent some time explaining our operations concepts to each other. We did not talk about how we would later work together, but focused on trying to understand each other's ways of doing business. Then we took them on a tour of ESOC's mission operations facilities.

The rest of the meeting was dedicated to discussing in detail all aspects of our interactions.

For this first meeting, we felt strongly that it was important to make responsibilities clear. While during meetings among European colleagues we do not normally evaluate statements by who is delivering them, we felt it would be very important to have topics explicitly covered by the person in charge of them in this first meeting with JAXA. We were also aware that our meetings occasionally become quite lively, with participants bringing up their views or opinions spontaneously on the subjects being discussed, sometimes even interrupting the speakers. We realized that this could blur the picture we were trying to establish, and therefore agreed that we would try to avoid that in the meeting.

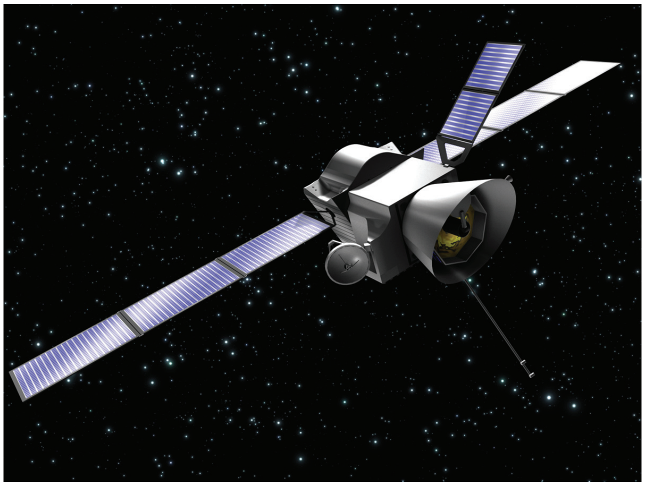
The meeting took two full days. We had about ten ESA participants and eight from JAXA. On the evening of the first day, we arranged to have dinner together at a nearby restaurant.

One of the cultural differences manifested in meetings with our JAXA colleagues is their approach to internal communications. The MMO project manager or the ground segment manager normally handles all interactions with other MMO team members, communicating with their team in Japanese and with us in English. This pattern remains the same whether the team is physically located with us, as was the case for the first meeting, or connected by phone or videoconference, as is now mostly the case. This has certainly contributed to removing the language barrier almost completely, since our interlocutors are fluent in English. On our side, there are now more spontaneous interventions from the team than in the first meeting, but JAXA's way of communicating helps keep discipline on our side.

Setting Up Interfaces

We have been holding yearly operations interface meetings since 2008. The initial meetings were aimed mainly at clarifying the requirements each agency placed on the other, in preparation for the ground-segment requirements review, which took place in November 2009. Our Japanese colleagues adopted very easily the ground segment interfaces that we proposed, based on our experience with other external agencies. But cross-support requirements needed to be consolidated in more detail. We have worked with JAXA to produce an implementation agreement, working out the responsibilities and services outlined in the program plan in detail, and as many interface-control documents defining the technical details of the relevant interfaces as necessary. Some of these documents—for instance, regarding ground station cross-support—are specific to the JAXA interface; others are shared across all external partners.

Some of the interface work has required considerable discussion, flexibility, and creativity. For instance, the MPO–MMO onboard interface is such that we are blind to what JAXA is uplinking to the MMO. This raises a concern on the difficulty for the two centers to support near-real-time interactive MMO operations, as is typically the case during near-Earth commissioning. We raised this point in the very first meetings with JAXA, and JAXA came back with their own



This artist's view shows the two BepiColombo orbiters mounted on top of their transfer module, forming a single composite spacecraft. Image Credit: ESA/C. Carreau

concerns on the matter in 2010. After analysis of the MMO database structure, we came up with some ideas on how to improve the visibility by extra nonstandard processing of the data blocks by our systems. Requirements have been placed and are being implemented.

Another specific aspect of this collaboration is the availability of technical documentation. JAXA only produces a subset of their documentation in English. We specified and justified very early on in the project the information to be shared with ESA. It is being provided either in a document in English, or translated in English within a document in Japanese. Instead of full documents, there have been cases—for instance, for joint reviews—where JAXA has summarized the review-relevant information in the form of viewgraphs. Though the amount of information we get access to is limited compared with what is normally available on a space program, it has until now been compatible with our needs.

Outlook

We are now moving into the ground segment implementation and operations preparation phase. A lot remains to be done, but we are benefiting from having established personal and formal interfaces with our JAXA colleagues early. Thanks to the preparatory work, the scope of the activities lying ahead of us is well-defined.

Any joint decisions with JAXA take a long time to prepare. Our Japanese colleagues do not normally make decisions during the interface meetings. The meetings are used to collect information, discuss issues, and endorse prepared decisions. So far, this has not been a problem, but it requires careful attention in the preparation and timing of the meetings.

I have taken Japanese lessons regularly between 2004 and 2011, and have been to Japan twice, in 2005 and 2009. Neither trip was related to BepiColombo. When I started learning Japanese, I was mostly interested in getting exposure to a non-Western culture. At that time, BepiColombo was very much in the background and did not enter into my decision to study the language. I will never speak nor read Japanese fluently—I study too little for that—but I have developed a keen sensibility for the Japanese culture. This experience has changed me, and certainly influences the way I handle the interaction with our JAXA colleagues.

The collaboration with JAXA is an aspect of the mission that I enjoy a lot. It is undoubtedly one of the challenges of the BepiColombo mission: we carry the huge responsibility of delivering the MMO spacecraft safely into its orbit. We have managed to establish a relationship based on mutual trust and respect. Though not sufficient, it is a necessary condition to overcome the difficulties expected on the way.

About the Author

Since 2007, **Elsa Montagnon** has been leading the flight control team for BepiColombo, the ESA–JAXA cornerstone mission to Mercury. Her responsibilities include the specification, acceptance, and validation of the ground segment preparation; validation of flight operations plans and procedures; and build-up and training of the flight control team.

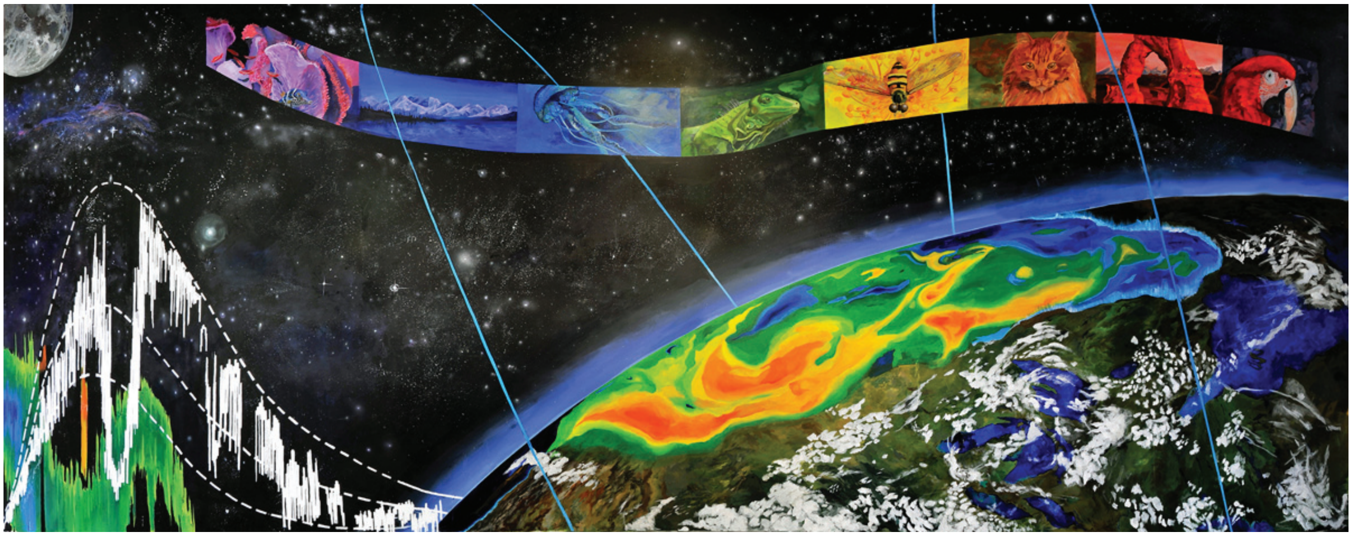
CLARREO: Bringing Disciplines Together

By David Young

Spring 2012, Issue 46

CLARREO, the Climate Absolute Radiance and Refractivity Observatory, is an Earth-science satellite mission in pre-Phase A (conceptual study) that is being designed to capture critical climate-change data much more precisely than has been possible with existing instruments. Its spectrometers, sensitive to the full range of infrared and visible radiation, will improve the accuracy of measurements of all the radiation leaving Earth by a factor of two to ten. That accuracy and the mission's ability to measure trends over a decade or more could help scientists know whether climate change will be less or more severe than expected as much as two decades earlier than current data allow. This could be a key determinant for decisions concerning our nation's response to changes in climate.

So it's not surprising that the 2007 decadal survey of "Earth Science and Applications from Space" considered CLARREO one of four high-priority Earth-science missions. In response to the survey, a small team of scientists was formed at Langley Research Center to define the mission. In early 2009, we gathered a full-fledged preformulation team including scientists, systems analysts, discipline engineers, and business analysts at Langley along with smaller teams at Goddard Space Flight Center and the Jet Propulsion Laboratory and about ten external organizations with the goal of developing a feasible concept for CLARREO.



A mural painted by summer student Amanda Cichoracki to represent CLARREO's mission.
Photo Credit: NASA Langley Research Center/David Beals

Bringing the Team Together

Having worked on other NASA science missions, including CERES (Clouds and the Earth's Radiant Energy System) and CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations), mission scientist Bruce Wielicki, mission formulation manager Steve Sandford, and I were well aware of a familiar pitfall—that the CLARREO scientists would want only the best possible data regardless of the practical difficulties involved in getting it. That would lead to time-consuming and potentially acrimonious trade talks when scientific desires came up against engineering and budget realities. To avoid that kind of problem, we were determined to bring the team together early and make the science and engineering decisions part of one discussion, not two. From the outset, the management team had a vision of forming a truly interdisciplinary team that involved systems thinking at all levels.

We began by holding a two-day off-site retreat, facilitated by 4-D team-assessment experts. The 4-D Systems approach focuses on critical "soft skills" for scientists, engineers, and project leaders. The retreat included some typical team-building activities, such as people talking about their backgrounds to get to know one another, but most of the team building came from doing actual project work: establishing a clear shared vision of the mission, defining roles and responsibilities, and dealing with bottlenecks that had already become evident by diffusing authority that was concentrated in one overworked individual. The 4-D facilitators also provided the team with training that helped us appreciate the benefits of continual engagement across the diverse skills of the team.

Back at Langley, the entire team was collocated in an open area that had once been a cafeteria. There were no closed offices, only cubicles and multiple meeting areas, so everyone was aware of what his or her colleagues were doing. The project leaders worked in cubicles, too, and were always accessible. We had not only an open-door policy, we had a no-door policy. This resulted in a dynamic, collaborative environment that furthered the bonding process that started at the retreat.

Although at times noisy and a bit chaotic, this arrangement made it easy to join in conversations and address issues as they arose. On multiple occasions, I was able to quickly provide clarification of technical aspects of the science in response to conversations in our break room. We encouraged systems thinking by including science and engineering representatives at almost every technical meeting. Communication was further enhanced through daily, early-morning, stand-up meetings to share late-breaking news and set daily priorities.

Our integration initiatives went beyond the Langley team. Internal and external science team members participated in weekly telecons in the first year as scientific goals and priorities were clarified. We also worked actively to bridge the common gap between scientist-observationalists, who focused on how to gather data, and the data users, who wanted the best possible data and didn't give much thought to issues related to the instruments that would gather it. We brought several teams of global climate modelers who would be the primary CLARREO data users into our requirements planning from day one. That has led to the development and use of innovative climate-observing system-simulation experiments that have not only demonstrated the utility of CLARREO data for improving climate predictions, but have been essential in setting rigorous accuracy requirements for the measurements.

The Science-Value Matrix

The most significant result of our integrated approach has been the development of the science-value matrix (SVM). This tool has helped clarify our trade discussions and weigh scientific value against cost, risk, and reliability as fully and objectively as possible. Like other work on CLARREO, developing the science-value matrix was a cooperative team effort.

The relative merits of competing goals are difficult to quantify for a complex mission with multiple science objectives. This is particularly true for a mission like CLARREO, where the measurements are applicable to a wide range of climate objectives. Without an objective means of calculating science benefit, our team could not effectively evaluate the relative costs and benefits of multiple engineering approaches. We met this challenge by developing the SVM: an innovative approach to quantitatively defining science value for key aspects of the mission, including measurement accuracy, orbit type, and record length. Benefits were measured based on the specific advances that CLARREO would provide in reducing uncertainties in the climate observations as defined by the Intergovernmental Panel for Climate Change. By rigorously defining relative science value across the broad climate objectives of CLARREO, the team provided a mechanism for optimizing science value relative to cost for a broad range of potential mission architectures.

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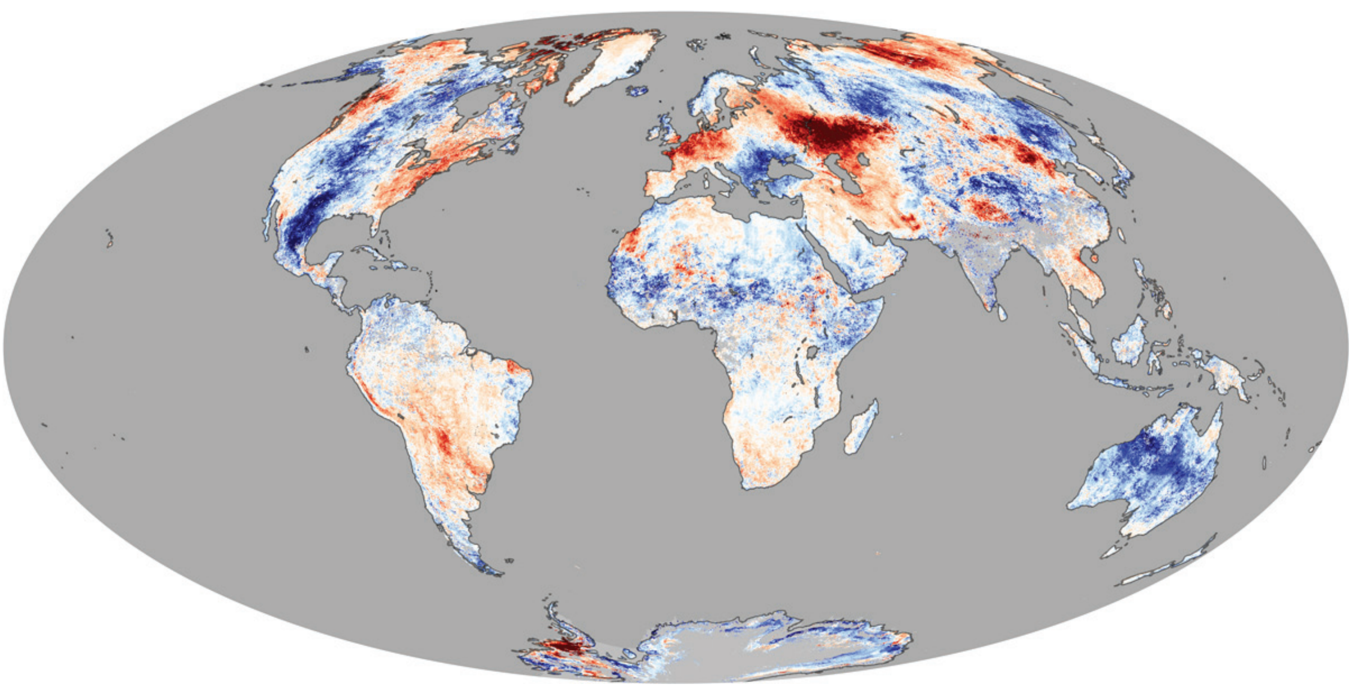
The SVM was also designed to be a management tool to be used over the project's life cycle. The matrix grounded and shaped discussions in objective fact and helped avoid what could otherwise easily have become formless, inconclusive debates. It definitely helped us guard against mission creep—the temptation to add just one more capability that could quickly lead to losing control of budget and schedule.

For instance, members of our external science team advocated the addition of a polarimeter that would use the polarization of light to analyze aerosols (particles suspended in the atmosphere) to CLARREO's instruments. They wrote a peer-reviewed paper arguing for the instrument. In fact, it would have been a potentially great addition, since aerosols influence the amounts of absorbed and reflected radiation. The question was, how would that added value compared to the added cost? The SVM allowed us to determine that a polarimeter would give us 30 percent added value but would raise the cost by 30 percent as well. Headquarters agreed that the instrument was a great idea but decided it was a great idea we couldn't afford within the CLARREO project.

The Future of CLARREO

The CLARREO team successfully passed its mission concept review in November 2010. The effectiveness of team integration was confirmed by the review panel's board chair, who cited the exceptional working relationship among science, project management, and engineering as a major strength of the project, leading to a mission concept that was extremely mature for that project stage. Due to budget considerations, CLARREO remains in an extended pre-Phase A.

NASA continues to fund efforts to refine the mission design and to look for cost-effective alternative ways to carry it out. For instance, we are examining the possibility of putting the instruments on the International Space Station instead of on their own satellite observatories. We have also been working on a study with a group in the United Kingdom, exploring possibilities for international partnering. And we are using the science-value matrix to search for a less expensive way to achieve the mission's science goals, perhaps with less capable but still adequate instruments.



This global map shows temperature anomalies for July 4–11, 2010, compared with temperatures for the same dates from 2000 to 2008. CLARREO's ability to measure trends over a decade or more could help scientists know whether climate change will be less or more severe than expected as much as two decades earlier than current data allow. Image Credit: Jesse Allen, based on MODIS land-surface temperature data available through the NASA Earth Observations web site.

The budget constraints are challenging, but we remain committed to this critical climate mission. This team experience has been one of the most rewarding of my career, and I believe that the trust and cooperative spirit the CLARREO team has developed in our years together will help us succeed despite these challenges.

ABOUT THE AUTHOR

David Young is the project scientist for CLARREO at Langley Research Center, where he has been working for more than thirty years to help understand Earth's climate. He currently serves as the deputy for programs in the Langley Engineering Directorate.

The Sky Crane Solution

BY DON COHEN
Summer 2012, Issue 47

The challenge was clear: how do you safely land a 2,000-lb. rover on the surface of Mars? Curiosity, as the Mars Science Laboratory is called, has nearly twice the mass of the landers that put Spirit and Opportunity on Mars in early 2004, and more than three times that of the Pathfinder lander that reached the planet in 1997. It is significantly larger than the Viking landers that touched down in the seventies.

For all these missions, entering and descending through the Martian atmosphere and putting an undamaged lander on the surface (the mission phase known as EDL, for entry, descent, and landing) has been technically demanding. It is much harder than landing on the moon—in part because of the planet's greater mass and gravitational pull, but especially because Mars has an atmosphere that heats and exerts shear forces on objects moving rapidly through it, as well as strong winds that can blow a spacecraft off course. And the relative thinness of Mars's atmosphere (it is less than 1 percent as dense as Earth's and as rarified at the surface as our atmosphere is at 100,000 feet) means it is not substantial enough to slow and land a sizeable spacecraft with frictional heating and parachute drag alone—the method used for Apollo and Soyuz space capsules returning to Earth.

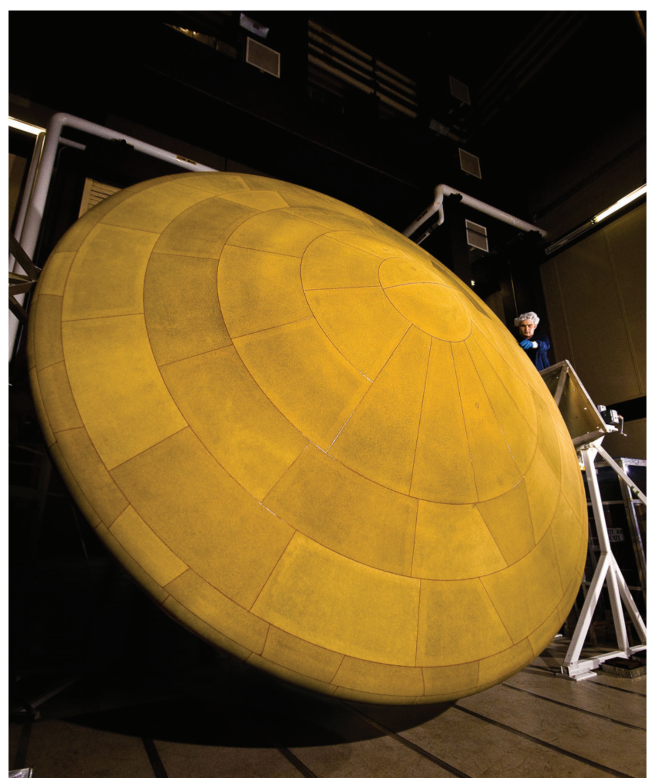
Past Mars missions have used a variety of techniques to solve the problem. The Pathfinder and Mars Exploration Rover (MER) missions used parachutes and retrorockets to slow the spacecraft and airbags to cushion the landers and rovers when they dropped to the surface. But the Mars Science Lab (MSL) team quickly determined that airbags would not be a viable solution for something as big as Curiosity. An airbag system designed to accommodate the size and mass of Curiosity would be very large and heavy and significantly different from the Pathfinder and MER designs. In addition, egress from the top of the deflated airbags and lander platform is a complex and tricky maneuver; it would be even more complex with an airbag design large enough for Curiosity.

Along with the huge difficulties presented by the physics of landing a large spacecraft on Mars, there are the challenges and pitfalls inherent in any ambitious mission—the mistakes to be avoided, the risks to be anticipated and eliminated or minimized. As Miguel San Martin, who designed the guidance and navigational controls for the mission, says, "There are the problems Mars creates for you, and the problems you create for yourself." A lot of learning, experience, design, testing, and review has gone into solving or avoiding both kinds of problems.

The novel solution the MSL team has developed is what they refer to as a "sky crane." After reducing its speed through a combination of atmospheric friction, parachute, and retrorockets, a descent stage with Curiosity hanging from it in a bridle of nylon tethers will use its thrusters to essentially hover as it lowers the rover to the surface—"a way of landing without landing," in the words of Steven Sell, who is responsible for verification of the EDL system. After touchdown, the bridle will be cut and a 6-second burn will ensure the descent stage crashes some 400 meters away.

LEARNING FROM THE PAST

After the failures of the Mars Surveyor and Mars Climate Orbiter missions in the late 1990s, it became clear that a Mars sample-return mission projected to launch in 2003 would be canceled. Knowing the mission would not go forward but still funded for a time, the sample-return team decided to



The finished heat shield for Mars Science Laboratory, with a diameter of 4.5 meters, is the largest ever built for descending through the atmosphere of any planet. Photo Credit: NASA/JPL-Caltech/Lockheed Martin

This artist's concept shows the sky crane maneuver during the descent of the Curiosity rover to the Martian surface. Image Credit: NASA/JPL-Caltech

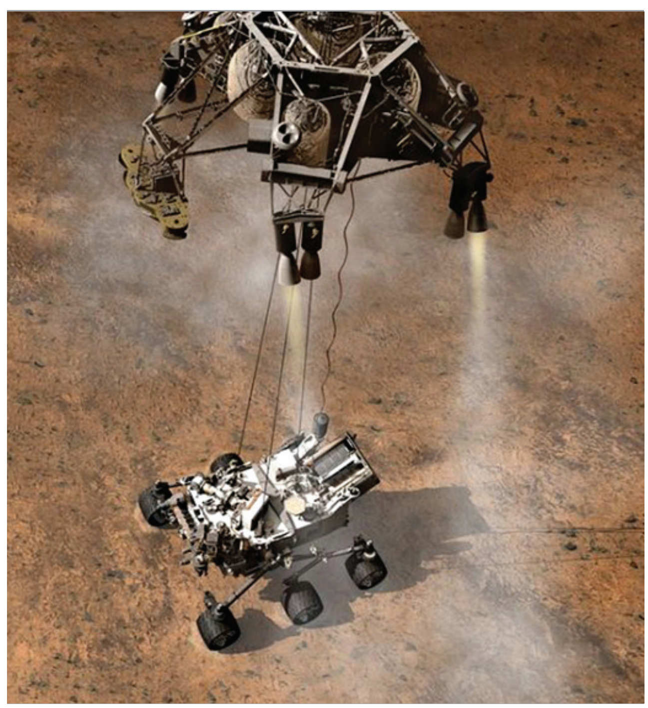
devote their efforts to going back to first principles and think about all the ways to design a lander and put it safely on the surface. One of the questions they explored was whether it was possible to get velocity control so good that you could land a wheeled rover directly on the surface, rather than cocooned in a lander. (At the time and for a couple of years afterward, the answer was "no.") Rob Manning, now the chief engineer for Curiosity and, years earlier, the chief engineer for Mars Pathfinder, wrote to the chief engineer of the sample-return team, asking, "Have you thought about 'helicopter mode?'"—what was also known at the time as "rover on a rope." This was 1999, and they passed on the idea for fear of the two-body pendulum dynamics inherent in the architecture. With two bodies connected by tethers, there was concern over the potentially chaotic dynamics of the swinging pendulum motion that might result. Ultimately, this was a controls problem.

The concerns of the sample-return team represented an essential hurdle for the creation of Curiosity and the sky crane. Perhaps the key ingredient to getting past that hurdle was the experience San Martin had taken from MER development. MER had taught San Martin that he could effectively steer the pendulum and control the two-body dynamics, the key requirement to attempt what would be called the sky crane maneuver. The MSL EDL team even brought in a helicopter pilot from Sikorksy to apply his experience to plans for EDL. As Manning says, "Had they started from scratch, they never could have achieved this."

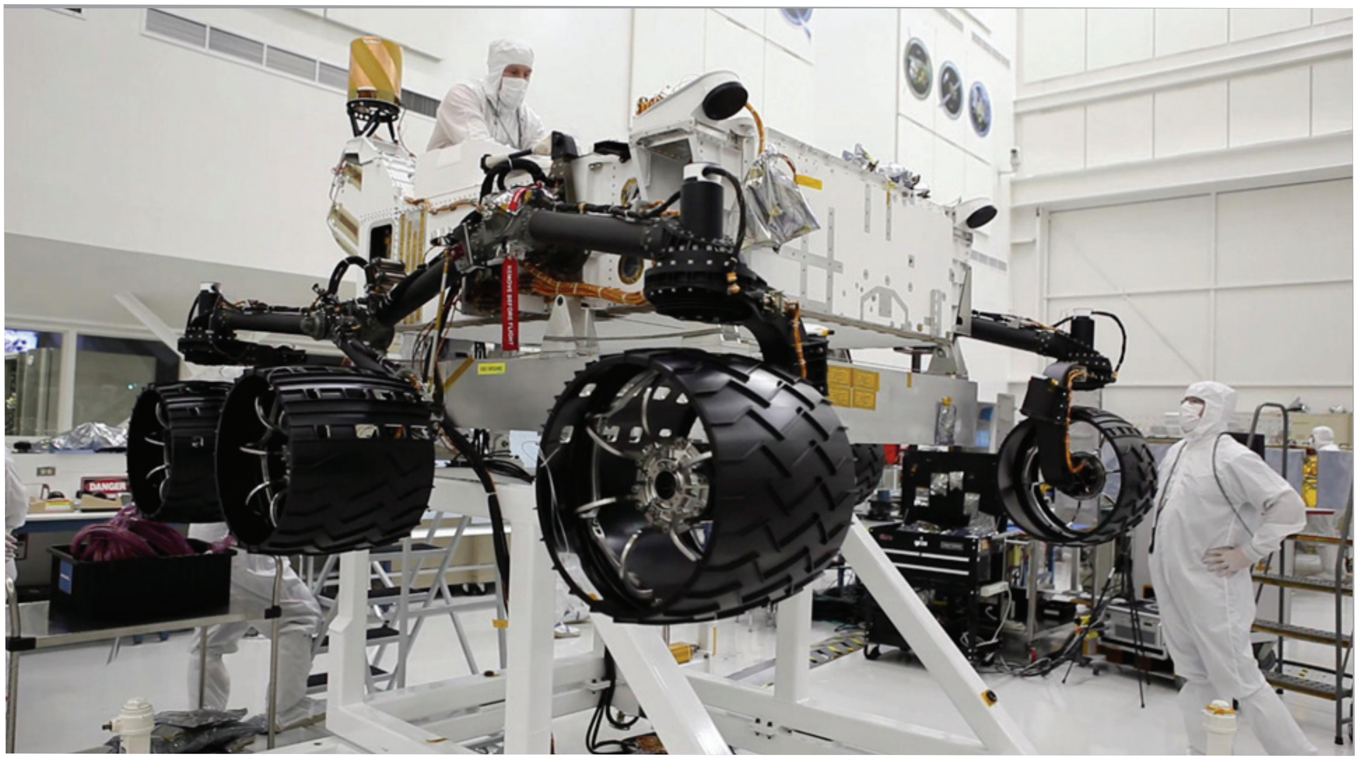
The sources of earlier experience they drew on included the Viking mission, which reached Mars more than three decades earlier. The engines on Curiosity's descent stage are an upgraded "reinvention" of Viking's throttleable engines, which the MSL team developed by studying available Viking documentation (which was not as comprehensive as they'd hoped), talking with Viking people, and reverse engineering still existing Viking-era engines. According to one team member, they "scrounged up" all the Viking data they could, a search that included locating an informative film of a Viking parachute test in the attic of a NASA retiree.

Parachute experience on Pathfinder and MER has also contributed to the MSL design. Getting as much information as possible about the behavior of large supersonic parachutes has been essential, especially since the MSL chute will be larger and will deploy at a higher speed than similar systems on past missions.

Another issue is the danger of aerodynamic interactions between the reaction-control system thrusters and the atmosphere, which, in the worst cases, can result in control reversal. As the plumes of retrorockets flow over the backshell of the descent stage, they can generate forces—like the lift created by air flowing over an airplane wing—that create undesired motion contrary to the intended one. The MSL design had to avoid that possibility. The team again went back to study their history, looking at Mercury, Gemini, and Apollo data; they even took a trip to the Virginia Air and Space museum to look at one of the few Apollo capsules. The EDL team deployed a series of cutting-edge computational fluid dynamics analyses and scaled tests to select thruster positions and orientations and verify that the resulting aerodynamic interactions were acceptable. The MSL team even passed on their finding to the Phoenix team, a tip that led the Phoenix staff to choose to turn off their entry reaction-control system for fear it might generate control reversals.



An artist depicts the moment that NASA's Curiosity rover touches down onto the Martian surface. Image Credit: NASA/JPL-Caltech



Engineers working in a clean room at the Jet Propulsion Laboratory installed six new wheels on the Curiosity rover.
Photo Credit: NASA/JPL-Caltech

MSL's large heat shield was another challenge. The team determined that the shield material they originally planned to use would not survive the shear forces created as the spacecraft entered the Martian atmosphere at high speed. The team wanted to use SLA-561V, which had worked on all the past Mars missions from Viking on. They baselined SLA and started testing it. The old standard seemed to be working until some of the final tests in June 2007, when things went very wrong.

"I was presenting the state of our EDL development at the project CDR [critical design review]. We thought everything was going well, including the TPS [thermal-protection system] testing, which was almost complete," said Adam Steltzner, who led the EDL development for MSL, "when all of a sudden my cell phone starts vibrating in my pocket with news of a TPS testing failure. The SLA had just dissolved in testing—complete failure!"

They were short on time for the 2009 launch and needed to solve this problem quickly. The team conducted a rapid search of possible replacement materials in a short-turnaround, make-or-break trade. "We really did not have much time to make the 2009 launch date," said Steltzner. They ended up with a heat shield made of PICA (phenolic impregnated carbon ablator). A lightweight PICA heat shield had been used on the Stardust sample-return mission, and SpaceX uses a PICA shield on its Dragon capsule. NASA's Crew Exploration Vehicle (CEV) team studied the material extensively. Although they eventually decided not to use PICA, their research was a tremendous boon to the MSL team.

That CEV work is one of many examples of research and experience elsewhere in NASA contributing essential knowledge to Curiosity. As Manning says, "The NASA community as a whole should be proud of MSL. Only Apollo and shuttle have brought NASA together to this extent."

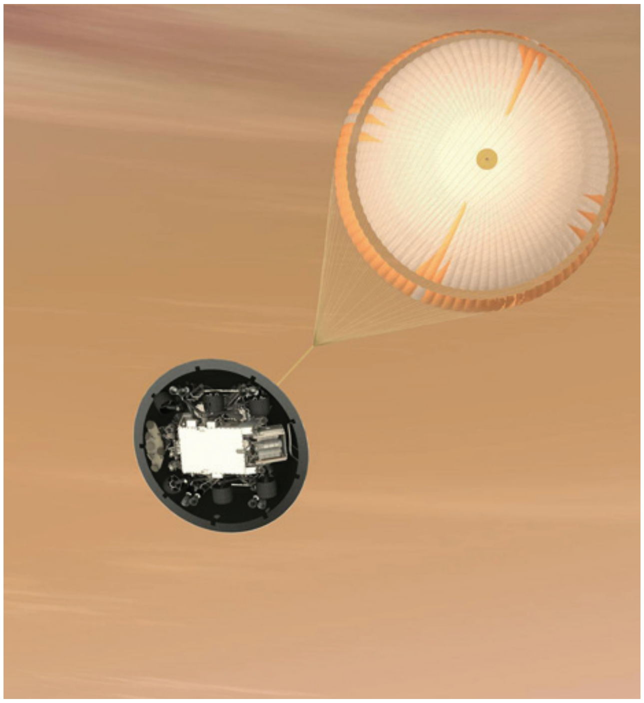
There were challenges, but, says San Martin, "No developmental shoe dropped during design and development"—that is, no major weaknesses in the concept were uncovered. Early, relatively small surprises meant small tweaks, but, he adds, "The final product looked like the early sketches." That is a testament to a well-conceived design, a point of pride for San Martin, arguably the most important contributor to the sky crane's architecture.

Although the team was able to get the EDL systems for Curiosity ready in time for the 2009 launch, the rover's wheel-drive actuators and avionics hardware could not make the launch date. The project ultimately slipped to the next favorable date for launch to Mars, in 2011.

THE SKEPTICS TEST

Convincing people outside the team that the sky crane was the right solution for Curiosity took some doing, maybe because it is hard for people to give up their long-standing idea of what the "right" landing architecture is—that is, setting down on legs with the engines below the lander. That describes the lunar landings, of course, as well as the classic landing procedure in hundreds or thousands of science fiction stories and films.

The MSL team rounded up skeptics—veterans of Viking, Apollo, and the Delta Clipper reusable launch vehicle program, among others—to test themselves, to "make sure we're not all drinking the Kool-Aid together." As expected,



The Mars Science Laboratory mission will use the largest parachute ever built to fly on a planetary mission. Image Credit: NASA/JPL-Caltech

the assembled skeptics picked at details of the plan, saying, "I don't trust this; I don't trust that." A main concern was those two-body pendulum dynamics that had stopped the use of the architecture the first time back in 1999.

A year later, when they brought the group together again, the team had solid answers to all those concerns. The process was repeated—more doubts expressed; those doubts set to rest a year later—until the skeptics were convinced and the team was confident that the sky crane would work.

No Mars mission is certain, obviously, but the team believes the likelihood of a successful EDL is very high. "We have margin all over the place," says system engineer Al Chen. Other team members agree that the risks are lower and the margin for error greater than on past Mars landings. In part, that is the result of having analysis and simulation tools that are an order of magnitude better than what was available for earlier missions. More computer power means better virtual testing; they have carried out more than 2,000,000 Monte Carlo landing simulations—randomly generated possible sequences of events played out on computers.

Partly, though, the sky crane landing architecture is clearly more robust than other options. For instance, landing on Curiosity's six wheels is inherently more stable than landing on legs. With a landing on legs, accurate touchdown detection is critical because a retrorocket burn of even a few milliseconds too long threatens to tip over the lander. A wheeled rover like Curiosity has much more leeway—a full 1.5 seconds for cutting the bridle connecting the rover and the descent stage.

Planning for the Future

As ambitious as it is, the Mars Science Laboratory mission is only one step in the ongoing history of planetary exploration. Vividly aware of how important their own learning from past missions has been, the MSL team is taking care to store documents detailing their work in an EDL repository that will be available to future project teams.

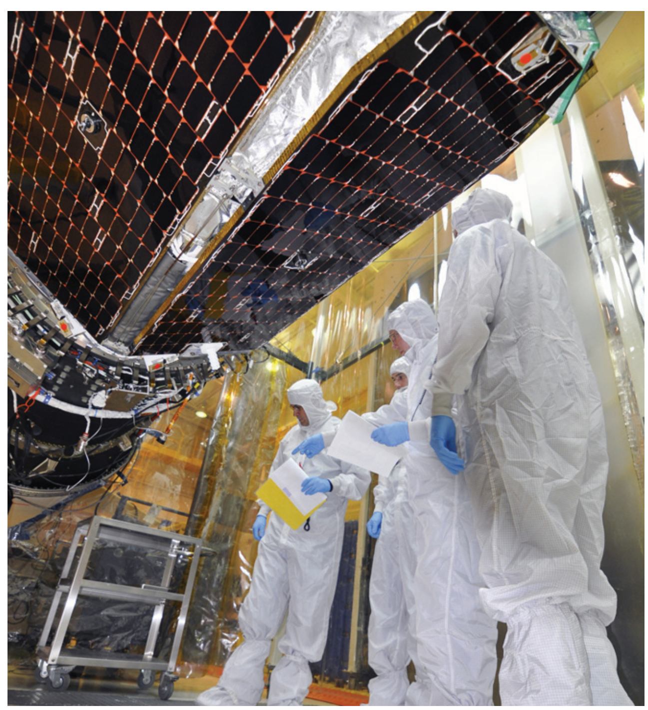
Equally or more important, they say, at least in the near term, is that "people will spread out." Just as veterans of Pathfinder and MER brought their hard-earned expertise to MSL, members of the MSL team will go on to join other project teams and apply the knowledge they gained from their Curiosity work to the next generation of entry, descent, and landing challenges.

Learning from the NuSTAR Launch Delay

By Don Cohen
Fall 2012, Issue 48

NuSTAR, the Nuclear Spectroscopic Telescope Array, contains the first focusing telescopes designed to look at high-energy X-ray radiation on orbit. It is expected to contribute to a better understanding of collapsing stars and black holes.

Because NuSTAR is designed to function in an equatorial orbit, it launched on a Pegasus XL rocket from a point south of Kwajalein Atoll, in the Marshall Islands, on June 13, 2012. Built by Orbital Sciences Corporation, the Pegasus is carried to approximately 39,000 ft. by an L-1011 aircraft. Released at that altitude, the three-stage, winged rocket ignites its first-stage motor to continue its journey to orbit.



Engineers in the final stages of assembling NuSTAR. Photo Credit: NASA/JPL-Caltech/Orbital

Technicians review their checklists after joining NASA's NuSTAR spacecraft with the Orbital Sciences Pegasus XL rocket.
Photo Credit: NASA/Randy Beaudoin

The June launch came almost three months after a planned early March launch date. The story of that delay—why it happened and what both NASA and Orbital Sciences learned from the experience—offers insight into how NASA deals with technical risks and into the agency's developing relationships with commercial providers of launch vehicles and spacecraft now and in the future.

Why the Launch Delay?

Two issues needed to be resolved before NuSTAR could be approved for launch. One involved the Pegasus fairing—the streamlined shell at the nose of the rocket that protects the payload during its climb to orbit. The Pegasus fairing hardware was similar to that of the Taurus XL, which had failed to separate on two recent NASA missions; its added weight kept the Orbiting Carbon Observatory and the Glory spacecraft from reaching orbit. The cause or causes of those failures had not been definitively determined—the rockets fell into the sea so there was no physical evidence to examine. The Pegasus fairing had been somewhat redesigned to reduce the likelihood of a similar failure, but that created its own uncertainty, since the new design had never been tested in flight.

A second issue had to do with the fact that the flight computer aboard Pegasus and the associated flight software and simulation software were new. This change was a jointly funded reliability improvement by Orbital and the NASA Launch Services Program (LSP) to replace an obsolescent, out-of-production industrial microcomputer (albeit with two decades of excellent performance) and bring the flight software and simulations up to current standards. Initially, the fairing issue seemed the more serious of the two. That expectation changed. The team studying the fairing issue concluded that the risk of a malfunction was minimal; the software concerns proved harder to resolve. NASA's software team expressed growing concern over the lack of adequate simulation and test data.

Reliable simulation data are essential. Omar Baez, NuSTAR's launch director, notes, "Rockets are not forgiving," and Director of Launch Services Jim Norman adds, "All the vehicles need to reach 17,000 mph. Errors are amplified by the energies expended." And, as NASA Chief Engineer Mike Ryschkewitsch points out, the only live "test" for a rocket is an actual launch. New aircraft, by contrast, can be tested bit by bit through a series of increasingly demanding flights that start by determining basic airworthiness and eventually map the limits of safe performance. Simulations matter for aircraft design and construction, too, of course, but not as critically.

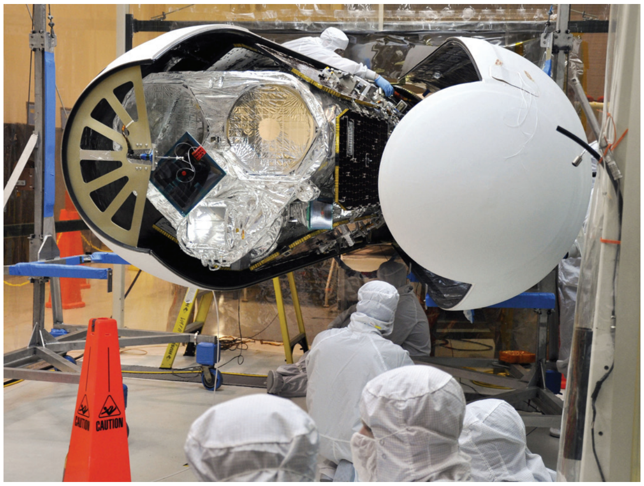
Although data were arriving late from Orbital, the LSP technical team worked extremely hard to execute the plan during February and early March, and the mid-March launch date still seemed achievable, provided no further serious issues were identified. Unfortunately, as the date for the all-important guidance, navigation, and control review approached, both Orbital and LSP were finding that simulations exhibited far too many failed cases to proceed.

With Orbital management responding to the magnitude of the problems, the contractor was providing large quantities of data and the LSP flight-analysis team demonstrated an ability to process it quickly and accurately. Suspected errors identified by NASA were being confirmed by Orbital right up until the night before the Flight Readiness Review (FRR). Both the LSP and Orbital teams put in extremely long hours that did not compromise the rigor and careful technical review and risk analysis. The LSP flight-analysis team held a final five-hour peer review on March 14, where every finding was either closed or identified as still open. Their rigor and diligence in the face of a launch deadline is an example of technical excellence not compromised by schedule pressure.

Late on March 14 it became clear that Orbital could not resolve all the remaining items without making changes to the flight code and simulation models. The technical team informed management, and the launch opportunity was scrubbed.

"Take the Time to Do It Right"

Part of the NuSTAR story is about the support the mission team got for carrying out the analytical work that needed to be done, even if that meant a delayed launch. Because the Kwajalein Atoll launch site was reserved for a classified mission after the NuSTAR March launch window, taking more than a few extra days to resolve the technical issues would force the



An Orbital Sciences technician completes final checks of NASA's NuSTAR inside the Orbital processing facility before the Pegasus payload fairing is secured around it. Photo Credit: NASA

mission to wait months to launch the spacecraft. Realistically, the team was looking at a delay of at least three months and the extra costs associated with it.

NASA has long been sensitive to the tension between technical risks that need study and possible mitigation and the desire—sometimes the pressure—to launch on schedule. The 1986 Challenger disaster brought the issue into tragic prominence. Reluctance to delay that launch was one of a complex of organizational factors that led to the disaster. Since then, the agency has improved its FRR process and practice to ensure all technical issues are heard and discussed, and that "launch fever" does not drown out voices expressing concerns about unresolved risks. (See "Getting to 'Yes': The Flight Readiness Review," by Matthew Kohut and Don Cohen, in the Winter 2010 issue of *ASK Magazine* for the story of a series of FRRs and technical work done before STS-119 was cleared for launch.)

Virtually everyone involved with NuSTAR agrees that technical teams got strong support for doing the work necessary to ensure a successful launch. Some individuals say they heard "mixed messages" from leadership—both "take all the time you need" and "hurry up and get it done." Certainly the desire to solve the problems and launch as soon as possible was clear, but the strongest and most consistent message seems to have been "do it right."

NuSTAR mission manager Garrett Skrobot recalls the meeting where Ryschkewitsch said, "If you guys need the time, take the time to do it right." Recalling the delay discussion later, Ryschkewitsch commented, "It was a hard conversation, but not really that hard"—suggesting that, although no one welcomes a launch delay, it was clearly the right choice in this case.

Mike Luther, deputy associate administrator for programs in the Science Mission Directorate, communicated the same message, saying, "We won't launch until we're ready."

Amanda Mitskevich notes that the project carried out regular extensive teleconferences with stakeholders about progress on the technical issues. The entire NuSTAR community (which included Goddard Space Flight Center, Jet Propulsion Laboratory, Orbital Sciences, and NASA Headquarters, among others) knew what was happening: why the delay was necessary and what was being done to resolve the software issues. So there were no groups within NuSTAR pushing for an earlier launch or expressing frustration because they were out of the loop and did not understand what was going on.

As a result of extensive support and good communication, Mitskevich believes, the teams working on the technical issues were not especially burdened by what she calls "additional pressure" to solve the problems faster—that is, in addition to their own internal drive to do the work thoroughly and as quickly as possible.

As soon as the specific nature of the difficulties came to light, the Orbital and NASA engineering and management teams blended complementary technical approaches to identifying and solving problems. The mutually reinforced technical rigor overcame problems in a relatively short time, while the management teams cooperated to delay the launch to give the engineers the breathing room they needed to implement all necessary fixes and validations.

If Orbital was initially largely "reactive" to NASA's concerns, it soon became much more proactive and constructive. What could have been an adversarial situation developed into a partnership. Both Orbital and NASA software teams worked "tremendous hours" to solve the problems, according to Baez. And Orbital began reviewing simulation software for other vehicles on its own initiative.

Later in the spring and comfortably before the rescheduled launch date, NASA and Orbital had made enough progress to be confident they would be ready to OK that June launch.

Some Lessons

Baez notes that the NuSTAR experience was "a software education for a lot of people." Certainly the problems were a reminder that software has grown to be an increasingly complex and absolutely critical element of all space missions. Failing to give it the attention it deserves invites disaster. (For a good analysis of this issue, see "Is Software Broken?" by Steve Jolly in the Spring 2009 issue of *ASK*.) The generally high morale of the NuSTAR technical team was tempered by the nagging suspicion that if software testing had occurred sooner—a prudent approach for new code and simulation tools—many of the problems could have been caught and corrected earlier.

In the case of Pegasus, NASA and Orbital failed to fully anticipate the difficulty in maintaining communication, continuity, and comprehension of the full software and simulation as a coupled system. This complexity added to the now obvious rationale to start simulation and software testing sooner.

The more general lesson, Skrobot points out, is that any new element in a launch vehicle should be looked at as early and as thoroughly as possible. Figure out what the hard questions are, says Skrobot, and ask them.

The L-1011 "Stargazer" carrier plane that gave NuSTAR and its rocket a lift to their airborne launch site is seen at sunrise on Kwajalein Atoll in the Pacific Ocean. NuSTAR and its Pegasus XL rocket are strapped to the bottom of the plane.
Photo Credit: NASA/JPL-Caltech/UCB

Toward a New Way of Working

The NuSTAR launch delay experience is important beyond this particular mission because it is a step toward defining NASA's developing working relationship with the commercial providers of launch vehicles and spacecraft that will be an important part of NASA's future. Both NASA and those companies are in the process of learning what they need to do—individually and together—to produce launch vehicles that are reliable but also relatively economical and profitable for their creators.

NASA has never developed rockets on its own, of course. Boeing, Douglas, Lockheed Martin, and other aerospace companies have had a major role in designing and building the Atlas, Saturn, Delta, and other launch vehicles the agency has depended on until now. But those vehicles were the products of extremely close (and expensive) cooperation between NASA and those contractors. In effect, those vehicles were jointly designed and extensively tested by both NASA and contractors.

Today, commercial companies like Orbital Sciences and SpaceX are building new rockets with much less direct involvement and oversight from NASA. The agency needs to be sure that these new vehicles are reliable, but must do it in ways that allow those companies to keep their costs down, ultimately reducing the cost to NASA as well.

In other words, NASA needs to develop—and is developing—some version of what Ryschkewitsch calls "parenting mode," trying to find the right balance of guidance and help on one hand and letting commercial providers make and correct their own mistakes on the other. Being too involved—asking for too much documentation or too much testing to prove reliability—reduces risk but drives up cost when the rationale for the new relationship with commercial developers is to find less expensive ways to send cargo and crews into space.

The NuSTAR experience is helping NASA and Orbital learn to define that balance. For a time, NASA may have been too hands-off in regard to the software issues. As Skrobot suggests, it is important to ask the hard questions. The lesson for NASA may be to carefully target its "parental" oversight—to identify the potential problem areas early and focus attention and resources on them. Asking tough questions about everything would be intrusive and wastefully expensive; asking the right tough questions is essential. Knowing what those questions are is not necessarily easy, though, except in hindsight. James Wood, LSP chief engineer, says, "I don't know how to ask the mythical 'hard questions' and neither does anyone else."

As NASA reduces its traditional high level of oversight, Orbital and other commercial providers need to ensure they devote the resources necessary to ensure vehicle reliability. Having a relatively lean team is important to efficiency and therefore profitability, but they need to know when lean is too lean. As NASA's "parenting" becomes less intrusive, their responsibility for quality and performance increases.

Testing or Flight Success

There are, notes Ryschkewitsch, two ways of determining acceptable risk: testing and documentation, or a history of flight success. Seventy to eighty successful Soyuz flights are a reasonable substitute for a lot of testing and documentation. Vehicles recently developed or under development obviously don't have that kind of flight history. Building a record of success through flights whose failure would not harm crews or programs is one strategy for developing the next generation of vehicles. So, for instance, NASA was willing to let SpaceX take responsibility for the launch of the Falcon 9 and Dragon that carried cargo to the International Space Station in May and October 2012. NASA's main involvement was ensuring that the approach and docking would work and not endanger the station. The success of that flight is (ideally) the beginning of a track record that will give NASA confidence in the reliability of a vehicle designed without extensive agency oversight.

Similarly, the successful NuSTAR launch helps build confidence in the current version of the Pegasus. That success and all the testing done are important preparation for the next Pegasus-based mission. The fairing analysis done for NuSTAR similarly will serve future missions. As part of the analysis, the NASA team removed a tiny piece of the frangible joint of the Pegasus fairing hardware to test its hardness. This made NuSTAR people unhappy, as would any change to their launch vehicle, no matter how small, but the information gained will benefit the Interface Region Imaging Spectrograph, which is expected to launch via Pegasus in 2013, and later missions.

But the flight-success criterion is not always as straightforward as it sounds. Pegasus had been in operation for more than twenty years before the NuSTAR launch and has had more than forty successful flights—the kind of success record that normally inspires confidence. But the modified fairing design and new flight computer and software had *not* been flight tested and therefore needed oversight. And this is far from a unique or even an unusual problem; long-lived launch vehicles frequently have some elements that become obsolete or unavailable and must be replaced—and tested to ensure their reliability.

An additional way to manage the new oversight relationship, Ryschkewitsch suggests, is to have NASA engineers sit in with commercial designers as companies develop their new vehicles or new vehicle elements. If the NASA people are satisfied with the design process and testing within the company, they recommend the appropriate (limited) amount of documentation NASA should require.

Shaping a New Partnership

Whatever ultimately characterizes the relationship between NASA and the developers of future launch vehicles, it is certain that it will be shaped by experiences like NuSTAR and the Falcon 9 program. The general outlines of what will be required are clear now—less control by NASA, more responsibility taken on by the commercial companies. But precisely how the partners should work together—the details that fill in that general outline—can only be developed through multiple experiences of facing and solving problems like the NuSTAR software issues.

Since every NASA mission has some unique elements, that learning process will continue, with better and better understanding of the potential and pitfalls of the new relationships. In the new environment the agency is operating in, NASA's Launch Services Program is both the pathfinder and the partner in a new way of working.

The Human Factor

International Life Support

By Kerry Ellis
Fall 2011, Issue 44

Supplying oxygen is only one of many life-support necessities for human spaceflight, but it's obviously one of the most vital. The main oxygen-generation system aboard the International Space Station has a backup system to ensure breathable air is always available. It is known by various names: the solid-fuel oxygen generator or SFOG; Vika; and TGK, an acronym for the Russian name of the system. In September 1999, one year before Expedition 1 was to launch the first crew to station for an extended duration, the TGK was undergoing urgent testing in Moscow because of a life-threatening accident.

Originally designed by the Russian Federal Space Agency, Roscosmos, the TGK provided additional oxygen for the Mir space station when more than three people were on board. It created oxygen by igniting a solid, oxygen-rich compound within a canister, commonly referred to as a "candle." About the size of a fat spray can, one candle contains nearly a liter of lithium perchlorate and, when burned, could provide enough oxygen for one crewmember for one day. The same system exists on civilian aircraft, using smaller candles per row to provide oxygen if those yellow masks pop out from the overhead compartment.

Astronaut Edward T. Lu, Expedition 7 NASA ISS science officer and flight engineer, eats a meal in the Zvezda service module on the station. The TGK system can be seen in the upper left without the ceramic mitigation screen in place. Photo Credit: NASA

Cosmonaut Sergei K. Krikalev works with the European Space Agency Matroshka radiation experiment in the Zvezda service module of the International Space Station. In the upper right of the foreground is the TGK backup oxygen system, with the ceramic mitigation screen in place. Photo Credit: NASA

Since the TGK had been tested and proven, first by the Russian space agency and then by NASA when plans for the International Space Station (ISS) assembly were being drawn up, the newly formed international team agreed it was the best supplemental-oxygen system available. During the assembly process, most of the TGK system—renamed the SFOG within NASA—launched to the ISS.

In February 1997, a TGK candle aboard Mir malfunctioned and burst into flame. The metal tube that contained the reactive, oxygen-producing chemicals inside the candle began to burn in the increased oxygen concentration, launching globules of molten, flaming metal into zero gravity that splattered onto the opposite bulkhead. The fire was a "raging blowtorch," according to American astronaut Jerry Linenger, who was on board during the accident. "I've never seen smoke spread like it did on Mir," he said. Crewmembers used three fire extinguishers to put out the fire, adding clouds of steam to the smoke filling the cabin. Russian cosmonaut Aleksandr Lazutkin recalled the accident in a BBC documentary: "When I saw the ship was full of smoke, my natural reaction was to want to open a window. And then I was truly afraid for the first time. You can't escape the smoke. You can't just open a window to ventilate the room."

Those involved in the still-developing ISS immediately shared the fear of the system having a similar accident aboard station, and both NASA and Roscosmos began their own investigations. Since all evidence of what had caused the mishap had burned during the incident, those on the ground had no definitive proof of what had gone wrong.

Meeting in Moscow

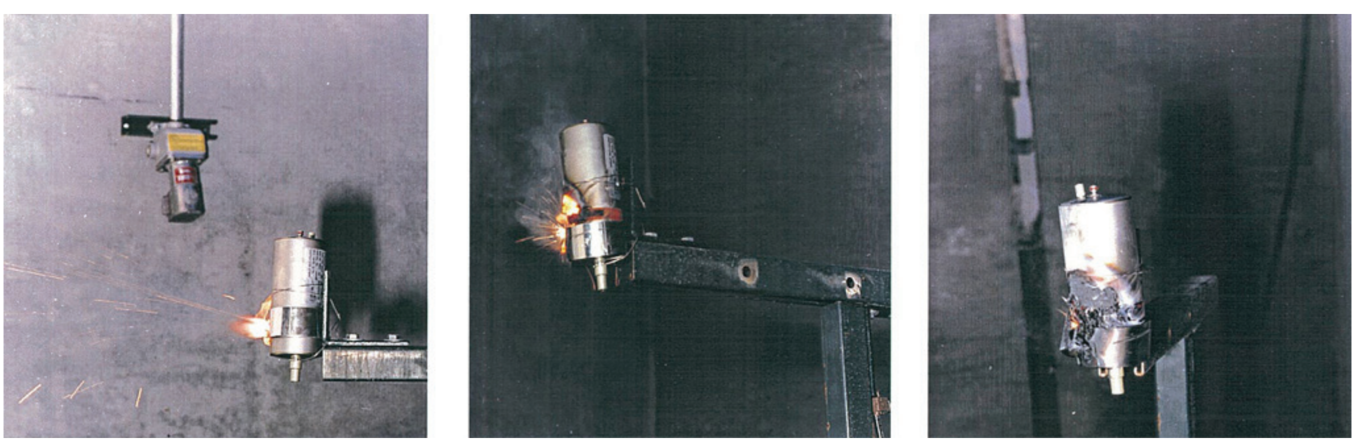
In the two years following the accident, after testing other options and designing their own alternative, NASA determined the TGK was still the best option available for the backup oxygen system. During that time, Russia worked to improve the safety of the candles and to develop a fire-resistant screen to help mitigate a fire in case another candle malfunctioned. To learn more about their improvements and mitigation efforts, NASA sent a team to Moscow.

David Urban, a microgravity scientist from Glenn Research Center, and Harold Beeson, an expert on materials flammability in high-oxygen conditions from White Sands Test Facility, arrived as part of that team in August 1999. Frank Buzzard, who was then the ISS chief engineer, paved the way for the new collaboration to go as smoothly as possible.

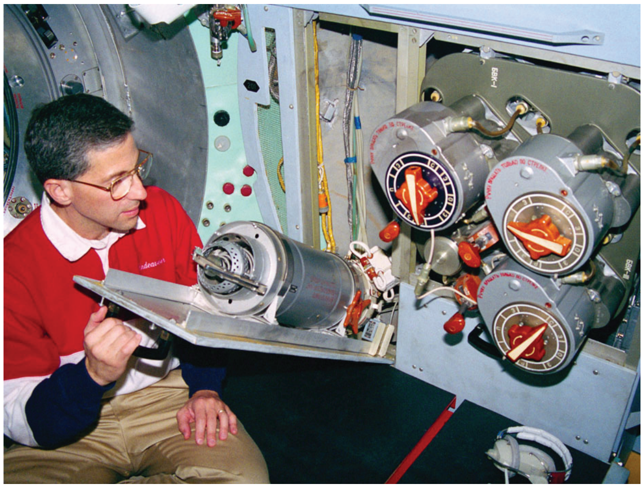
"The culture there is very different than NASA," said Urban, "things that are beyond the language. In a NASA meeting, you would have a printed copy of PowerPoint slides in front of you. In Moscow, a question would be asked, and one piece of paper would come out of a folder to circulate around the table and then go back."

There was also a delicate political balance to maintain.

"You didn't want to be the ugly American that's standing back and saying, 'You had a failed system,'" Beeson explained. "We wanted to make sure that we could build the team that was



After igniting a contaminated candle, a fire begins and progresses (from left to right) to a flame jet, then slows down until the fire stops. Photo Credit: NASA



Astronaut Jay Apt looking at a solid-fuel oxygen generator like the one that caught fire on Mir. Photo Credit: NASA

trying to solve this problem, with everybody's focus on the problem and not on assigning blame."

"We had to convince them that we were there to work with them and not there to shoot the system down," added Urban. Part of showing their support for all the work the Russians had done was to refer to the system by its original Russian acronym, TGK, instead of the NASA acronym, SFOG.

The team needed to collaborate well, and quickly. The remainder of the TGK system and additional candles were already on board the first Progress spacecraft to supply the ISS.

In an attempt to foster good relationships at the outset, the NASA contingent would invite their Russian teammates to lunch each day. "It took us a week to get them to let us eat with them," recalled Urban. The first day the NASA team arrived, the Russians said they should plan for lunch and recommended a restaurant. "We all loaded up into the van when lunchtime came and pulled up outside the restaurant. We get out, and none of them come in. Fortunately, astronaut Sandy Magnus was there, who spoke more Russian than the rest of us, so she helped us interpret."

Urban and Beeson quickly learned that the restaurant was not affordable for their Russian teammates, but the Russians were unwilling to take their NASA colleagues to their cafeteria. A few days later, they visited a remote testing site. "The guy who ran the site had been to NASA in Cleveland, so he was more comfortable with us, and we went to the cafeteria," said Urban.

"That was great."

"When we actually went to their cafeteria and were able to eat with them, sit down with them, that helped," added Beeson. "A meal is always a good thing to share."

The working relationship among the team swiftly improved after that. Urban explained, "We'd built a familiarity, they were relaxing, we had spent some time together and communicated during meetings."

The plan that then developed included the Russian team preparing four TGK cassettes designed to ignite while NASA's White Sands Test Facility would make several copies of a TGK simulator that could be burned up in testing. The Russians would provide a test facility, the protective screen, and support staff to operate the experiments. White Sands had to create a simulator that captured the major features of the TGK and would interface with the Russian system. Paralleling these decisions were discussions about providing support analysis of the heat and product released from an event of this type. This would allow them to more easily share the results of their respective testing.

"Everybody came to understand that this event was something that could happen again," said Beeson. Because most of the TGK was already in space and limited funds prevented Russia from building an on-the-ground fixture for testing, NASA would build the test system and Russia would provide the candles and fire-mitigation screen they had developed. In one month, they would bring the pieces together to see how the modified TGK performed.

Testing with Limited Time

NASA's team had a little over one month to design, build, test, and ship a TGK test unit to Moscow. Since the original TGK evidence had burned up on Mir, NASA's microgravity and combustion experts had to first recreate the accident as best they could. This would allow them to verify if the protective screen the Russians designed for the system would successfully mitigate a fire.

Russia's extensive testing after the Mir fire resulted in several theories about the cause of the accident, but the definitive cause could never be known since the fire destroyed the evidence. "They found two techniques that would do it, and one of them they thought was more plausible than the other," explained Urban. "Either they had a small piece of material in the ignition system that was mismixed so it had more energy-producing material that would cause the reaction to run away, or they had a small amount of contamination inside the canister—such as a four-square-centimeter piece of rubber glove folded in between the interior and side wall. There were people wearing rubber gloves when making the canisters, so they believed that was the obvious cause." Using these theories provided a basis for the joint NASA–Roscosmos testing.

Once the test fixture was completed, NASA shipped it to Moscow in a 4 x 4 x 6–foot crate. "The TGK itself is not a huge unit," Beeson explained, "but we had to design and put together the test stand and holders for the canisters. We had to include a way to interface our ignition system with their canisters, and also ship all our tools and instrumentation. We needed to measure thermal levels so we could understand if their mitigation screen was getting too hot. We shipped everything, including our welding goggles, because this is molten metal burning, and you don't want to be viewing that with your naked eye."

The NASA team reunited with their Russian teammates in Moscow in mid-September, where all the pieces would finally come together for joint testing. Astronauts and cosmonauts who had experience with the TGK provided their insight as well. This included astronaut Sandy Magnus, who was assigned as a "Russian Crusader" in 1998 and had been traveling to Russia to support hardware testing and products development, and cosmonaut Aleksandr Lazutkin, who had witnessed the 1997 Mir fire. "He came in for a short period of time to view the videos of fires we had created at White Sands, and he was able to say, 'That's what that fire looked like in Mir,'" said Beeson. This helped confirm that they were creating a fire large enough and hot enough to stress the system and mitigation screen.

The screen itself was made of ceramic and provided a housing, much like a fireplace, to control any fire that might occur and contain molten metal that could fly off a burning canister. It covered the back, sides, and bottom of the system and included a front screen to prevent spatter but allow oxygen to filter through for the igniting spark required for the candle. The screen withstood the joint testing in Moscow, but the team discovered an issue with operating procedures the Russians had provided for the screen.

"The original operations concept required the astronauts to have the fireplace screen at the ready, but they wouldn't necessarily attach it unless they had a fire event," said Beeson. "We questioned that. And once we lit off the first canister, it became clear to the Russians that it was not going to be an appropriate operations concept. They saw just how much molten, burning metal was coming off the canister." As a result, the operations concept changed. Once the astronaut placed the candle in the TGK, he or she would install the screen before igniting the canister.

A little over one year later, in October 2000, Expedition 1 launched with the first crew to take up residence aboard ISS. And while the TGK system has changed a little over the years, it has not experienced a fire since its installation on the station.

A Memorable Beginning

The ISS did not have a smooth start. When the program was announced, Russia was still recovering from the social and political turmoil of perestroika, the United States did not have long-duration human spaceflight experience, and both countries were figuring out how to work together after the end of the Cold War. But amid such chaos, individuals from NASA and the Russian Federal Space Agency were able to create cohesive teams. Ensuring the TGK was safer and ready to sustain life aboard the biggest, newest internationally collaborative effort was just one of many instances of this teamwork.

"There's things in your career that you really remember," said Beeson. "This is one of those. I really felt like I had a direct contribution to the astronauts' safety, which is so important to us. And understanding this failure and successfully working with our international partners to mitigate it was a memorable event. We worked with a great team."

Building the Future Spacesuit

By Dava Newman
Winter 2012, Issue 45

The BioSuit is a "second-skin" spacesuit that would allow for greater degrees of freedom in movement.
Photo Credit: Professor Dava Newman: Inventor, Science Engineering; Guillermo Trotti, A.I.A., Trotti and Associates, Inc. (Cambridge, MA): Design; Dainese (Vincenca, Italy): Fabrication; Douglas Sonders: Photography

For the past dozen years, I have been working with colleagues and students here at the Massachusetts Institute of Technology (MIT) and with collaborators in various disciplines from around the world to develop a new kind of spacesuit. My hope is that the astronauts who some day walk on the surface of Mars will be protected by a future version of what we are calling the "BioSuit™."

Beyond the Balloon

The suits that kept NASA astronauts alive on the moon and those worn by Space Shuttle and International Space Station crewmembers for extravehicular activities (EVAs), including the Hubble repair missions, are technological marvels; in effect, they are miniature spacecraft that provide the pressure, oxygen, and thermal control that humans need to survive in the vacuum of space.

MIT student Kristen Bethke works on the BioSuit knee joint. Photo Credit: Professor Dava Newman: Inventor, Science Engineering; Guillermo Trotti, A.I.A., Trotti and Associates, Inc. (Cambridge, MA): Design; Dainese (Vincenca, Italy): Fabrication

The greatest problem with these suits is their rigidity. The air that supplies the necessary pressure to the bodies of wearers turns them into stiff balloons that make movement difficult and tiring. These suits are officially known as EMUs— extravehicular mobility units—but they allow only limited mobility. Astronauts who perform repair work in space find the stiffness of spacesuit gloves especially challenging: imagine manipulating tools and small parts for hours wearing gas-filled gloves that fight against the flexing of your fingers.

The suppleness of these gloves is improving. Aerospace engineer Peter Homer has won two NASA Centennial Challenge competitions with designs that add an X-shaped bit of fabric to finger joints, creating a kind of hinge that increases dexterity. But that improvement, though significant, has been made within the context of the fundamental limitations of a glove that remains a gas-filled bladder.

Future space exploration will be expensive. If we send humans to Mars, we will want to maximize the work effort and science return. One contributor to that efficiency will need to be a new kind of spacesuit that allows our explorer-astronauts to move freely and quickly on the Martian surface. That could be the BioSuit.

A New (and Old) Approach

The BioSuit is based on the idea that there is another way to apply the necessary pressure to an astronaut's body. In theory at least, a form-fitting suit that presses directly on the skin can accomplish the job. What is needed is an elastic fabric and a structure that can provide about one-third of sea-level atmospheric pressure, or 4.3 psi (approximately the pressure at the top of Mt. Everest). The skintight suit would allow for a degree of mobility impossible in a gas-filled suit. It also would be potentially safer. While an abrasion or micrometeor puncture in a traditional suit would threaten sudden decompression puncturing the balloon and causing a major emergency and immediate termination of the EVA—a small breach in the BioSuit could be readily repaired with a kind of high-tech Ace bandage to cover a small tear.

The mechanical counter-pressure spacesuit is not a new idea. Physiologist Dr. Paul Webb introduced the concept in the late sixties and developed a prototype in the early seventies. It was a great idea that came before its time, in my opinion; advanced materials that could exert the necessary pressure on the skin were not available then. In addition, the wearer needed help getting Webb's prototype suit on and off (as do astronauts donning and doffing existing spacesuits), which results in expensive downtime for astronauts. A really practical BioSuit would be one the wearer could don and doff herself in, say, less than ten minutes.

In the late nineties, colleagues and I revived Webb's innovation and began work on second-skin spacesuit designs. Our hypothesis was that new developments in materials (for instance, Spandex and its more sophisticated polymer descendants) plus supportive patterning of the material could make a successful counter-pressure suit feasible.

Learning Together

Thanks to some funding from the NASA Institute for Advanced Concepts, we were able to gather a team to begin the practical work that would test our hypothesis. Students have been part of the core team from the beginning. Like most research at MIT, the spacesuit work is about teaching as well as practical results. MIT engineers and biomedical engineers are part of the team, as is Jeff Hoffman, a professor who has flown on five shuttle missions, including a Hubble repair. As someone who has worn and worked in current operational spacesuits, he can use his experience to tell us where we may be going wrong in our design.

Collaborators outside the MIT community include Trotti and Associates, an architectural and industrial design firm in Cambridge, Mass.; engineers from Draper Laboratories; and Dainese, an Italian manufacturer of motorcycle racing "leathers"—leather and carbon-fiber suits designed to protect racers traveling at up to 200 mph.

Bringing together designers from Trotti and Associates and students from the Rhode Island School of Design and my MIT engineering students has greatly influenced the way our groups work. In our early sessions together to realize a second-skin spacesuit, my engineering students spent much of their time hunched over their laptops, calculating and analyzing the governing equations, while the designers—visual thinkers—took out sketchbooks and immediately started drawing to attack the problem. After working together for weeks, the engineers got more comfortable with the idea of sketching solutions and some of the designers added Matlab and its more analytical approach to their repertoires. We all ended up better off.

We have "collaborated" with researchers from earlier eras, too. Not only Paul Webb (still active, he is an advisor to our team), but also Dr. Arthur Iberall, a physicist who did important work on mobile spacesuits. He died in 2002, but his daughters—happy to see his work continued—gave me access to his papers. We have expanded his great idea of a pattern of three-dimensional lines on the body that do not extend by deriving the mathematical representation and visualization of what I call a soft exoskeleton and structure for the BioSuit. There is also Dr. Karl Langer, the nineteenth-century Austrian anatomist who experimentally studied and mapped the tension lines in human skin.

Iberall's and Langer's work informed our thinking about possible patterning designs for our suit, and we've patented our innovations. Elastic fabrics alone cannot provide the essential combination of sufficient pressure and flexibility we need, especially at knees, elbows, and finger joints. (The flexible parts of the body are the biggest challenge, of course.) Laminating our mathematically derived web of less-flexible lines, or the soft exoskeleton pattern, to our elastic compression suit has gotten us closer to the necessary pressure production goals, and we've exceeded our mobility and flexibility performance goals.

Tremendous challenges remain before we can vacuum test a complete BioSuit, and that will be only one step on the road to an operational system that astronauts could wear in space. So far, we have been testing leg prototypes in a vacuum chamber at MIT. We are within striking distance of our pressure goal. Adding wearable sensors to the suit is another challenge that we are working on currently, and we've designed a new gas-pressured helmet, one that is closer fitting than current globe-shaped helmets. We would like to give astronauts the ability to turn their heads and look over their shoulders, which means designing a new kind of airtight joint between the helmet and the rest of the BioSuit.

There is also the question of how to package life support for the suit. The large backpack that supplies oxygen, thermal control, and other necessities to current spacesuits tends to unbalance astronauts working in partial-gravity environments. We have tapped into the professional diving community for help designing a new life-support system for the BioSuit, perhaps a modular one to allow astronauts to carry only what they need and provide quick bottle changes for their extreme exploration assignments.

Given a full core team of about a dozen people (which we do not have presently because of lack of funding), I think we could have a complete suit ready for testing within three years. But, as with any research and development project, it is important to keep an open mind in this process. We even need to be willing to accept evidence that our idea won't work. (So far, fortunately, we haven't found any deal breakers; our results suggest that the BioSuit is technically feasible and could become a practical reality.) And we have to consider alternatives that may prove more practical than our original concept, though not as elegant—for instance, a hybrid suit that combines mechanical counter-pressure arms and legs with a gas-pressurized trunk.

The Potential

We started this work with a vision of bio-suited explorers on the surface of Mars. That is still our goal, but for the past five years we have received National Science Foundation funding for applications on Earth that are also exciting.

We have been working with colleagues at Children's Hospital in Boston, Harvard's Wyss Institute, Boston University, and Draper Laboratory to see if we can use our technology and engineering designs to help infants with brain damage that affects motor skills, children with cerebral palsy, and stroke victims, who typically lose motor skills on one side of their bodies. The idea is first to use BioSuit "sleeves" with built-in sensors on the legs to measure movements—to understand, for instance, how much motion and kicking by infants is typical and compare that with the limited kicking and motions of children with cerebral palsy. The next step—a big one—is to add actuators that can enhance and direct movement. In the case of cerebral palsy and stroke victims, that would be a way of giving back some of the lost motion. People with cerebral palsy expend a lot of energy moving and have stiffened muscles; our BioSuit technology and know-how could guide movement and enhance mobility to make it more efficient. And because the brains of newborns are still so plastic, enhancing the natural kicking of infants with potential motor problems from brain damage might actually reshape the motor programs and partly "heal" their brains.

Like an operational bio-spacesuit, the biomedical applications are in the future, but we are making encouraging progress. In the process, we are learning about materials science and biomechanics; creating diverse cooperative communities of engineers, designers, scientists, and artists; and training a new generation of creative engineers. The possibilities are endless. How about putting actuators on

MIT student Kristen Bethke works on the BioSuit knee joint. Photo Credit: Professor Dava Newman: Inventor, Science Engineering; Guillermo Trotti, A.I.A., Trotti and Associates, Inc. (Cambridge, MA): Design; Dainese (Vincenca, Italy): Fabrication a skintight spacesuit to give astronauts more-than-normal speed and agility? No one knows how far we can go. Stay tuned.

About the Author

Dava Newman is professor of aeronautics and astronautics and engineering systems at the Massachusetts Institute of Technology (MIT). She is also the director of the Technology and Policy Program and a Margaret MacVicar faculty fellow. Her expertise is in multidisciplinary research that combines aerospace biomedical engineering, human-in-the-loop modeling, biomechanics, human-interface technology, life sciences, systems analysis, design, and policy.

"What Works" Luncheon

By Maureen Madden
Winter 2012, Issue 45

I love to learn about all the cool things we work on here at NASA, but I don't have time to read all the press releases or go to all the workshops and conferences. So in 2005, I started my public service activity of taking coworkers out to lunch. I am a senior systems engineer who has worked on everything from particle detectors that study the sun to ground systems that will capture data from weather satellites. When I am working on a project, I see the same group of coworkers, and we talk about our project. I feel that I am missing out on what other projects are doing. The lunches help me catch up with old colleagues and get energized by their passion for their projects.

Listening to colleagues' success stories is a great way to learn from and build on what worked for them. Why reinvent a solution to a problem when you can improve or adapt what someone else has already discovered? No one at NASA knows all there is to know about everything.

I am one of the rare extroverts at Goddard Space Flight Center, and I have no problem inviting scientists, engineers, technicians, attorneys, managers, and directors out of the office for a friendly lunch. What I like about the lunches is that I learn something new at every event, as does the person I invite. They also appreciate my effort to get them out of their routines and their offices. It is like giving them a gift. Over the past six years I have taken hundreds of coworkers to lunch—Dutch treat, of course. This year I decided to step up my lunches by bringing my network of friends from around Goddard together to share their success stories with others who may need their knowledge, or who might hear about a solution to a problem that can be adapted to another challenge in another part of the organization to make improvements.

It is not hard to locate an open conference room and send out an e-mail to my friends inviting them to talk about what is working here at Goddard. I hold the lunches monthly and rotate the days of the week so that no one will be left out because they have a standing meeting at lunchtime on a particular day. Then I collect the RSVPs and see who is free to meet this month. The turnouts have been a diverse group of about ten to twenty people from most of the organizations on center.

When firsthand knowledge and experiences are exchanged in story form, we connect to that expertise on an emotional level. Also, we can immediately ask questions to get a better understanding of the situations and actions taken. And we connect with the storytellers, building relationships that expand our network of subject-matter experts.

Everyone needs a break to improve his or her productivity. These monthly lunches offer a break from routine, from the back-to-back meetings, endless e-mail, and quick lunches in the office. Everyone is welcome, whether or not they have a story to tell. Sometimes people just want to listen and learn from others; sometimes they don't have a new success story they are ready to share. That's okay. Just by coming, people see a positive outcome and have new energy to take back to their offices.

Stories have included a variety of topics: How did you find the funding for that needed test? How did you promote your employee? Why are your meetings so productive? How did you solve that high-priority issue? How did your team solve that anomaly? How did you develop trust with Headquarters or your contractor? How did you solve that technical challenge or develop that new technology? How did you move that plan to implementation? How did you move the funding around so fast? How did you win that proposal or secure that contract? How did you save the project money? How did you support a colleague's success? How do you get through all your e-mail?

Participants have offered stories on turning a "no" into a "yes," solving an "impossible" problem, turning an almost cancellation

into a success story, and having a successful promotion. There are also stories about how two diverse proposal teams affected morale and motivation, creative and collaborative ways to present at a project monthly review, and how the Information Technology (IT) and Communications Directorate can help in ways we didn't know about.

The successful promotion story was about getting the facts right and resolving misunderstandings. A couple of listeners were also advocating for a promotion but didn't understand the process or requirements. This story helped answer some of their questions and encouraged them to have conversations with their supervisors to get to an understanding about their particular requirements.

Eric Newman, from the Management Operation Directorate, shared a story about fixing an "impossible" problem. In procurement, where Eric works, everyone uses the same web site to research past procurement precedents before they develop new procurement documents. Over time, the procurement policy page had grown larger and larger; there was never really a "master plan" for its layout and development. The result was a page that was inefficient and not user friendly. The user had to know where things were or had to look through long lists of information, often in multiple places. This process was extremely inefficient and caused important guidance to be overlooked because it was so hard to sift through all the information to find what was relevant. Everyone knew this was a major problem,

but no one had the time or knowledge needed to redesign such a complicated search tool.

Eric stepped up and started to gather a team of friends and coworkers who he thought understood the details of the problem, had ideas to make improvements, and were motivated to get to a solution. It took a lot of effort just to get everyone to meetings but, once they saw that success was possible, people became committed to the project. He also used his network to find an IT person who could work on the web site. He found out that procurement fell within the center's overhead budget and specific funds would not need to be found to cover the cost of the Information Technology and Communications Directorate to provide a web designer.

The response to the new web site has been overwhelmingly positive. Since it went live, Eric has received numerous phone calls from coworkers who were excited about how quickly and easily they were able to find what they needed. The web-site redesign team recently won an award for innovation. The award write-up said, "The results of this work benefit an entire operational community who use this information daily to award and administer contract instruments. We couldn't be more excited about the new look and feel. It is user friendly and will save contract specialists time and energy in finding the information that they need." So, thanks to leadership, persistence, and networking, this team developed an efficient new user-friendly tool that benefits the whole office and entire center. A lunch participant who heard Eric's story also needed a new web site but did not have the funds. His story moved her to contact the Information Technology and Communications Directorate to see if they could help.

You don't know what you don't know, and you never know what may be useful. At the lunches, people hear about creative new ways of solving old problems. We learn from and support each other at no cost for the knowledge transfer. That is why I have named the lunch group the "Collaborative Collective." The group is stimulating innovation by creating a culture more open to change and willing to leave behind old habits that no longer serve us, like eating in our offices instead of talking to each other over lunch.

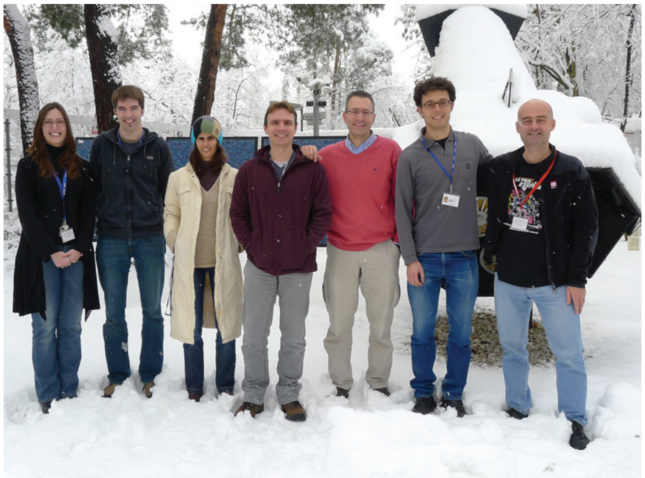
Even this article is an example of how the Collaborative Collective works. Steve Scott, the Goddard chief engineer, suggested at one of our lunches that I write it. Now maybe reading it has given you ideas about a new way to share your knowledge. What success story do you have? Who can benefit from hearing it and help move NASA forward?

About the Author

Maureen Madden began her career at Goddard Space Flight Center in 1990 in the High Energy Astrophysics Lab as the solid-state detector lead. In 2001 she served as the Small Explorers mission director and is currently a senior systems engineer supporting the Joint Polar Satellite System Ground Segment project.

The Importance of Human Factors

By Alessandro Ercolani
Winter 2012, Issue 45



The HSO-GDS team. Photo courtesy of Alessandro Ercolani

Since joining the European Space Agency, ESA, in 2000, I have developed my whole career at the Department of Ground Segment Engineering. The main task of my section (HSO-GDS) is to provide mission data systems software—mission control systems, simulators, mission planning systems—to the ESA science (astronomy, interplanetary, and solar) missions controlled from ESOC, the European Space Operations Centre in Darmstadt, Germany.

My initial assignment was the mission control system to operate the Rosetta spacecraft, an ambitious ESA mission to catch a comet in 2014. For three intense years, I participated as software coordinator in the launches of three successful ESA missions: Mars Express (2003), Rosetta (2004), and Venus Express (2005). After later working on the Galileo and Gaia missions, I was awarded the post of head of HSO-GDS in 2009, and life changed quite a bit.

From Technical Officer to People Coordinator

Suddenly the focus of my daily job diverged from classical technical matters to a whole new set of tasks. After a while I realized that I had to change my attitude in order to avoid frustration and be a good support for the people in my section. I had to accept the fact that my direct involvement in development of technical systems was gone forever (no more launches as software coordinator from the main control room, sigh!). And I had to start to thinking about what was needed to allow every section member to work in the best way.

After two years in the post, I'm still learning, but there is one thing I have no doubts about: having technical skills available in the team is no guarantee of success; the quality of the working environment is at least as important.

The Working Environment

We spend a considerable part of our life at work; we see our colleagues for more hours a day than our partners at home. The conditions we experience at work have a fundamental influence on the quality of our lives, so one of a manager's most important goals is to ensure that people come to work with a good attitude and spend their day in a pleasant environment.

Sounds obvious, right? But it's easy to lose sight of that fact when technical challenges and deadlines clamor for attention.

What do I mean by a "good working environment?" First and most important for me is to realize that colleagues in the section are trusted and trusting, open, supportive, and friendly people. We are a team of people who work together and try to help each other, rather than a collection of individuals who just ensure that their own projects are successful. Everyone is aware of the others' tasks: the successes of one project are successes for the whole section. If a project has issues, everyone else feels that they need to give a hand and solve the problem.

The "Space Musketeers"

You may be thinking, "Too good to be true." Time for a real-life example. At the end of last year, the situation became difficult for Phil, a new team member, who found himself under pressure during his handover period because of multiple demanding tasks.

He had joined the section a few months earlier and was working as the prime data systems manager on the mission control systems (MCS) of Rosetta, Mars Express, and Venus Express. A former member of the software support team for Venus Express at the time of launch, he already had all the technical background needed for the job. Suddenly, one of our core contractors resigned to accept a staff position at the European Meteorological Satellite Organization, and I found myself in the unenviable position of losing a key person involved in the maintenance of MCS for four flying missions: Integral, X-ray Multi-Mirror (XMM), Herschel, and Planck.

I asked Phil to become "the man in the middle" and work with the departing person in order to later transfer the knowledge to the newcomer. The rationale for this decision was that the MCS of Integral and XMM are all based on the same infrastructure version as those of Rosetta, Mars Express, and Venus Express, and he was the best choice from a technical point of view. He also got Herschel/Planck because I wanted to avoid having too many people involved in the handover, and the other members of the section were all under pressure, too.

In case of overload, there is always someone else who can help complete some work, while it can take dramatically long to recover from a burnout.

The causes of the problem were that I assigned too many tasks to him, and some unexpected problems consumed more effort than foreseen.

Venus Express controllers in ESOC main control room.
Photo Credit: ESA

Luckily, Phil understood the philosophy of the section, so rather than keeping the problems to himself and struggling until the final disaster, he came to me. In case of overload, there is always someone else who can help complete some work, while it can take dramatically long to recover from a burnout. I called an emergency section meeting, explained the situation, and asked for support from the rest of the team. I gave some indications of possible work redistribution, but invited everyone to suggest alternatives and propose ways in which everyone could help with any of the tasks.

Considering that each person is typically following many projects in parallel, I was particularly pleased by the outcome. Most people were already overloaded, but each nevertheless found a way to lend a hand.

One colleague offered to take over all the administrative and managerial tasks on Herschel/Planck (she was the backup data systems manager for Herschel/Planck and essentially switched to a full prime role). Since this would have created problems in the testing schedule for a recent delivery of the Lisa Pathfinder MCS, another colleague offered to give a hand with that, sacrificing a bit of the work on the Gaia MCS, which was in a less critical phase. All people involved in this extra effort identified a few work items that could be postponed to a later date to make room for the new tasks.

It was important to explain to the various missions the phase we were in. I made sure they understood that we had an emergency situation; I explained the details of the handover and clarified that some tasks would have been delayed and some others would have been "degraded" for the next few months. I believe that transparency and honesty helped to gain their support.

When the new core contractor joined our section, the second handover period started quite smoothly and, thanks to the technical skills and good relations among the persons involved, we completed this phase smoothly. Open and frank discussion helped us find the best combination of tasks, and after a few months we were back to a normal situation. One for all and all for one!

I was more or less aware of the steps needed to make things work, but most of the useful hints came directly from the staff during our open discussion. More importantly, I didn't have to impose my thoughts by telling people, "You now do this, you do that," because they identified who could help where. If they had not volunteered, I would have had to make a decision myself, of course, but that didn't happen.

Never Feel Alone

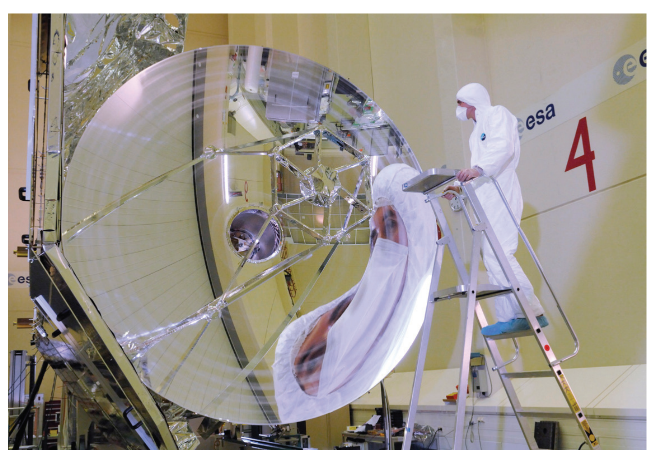
I trust that when someone requests a period of leave he or she has checked that it would not cause problems with the mission, and I approve without questions or further check on my side.

The way work is structured in the section helps this kind of mutual assistance. Everyone has, in principle, the same range of skills and performs similar activities, although on different missions. This allows one person to quickly become proficient in a different mission's environment once the specific tasks are identified. At least two people (prime and backup) are assigned to each project in the section, so there is no dependency on a single person for any activity. Having all the knowledge on a subject in the head of a single person is obviously a danger. Everyone should be a valuable asset, but nobody should be indispensable. Having the organization to ensure division of tasks and responsibilities is a complex exercise that results in more effort for people but has obvious benefits.

Anyone can go on leave without putting all their work on hold. The availability of a responsible backup is very important also in case of sickness or job change. Even more important for me is the case of maternity leave. Luckily, ESA staff rules and regulations guarantee exceptionally good conditions for women becoming mothers, and I try to ensure that this event is seen as a fantastic experience and not as a threat to a woman's career.

Holidays

There is an open goal in the section: everyone should try to use all leave days available in the year. I trust that when someone requests a period of leave he or she has checked that it would not cause problems with the mission, and I approve without questions or further checks on my side.



The Herschel telescope. Photo Credit: ESA

XMM preparation. Photo Credit: ESA/D. Parker

This has worked smoothly so far, has saved me a lot of time, and has increased the sense of responsibility and independence of the individuals. I try to be a good example and typically run short of annual leave before the Christmas holidays.

I stress the importance of balance between work and private life, and balance means that there can be periods where it becomes impossible to use all available leave days. For me, working overtime, including weekends, was the norm between 2002 and 2005. I have supported four launch campaigns in three years, and in that period I accumulated seventy-five days of compensatory leave! In the following years I have used these additional leave days. Overall, our workload follows the phases of the missions we support, so there is a time for sweat, blood, and tears, and a time for snow, sand, and sea.

The International Background

ESA is international by definition, so cultural differences are constantly part of the game. In my section, we have two Brits, two Portuguese, one German/French, and two Italians; two women and five men in total. We are of course different from each other, and we try to understand and appreciate our different views. Sometimes when you set up an appointment, you have to specify whether it is "Spanish time" or "German time." The first means that you are expected to show up at least half an hour after the time of the appointment.

In some cultures, like the Italian one, it is quite normal to have heated discussions. Voices may be raised and movement of the hands and body language may be a bit extreme, but what to outsiders could seem like the beginning of a physical confrontation is probably just a "lively" conversation.

As long as people are aware of these known characteristics of cultural groups, there is no problem. The moment you have a German waiting half an hour for a Spaniard or an Italian shouting at a Brit, the differences are not fun anymore.

We have an excellent tradition, which started spontaneously, of organizing "cultural evenings" at someone's place, with food and drinks of the country of origin and very often board games as well. We have, in fact, a board-games tournament spanning the whole year, with an overall classification that determines who holds the "GDS gamer of the year" trophy for the next twelve months.

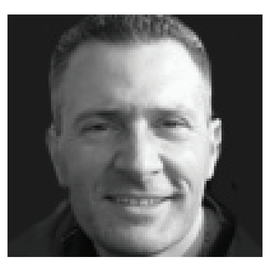
People First

I believe we live in a kind of small family in our section. Whenever there is some change in the composition of the section, I always try to think about how to preserve this environment. A new candidate is selected not just for technical skills, but also for the capability to integrate in the peculiar environment we have created. I have always been supported by my line management in this approach. I'm convinced that the spirit of the current group can continue for years, even with changes in the team. One of my global goals is to ensure that current values and habits become an integral part of the section's DNA, and I'm sure that it will not be so difficult to convince newcomers (even a new head of section) to adopt them.

Time will tell whether or not this is a sustainable model. So far our customers are happy with our support. I'm convinced that the quality of our technical output is related to the positive environment we work in. I am aware, naturally, that this situation is in large part due to the combination of a number of lucky factors (size of the section, character, attitude, age of individuals, and type of work) and that there is no single "recipe for happiness" that applies to all situations.

An obvious enabler for our nice working environment is the favorable conditions offered by ESA. The introduction of flex time, part time, and telework have all facilitated the increase in balance between work and family life. Moreover, the support for sport and social clubs gives people a chance to know each other in various external contexts, and then have a better relationship on the job. I believe we have good foundations for building a socially satisfying and stimulating work environment.

About the Author



Alessandro Ercolani began his career at the European Space Agency (ESA) in 2000 as a software engineer in the department of Ground Segment Engineering in Darmstadt, Germany. He is currently leading the Science Mission Data Systems section, whose task is to provide mission control system and operational simulator software to ESA interplanetary and astronomy missions. E-mail: alessandro.ercolani@esa.int

Managing Multicultural Teams

By Conrado Morlan
Spring 2012, Issue 46

Having the opportunity to work for a company that operates in more than two hundred countries and territories and is a global leader in logistics has given me the opportunity to lead large global and regional information-technology projects. While technology made the work complex, the element of culture, both national and organizational, amplified the complexity.

A Global Project

The objectives of my first assignment were to lead the convergence of existing invoicing applications hosted and managed by country IT teams to a centrally managed single platform hosted in one of the regional data centers, and to standardize operations and processes. The new invoicing platform would be used by all countries in the Americas region; changes would follow a formal change-request process.

Although the existing invoicing applications shared core functionality, IT departments in individual companies had customized them by adding nonstandard functions that often did not comply with regional guidelines. This uncontrolled behavior led to new functions and processes that disrupted the standard operations at country and regional levels.

The technical team supporting the countries was challenged by reported incidents that often related to the customized functions, not core functionality. This was a source of conflict between the country IT teams and the technical support team, which many times was unable to address the issue. Business users did not produce invoices on time and their level of satisfaction was low. All this affected country and regional cash flow.

The Americas management board sponsored the project and mandated that all countries stop using any feature or function not aligned with the regional invoicing standards.

The Project Team

The project team consisted of stakeholders, the deployment team, and a technical support team. Stakeholders were the permanent regional management board and rotating country officials, including general manager, finance officer, and IT officer, who joined when the new platform was deployed in their particular country. The core deployment team was the same from project inception through completion and consisted of a project manager, technical-support team lead, and subject-matter experts in technology and invoicing. The rotating team members included country resources, both technical and end users. The technical support team, remotely located in Asia, supported day-to-day operation during the Americas business hours.

During team formation, team management became complex as some stakeholders and members of the deployment team changed when a new deployment started. New members came on board and others departed as the deployment in their countries was completed. I had to understand how to integrate new members into the team smoothly, convincing them to accept change and promptly collaborate with the project.

I learned that I needed to develop cultural competencies to manage the project team effectively and establish connections with team members when they came on board. A kick-off meeting to explain the purpose and benefits of the project helped establish the bond between new team members and the project. The most important part of connecting was stressing the importance of their roles and how their local experience would enrich the project, as this created a sense of belonging that translated into engagement. But the connection was strengthened by understanding and respecting the different communication styles and preferences of the national cultures involved.

There are many books about national cultures, but few resources explain how to deal with national cultures in project teams. While attending project management congresses, I was able to connect with other project management professionals who had faced similar challenges and learn from their experiences. I also learned from my own mistakes. During my first visit to Asia, I met with the technical-support team lead and his team and inadvertently broke the local meeting protocol when I started asking direct questions of team members. After catching the nonverbal cues of team members that showed they were asking the team lead for permission to answer, I switched to directing questions to the lead. He then selected the person to answer the question. At the end of the meeting, I apologized to the team lead and team members for my oversight and made it clear that my intention was not to make them uncomfortable or violate local meeting standards. I quickly shared what I learned with the rest of the deployment team.

Speaking foreign languages is a must in a global project environment, but language skill alone does not make a cross-cultural expert. It is necessary to understand other cultures' values, beliefs, and communication preferences. Knowing how they manage and resolve conflict is essential, for obvious reasons.

During my first visit to Asia, I met with the technical-support team lead and his team and inadvertently broke the local meeting protocol when I started asking direct questions of team members.

It is also important to understand your own culture's norms and behaviors. That knowledge helps guard against interpreting other cultures' behaviors in terms of your own unexamined expectations. Reflecting on your own culture helps you understand and interpret why people from other cultures act the way they do.

With those recommendations in mind, I looked for ways to improve my cultural awareness in order to better understand my team members. As the project progressed and my cultural awareness improved, my connection with international team members became closer and more robust. When I had to spend more than two weeks in a country, I usually spent my weekends visiting popular spots where locals met: restaurants, farmers' markets, coffee shops, and occasional sporting events where I observed people's customs, traditions, and behaviors. My observations in those settings helped answer my questions about culture. When in doubt, I asked questions either of the locals or my colleagues.

Intracompany Networking

I often met with country management boards during the course of the project; these meetings offered good opportunities to establish long-lasting business relationships. I learned the importance of doing "my homework," gathering all the relevant information prior to any meeting and knowing the audience in advance. Having established strong relationships in the initial phase of the project helped me get insight into country officials from people who had already dealt with them. Knowing the preferences and sometimes the opinions of a country's management board about the project helped me to build the right deployment strategy and know what to expect from meetings.

In every meeting with country management boards, my team and I wore business attire and arrived on time. Board members arrived gradually and the general manager usually arrived late, demonstrating his status. The meeting started with preliminary discussions that helped build rapport. Deployment discussions occurred only after rapport was established. Usually, the first meeting exceeded the original allotted time and a second meeting was required to make the final decisions.

In this kind of project, it is important to have a well-defined circle of people who can influence the outcome. It can be like having "invisible" team members who support important functions and contribute to project performance.

Relationships should span all levels of the organization and not be limited to the higher ranks. Establishing a good relationship with users gives you feedback regarding the operation of the application and how it can be enhanced. For instance, Costa Rican users helped solve a common problem: end-of-day activities that involved several steps that required constant attention and, often, work after regular business hours. They suggested assessing the feasibility of automating these tasks. The assessment was positive and the tasks were automated, enabling Costa Rica and the other countries to avoid overtime payment.

A New Project Manager's Role

In an environment where organizations depend on global projects for benefits that contribute to strategic objectives, the project management professional needs to explore new ways to lead, execute, and deliver projects supported by dispersed and diverse teams. Technical expertise is not enough. Project managers must adopt a business-oriented approach and cultural awareness and other soft skills. The most important knowledge and skills include the following:

Strategic Management. Understanding an organization's strategy will provide the backdrop for future assignments and an understanding of project selection criteria. Only projects that help the organization fulfill its intended purpose should be selected.

- **Mindful Communication.** Communication is crucial to project success. Communication needs to be customized to the specific cultures involved in a diverse project team. Good communication influences and inspires project teams and helps build strong relationships across the organization.

- **Adaptability.** New leadership styles that fit the global project are required when working with diverse and dispersed teams located across time zones.

- **Resilience.** Realigning or repairing projects facing unexpected hardship because of miscommunication and problematic behaviors as well as cross-cultural issues and conflicts will be a regular part of the project manager's task.

- **Transparency.** Adherence to an organization's values and culture as well as professional codes of ethics is mandatory in global projects. The state of the global project needs to be shared promptly with relevant parties whether the project is in good shape or facing hardships.

In this new role, the project manager will turn into a perennial learner striving toward excellence, a great communicator, and a business partner who ensures that projects will produce the benefits the organization is seeking.

Key Questions

- As a global project manager, how do you deal with cultural issues in your project team?

- What is your strategy to deal with conflict in a cross-cultural team?

- Do you enjoy the challenge of being a global project manager?

About the Author

Conrado Morlan has more than twenty years of experience as a project and program management practitioner, leading complex projects in North America, Latin America, and Europe and managing complex negotiations and influencing organizations across functions and levels. He routinely shares his knowledge and experiences through events sponsored by PMI and PMI Chapters in the United States and Latin America. He can be reached by e-mail or on Twitter, @thesmartpms.

"RU" Ready for the Future? Rocket University Helps Pave the Way

By Steven Sullivan and Chris Iannello
Summer 2012, Issue 47

Students fill a balloon for the team's project test flight with the Rocket University payload launch and recovery lab. Photo courtesy of Steven Sullivan and Chris Iannello

As the Space Shuttle program came to a close in 2011, hundreds of engineers at Kennedy Space Center began redirecting their efforts from shuttle processing toward flight-systems engineering. To support this new focus, Kennedy managers developed a small, low-cost training program: Rocket University. Rocket University, or RU, is a HOPE-style (Hands-On Project Experience) program that promotes agencywide collaboration, technical skill development, and technical team building while simultaneously fostering systems engineering skills. RU classes and labs provide valuable experiences similar to those gained during long-term, large-scale flight projects, but on a smaller, short-term, low-cost scale.

Good systems engineers can handle technical leadership and systems management. Both skills are critical when developing and operating any space-related system. We developed RU's curriculum around this idea and built it using a combination of vendor-purchased training and civil-servant-developed courses.

An important goal of the RU curriculum is to incorporate the teachings of NASA's well-respected APPEL (Academy of Program/Project and Engineering Leadership) training into its program. By incorporating a technical curriculum to compliment the APPEL program, RU focuses on teaching systems engineering of the integrated project as well as within each discipline. RU students take classes that combine APPEL's broad systems engineering training with technical training in unfamiliar disciplines. Once trained, the students are challenged to use their new skills as part of a project team to conduct a lab flight project or experiment. They must work on this project from its inception to its completion, immediately demonstrating their new skills as they simultaneously apply their systems engineering training throughout a complete project life cycle.

This immediate application of newly learned technical and managerial skills is what makes RU different from other training programs.

Balloon Payload Launch and Recovery Lab

In October 2011, RU began offering weather-balloon courses as part of its near-space environments lab curriculum. These classes were meant to introduce Kennedy engineers to the benefits of using balloons to achieve inexpensive and long-term science and technology objectives. The labs include a series of iterative challenges to be achieved during four incremental test flights.

According to one RU mentor, Nicole Dawkins, "Participants of Rocket University's near-space environments team are developing expertise in everything from composite manufacturing to the latest in avionic and software design techniques. The added bonus is that the engineers are learning these skills as they build and fly real products that impact future NASA programs."

For test flights, Johnson Space Center is the principal investigator. The students' main flight objective is to provide Johnson with test-flight data that will help them create the final design for an unmanned capsule that can be deployed from the International Space Station to Earth.

The first balloon-lab test flight has been completed. For this flight, RU students designed and built an instrumented payload, launched and tracked a balloon from the Kennedy Visitor's Center, and tracked a dummy payload receiver using a global-positioning system (GPS). The balloon reached 95,000 ft., but the payload landed 45 miles offshore and was not retrieved. This balloon flight was the first step in incremental development, where RU coursework and projects evolve into the avionics that will support our aeroshell drop-test customers as well as all other RU flight objectives. The lessons learned from this first lab will also be used to improve the second balloon-flight test, which will feature additional challenges, such as using a flight computer, providing two-way telemetry that handles commands and responses, establishing a flight-termination system, providing data-recording capabilities, and predicting the balloon's landing location within 1 mile.

"Every time the near-space environments team successfully launches a balloon payload, we are demonstrating new skills and techniques learned within the curriculum of Rocket University," explained Dawkins. "There is a lot of satisfaction in knowing that we designed, built, tested, and flew a product that will impact future NASA programs."

Lessons learned from the second test flight will be used to plan and conduct the third flight, which will include deploying a small (7- to 8-lb.) capsule that will land in the ocean. This aeroshell-scale drop test will require new design efforts such as creating the small-scale test capsule and designing the landing parachute. Performing this small-scale model drop test will help the Johnson design team catch failures early as the data generated during the test will be used to design a larger, 200-lb. aeroshell capsule. This larger capsule will eventually fly on a stadium-sized balloon in Fort Sumner, N.M., and is being offered by the Wallops Balloon Program Office and the NASA Columbia Scientific Balloon Facility in Palestine, Tex. The capsule will be dropped at around 120,000 ft. to collect data that can be used by Johnson to design their final product.

Focusing on the Individual

RU's "technical discipline leads" teach a variety of classes. In several cases, the technical discipline training classes were conducted in collaboration with experts from other NASA centers who developed coursework and taught the classes. The curriculum also covers major technical discipline areas:

- Systems engineering (provided through APPEL training)
- Flight structures
- Avionics/embedded systems
- Propulsion (liquid and solid rocket)

Once students complete their technical discipline classwork, they apply their newly gained knowledge and can test their proficiency on a lab project or experiment. The final exam for the lab is the flight project itself.

RU currently has four main lab/experiment project types:

1. Near-space environments
2. Unmanned aerial systems
3. Rocketry (transonic and hypersonic)
4. Propulsion system test beds

To date, these labs have resulted in more than a dozen rocket launches and two balloon launches, each of which involved incrementally designing custom flight hardware and software.

RU labs operate with a large number of project teams, but each team is fairly small and given very small budgets. Limited manpower and a low budget: these realities set the stage for team labs.

The RU team shows the Kennedy Space Center Engineering director the analysis associated with the team's first certification build. Photo courtesy of Steven Sullivan and Chris Iannello

The NASA model rarely leaves one person solely responsible for building a critical subsystem, but this is not the case at RU where, because of limited manpower, one engineer can sometimes be assigned to work within an entire system. This means a lot of hands-on engineering that provides lessons and insights that can't be gained in any other way. Thomas Edison said, "Opportunity is missed by most people because it is dressed in overalls and looks a lot like work." At RU, our labs provide each student with lots of "overalls" moments and opportunities for personal and team successes.

Students work with a principal investigator to set project objectives as well as with mentors, who support them throughout the project. As students begin their work, they become believers in applying agency guidelines for program management because they quickly learn that organization can solve a lot of frustrations between systems engineers. They also soon realize that agency collaboration is required to help find technical solutions from experts across NASA and across different disciplines. Finally, the project team must report to all levels of management (that is, engineering director, chief, division/branch chiefs), who actively participate in major project reviews. Given the limited manpower assigned to each project team, the entire process stresses responsibility and leadership on the part of each individual.

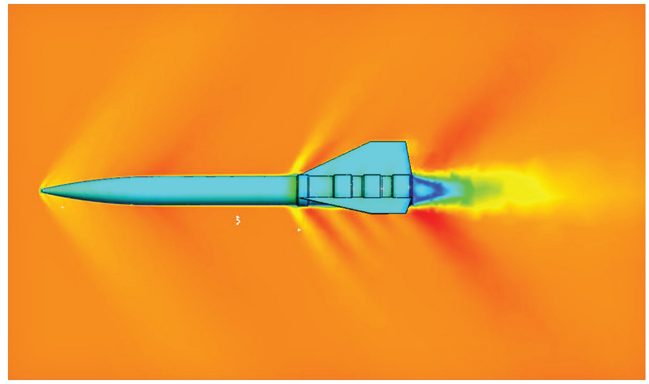
In addition, small budgets often force team members to build, by themselves, the functions or systems they require to complete their project (for instance, data-logging telemetry downlinks or inertial navigation systems). Doing this work gives team members a deeper understanding of flight functions than they would get if they could simply buy technical solutions. It also forces them to find and use low-cost materials and resources. Many students have become more knowledgeable about how to apply commercially available hardware and software to their projects, which opens their minds about using commercial-grade constituent parts as they create custom-built hardware and software designs to meet lab requirements.

Additional Accomplishments

In addition to the success achieved with RU's near-space balloon launches, several other labs have seen similar accomplishments since RU began in the early fall of 2011.

Avionics

The RU avionics discipline supported the balloon lab's first untethered launch by designing a custom avionics system that used the latest in mixed-signal embedded electronics. This system is much more capable than similar systems available either commercially or within academia. Amazingly, the hardware cost of the system was under $350, with the majority of the expense going toward purchasing the downlink transceiver and the Ublox GPS with integrated antenna. The system consists of a 32 bit microchip PIC with 512 KB of flash RAM and, stretching outward from the microcontroller, high-speed synchronous and asynchronous serial busses that connect sensors as well as radiofrequency links. The low-cost, high-performance embedded electronics used in this flight served to further develop RU's technical skills in that we learned to use nontraditional hardware types. This avionics package is in its first revision and will be improved upon by RU avionics students with each balloon-lab test flight.



Computational fluid dynamics analysis for the Rocket University advanced rockets workshop. The second stage was analyzed at Mach 1.4 to determine the aerodynamic performance of the rocket at its maximum expected velocity. The colors in the image correspond to velocity of the air, with multiple minor shockwaves seen emanating from the rocket as it flies supersonic. Photo courtesy of Steven Sullivan and Chris Iannello

Transonic Rocketry

During the introductory class on basic rocketry, students learned about center-of-pressure calculations, center of gravity, available models and simulations, and their accuracy. In the lab, students handcrafted their own high-powered rockets and flew them with rocket-enthusiast clubs sanctioned by the Federal Aviation Administration. From these launches, students learned lessons regarding the performance of off-the-shelf accelerometer data-collection devices; the benefits of live video and sound streams to examine the environments, rate, and violence rockets are exposed to; and parachute deployments that resulted in either reparable rocket damage upon landing or no recovery due to high-wind conditions. The class was a great start for future transonic-rocketry studies.

Unmanned Aerial Systems (UAS)

A series of training sessions provided students with an introduction to UAS: practices and principles; flight dynamics; modeling and simulation; guidance, navigation, and control; communication systems; composite-material manufacturing complete with a familiarization of Kennedy's prototype shop; and systems engineering and integration workshops. These courses were taught through a collaborative effort between NASA and Embry-Riddle Aeronautical University (ERAU). The extremely challenging lab project for UAS students involves designing, manufacturing, and testing a viable UAS. The project anticipates flight testing to begin in summer 2012, culminating in a planned autonomous UAS mission.

Educational Outreach

As RU progresses, it seems natural that the university and its curriculum could also be used to foster outreach opportunities between NASA and public/private engineering institutions.

Since all RU classes are videotaped, they can easily be offered to outside universities; and because of the low cost of lab materials, the program is affordable to implement. Already the University of Central Florida and ERAU have sent faculty to teach at RU. These institutions are also providing students to work as special teams to assist NASA engineers during design, manufacturing, and testing procedures.

Hands-on opportunities and working side by side with NASA engineers help make these students workforce-ready. As RU's educational outreach expands, it could also be disseminated to high-school or middle-school levels to support national science, technology, engineering, and math initiatives. The collaborative possibilities between educational institutions and government agencies will continue to grow.

What Lies Ahead

Rocket University continues to expand its curriculum, finalize "graduation" requirements, further identify opportunities to collaborate with educational institutions, and work toward creating an exciting agencywide technical challenge. This challenge would be offered to all NASA centers and would culminate in a competitive, yet collaborative, effort among the centers. Each team would congregate at one NASA location to present their concept and design, conduct a demonstration to show how their design satisfies challenge requirements, and, finally, discuss their results and lessons learned.

RU interested? If so, please contact the Rocket University program manager, Kathleen O'Brady, at 321-861-3300 for more information.

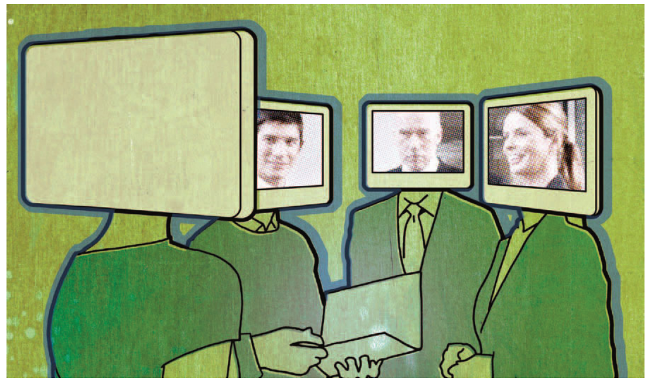
About the Authors

Chris Iannello began his career at Kennedy Space Center in 1989 in the ground power systems group and has more than twenty years' experience in power systems. He has been involved in some of manned spaceflight's most challenging technical issues, and he has served or led on assessments for the NASA Engineering and Safety Center. As a researcher, he has published over twenty papers in engineering journals, leading discipline conferences, and tutorial seminars.

Steven Sullivan is the chief engineer of NASA's Commercial Crew Program at Kennedy Space Center. He began his NASA career in 1985 as a shuttle engineer and served in various roles within the Space Shuttle program, including branch chief and later division chief for electrical systems and chief engineer of launch-vehicle processing in Kennedy's Engineering Directorate. He also led resolution of engineering issues related to processing and launching shuttles Discovery, Atlantis, and Endeavour.

The People Behind the NASA Engineering Network

By Manson Yew
Summer 2012, Issue 47



This article has been several years in the writing. Sure, part of the reason it took so long was lack of time; part of the reason was fear of putting words out there, though I had no problem talking about the NASA Engineering Network (NEN). I have done presentations about NEN at countless meetings, at all NASA centers, and at conferences here and abroad. I talked about the ability of NASA engineers to search for knowledge across three million documents in forty repositories, and about leveraging the official lessons learned from NASA's past, including more than two hundred new lessons from the Space Shuttle program. I talked about the resources from the twenty-eight communities of practice representing core engineering disciplines. But I wanted to write a story for the ASK audience that would show readers how and why NEN worked.

I found that story at the NASA PM Challenge in February 2012, at a session titled "Building Communities of Engineers to Share Technical Expertise" and co-presented by Daria Topousis, NEN's lead for the communities of practice task; Lorraine Fesq; and Rich Mrozinski. As these three wonderful presenters interacted at the podium with grace and trust, it occurred to me: the story was not just about the NASA Engineering Network. The story was about people: Daria at the Jet Propulsion Laboratory (JPL), Neil Dennehy at Goddard Space Flight Center, Dawn Schaible, Lorraine Fesq, Ed Strong, Michael Bell, and countless engineers, scientists, and managers who are working to make NASA better by building networks across distance, time, and disciplines.

The Origins of NEN

NEN started as the vision of Greg Robinson, NASA's deputy chief engineer. When he first assembled the NASA Lessons Learned Steering Committee, he heard about all the different ways lessons learned were missed—perhaps due to time pressures or culture or a lack of information technology and knowledge management sophistication. He reached out to Pat Dunnington, then NASA's chief information officer, who brought Jeanne Holm from JPL, a recognized expert in knowledge management, into the conversation. From the beginning, we knew that what was required was more than just an upgrade of the Lessons Learned Information

System. In the shadow of the *Columbia* tragedy and the accident investigation board's conclusion that NASA did not demonstrate the characteristics of a learning organization, the task had even greater importance. We felt that the solution required much more than tools at hand, more than discussion forums, wikis, search engines, lessons learned databases, and content management systems.

We learned to take a chapter from the past, when communities of shared practices would congregate in lunchrooms, at water coolers, and around common activities to share knowledge. The advent of technology had created a different way of doing business that allowed greater personal efficiencies at the expense of social interaction. What technology took away, technology could perhaps recreate. An online collaboration space for a specific discipline might help reestablish these crucial interactions, creating virtual watering holes where people could find knowledge and experts in their area of practice and interact with other practitioners.

The beginnings were rocky. Having observed many instances on the web of discussion boards where people sign up, ask questions, present problems, and have a community of people provide answers and feedback, we focused on discussion forums. We seeded the forums with questions, we presented trivia and challenges, we asked people to post. Nothing much happened.

Success

The work of Daria and Neil changed that. The Guidance, Navigation, and Control community of practice was one of the first communities on NEN and a source of experiments, lessons learned, successes, and failures in establishing a vibrant community. Neil is the NASA tech fellow for guidance, navigation, and control (GN&C), and the lead of the GN&C community of practice. He did not need to be sold on the benefits of sharing knowledge and building a community of practice. He was excited to have a virtual community that would reach out to all the practitioners, junior and senior, across NASA. Though Neil was a highly in-demand resource at NASA, a person whose voicemail would fill up within hours every morning, he committed to working with Daria to establish his community.

When trusted members of the group bring ideas, tools, or technologies they have tried, vetted, and can recommend, however, those technologies have a greater chance of being adopted.

She started with two requirements: a picture of Neil and a community charter. They worked together to establish the charter so that members understood the mission of the community (the picture was harder to come by). Neil recruited Ken Lebsock, his deputy, to work with the practitioners to collect key documents, standards, lessons learned, and best practices. They also published the "State of the Discipline." The strategy was to create vibrant engagement among a small group of practitioners, and then slowly build the membership. The plan also recognized that there were different modes of engagement. There would be a core group, but there would also be lurkers and seekers who visited to see if they could find a solution to an immediate problem; there would be people interested in periodic messages and announcements and people who belonged in another discipline that is loosely coupled to GN&C. The collaboration tools, resources, and knowledge base were engineered so each type of member would find something that catered to their needs.

But perhaps the key ingredient of success was that Neil recognized that Daria was a part of the community, alongside the PhDs and branch chiefs. Her contribution was expertise in the practices and technologies of knowledge sharing. She participated in every teleconference for GN&C, listening for opportunities that would benefit the community as a whole if it were put up on NEN. She was invited to the annual GN&C face-to-face meeting. Kayaking with other members, catching lunch and dinner with them, and talking in the hallways during breaks, she heard suggestions for knowledge to share and was asked about improved capabilities. Community members collaborated with her on deciding what online tools would enable their work.

Her role as community facilitator evolved into the role of technology steward. Groups often resist new technologies that outside organizations try to get them to use; like the door-to-door vacuum cleaner salesmen of old, people selling tools are looked on with suspicion. When trusted members of the group bring ideas, tools, or technologies they have tried, vetted, and can recommend, however, those technologies have a greater chance of being adopted. With Daria as technology steward, the community tool set grew to include a vendor database, "Ask an Expert," ratings, reading room, standards, and advanced search. Most recently, the community rolled out a monthly webcast covering such topics as "Fundamentals of Deep Space Mission Design" and "Space Situational Awareness." NASA personnel can participate live or watch the webcasts online afterward.

But the community was not mainly about the tools and technologies; the most remarkable activities were people helping people. Recently, when a member used "Ask an Expert" to gather information about reaction-wheel failures, Neil surveyed his core team, then contacted an expert in the Mechanical Systems community of practice, and personally assembled the response. This led to other members providing input from their experience.

The story of the GN&C community teaches two essential lessons about what makes online communities successful:

- They work best when community members also meet and work together in person and regularly connect in various ways (for instance, through teleconferences).

- They need to be actively facilitated by people who understand the community and are trusted by its members.

The Autonomous Rendezvous and Docking Community

The GN&C community of practice grew from approximately fifteen members in the first year to nearly two hundred registered members, plus countless visitors. Recently, the lessons it offered about creating a successful community have been applied to theAutonomous Rendezvous and Docking (AR&D) community, whose formation Daria has supported. Accomplishing their work is helped by a synergistic blend of meeting face to face; sharing knowledge in person, online, and by telecon; and providing energetic, informed facilitation. Despite the challenges of limited budget and changing priorities, the community has grown to ninety-eight. The persistent knowledge that emerged from those interactions can be found on NEN, including the seminal white paper on AR&D, "A Proposed Strategy for the U.S. to Develop and Maintain a Mainstream Capability Suite ('Warehouse') for Automated/Autonomous Rendezvous and Docking in Low-Earth Orbit and Beyond."

Since the early nineties, NASA had identified as a fundamental technology for all classes of future missions the ability for space assets to rendezvous and dock without human intervention. This technology requires the expertise of various sciences and disciplines, including guidance, navigation, software, sensors, flight, and aerosciences. No single mission could fund the complete suite of AR&D capabilities, and various missions that require AR&D have developed what their resources allowed, often trading long-term effectiveness for short-term capabilities. Despite these challenges, experts at NASA have continued to figure out ways to advance NASA's capabilities. But 2009 saw perhaps their biggest setback, with the near simultaneous cancellation of the Space Shuttle and Constellation programs.

As they picked up the pieces of their work, the champions of AR&D assembled a team of experts at Johnson Space Center in the spring of 2010 to ensure that NASA would not lose its hard-earned AR&D expertise. The synergy exceeded expectations. Participants were energized by the new possibilities of working together as a community. But Neil understood that this commitment would not last long before the daily grind back at each person's home center would dilute their enthusiasm. Having worked with Daria on the Guidance, Navigation, and Control community of practice, he invited her to join and facilitate this community's development. Drawing on her expertise in the art of creating virtual communities, she led the group in formulating their charter, gathered key knowledge, helped members collaborate and share their plans, and established the AR&D community of practice on NEN. Though the experts dispersed to their various centers, they now had an online touchstone where they could continue their collaboration and knowledge sharing. The community was further invigorated by their work developing a coordinated flagship technology demonstration for AR&D, and the collaboration tools on the AR&D community of practice proved invaluable. They held a telecon at least monthly and shared their best technologies, practices, and theories toward developing the demonstration, and along the way used each other's expertise to assist with other tasks and research at their centers.

In 2011, the flagship technology demonstration went away amid budget and strategy constraints, but the momentum of the community was not slowed. Now they met weekly. They uncovered opportunities to work together across centers and across projects; trust among participants allowed Langley Research Center, JPL, and Johnson to develop joint proposals and develop common sensors; Goddard offered their test bed for AR&D; others explored opportunities to collect data from existing missions to further AR&D; and Rich Mrozinski of Johnson led the writing of an AR&D strategy white paper that assembled NASA's best practices and proposed a capability warehouse to ensure future efficiencies of their tool suite. When the Office of the Chief Technologist issued a new announcement of opportunity for AR&D, the community felt that NASA would be best served with a joint proposal from the community, not competing ones.

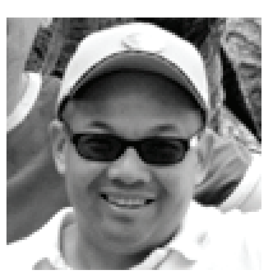
The story of AR&D at NASA continues to be written. The artifacts of their trust and collaboration, including the aforementioned white paper, can be found on NEN, but that's just a small part of an amazing effort.

All forty engineering communities of practice on NEN have similar stories. Fault Management just held a workshop and is working to implement a new NASA standard and handbook on this critical discipline. The Structures community of practice has a thread of "Greybeards' Advice for Young Engineers;" the Passive Thermal and Mechanical Systems communities have a cross-discipline discussion on piezo motors and actuators. NASA Deep Space Navigation holds monthly knowledge-sharing meetings. Program, Planning, and Control just came online after participants at the 2011 PM Challenge suggested it. And Daria or a member of her team continues to participate in the telecons with each community and to speak at face-to-face meetings, pushing people to continue sharing knowledge. Neil continues to shepherd the GN&C discipline as the NASA tech fellow.

Despite budget constraints, strategic course corrections, and any number of challenges our missions face on a regular basis, our engineers endeavor to come together and build the creative connections that contribute to solutions. I can honestly say that there is a seat at the table for anyone to contribute to our shared mission and shared future. Wherever one finds him or herself in their career at NASA, they are welcome in any of the communities on the NASA Engineering Network.

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 Author

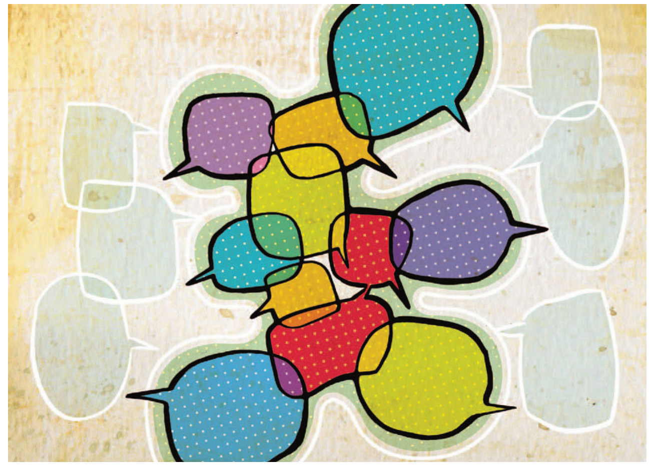


Manson Yew is the enterprise systems project manager at the Jet Propulsion Laboratory.

Knowledge Topics: A Vital Project Resource

By Don Cohen
Summer 2012, Issue 47

To put it in the simplest terms, social capital is the value of the connections between people.



NASA projects require a variety of resources. Money, of course. Appropriate technical and management skills. Raw materials and (often) existing components, an infrastructure of equipment for building and testing hardware, a launch vehicle or aircraft for flight projects. Enough time to get the work done.

There is another resource vital to successful projects that is unlikely to be mentioned in plans, budgets, or technical documents: social capital.

What Is Social Capital?

To put it in the simplest terms, social capital is the value of the connections between people. An individual's social capital typically consists of an informal network of relationships—the people you can go to for advice, information, knowledge, and assistance. (And those same people will come to you for similar help.) In organizations, these personal-professional networks are essential to getting a lot of work done, but they are not recognized on org charts or other official documents.

People naturally seek out colleagues they have gotten to know over the course of their careers whose abilities they respect and—equally important—whom they trust to understand their requests and respond to them constructively. When faced with an especially tricky problem, established professionals are much more likely to go to these colleagues for help than they are to consult a database or other "knowledge repository." Almost by definition, the tricky problem involves subtleties that cannot be explained in a written report or database entry, subtleties that can be teased out and understood in conversation between professionals. Discussing an issue with a colleague usually involves more than being handed an answer; it is an opportunity to collaborate on your problem, to think it through together.

That preference for going to a trusted person for help is doubly strong when the issue involves judgment and not just technical expertise. In fact, though the personal connections of social-capital networks are essential pathways for the transfer of technical knowledge, they are at least as important as sources of information and advice about "how things are really done around here"—the political realities, workarounds, unwritten rules and expectations, and influences that have such a powerful effect on project and personal success.

How Is Social Capital Developed?

Probably the most important builders of these social-capital networks in organizations are the experiences people have working together over time. In an organization like NASA, where most work is project work, being part of a series of project teams with overlapping but changing membership creates opportunities to form lasting relationships that are career-long sources of knowledge and assistance. Opportunities to spend time with people involved in similar work at conferences and workshops also help build these personal networks.

But there is nothing automatic or certain about that relationship building. It depends on and benefits from a set of conditions that may or may not exist in a given organization or part of an organization. Foremost among them is a culture of trust—a sense that good will, honesty, and cooperation (though not universal in any organization) are the norm rather than the exception.

Trust in organizations develops over time, built by interacting with leaders, managers, and colleagues who are trustworthy, by the experience of fairness in promotion and giving credit for accomplishments, and by people being trusted enough to be given some autonomy in deciding how best to get their work done. Many experienced project managers at NASA and elsewhere talk about telling their team members what needs to be done and when it needs to be finished, but leaving the how up to them. (The opposite of this kind of trusting behavior is micromanagement that overwhelms the micromanager with work even as it undermines the initiative, talent, and goodwill of the person being managed.)

For obvious reasons, having a shared meaningful goal enhances trust and cooperation. Knowing that both you and your colleagues are working toward an aim that you all value and that is larger than personal success or advancement is a solid foundation for a collaborative relationship. It can counterbalance some personal differences that might otherwise stand in the way of helping one another.

Long tenure is also a social-capital builder. The longer individuals are in an organization, the more people they meet, and the more chances they have to solidify relationships through repeated work together and opportunities to meet. And, in most cases, the more they know about the organization and how to do their work—that is, the more knowledge they have to share.

No organization is uniform. NASA, like every diverse and dispersed organization of any size, has many subcultures and different employee experiences good and bad. So it is not possible to generalize confidently about social capital at NASA. But there are features of the organization that strongly encourage these networks. I have already mentioned the extensive project work. As much as any organization in the world, NASA is characterized by important shared goals. The vast majority of civil servants and contractors are passionate believers in NASA's missions to advance science, technology, and exploration. Experienced project managers talk about how reminding teams of their shared mission has the power to counteract personal disagreements and potential discouragement over budget constraints or intractable technical problems. And people who work at NASA tend to stay many years, building up their networks over decades. Even many retirees stay involved, offering their "graybeard" expertise to younger colleagues both informally and through their involvement in review boards and advisory groups.

Some NASA Examples

Probably every NASA project can offer multiple examples of social capital at work—instances where team members went to trusted mentors or former colleagues or other professional acquaintances for help solving a technical problem or an issue related to how their project is being carried out or how it is perceived or supported by others. Here is one example of the power of social-capital connections to address a tricky technical issue.

"Give Me Two Pictures"

Rob Manning, chief engineer of the Mars Exploration program at the Jet Propulsion Laboratory, tells this story about a design breakthrough for entry, descent, and landing of the Spirit and Opportunity rovers:

> *We put these three rockets in the backshell and a little inertial sensor that allows us to figure out which way was up. The problem is, winds could be pushing along horizontally. I'm thinking, I've got to get a horizontal velocity sensor. If there's a big steady wind pushing it along horizontally, right now the vehicle has no idea that's happening. If the spacecraft knew the velocity, it could use the small rockets to adjust for that. I told my friend Miguel San Martin, "I need to get Doppler radar on the vehicle to measure velocity." He puts two fingers up and says, "Give me two pictures." I said, "Oh, my God, what a brilliant idea. Who should I talk to?" He says, "Call Andrew Johnson. He does two dimensional image-correlation algorithms." I knew this was not going to go over well with the project management. Emergency systems engineering, adding new subsystems at the last minute, is a sign of weakness. Luckily, it turns out we built rover electronics with ten camera ports but only nine were needed. We wanted to modify one of the existing science cameras and put it looking down and have it take pictures on the way down. It could compare two pictures. If they shifted by a certain amount and if you knew the time between them, you'd know how fast you were moving. We took three pictures—to double-check. Within six months it was in the design. Had we not used it, we would have ended up bouncing at 60 mph right toward the southern rim of Bonneville crater, where those sharp, wind-carved rocks called ventifacts lived.*

Manning's story offers a vivid picture of social capital at work. A conversation with a friend quickly leads to an innovative technical solution to a problem that a much longer formal knowledge search of documents and databases would probably never have found. And the friend directs Manning to someone in his personal network who has the specialized expertise needed to make the idea work. Getting that new contact shows another aspect of the power of social networks: they frequently provide access to the acquaintances of one's acquaintances, vastly expanding the potential resources of knowledge and support.

The Orbital Boom Sensor System

After the *Columbia* accident, the shuttle fleet was grounded until the orbiters could check for thermal-protection system damage before returning to Earth. Kim Ess was project manager for the orbital boom sensor system, which gave them that capability. She notes:

> *We didn't have to convince anyone that the work mattered to the space program and to the safety of our astronauts. And the importance of returning to flight and preventing future catastrophes gave us a defining and unifying goal that inspired hard work and cooperation, although, as with any project, it was important to help team members keep the goal in view as they dealt with the details, complexities, and inevitable frustrations of their parts of the work.*

Teleconferences were important for sharing information, but, she says, "Travel, travel, travel was the most important part of our communications strategy." It was the only way for people to develop real working relationships—robust social capital.

An important shared goal—a "unifying aim"—fostered cooperation, building trust-based social capital. Ess also emphasizes the importance of personal contact. Teleconferences were important for sharing information, but, she says, "Travel, travel, travel was the most important part of our communication strategy." It was the only way for people to develop real working relationships—robust social capital. She adds: Over time, we established a we-have-a-problem attitude rather than a they-have-a-problem attitude. Having people travel from site to site contributed to this change. As people got to know and trust each other and recognize that we were all working toward the same goal, information about problems became just data for the team to work with, not indications of failure.

Reviews and Social Capital

The reviews that are a standard part of NASA projects are an interesting example of a meeting place of formal process and informal social capital. Most NASA projects include milestone reviews (such as preliminary design review and critical design review) during which a board of experts from outside the project examines its progress and questions project team members to determine if the work is technically sound enough and adhering to schedules, budgets, and other managerial requirements well enough to proceed to the next stage of development. They often pose tough questions that show the project team where serious work needs to be done. Part of the process—the social-capital part—involves both the formation of the review panels and their questions and recommendations. Often, the project team leaders have some say in who will be on the boards and suggest members whose expertise and commitment they especially respect. So, although they are outside the project and likely to be tough critics, they are generally trusted colleagues, not strangers. Often, too, when they find a weakness or risk in the project that needs to be addressed, the review board members bring their social networks into the picture, saying, "You probably want to talk to X at Langley," or, "Y at Goddard is an expert in this." So the review process helps expand the network and the knowledge resources of the project team.

Maintaining the Resource

Managers who recognize the importance of social capital as a project resource will take steps to protect and enhance it with the same kind of care they devote to other vital resources. Investing in social capital is not expensive and the dividends it pays are immense. These are, in summary, a few of the ways project leaders can help develop and maintain it:

Trust team members to make decisions about how best to do their work.

- Give people time and space to talk to colleagues inside and outside the project. Recognize that informal conversations away from the computer or workbench (over coffee or a meal) often contribute to knowledge sharing and problem solving.
- Invest in travel for yourself and others on the team: face-to-face meeting matters.
- Help the team keep their shared goal in mind.
- Be open to good new ideas from any source.
- Give team members enthusiastic, public credit for the good work they do.

Changing the Project Execution Culture at NASA Dryden

By Thomas J. Horn
Fall 2012, Issue 48

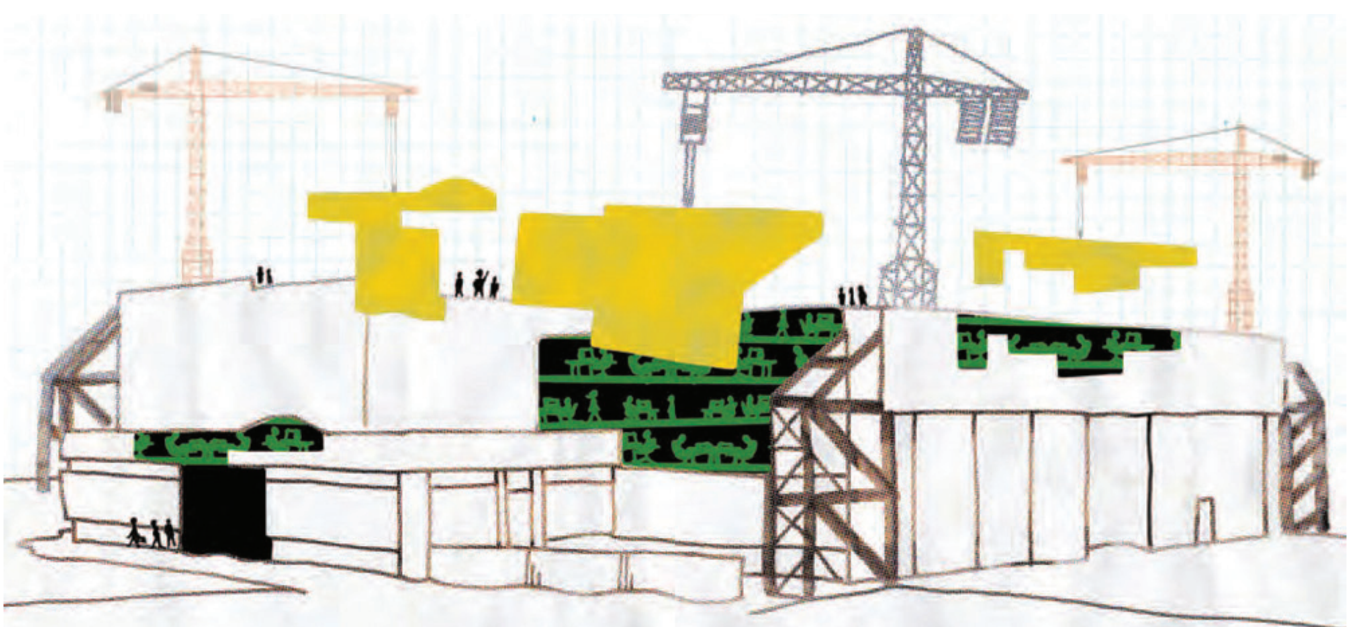
A series of audits and workforce surveys at Dryden Flight Research Center in 2009 and early 2010 identified declining on-time performance and workforce morale as major issues at the center. Dryden's senior management decided that something had to change in the way we managed our projects.

The center has been delivering high-quality flight-research projects for more than six decades. Budget realities and changing mission assignments have changed the center's focus from a relatively small number of major flight-research projects to a plethora of airborne science missions and generally smaller (in terms of budget, staffing, duration, and research focus) research projects. Old ways of tracking and managing the center's work were no longer effective and workforce stress was skyrocketing.

Dryden was the poster child within the agency for high levels of multitasking both at an organizational and individual level. Change had to happen and had to be deeper than using some new software tool to gather data to tell us what we already knew. That had been tried before. Real change also had to change the project management philosophies that had guided successful operations for many years. This wasn't going to be easy.

To change the perception that raising issues was punishment, management altered how we probed those issues. As an engineering and research organization, we tended to ask "why" things didn't work the way we expected. But "why" questions generate defensiveness and can turn discussions of issues into interrogations.

Dryden's senior management chose to implement the tools and philosophies of critical chain project management. (A web search will provide many sources of information on CCPM.) I was asked to lead that effort through the first year of implementation. As expected, we experienced



challenges during that initial phase. I hope this description of Dryden's experience will provide some valuable lessons for others.

Facing Workforce Resistance

The first two challenges we faced were directly related to the central CCPM tenets of rapid issue resolution and limiting the amount of "work in progress" at any given moment. Management's efforts to probe issues surrounding slow progress on projects were perceived as punishment. Efforts to limit work in progress generated perceptions of micromanagement in a workforce that prided itself on keeping "all the plates spinning." We did not intend either to punish or micromanage, but those perceptions led to resistance in communicating issues up the management chain and even reluctance to communicate information about what work was being done.

Regardless of our good intentions, we could not simply figure out what was wrong with the workforce and then change it. In fact, we could only control, and therefore change, our own behaviors and actions with the hope that those new behaviors and actions would change workforce perceptions.

To change the perception that raising issues was punishment, management altered how we probed those issues. As an engineering and research organization, we tended to ask "why" things didn't work the way we expected. But "why" questions generate defensiveness and can turn discussions of issues into interrogations. Turning "why" questions into "what" questions tends to focus the conversation on understanding the issue and moving forward—as long as we stay away from questions along the lines of "what were you thinking?"

A second key behavior is to provide timely help to resolve issues. Perceptions change when the workforce sees issues being effectively resolved before they become big, difficult problems.

Early in our CCPM implementation, one of our flight projects needed to replace a faulty pressure transducer required for research. This issue was identified at our weekly center work review as preventing progress on the project. Questioning focused on what was needed to acquire the replacement. Much to everyone's surprise, the director for Research and Engineering said he had sufficient funds in his budget to cover the $1,500 cost and told the project to submit their purchase request. This seemingly simple resolution made everyone in the room sit up and take notice: raising the issue resulted in concrete, immediate help instead of an inquisition.

The perception of micromanagement is much harder to change. Any change—not just the work scheduling aspects of CCPM—can arouse feelings of micromanagement as organizational leaders try to prescribe, motivate, enforce, and otherwise develop new processes and behaviors. Large changes are often, if not usually, driven by long-term goals that may not begin to manifest their benefits at the workforce level for months or years.

Dryden's CCPM implementation has several long-term goals associated with reducing workforce stress and other workforce issues. When the workforce didn't start to see those benefits after a few months of implementation, the micromanagement sentiment began to increase. I believe this situation must be dealt with in the change-planning process by carefully crafting not only long-term goals but goals and expectations throughout the implementation process. The workforce needs to be able to see progress and ideally reap some benefit throughout the whole process. For example, Dryden's CCPM implementation may have benefited from more easily achieved and recognized goals of providing desktop access to task-priority information and upcoming tasks followed by individual multitasking targets. The ultimate goals of better on-time performance and increased time for research and skill development should have been deemphasized in favor of nearer-term expectations.

In Dryden's case, the implementation of CCPM was intended to improve the performance of the center in part by improving our ability to move people between projects. This runs counter to Dryden's previous culture of dedicated project teams, each trying to get its project done without much consideration of their impact on other projects. In addition to the pride and *esprit de corps* felt by a Dryden project team as their project literally takes flight, there are issues of insufficient technical depth and knowledge loss encountered when people shift from one project to another.

The focus of pride and *esprit de corps* can be widened to include larger organizational goals through the choice of metrics and rewards. For instance, lateness may be measured as an aggregate organizational metric instead of an individual project metric. Rewarding individuals and projects that sacrifice a little schedule performance on their project to help another struggling project is another important strategy.

The issues of technical depth and project knowledge are far harder to deal with and can have dire safety and productivity consequences if not managed appropriately. Cross-training of the workforce and proper phasing of the organization's work can help maintain the necessary levels of expertise on each project even when skilled team members move to other projects. Our CCPM implementation has highlighted areas where cross-training would be of benefit, and it has occurred in some areas. Widespread cross-training has been limited by the costs (course tuition and time) associated with that training, however. Phasing of the work has been much more prevalent. As a branch manager, I have much better information at my fingertips to help me phase work within my branch as well as to anticipate and prepare for periods of high demand in the future.

Learning from Change

Change usually comes in the form of doing something new and different—a step into the unknown. We therefore want to make sure every detail is right before we step off that ledge so the change doesn't cause unnecessary problems and turmoil in the organization. Unfortunately, trying to get every detail right can lead to "paralysis by analysis," burdening management and the change-implementation team and ultimately preventing rather than preparing for change. Furthermore, getting every detail right isn't really possible when those non-deterministic systems we call "humans" are involved.

There are certainly some "showstopper" issues and large-scale business practices that must be dealt with prior to implementation. We should focus energy on those things that might cause the whole organization to grind to a halt.

In the case of our CCPM implementation, accurate but not overly detailed schedules were needed to provide prioritized task lists for managers and team leaders. It was therefore necessary to have a process and resources available for efficiently building and revising project schedules before going "live" with CCPM. Rather than wasting time before implementation on imagined issues that might not actually manifest themselves, we should let the implementation itself tell us which details need attention. The key is having implementation team capacity and a plan in place to deal with the inevitable issues that arise during early implementation. Having processes in place to collect questions and problems, evaluate them, and act quickly to resolve the significant ones is critical. It is also necessary to have the capacity to coach new behaviors and revisit pre-implementation training when "book learning" meets reality. Finally, the implementation team must include people who have currently or recently performed the affected functions and understand the change being implemented. Those people have the best chance of understanding when pre-implementation planning has reached the "good enough" point. Also, they have the respect that is critical in leading their peers through the change.

The final two challenges I want to address are phased implementation and the ability of the organization to focus long-term attention on the change. Phased implementation, though sometimes necessary for any number of reasons, has certain negative effects that a "cold turkey" implementation would avoid. A phased implementation prolongs the change process and sets up situations where different parts of the organization operate under different rules. In the case of Dryden's CCPM implementation, most of our airborne science missions were to be phased into CCPM *after* the initial implementation, which included our aeronautics research projects. This was due to the limited capacity of the implementation team and the different character of the science projects. Aeronautics research projects were prioritized based on predicted lateness while airborne science projects received no such daily prioritization. It was therefore difficult for managers and team leaders to judge the relative daily priority of tasks across Dryden's full portfolio of projects.

We learned these lessons about phased implementation:

- If a phased implementation is absolutely necessary, carefully define the scope of the essential phases to minimize the number of sub-organizations that have to operate both in and out of the change.
- Whether phasing implementation or not, always err on the side of overestimating required implementation resources.
- Eliminate old processes, procedures, and ways of doing business as quickly as possible. Leaving pockets of "old ways" in the organization will only put drag on the change effort.

Increasing the duration of change implementation through phasing only makes it more difficult for organizational management to maintain needed focus on the change. Issues surrounding budgets and staffing levels and demands from Headquarters will necessarily draw management's attention away from the change effort. They will likely leave it in the capable hands of their implementation team. But that team still needs management attention to approve process and procedural changes, maintain ownership of the implementation design, and generally promote and champion the change.

It is important for a senior manager and her organization to be responsible for implementing and sustaining the change. An ad hoc implementation team is still important, though, to provide extra staffing to push the change design and implementation and bring affected organizations into the process. Management must lead the change by example, and only management has the authority to change the underlying rules, processes, and procedures of the organization.

Progress and Lessons

After nearly two years of implementation, Dryden is still working to fully implement the processes and philosophies of CCPM in all its projects. Several things have helped achieve the desired change:

- Having representation from each affected directorate on the initial implementation team
- Providing solutions when issues are raised
- Management taking ownership and responsibility for continued implementation of the change

Some things I would do differently if I were doing this work over again:

- Instituting near-term goals, metrics, and rewards for the initial implementation to provide motivation through the challenging times of initial implementation
- Including two representatives (instead of one) from each affected directorate on the initial implementation team; this would allow one to focus on solution design and the other to focus on training and coaching

I want to leave you with some key points that I hope will make your next change implementation more successful:

- True change that significantly improves the performance of our organizations comes from changing how people think about and execute their jobs at all levels of the organization. This is hard.
- It takes a lot of resources, particularly people, to implement the change. Don't underestimate those requirements.

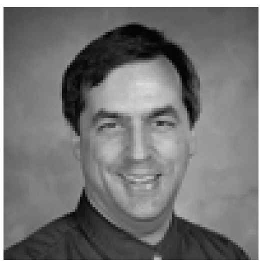
- Choose near-term and ultimate goals, metrics, and rewards carefully. They need to be constructed to demonstrate and celebrate early progress toward ultimate goals and drive the desired new behaviors.

- Once change is launched, execute implementation quickly. Purge old ways of doing business from the organization and make the new philosophies and tools the way the organization operates.

- Senior management must lead the way through communication and action. Questions to their staff

- should force people to think about going forward into the change, not looking back to justify past actions.

About the Author



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Understanding International Project Management

By Angela Marsh
Fall 2012, Issue 48

At the Marshall Space Flight Center Mission Operations Laboratory, we provide facilities, systems, and ground-systems services to other NASA centers, universities, and research centers and to international space agencies. International Space Station (ISS) payload operations are among the services we offer at our control center. The payload operations include command and control of science payloads aboard the ISS and communicating data from the experiments to organizations in the United States and to our international partners.

As mission operations systems manager and co-chair of the ISS Ground-Segment Control Board, I've become aware of some of the challenges and subtleties of working successfully with our colleagues at the European Space Agency (ESA), the Japan Aerospace Exploration Agency (JAXA), the Canadian Space Agency, and the Russian Federal Space Agency. I took the Academy of Program/Project and Engineering Leadership's International Project Management (IPM) course in February 2012 in hopes of getting some tools and insights that would help us ensure that those international partnerships are as productive and effective as possible.

Crisis Response

Normal ISS payload operations are complex to begin with. An unforeseen crisis adds to the complexity, and not having a good understanding of how international partners operate can make a difficult situation even harder to evaluate and manage. Around midnight on March 10, 2011—the morning of March 11 in Japan—our Huntsville Operations Support Center ground controller received a call from the ground controller at the Space Station Integration and Promotion Center (SSIPC), which monitors and commands Kibo, the Japanese experiment module, at JAXA's Tsukuba Space Center. Our log reports that the Japanese controller sounded "scared" as he relayed the news that the trans-Pacific circuit was down.

The source of the problem, of course, was the undersea earthquake and tsunami that caused such devastation in Japan. The ground systems for Kibo and Japan's H-II Transfer Vehicle (HTV) were damaged, and circuits between SSIPC and Johnson Space Center were lost. But the link between SSIPC and Marshall remained intact.

Nevertheless, we did not hear from JAXA for two full days after that log entry. The IPM course brought clarity to what was happening during that time. In a situation like the tsunami, people are worried and confused about what to do. Knowing the level of management decision required by the Japanese, those days were surely spent getting required approvals from line management for forward plans. After the course, I could have better explained to our ground controllers what was happening and told them not to worry as much—that JAXA was taking care of business the way they needed to and we would hear from them when decisions were approved.

Almost a year later, the IPM course identified the likely primary cause of that silence. In *Cultures and Organizations*, the main text for the course, Geert Hofstede discussed the relationship between bosses and subordinates and the process of making decisions in Japanese organizations. Those two days were almost certainly spent in methodical and detailed work and team reliance on leaders to make final decisions for the group.

In the grasp of the International Space Station's Canadarm-2, JAXA's Kounotori-2 H-II Transfer Vehicle is moved from the space-facing side of the Harmony node back to the Earth-facing port of Harmony. Photo Credit: NASA

The International Space Station Payload Operations Center at Marshall Space Flight Center. Photo Credit: NASA/Marshall Space Flight Center

On March 13th, the decision was made, and our Japanese colleagues requested a change in voice formats. On the 14th, voice was re-routed through Marshall. That remained the active link until the Johnson circuit was recovered on March 18th.

Learning About Our Partners

The IPM course covers cultural challenges, legal concerns, and teaming issues likely to be encountered when working with international partners. Some of the material is very straightforward. Things like being aware of time differences and foreign holidays when scheduling meetings and setting deadlines are simple but important, both as practical issues and as signs of respect and consideration.

There are many additional ways to show respect and begin to develop the trust that is essential to working well together, from learning greetings and common phrases in partners' native languages to trying local food and drink to subtler social issues like the meaning of particular gestures or ways of speaking in a given culture.

A lot of these elements are discussed in Hofstede's book. He explains how the cultural characteristics of various countries are likely to play out in business transactions and suggests the kinds of adjustments in communications, negotiating styles, and expectations that need to be made in various international work situations. Speakers at the course supplement his advice with information specific to international cooperation in space—for instance, how different space agencies manage their projects, and the influence of trade regulations on sharing aerospace technologies.

As useful as the information provided by readings and presentations is, the most valuable part of the course may be the opportunity it provides to meet and work with the foreign nationals who are taking it. Interacting with them informally and in class activities that involve playing out a multicultural project together bring the cultural issues to life and make our differences—and our similarities—vividly real. It also helps bring language issues to light.

English is the official language of the ISS, so our international partners are working in what for them is a foreign language. Helping out with translation and taking time to make sure that everyone has a common understanding of the subject under discussion are essential to avoiding problems. Remaining aware that our international colleagues are not native English speakers also contributes to our appreciation and admiration—they speak English so much better than most of us at NASA can speak any other language.

Things like being aware of time differences and foreign holidays when scheduling meetings and setting deadlines are simple but important, both as practical issues and as signs of respect and consideration.

Bringing the Lessons Home

The IPM experience gave me the ability and courage to be a better mentor to my team and coworkers, making me more confident that I could give them useful guidance about working with different cultures and countries.

Sensitivity to cultural and organizational differences is essential to the success of all our ISS work with our partners. For example, the alpha magnetic spectrometer Asia Payload Operations Center in Taiwan will be responsible for the safe operation of the spectrometer for the next ten years. A high-level university professor who will lead some of that instrument's cosmic-ray research mentioned that he would like to visit or send someone to visit Marshall and the Huntsville Operations Support Center. This would give each of us insight into how the other works.

Business invitations between organizations in the United States require an understanding of business etiquette. Business invitations between a U.S. organization and a foreign agency involve additional layers of understanding and finesse. Thanks in part to the IPM course, I was aware of the importance of some of the details of this situation: whom the invitation should be addressed to, who should send it, what the expectations of the visit should be.

Another example: I recently received an e-mail from one of our international partners informing me that he had received an e-mail from Marshall security officials requesting information about their control center assets. Of course, it didn't take

JAXA's "Kibo" mission control room in Tsukuba Space Center. Photo Credit: JAXA

participation in the IPM course for me to know that this was an error that had the potential to upset our partners. But the course did help me understand how important correcting it forcefully and quickly would be to maintaining our relationship of trust and cooperation. I immediately sent an e-mail to our partner, with copies to our other partner centers, explaining that he was not required to send that information and thanking him for bringing the request to my attention.

A more far-reaching security issue relates to compliance with Homeland Security Presidential Directive 12, a mandate that requires government agencies to know who is accessing government systems and whether they can be trusted not to compromise them. Our ISS international partners had a hard time understanding and accepting the idea that the U.S. government would not recognize their own governments' security credentials.

The IPM course taught that trust is the bottom line of the relationships with our international partners and here we were basically telling them we didn't trust their security processes and would require them to re-establish their identity using NASA credentials. Not wanting to compromise our relationships yet needing to comply with the security regulation, we decided to redesign our Huntsville Operations Support Center systems to authenticate foreign national users using their NASA user identities and RSA-token identification credentials. This approach still meant we had to convince our partners to load a user-identity verification system at their centers, but it would require no further effort on their part.

Convincing the international community that their systems would not be affected by the additional software took many hours of design review, consultation, and training (and a promise that there would be no cost to the partners)—and it required the trust we were working to preserve. ESA especially and understandably took exception to NASA's unwillingness to accept their identity and credential system, and it took all our relationship skills to win them over.

In the end, we gained access to our IT systems for the 365 foreign nationals we work with. Putting ourselves in their shoes and making the extra effort to design a system that would have as little impact on them as possible helped maintain the cooperative, trusting relations we have worked so hard to create.

As useful as the information provided by readings and presentations is, the most valuable part of the course may be the opportunity it provides to meet and work with the foreign nationals who are taking it.

Trust and Respect

As these examples suggest, trust and respect are key to successful international partnerships. That is the underlying lesson of the IPM course and of our experience working with our international ISS partners. The reliable service and support we have provided over the years have gained and kept our partners' trust and built a high level of mutual respect.

We continue to receive regular requests for new system designs and services. ESA has recently requested a new ISS delay-tolerant network. JAXA has asked us to provide Ku-band access to their ISS Japanese Experiment Module laboratory. Years ago, it would have been hard to carry out this request. The language barrier would have been part of the difficulty but so would the formality of documentation they required and the complexity of their management decision process. Over time, though, working together has become significantly easier as trust has developed among the personnel at each center. Sometimes decisions are made at a lower level than would have been possible in the past and with less need for extensive formal assurances. This progress makes us smile because we know we are being successful at a different level, an international level.

About the Author

Angela Marsh serves as branch chief for the Marshall Space Flight Center Mission Operations Laboratory Mission Operations Systems Branch, managing day-to-day operations of the Huntsville Operations Support Center, which includes the ISS Payload Operations Center and the Fast Affordable Science and Technology Satellite Control Center. She also serves as the deputy chairman for the ISS Ground-Segment Control Board.

Interviews

From Masters with Masters: Jack Boyd and Hans Mark

Fall 2012, Issue 48

In August 2012, NASA Chief Knowledge Officer and Academy of Program/Project and Engineering Leadership Director Ed Hoffman sat down with Hans Mark, from the University of Texas at Austin, and NASA's Jack Boyd at the Ames Research Center as part of the Academy's Masters with Masters series. Dr. Mark has held several roles, including NASA deputy administrator, Ames center director, chancellor of the University of Texas, secretary and undersecretary of the air force, director of the National Reconnaissance Office, and director of research and engineering at the Department of Defense. Jack Boyd has worked at Ames for more than sixty years and is the senior advisor to the Ames center director. He has been the NASA associate administrator for management, and has also served as the acting deputy center director for Ames.

Hoffman: How did you start working together?

Boyd: I got a call from the about-to-be administrator, Jim Beggs, saying he had this young fella he wanted me to show-around Ames. So Hans came and spent a day.

Mark: When I came to Ames in February of 1969, I was clueless. The person in the director's office who taught me how to do things is Jack Boyd, because he was Harvey's executive assistant. And then both of us worked for Edie Watson for some years, which really got us started.

Hoffman: You're both extraordinary leaders. What do you think are the characteristics of being an exceptional leader?

Mark: I think the critical thing is the creation of an atmosphere where people can develop themselves and things can happen. Occasionally, I like the term "management by exception"—that is, you manage when you think something is going wrong and say, "Okay, we have to do something." But, by and large, you hire people who are smarter than you are, and that works by itself. I've had that as a principle for sixty years now.

Boyd: I like to look for someone who loves what they are doing. Also, and I have done this most of my life, you've got to rely on other people to get things done. If you don't get along with other people, you're not going to get things done very well. We have a saying at NASA, which I mostly agree with: "Failure is not an option." I think failure is an option in the technology world because you've got to try new things and sometimes you are going to fail, but don't let that stop you from doing things. Don't give up.

Hoffman: One of the key aspects of leadership is how effective are you in times of transition, crises, and change. Both of you, at different points in NASA history, have dealt

Ames engineers (left to right) Allen Faye, Merrill Mead, and Jack Boyd discuss aircraft design and handling. Photo Credit: NASA/Ames Research Center

At a farewell party for Dr. Hans Mark, Ames center director from 1969 to 1977, are (left to right) Alan Chambers, Dale Compton, Jack Boyd, Hans Mark, Lloyd Jones, and John Dusterberry. Photo Credit: NASA/Ames Research Center

with that. What should NASA be doing today to be able to respond to a time where there is a lot of uncertainty?

Mark: Many people sitting in this room today remember the crisis we were in in 1969, after we had successfully landed on the moon. People began to say, "OK, you've done it. What is next?" For the next two years, there was a genuine crisis in the sense that we were cutting back, and we were doing things that were really no longer part of what administrators had in mind. I think that we got out of the crisis by changing the emphasis of the center from the Apollo program, which we all contributed to, to what we were good at. Of course, aeronautics came up first. One of the things that Roy Jackson, our boss at the time, did was initiate a new experimental aircraft program. In the eight years I was here, we developed five or six experimental aircraft. The tiltrotor aircraft came out of that. I think that is an example of making a change that revived our ability to hire people and to do things.

Hoffman: Is NASA as comfortable taking risks today as when you were providing leadership a few decades ago?

Boyd: I think generally not, but I should say that with some hesitation because we just saw one with MSL [Mars Science Laboratory], which was one hell of a risky thing to do, and we did it successfully. In the NACA [National Advisory Committee for Aeronautics] days—remember we were a very small organization—we weren't very high on anyone else's radar screen. So we could do what seemed to be dumb things and get away with it. Some of those dumb things turned out to be remarkable activities. For example, R.T. Jones, who developed the swept-back wing that is on every airplane that flies anywhere in the world, was not permitted to publish his paper when he first talked about it. They thought it seemed like a dumb idea: birds don't have swept-back wings, why should we? Harvey Allen and his "blunt body," which is on every spacecraft that goes into planetary atmosphere, we did that here.

I don't think we're quite in a mode today of taking those kinds of risks, but I am going to say MSL was one heck of risky activity, which was wonderfully successful.

Mark: I would answer your question by saying the biggest risk we took programmatically when I was here was to take on the development of the first large massively parallel computer, the ILLIAC IV, because no one knew how to program the thing. But we had Harv Lomax here, we had Dean Chapman, we had R.T. Jones, and then we brought in Bill Ballhaus and Paul Kutler and Ron Bailey, and a bunch of people that then sat down and made the thing work. So what did we do? We hardwired it, basically. We didn't have an operating system or a program, but we showed that the parallel computer configuration could do a calculation in 15 minutes that took the CDC 7600 several days to do. Today, every large computer has parallel architecture. I think that had an enormous impact, and we started it right here.

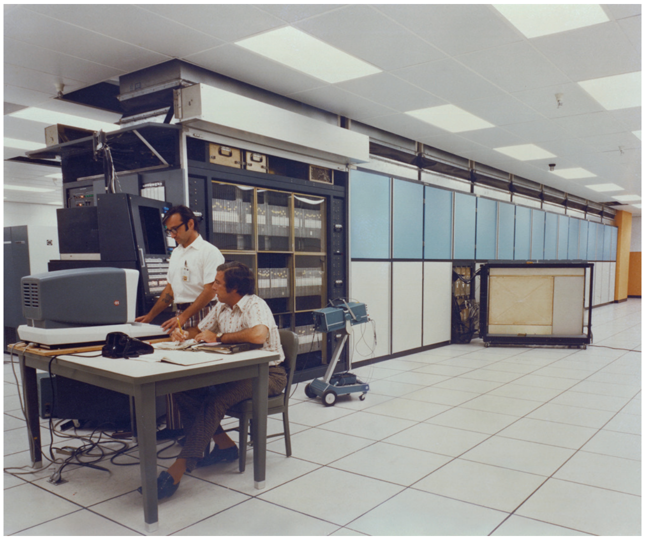
Hoffman: What are your thoughts about the vision for NASA? What are some of the things that you hope for the future of what we're doing?

Boyd: I'll quote our Russian friend, Konstantin Tsiolkovsky who said, "The earth is a cradle of humankind, but you can't stay in the cradle forever," so we've got to go outside. I think Von Braun said, "Let's do it for the fatherland." Carl Sagan said, "Let's do it for science." And a guy named O'Neil, who Hans knew quite well and used to come visit us, said, "It is human destiny to explore; exploring the solar system is human destiny." That is the way we got to do things. Now, how you go about doing it, what processes you use, what steps you take, I've got my own thoughts about. I'm not sure they are all that relevant now, but to go out and do those sort of things require you to be a pretty good salesmen, too, in order to get Congress and the people of the United States behind us. I wouldn't give up on any of this. If you fail one time, don't stop. We can't give up.

Mark: Let me separate aeronautics from space exploration. The vision for aeronautics goes back to NACA and was driven by the fact that in World War I, the United States did not have a single combat aircraft at the front. We were way behind. So for a hundred years now, we have been the leading nation in aeronautics in the world. Aeronautics today is not quite the largest, but almost the largest manufacturing industry that still has a very large balance of trade, roughly $75 billion a year give or take. So the vision for aeronautics is clear: the United States will continue to be the leading nation in aeronautics in the world. Period. The end.

Now, what about space exploration? Aeronautics is done because we have a social imperative to do it. We have victory in war, and we have the transportation system, and there are several million people who have jobs in the aeronautics industry. This is one area where NASA should stand up and say, "We know how to make jobs!"

The space industry alone doesn't employ that many people, but there are two issues. One is that the scientific work



Quadrant of ILLIAC IV, the first large massively parallel computer, with V. Tosti (standing) and S. Kravity. Photo Credit: NASA/Ames Research Center

we've done in space has become very, very important. You know, I've heard political folks tell me we don't really need satellites; when you go home today and drive your car, have you got GPS in front of you? Most people don't know where it comes from. How many people know that two Nobel Prizes have been awarded for work done with NASA spacecraft? Riccardo Giacconi got the Nobel Prize for the work he did with the Chandrasekhar satellite [Chandra observatory] on X-ray astronomy. And John Mather got it for the Cosmic Background Explorer for showing that the cosmic background is not isotropic. With Earth-orbiting vehicles, we have done science that has new, genuinely important information about how the universe works. We haven't done that yet in the planetary area, but we should do both. And in the planetary area, I think the objective must be very simple; we're going to put people on Mars. You don't spread it around too much. Just say that is the objective.

Audience: NASA is working on just a half a cent of the budget dollar. How and who do you recommend we send out to Congress to get the other half a cent?

Boyd: Engage the young people around the world and in this country. This summer we've had nine hundred students here at Ames, many of whom were foreign nationals. If we could somehow harness the power of these young folks who are really enthusiastic about what they see when they come to a place like Ames, I think that would help us tremendously.

Mark: The necessary foundation of this place has to be technical competence. If you bring a few technically competent people in, others will come. In addition to the salesmanship, there has to be technical competence. The position of a NASA center director is enormously powerful. It's powerful not because we're all that good at getting money from Washington. It is because we can choose people to do the jobs that we know they will do well.

Audience: Where do you see someone with less technical experience but with more management experience in NASA leadership?

Boyd: I think the management here at Ames recognized some time ago that technical excellence alone isn't going to hack it at a research technology center. In the mid-sixties, they said, "OK, you've done your technical things, now we're going to send you off to the Stanford Sloan Program because we need people who understand finance, procurement, what have you."

I said, "I don't want to go to the Stanford Sloan Program. That's got to be dull."

But I went, and it was probably one of the best experiences I had. It helped me understand where other people were coming from, too. I think that mix of the technical and engineering background, and a business background, is quite useful to me. So you need a mix, clearly.

Mark: I agree.

Hoffman: One of the things I wanted to get your thoughts on is recommendations for people starting their careers. I was mentioning a personal story I had to Hans and Jack. The first time I met both of these leaders was in 1983 as a graduate co-op student. I was doing research into leadership competencies, on how project teams perform, at Columbia University. Hans would have social events for the different co-ops, interns, and students. I had a friend coming up from Columbia, and I said, "Let's go to the deputy administrator of NASA's party."

He said, "No, no, let's not do that. That'll be boring."

To me, it met the number-one criteria for a graduate student: I knew it would provide free food. So I talked my friend into it.

The development of the XV-15 tiltrotor research aircraft was initiated in 1973 with joint army–NASA funding as a "proof of concept," or "technology demonstrator" program, with two aircraft being built by Bell Helicopter Textron in 1977. Photo Credit: NASA

Ames employee breakfast with Dr. Hans Mark.
Photo Credit: NASA/Ames Research Center

Leadership was there at the event, and there were about thirty of us students, so there was a lot of activity for the first half hour.

All of a sudden, Dr. Mark gets everyone around him at the center of the room. I'm stuffing my face and I hear Hans say, "I want to welcome all of you here to this event, particularly the students, because you're the future of us and it's critical that we bring on board the best. I see that we have twenty-nine of you who are aerospace engineers, and I know why you're here. One of you is a psychology guy from Columbia, and I have no idea what you're doing here."

I think that mix of the technical and engineering background, and a business background, is quite useful to me.

At this point, I get this ball of sweat right on the back of my neck. I know where this is going. Hans says, "Can you identify yourself?"

I say, "I'm Ed Hoffman. I'm from Columbia University."

He says, "Well, why are you here?"

You realize how great of a question that is. You would think someone would know why they're at NASA, but that was the first time it really locked in. Why am I here? I said, "I'm here helping teams, how they work together, how leaders perform."

He says, "Well, I'm a leader. Can you help me become more effective?"

I throw the question back, and I said, "Well, can you give me an example of an effective leadership practice that you use?"

He said, "Well, one of the things I like to do is write down what are called 'Hans grams.' I write down notes on little stickies at the end of the day and leave them with my management team. Does that make me a good leader?"

Behind him, he can't see, but his management staff is giving all kinds of signals to tell him why it is not. So I said, "Why do you think that's a good practice; why do you do it?"

He said, "I communicate with my folks, they know it's a priority, and I know when they first get in in the morning they know what I'm expecting."

I said, "Well, based on what you're saying, that sounds like a good practice."

Thirty minutes later, he invites me to his office with a couple of other students, and he's showing me different awards and medals, and he said, "By the way, I'm still totally not sure why you're here, but I liked your answer. You handled that really well."

That was when I had an appreciation for being prepared and what a testing organization meant, which means you should know why you're at a place. There was a strong community then and you could go to these events and meet the leadership, and they would test you and ask questions, but mostly interact with you.

What do you recommend for folks who start at NASA, or what are your recommendations for young professionals in terms of being successful or having a career?

Boyd: First, find a mentor. Find one or more mentors.

Hoffman: How do you find a mentor?

Boyd: Most people are really happy to do it. Just talk to people. Most of them would be happy to deal with you. Be persistent if they're not. Otherwise, get to know your colleagues as best you can. Get to know them because you're going to work with them for the rest of your careers, for the rest of your life sometimes.

Mark: I teach a freshman course in the aerospace department, and at the end of the first and second years I always pick a group of people to send to NASA centers. NASA has this scholarship for summer jobs. I think that—and this is advice for, I might call it, "pre-professional"—the people who have had intern positions and co-op positions have no problem finding jobs even today in the current environment. So, get with it early, that's the short advice. Do it as soon as you can.

I like the term "management by exception"—that is, you manage when you think something is going wrong and say, "Okay, we have to do something." But, by and large, you hire people who are smarter than you are, and that works by itself.

Hoffman: Who were your mentors?

Boyd: I had three that I remember. Harvey Allen, who was just a delightful man and brilliant. R.T. Jones was the one who told me when I got here, "Read everything that you can find out. We'll give you six months before we give you a real job to do."

Those two and Walter Vincente, who was another giant in the 1-by-3-foot supersonic wind tunnel. He was instrumental in teaching me how to write. Engineers are notoriously poor writers—and not too good at speaking for that matter—but the combination of those two, he helped me with.

Mark: Well, my father was a scientist, so obviously he was the number-one mentor. He had a student by the name of Edward Teller who became my second mentor. In the area of dealing with high-level politics and so on, I would have to say that Johnny Foster was my mentor there. We had an associate director here named John Foster, but I'm talking about the one who was in the nuclear weapons business and then went into the Pentagon. John Foster was a good physicist, and he also understood management. So I would say those three.

Hoffman: So the importance of finding a mentor is very clear, and also being able to answer the question of why you are here is one of the things that I would share. I've been here twenty-nine years, and this is one of those days I'll always cherish and remember.

Interview with Lynn Cline

By Don Cohen
Fall 2012, Issue 48

During her thirty-six-year career at NASA, Lynn Cline led U.S. delegations to the United Nations Committee on the Peaceful Uses of Outer Space and served as NASA's lead negotiator of the agreement that resulted in Russia becoming a partner in the International Space Station (ISS). At the time of her retirement at the end of 2011, she was NASA's deputy associate administrator for Human Exploration and Operations.

Cohen: How did you become lead negotiator for Russian participation in the ISS?

Cline: I was in the office of international relations, involved in early discussions of cooperation on human spaceflight, when the Soviet Union became Russia. Because I'd done that, my boss decided I should be the lead negotiator for the revision to the ISS agreement that was required to bring Russia in.

Cohen: What was especially challenging about the negotiations?

Cline: The multilateral dynamics. The original partners with whom we had legally binding international agreements did not want to become an afterthought or be viewed as less important just because they had a smaller budget or weren't providing as large an infrastructure as the Russians. Group relations changed from when you were speaking bilaterally to when you were speaking multilaterally and depending on which combination of partners you had in the room.

Cohen: Was there an element of good-cop bad-cop in the multilateral negotiations?

Cline: Absolutely. As lead negotiator I most often had to be the bad cop because the original partners—Canada, Europe, and Japan—were nervous that they would somehow lose rights and obligations by bringing in this larger partner. So when we were meeting without the Russians, either multilaterally or bilaterally, I would hear, "You can't let the Russians do this, we insist on that, we can't change this, we must have that." When we got in the room with the Russians they would rely on me to do the talking. There were times when partners would play off of one another's views. I could do it, too. I could tell the Russians, "Gee, I'd accommodate you but then I'd lose the Europeans." Or "the Japanese can't change." The other partners did the same thing. It was a challenge to understand what were the real issues and what we're negotiating tactics.

Wherever we went, there was somebody who organized a dinner or something that we could do together. We got to know who was married, who had kids, where they went on vacation, what their hobbies were.

Cohen: What were some of the challenging issues?

Cline: In the first round of negotiations, before Russia was brought in, there was a provision that said we'd endeavor to minimize the exchange of funds. If the U.S. was going to be the primary operator of the station and everyone was sharing the operational cost, then the partners would need to pay us their share. They did not want to send cash to the U.S. to meet those financial obligations; they wanted to provide goods and services instead. Out of that came things like the European Automated Transfer Vehicle. They wanted to spend their money on jobs with European industry and provide cargo services to pay part of their operating costs rather than send money to the U.S. Once we agreed to that understanding with Europe, Japan wanted to do the same. That's how we ended up with the HTV [H-II Transfer Vehicle], the Japanese cargo vehicle. What we did in the discussions was ensure that the European and Japanese cargo vehicles were quite different to make them complementary. Similarly with the Russians, we did not want to be sending them money and they did not want to be sending us money. So we had to figure out how many things we could barter back and forth to help balance out those financial obligations. We ended up trying to trade off and come out even. We both have a mission control, one in Houston one in Moscow: let's call that even. We both train astronauts: let's call that even. We tried to balance everything out. In the end, there were some remaining financial obligations over and above the things that we traded off.

Cohen: For instance?

Cline: A lot of it ended up being U.S. payments to Russia for certain things. If we had nothing left to trade against, then we'd pay for it. The first element of the space station that was launched was built by the Russians but actually paid for by the U.S., and in the legal agreement is considered a U.S. element.

Cohen: There were so many moving parts in the negotiations; it's amazing it all came together.

Cline: It was definitely a challenging and complicated process. Keep in mind that the negotiations took four years to accomplish. The invitation to the Russians to join the partnership officially was issued in 1993, and I guess it was '97 when the negotiations were finally completed. Then the language of the negotiations had to be verified and so on. It was early '98 when the signing ceremony was held.

Cohen: How much time did you spend actually meeting and negotiating?

Cline: I was on the road very frequently. There were multiple negotiations ongoing. At the top level, I was one of the NASA representatives to the intergovernmental agreement negotiations. That was a State Department–led political multilateral agreement above the space agency–level memoranda of understanding. We met periodically, one meeting in the U.S., one overseas, one in the U.S., one overseas. At the space agency level, they are all bilateral agreements. If Europe asked for changes, I would have to convey them in turn to Canada, Japan, and Russia and get all those countries to agree before I could agree to them. In the end, even though there are separate bilateral agreements, there are certain provisions that have to be identical across the board because you can't have five different management approaches. Since we were meeting bilaterally, it was a highly iterative process. You had to come back to the same points over and over. How many rounds do you have to go before everyone is on board for the same compromise for that particular provision? It was very time consuming.

Cohen: Did you enjoy the process?

Cline: At times. At times I was ready to tear my hair out. One of the things we agreed to at the beginning of our negotiations—here is a lesson in human nature—was that it would be good for us to get to know each other as human beings outside the negotiating room. We agreed that whoever was hosting a round of negotiations would organize a social event. Everybody would pay their own way. Wherever we went, there was somebody who organized a dinner or something that we could do together. We got to know who was married, who had kids, where they went on vacation, what their hobbies were. It made it a pleasure to work with these people. You could disagree across the table—everyone respected that we were representing what our agencies needed—and then you could leave the disagreements on the table and go out and enjoy one another's company. I made so many friends and learned so many things. I don't regret doing it at all, as difficult as it was.

We started out fighting over principles that we thought were going to be really important, but once people start working together and build trust and respect for one another, they figure out how to work together without having to go back to chapter and verse of the agreement …

Cohen: Were there wrong turns or dead ends in the negotiations?

Cline: The most difficult issue was the allocation for operations and utilization. In the first round of negotiations, before Russia joined the partnership, there was a calculation done of the approximate value of each partner's on-orbit contribution. Everybody had a certain percentage allocation and that percentage number determined how much crew time you got, how often you were allowed to fly an astronaut from your agency. It determined your cost obligation as well. We tried to figure out how to bring Russia into the scheme and could not do it. No matter what I proposed to the Russians as the basis for valuing their contribution, they had a different view. We couldn't figure out how to reallocate all the resources after adding in Russia. That was a major sticking point. We pushed to fully integrate Russia into the rest of the program and make it a single, unified, cohesive international space station. In the end, we backed off and ended up with what we refer to as the "keep what you bring" solution. The Russians get to keep all the allocation of operation and utilization resources and obligations for elements that they contributed. On all the rest of the station, we maintained the sharing on a percentage basis from the original negotiations, though the percentage shares evolved over time. That was one issue where we never could reach a common understanding, so we ended up with these two parallel approaches.

Cohen: Does that mean there are resources not shared with the Russians and vice versa?

Cline: Yes, but the allocation agreements allow for barters of various sorts. As the program evolves and things change, we have made trades across those borders. For example, the U.S. negotiated with Russia for the U.S. to provide power from the U.S. power system to operate the Russian segment elements, rather than them bringing up a whole separate power system. As difficult as they were to negotiate when everything was on paper and hypothetical, those allocations are only starting points.

Cohen: Am I right in thinking that you undertook this work without a technical background?

Cline: That is correct. My background was French language and culture. I came into the international office as a co-op student when I was in college. As lead negotiator, I was not expected to be the technical expert. I had a whole team: someone from the program office; someone representing the science community; someone from Houston who did a lot of the coordinating with the different elements at Johnson Space Center—the crew office, the safety office, the engineering folks, etc. I had someone from the legal office for all the legal terms and conditions. We had pre-meetings and we had a postmortem after each negotiating session. I relied on the other members of the team to make sure we understood what concerns other organizations at NASA might have that we needed to represent. We had constant feedback on all those sorts of things.

Cohen: So lack of technical knowledge was not a problem?

Cline: Keep in mind that the agreements at this level are not highly technical. They're more about the management structure, the rights and obligations. In parallel with what we were doing, there were ongoing technical discussions. We did have feedback going back and forth between those two levels. As an example, one of the things in the memoranda of understanding is a list of what each partner is providing. It was pretty well fixed for the U.S., Canada, Europe, and Japan because we had been at this for a while. I had a list of elements the got to the next round of negotiations, I'd be told the list wasn't correct any more because they had discussions with JSC [Johnson Space Center] and decided to change a few things. The technical guys were off doing their technical thing. Sometimes I was ahead of them, and sometimes they were ahead of me. We just tried to keep in communication.

Cohen: In retrospect, would you say the ISS agreements have been an effective basis for operating the station?

Cline: The framework I inherited from earlier negotiations is flexible. One of the things you need to avoid as a negotiator is getting too precise because things change, especially on a long-term program. Technical issues will arise; the policies of governments will change; administrations will change. I think these agreements have been remarkably flexible. We started out fighting over principles that we thought were going to be really important, but once people start working together and build trust and respect for one another, they figure out how to work together without having to go back to chapter and verse of the agreement and insist on what it says in Article 4, Chapter 3. It just becomes people working together who have a common goal. There were huge concerns in negotiations about would the U.S. ever exercise its right to make a decision even if the partners objected. Those were very important principles during the negotiations and certain rights were part of the agreement. But the fact of the matter is everything one partner does affects the others. The incentives are there to compromise and make things work. Once you get the politicians and the negotiators out of the way and you let the program people run the project, there's a lot of freedom to make the program work the way you need it to.

Cohen: The shared goal is so important.

Cline: We each came to it with a slightly different perspective and so the goal may not have been flavored identically for every country, but we all shared that vision. The program has evolved and survived some very difficult things. One was the fact that the Russian element— the first element—was delivered eighteen months late, I think it was. That pushed back the entire schedule. Then we had the Columbia accident. I think it's amazing that the partnership was strong enough to keep going by relying on the Russians and reducing our crew size to limit the logistics requirements. We came through that and resumed assembly.

Cohen: Are there lessons from this negotiating experience that apply to other kinds of international issues?

Cline: There are common elements to international negotiations. Some are common sense things: understanding, for instance, what your partner's objectives and needs are. You can't just be a dictator and say, "This is how it's going to be." You have to have that give and take and listen and understand the other person's perspective. A lot of it is basic good communication and building trust and relationships.

Cohen: Aside from good communication and building trust and understanding, are there other lessons you'd pass on to other negotiators?

The Space Station agreements didn't happen magically. There were years of pre-discussion that identified common interests.

Cline: Sometimes what you think is the issue may not be. There were a couple of articles in the agreement that the Russians knew were really important to the United States. They were provisions on which I had zero flexibility. The Russians refused to agree to any of those terms. Toward the end, my counterpart Alex Krasnov and I could have traded places and given one another's speech on one article, we'd done it so many times. When we reached the last round of negotiations, I put on my flak jacket and was ready to go through it again, expecting no change. But the Russians had finally got everyone on board internally; they were ready to sign the agreements. I started on my normal talking points and my counterpart from Russia said, "OK, no problem." I almost couldn't talk for a minute. That happened three or four times. Things that were really tough sticking points for me, that I had no flexibility on, they took advantage of to keep the negotiations going until they got the other things that they needed and did whatever they needed to do domestically to get everyone on board. I thought they really cared about those points, that they really meant it when they were fighting me tooth and nail about all those clauses. They didn't. What a negotiator is telling you across the table might be what they really need but it could also be a negotiating tactic.

Cohen: Before he agreed …?

Cline: There were times I wasn't sure we would ever get there because I couldn't come up with any more arguments to use.

Cohen: So the lesson is, hang in there because circumstances may change.

Cline: Right. And suppose those were points I did have flexibility on. I might have compromised and agreed to things I didn't need. If you have a principle that you feel strongly about, it's worth sticking to.

Cohen: Are there opportunities for future international space negotiations coming up?

Cline: It's not clear to me how soon. The most important thing is to keep the dialogue open so that when real opportunities do become available, you've already built the foundation. The space station agreements didn't happen magically. There were years of pre-discussion that identified common interests. Groups like the International Space Exploration Coordinating Group, which has fourteen space agencies in it, talk regularly about what sorts of things they're thinking about. No one has a specific plan; they're not negotiating agreements. They're carrying on the dialogue. When there is a desire to do the next human exploration spaceflight activity, they're poised and ready and know what the various countries' likely interests are and where they can contribute.

Case Study: Project HOPE

Case Study: Project HOPE

A young team of engineers had one year and a lot to learn before getting their rocket off the ground.

Project Hands-On Project Experience (HOPE) offered a team of young engineers the opportunity to design, develop, build and launch a suborbital flight project within one year. The concept for HOPE originated with a request in 2006 by then-NASA Chief Engineer Chris Scolese to find creative ways of giving young NASA employees the skills needed to lead future projects and programs. The result was a collaboration between the Academy of Program/Project & Engineering Leadership and the Science Mission Directorate to stand up a yearlong training program for young engineers.

The first team selected for Project HOPE was the Terrain-Relative Navigation and Employee Development (TRaiNED) project from the Jet Propulsion Laboratory (JPL). Its mission built upon a 2006 initial development test conducted on a sounding rocket flight. The previous flight had collected analog ground imagery during the descent portion of the rocket's trajectory and inertial measurement unit (IMU) and GPS data from launch to landing in order to further develop terrain-relative navigation computer algorithms. The TRaiNED project expanded on the initial mission to include exo-atmospheric imagery in addition to descent imagery. TRaiNED was part of JPL's Phaeton Early Career Hire Development Program.

The Academy captured the TRaiNED team's experiences, challenges, and insights on video throughout the year. The first of five episodes was released this month is available on the APPEL YouTube and iTunes University sites. Watch their yearlong story unfold.

QR code to the case study YouTube playlist.

"There really isn't a better way to learn how to do something than to actually go try and do it."

~ Don Heyer, TRaiNED Project Manager

ASK the Academy

Young Professional Briefs

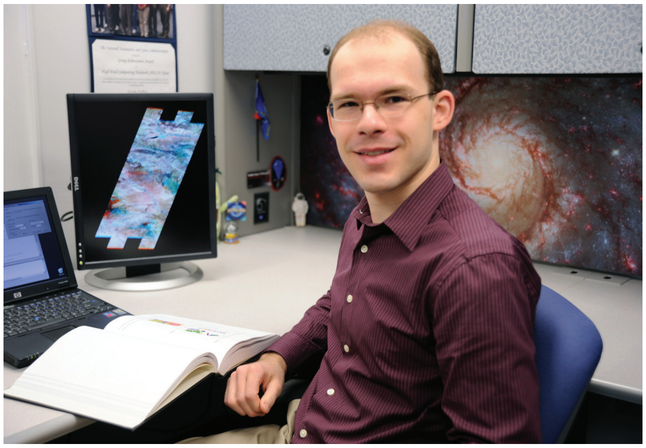
Kevin Fisher

January 26, 2012 — Volume 5, Issue 1

Kevin Fisher made his entrance into systems engineering as a freshman on a team of seniors.

Kevin Fisher was ready for a change. After three years of software engineering on various small research projects at Goddard Space Flight Center, he wanted to move into systems engineering. At a Goddard software engineering division picnic, he got his chance when he crossed paths with the head the of software systems engineering branch and expressed his interest.

"He looked at me with an expression that said, 'Seriously? This young person actually wants to get into systems engineering?'"



Kevin Fisher, software systems engineer at Goddard Space Flight Center. Photo Credit: NASA Goddard Space Flight Center/Debbie McCallum

Fisher recalled from their conversation. "I looked back at him thinking, 'He actually wants to give me a shot at this?'"

Fisher ended up in the Geostationary Operational and Environmental Satellite (GOES) Program, which launched its first satellite, GOES-A, in 1975. The current satellite, GOES-R, is set to launch in 2015. It is a collaborative effort between NASA and NOAA, with Lockheed Martin building the spacecraft and Harris Corporation building the ground system. "I wanted the opportunity to see a project from beginning to end," said Fisher.

Now a two-year veteran on GOES-R, he has had the opportunity to shift his focus from technical work to learning about project management and systems engineering practices.

Freshman on a Team of Seniors

At age 27, Fisher is one of the youngest people in the GOES-R Ground Segment Project, if not on the entire program. "It's like being on a football team that's all seniors. Almost everyone here has worked on programs like this before. They know what works and what doesn't. This is their year to go off and win a championship before they leave, and it's all freshmen again," he said.

Fisher recognizes that a lot of important information and knowledge on a project lives in people's heads and inboxes and not in official documentation. "I could read every document the Lunar Reconnaissance Orbiter team ever wrote, but those documents won't talk about every little problem that cropped up or the alternatives the team considered and said 'no' to, or why they said 'no.'"

He wants that knowledge before it walks out the door. "If I could go back as an intern, I would take an old expert out to lunch every single day for the ten weeks I was here and just let them talk," said Fisher. What happens if you inadvertently hit the red emergency stop button on a satellite dish while working the graveyard shift on Christmas Eve? "I don't need

Kevin Fisher and his "duckie" award for the GOES_R Ground Segment Project. This project peer award is spontaneously given to team members for having their "ducks in a row." Photo Credit: Kevin Fisher

to be in that room on Christmas Eve at midnight, but now I have a sense for what it was like. I know the story."

Seemingly Simple Systems Engineering

As the systems engineer for the GOES-R Antenna System, Fisher works under the guidance of Richard Reynolds, the chief staff engineer for the entire ground segment. He is struck by how Reynolds makes the job look easy. For instance, Fisher explained, a concern arose about potential signal distortion from atmospheric ionization on the polarized signals transmitted from the spacecraft to the ground antenna. The issue became more complex with discussion of electron rotations and cross-polarized signals – things Fisher made notes to look up later.

"[Reynolds] may not know as much as the antenna wonks do about this specific topic, but he's been on the project long enough to know that this sort of thing flares up during solar cycles, which are every eleven years. He's worked through several cycles and knows how bad the ionization can get," he said. "This experience helps him make decisions about whether to get another technician to help or if the problem is even worth analyzing." Fisher realizes his knowledge base is still growing. "I know that I'm learning a lot of the concepts. I just don't have the depth that they do just yet."

GOES-R Satellite. Image Credit: Lockheed Martin

Under the Hood

The Apollo Guidance Computer was limited to 13,000-36,000 words of storage lines. Orion has one million lines of high-level code. Fisher's generation of engineers live in a new project world. Software is everywhere and poses risks that haven't been fully grasped yet.

In "Is Software Broken?" (Issue 34 of *ASK Magazine*), Steve Jolly, Lockheed Martin chief systems engineer for GOES-R and former system design lead for the Mars Climate Orbiter, wrote:

> *The game has changed in developing space systems. Software and avionics have become the system…To be a successful system integrator, whether on something as huge as Orion and Constellation or as small as a student-developed mission, we must engineer and understand the details of these hardware-software interfaces, down to the circuit level or deeper… If one merely procures the C&DH [Command and Data Handling] and power components as black boxes and does not understand their design, their failure modes, their interaction with the physical spacecraft and its environment, and how software knits the whole story together, then software will inevitably be accused of causing overruns and schedule delays. And, as leaders, we will have missed our opportunity to learn from the past and ensure mission success.*

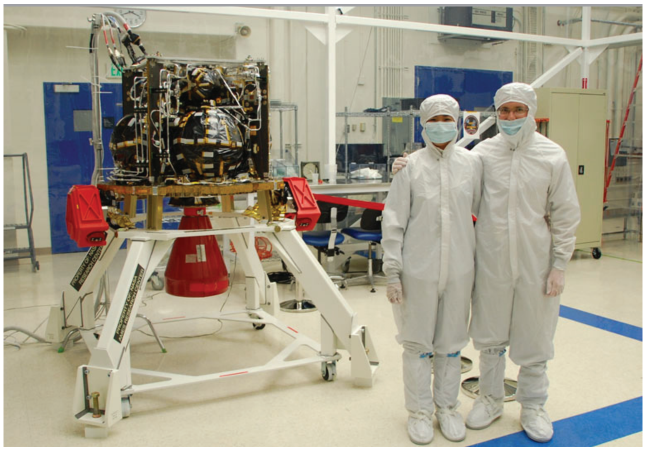
Fisher sees software as the glue holding everything together. "You [combine] all of these devices from different companies and you slip software in as the interface to grab data off of one and plug it into another." It can seemingly fix anything in a second, and then fail just as quickly.

"Systems are designed and integrated at steadily higher levels of abstraction," said Fisher. The calculations for the first lunar spacecraft were performed with slide rules. Today, engineers use computer-aided design software that makes many fundamental calculations and assumptions for them. "You're kind of building this scaffolding one layer at a time," he said, stacking his hands on top of each other. "You start people at the [bottom] layer and have them build up. Then the bottom layers get neglected and start to decay." The calculations for the first lunar spacecraft were performed with slide rules. Cars were built with four wheels because it was the most stable design in 1900. Today, Segways use sophisticated computers and sensors to balance on just two.

"You begin to take that layer of things for granted and no one is really digging back in and questioning it," said Fisher. "We need people to do that. What if we had different blocks to build with? What would we do with a clean sheet of paper?"

Josephine Santiago-Bond

July 31, 2012 — Vol. 5, Issue 7



Josephine Santiago-Bond and her husband Chris stand next to the Lunar Atmosphere and Dust Environment Explorer (LADEE) propulsion structure at Ames Research Center. Image courtesy of Josephine Santiago-Bond.

Josephine Santiago-Bond left her comfort zone when she moved from one coast to another, going from ground systems at Kennedy to working on a lunar mission at Ames.

She didn't think she'd end up at Ames Research Center (ARC) for her Systems Engineering Leadership Development Program (SELDP) year-long rotation. Bond started at Kennedy Space Center (KSC) as an electrical engineer on ground systems for the Shuttle and Constellation programs at KSC, and has worked her way into systems engineering. "I thought maybe they would send me out to Goddard or Dryden," she said, adding that her experience gaps indicated that she would benefit from experience working on a satellite or aeronautics project.

Instead, she ended up on the mission systems engineering team for the Lunar Atmosphere and Dust Environment Explorer (LADEE), a lunar orbiter that will study the moon's atmosphere and dust environment. "LADEE is totally different in the sense that it is a spacecraft. [I] never worked outside of this human spaceflight arena and never worked on a payload, and now I am here with a team working for mission systems engineering and putting together a spacecraft," she said.

The differences between KSC and ARC were readily apparent. KSC is large and operations-focused, where people are always on the go, while ARC is researched-focused and smaller. "People have a different pace here," she said. Normally used to several layers of hierarchy and multiple subsystems that go along with ground systems and operations at Kennedy, LADEE's team is much smaller, she explained. "It is comparable to maybe a couple of sub-systems at Kennedy, where we're used to having one systems engineer per subsystem."

The SELDP experience offers a series of workshops, training, coaching, and mentorship throughout the year. "There are certain things that you need to hear even though it might sound like common sense," said Santiago-Bond. Her mentor, the LADEE mission systems engineer, also shifted her perspective on traditional mentoring. "He not only gives me insight into what mission systems engineering is for my development, but he also allows me to have that communication go both ways," she said, adding that typically mentorship is viewed as one-way. "He opened up the door and said, if you see anything at the meetings or I am not leading the team appropriately, let me know. So he has allowed me to develop him as well."

She also observed and appreciated the "badge-less" team culture. "When I first came, I thought the people who were seated around me were all NASA people, but I later realized it was mixed," she said. "You didn't care whether the person you were working with was a contractor or a civil servant."

When Santiago-Bond joined the project, LADEE was about to go through its System Integration Review (SIR). The review didn't go as well as the team had hoped, and passing the follow-up review became one of her primary jobs. The LADEE project has also allowed her the opportunity to interface with other centers. "I'm used to interfacing with KSC folks for launch, but now we have Wallops," she said. The spacecraft is set to launch from Wallops Flight Facility in 2013. Today, the LADEE team is working to finish up spacecraft integration and poised to begin payload integration and preparation for a "delta SIR" (follow-up review) in August.

Santiago-Bond will return to KSC just after the review, taking what she has learned from LADEE with her. "I've always been on the ground side of the rocket looking at the interface of the rocket with the launch site, but now I've seen more of the interface of the spacecraft as the payload of the launch vehicle," she said. This experience will afford her the opportunity to work in different areas when she returns to KSC.

Josephine Santiago-Bond with NASA Chief Engineer Mike Ryschkewitsch (left) and NASA Administrator Charlie Bolden (right) at the Systems Engineering Leadership Development Program (SELDP) in June 2012. Photo Credit: NASA HQ / Carla Cioffi

"I am going back to the same branch that I came from when I was at KSC, but I am not going back to the same tasks," she said. Santiago-Bond will have the opportunity to work on different subsystems within Ground Systems Development and Operations program, but she's also exploring the possibility of expanding to work on ISS payloads and possibly commercial crew.

In the future, Santiago-Bond looks forward to broadening her experience, beginning with a detail assignment at NASA Headquarters in the next few years. "At some point, I would also like to try out a different agency. I don't want to leave NASA, but I would like to see how other government agencies work outside of NASA," she said, citing agencies like the Department of Defense, Department of Energy, or NOAA. "I just feel my view of the government as a federal employee is very one-sided. I've only worked at NASA, and I want to see the bigger picture."

Agnieszka Lukaszczyk

September 27, 2012 — Vol. 5, Issue 9

Once told she'd never make it in the space sector, Agnieszka Lukaszczyk shares what it took to build her career.

Now in her fourth year at the Secure World Foundation, an organization that promotes sustainable and peaceful uses of space, Agnieszka Lukaszczyk is currently the director of its Brussels office. In addition to her day job, she was formerly the Executive Officer of the Space Generation Advisory Council from 2006 to 2009 and then its Chair from 2009 to 2011, making her a regular presence on the international stage in aerospace. Still early in her career, Lukaszczyk took the time to reflect upon what it took to get to where she is today with ASK the Academy.

***ASK the Academy* (ATA):** You once observed that people are sometimes skeptical about young people walking right into the space industry, and that they really need to prove themselves and build credibility. Why do you think that's true?

Agnieszka Lukaszczyk: I think the main reason for that is that there is a big generational gap in the space sector. For instance, when I entered the industry, I noticed that the population skews older and is mostly men, not much in the middle age range, and then you have a lot of young professionals or students. I think what happens is that there hasn't been really a natural progression like with other sectors where you have people of different ages and from different groups. It's just very strange for people who have been here forever, for twenty or thirty years. They think they know everything [because] they've been doing it for a very long time.

I go to a lot of meetings or conferences, and most of the time I'm the youngest person in the room and very often I'm the only woman. My area of interest and my expertise is now in space policy. It's a lot of politicians and decision-makers that go to a lot of UN meetings, multilateral or bilateral meetings, NATO, etc. Those are diplomats who have a lot of experience. When I came in, no one took me particularly seriously. They thought I was probably an intern or a student who was doing research for school. What do I really know? What can I really bring into the table that [they] don't know already? A lot of these people have had to work for years to get…to be invited to these meetings that I'm invited to at half their age. So sometimes it almost feels like they feel like it's inappropriate. I have to work myself up to that. I felt like I had to work—and not just me, a lot of young people—we really have to be extra savvy, working more and engaging more to show that we really have something to say that's relevant, and that we can contribute to the conversation.

I was based in Vienna before I was based in Brussels. I was in Vienna for four years when I was working for the Space Generation Advisory Council (SGAC), and when I was there I had the privilege to present to the UN Committee on the Peaceful Uses of Outer Space (COPUOS). SGAC did not have a representative for a very long time, so they hadn't really seen anybody there for a while. And I show up at 26 at the time and I make my first statement. Of course, I was extremely nervous and overwhelmed, and it was a room filled with a lot of high-level people and then there was me, a young person with my first job. So I made my statement, and afterwards one gentleman from one delegation came up to congratulate me. He told me "Ah, this was a very good statement, well done, I'm sure this was a really great experience for you. You know, friendly advice, you should probably look for other opportunities because you are never going to make it in this game, in this environment."

I was really shocked to hear that. And he was nice about it. It was almost like he thought he was doing me a favor, saying

Agnieszka Lukaszczyk is currently the director of the Secure World Foundation's Brussels office. Prior to her current position, she served as Executive Officer and Chair of the Space Generation Advisory Council. Image courtesy of Agnieszka Lukaszczyk.

something like that to me. Of course, he didn't know me enough to know that such a statement would only motivate me to do better and that I'm going to work very hard to get to where I wanted to be. It took a long time to put myself on the map and show that I'm doing something here that matters and I'm still learning, but nevertheless I should be taken as seriously as anybody else.

ATA: So how have you seen young space professionals go about building credibility?

Lukaszczyk: I think my general advice would be for young people to be very motivated and serious about what they are doing, and simply do their best, not give up, and not sit in a corner. I was actually given this advice once. Right before that statement I gave to the UN, I was extremely nervous and I didn't know if I could do it well, and I was really, really worried. I had one mentor I had met there just a few weeks ago, who was the director of the UN Office for Outer Space Affairs (UNOOSA) at the time, and I was talking to him and I said, Look, what can I say that these people don't know? I don't know if they really want to listen to me, etc., etc.

He said, "You have a voice, you have a seat here—a permanent observer's seat—you have a right to speak. You're representing a young generation, and they should hear what you have to say." He told me that at the beginning you never let anybody put you in a corner, or you will stay there for a very long time, if not forever.

I think you need to have some sort of confidence, and I think there is a big difference between confidence and arrogance. There's a fine line there because I've noticed that when you work with people who are very accomplished, well known and established, they don't like people who walk in thinking they own the room and that they know everything better. That's not the way to do it. One has to be humble but confident at the same time, and persistent in their activity.

So I've always showed up to the meetings, I've always showed up prepared, always have done my readings, I've always done my research. I was very assertive in terms of meeting people, setting meetings, showing that I care, that I'm impassioned about the kind of work that I'm participating in, and that I'm making some progress. I think that in general this is something that I would advise to every person. Try to do your best, be humble, but be confident, and try to make sure that your voice is heard even if it's not always received. If you keep repeating the same thing over and over again, someone will finally catch on to it.

And after some time, months or even years, people will get used to the fact that [you're] always there in meetings and always participating in them, submitting opinions and expertise. I think that's my advice. Don't be intimidated and don't be overwhelmed and become an assistant to somebody because they're more important and older. Be useful to them and assist them, but don't make yourself a coffeemaker or a copy maker.

ATA: What role has mentorship played in your young career?

Lukaszczyk: For me it was quite important. I have to say I was very new to the space sector when I entered it. I didn't study space. If you talk to the people with technical backgrounds and those who are engineers and working on techie stuff, this is probably something that they've always wanted to do. They've always wanted to be an astronaut, that's their passion and dream, and so they've researched things before and maybe they knew people already before they entered the sector as students.

My story was a little bit different. I studied international politics and security, and it just happened that my first job ended up in space. I didn't know anybody. I didn't have any network. I didn't have any contacts. I was very fortunate that at the beginning I met a few key people who were very, very helpful to me in many ways. I don't think they even realized what impact they had on me and my career.

These were people who were usually older and usually had established positions. These were the people who took time to answer my emails, met with me, gave me advice, and talked to me if I had problems—and they cared, they genuinely cared. They saw that there's this young person kind of freaking out and nevertheless determined and trying to make a difference here, and thought it was worthwhile for them to help me out.

One of them, the director of the UNOOSA, who was a very busy guy in an extremely high position, would [send me] emails…at 3:00 a.m., when he was still in the office. I said to him, "You always meet with me and you always answer my emails. I'm really impressed and I really appreciate it. Why do you do this?"

He told me, "You know, a lot of people helped me at some point, and it's my opportunity to pay it forward."

So I think that this is something that I hope everyone will remember one day when we are in positions to help others and to pay it forward. It wasn't about getting me a job or getting me a raise, or anything like that. It was more of a substantive kind of help, and I knew I had a support system and two or three of these people I'm in contact with still to this day and still bother every once and a while. I feel very fortunate that our paths have crossed.

ATA: What do you think is the biggest challenge facing the next generation workforce?

Lukaszczyk: I think in particular we always hear about this problem that not enough young people in general are interested in hard sciences. That now it's very cool to study to be a lawyer or to study marketing or finance or advertising and PR or whatever. Or if you're an engineer you go into IT or something, that's where the money is. So I think for the future we need to make sure that we do proper outreach and raise awareness about what space is and how it brings all kinds of benefits to society, and work on the stigma. When I talk to people who are not involved in space and I tell them that I work in the space sector it sounds extremely intimidating. Everyone says, "Whoa how did you get this job? You must be like a genius or a rocket scientist." And I think, well, not really.

I'm always surprised at how many people with various backgrounds, besides the usual types like astrophysicists or engineers or astronomers work in the space sector. There are people who are lawyers, economists, and environmentalists, there's geography, cartography, etc. Various backgrounds are included and I don't think people quite know about this. A lot of people think space is cool, but I'm never going to get a job there, so I need to do something that is more useful. It sounds so prestigious and incredibly difficult and hard to get to, and a lot of people don't think it's a possibility. So you want to make sure that we get bright minds in our sector and they're not running away from us to the IT sectors or auto manufacturing, etc. We need to do a little better job of attracting people by offering jobs that are interesting and rewarding.

ATA: In your experience, what ways do you think are most effective for the more seasoned and established practitioners to share what they know with the next generation?

Lukaszczyk: I don't think it's as difficult as some may think. First of all, if they hire somebody who is young or have somebody on their team who is young, they need to have them there for a reason. They need to have a purpose for them. They need to include them in the activities that matter and not to just think, "Oh you're in the bottom of the lot, therefore you're not important or your opinion is not important." Take time to have a discussion on a topic that is important at the moment in the work environment, and listen to their opinions. There may be an idea for publishing a paper that's going to help them. That's going to help their resume and that's going to force them to do research that is of course important for their job. Or send them to a conference that may broaden their horizons. Keep the fire going.

This is exciting what we're doing here and whatever that might be if you're an engineer or a project manager or a space lawyer, I think in general our sector is extremely exciting. The people who come to this sector are the people who care about it a lot and who have a lot of passion and enthusiasm, and I think it's in the best interest of every company and organization to keep that enthusiasm going because they're going to be working very hard and they're going to be coming up with new and innovative ideas and they're going to be the ones who are willing to stay extra time. Don't burn them out, but make it very exciting so that they grow.

I have a friend who just got a job in a space organization a year ago, and she told me her boss rarely talks to her. Of course he knows her name and he sees her in a hallway and he says, hello how are you. She said, "I wish he would sit down with me for coffee or lunch and ask me how I am doing. What is it you like about this job? What would you like to change? What do you think about this project that we're working on? I would love that, but I don't think he thinks I know enough to contribute." She's demotivated. Paying attention to young folks really makes a difference.

ATA: Do you think it's because people are too busy?

Lukaszczyk: Time is definitely an issue, but I think it's a matter of where there's a will, there's a way. I think a lot of it depends on the personality really. There are some people who, when they become very important they feel like they don't really need to hear so much input, particularly from somebody who is new and fresh in the sector because they don't feel like they have anything interesting to say. You hear about this all the time.

Then you hear about this boss that is so wonderful. I was telling you about one of my mentors, who is an extremely high-level guy and extremely busy. Yes, he took the time to meet with me, but it's not like we were meeting every day. When there was a need, he always found some time. Even being on the phone for like ten minutes made a difference. Even answering my email. If I knew somebody like that answers my email directly and it wasn't his secretary. I thought, wow that's really cool. This guy actually reads what I have to say, that's really awesome, so I need to make sure that I'm sending him good stuff so that he actually reads it, so I'm going to make an extra effort there.

Of course we're all extremely busy and we're juggling several balls in the air and running from meeting to meeting. It's not that we have bad intentions but sometimes we forget that there's this sort of legacy that we want to leave and we should slow down a little bit and pay it forward because that's the right thing to do.

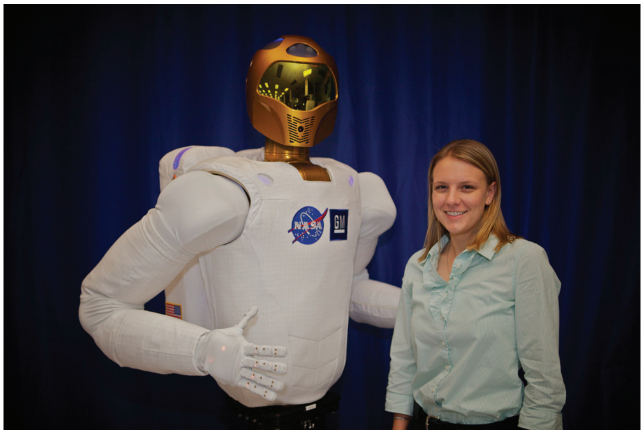
R2 and C.J. Kanelakos

October 31, 2012 — Vol. 5, Issue 10

Straight out of graduate school, Carolynn "C.J." Kanelakos had the opportunity to build Robonaut 2's lower half.

On February 24, 2011, Robonaut 2 (R2), the NASA-General Motors humanoid robot torso, launched to the International Space Station (ISS). With its state-of-the-art dexterity, unmatched weight-lifting capability, and slick helmet, R2 was designed to perform anything from routine, time-consuming tasks to high-risk work. A step forward in humanoid robotics in space, the robot serves as a teaser to futures imagined by Isaac Asimov. It also begs the question: Where are its legs?

C.J. Kanelakos, mechanical engineer at Johnson Space Center, with the R2 torso and legs on the table in the background. Photo Credit: NASA



C.J. Kanelakos, mechanical engineer at Johnson Space Center, with the R2 torso. Photo Credit: Joe Bibby

LEGS FOR CLIMBING

Two years ago, Kanelakos, a mechanical engineer fresh out of a master's program, had the opportunity to become part of the R2 team of coders, controllers, electrical engineers, and mechanical engineers at Johnson Space Center. Her job: design and build R2's lower half.

The R2 torso could be adapted to different types of "legs": a Segway-like roller, a six-wheeled rover called "Centaur" or a bipedal set of legs. Kanelakos started work on a pair of walking legs for R2, but a shift in vision for the program resulted in the need for a different type of legs. R2 currently resides inside the space station—a place where walking is not a prerequisite.

In a microgravity environment, legs serve a different function than they do in a 1g environment. "Humans don't really use their legs that much in space except to keep themselves from floating away," explained Kanelakos. "[Astronauts] anchor themselves with their feet while they do stuff with their hands. For our purposes, we wanted to use the legs to be able to climb around."

Kanelakos and the R2 team considered a number of possibilities for R2's new ISS-ready legs and observed how humans naturally move about the station. "We couldn't really have the robot climb efficiently using traditional joints like humans have in our legs," said Kanelakos. "The legs that we're designing have some additional degrees of freedom, which means [building in] extra joints. "The team addressed a number of questions: What will the R2 legs interface with? How will they actually move the R2 torso around? What size do they need to be in order to fit inside the space station? What do they need to look like?

"We wanted to make sure that they were long enough to reach across a hatch and still fit inside the space station because they were [and] are designed for intravehicular activity (IVA)," said Kanelakos. "From there we started taking input from everyone on the team and asking, what are the things that work well in the upper body and how can we improve the actuators (a type of motor used for controlling a mechanism)?"

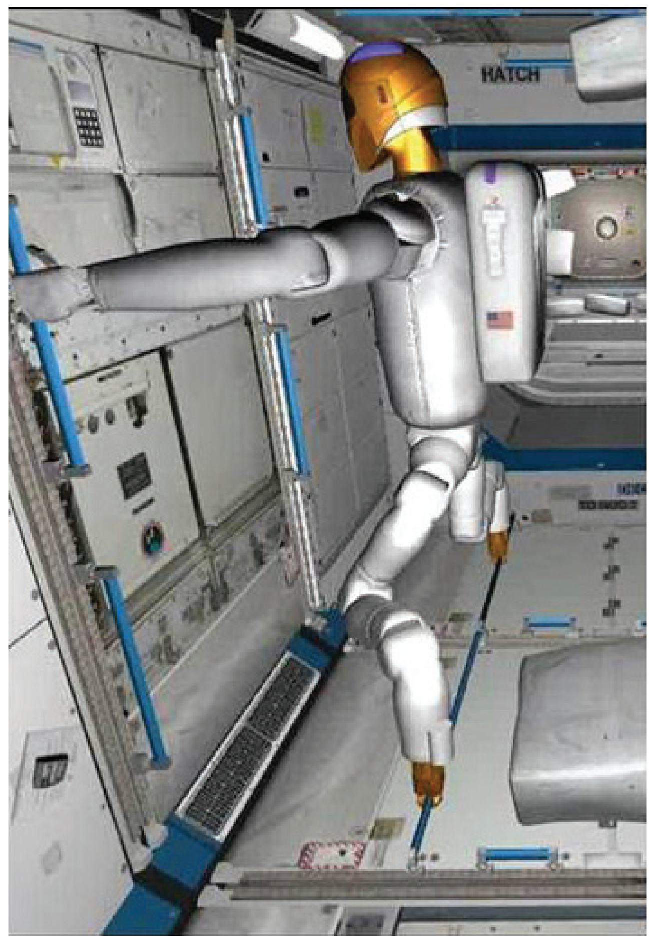
At this stage of the project, Kanelakos ran into a knowledge gap. "I didn't know the way things were done and I really didn't know much about the torso at all because I didn't work on it," she said. The Robonaut program had a previous 12 years of history, and she needed to catch up.

CLOSING THE KNOWLEDGE GAP

The R2 team skews younger than most others at NASA but is supported by a wealth of expertise and robotics knowledge. If she needs to know something, Kanelakos usually will go straight to a team member who has specific expertise or has been around the program longer.

"When we started on the climbing legs, I thought, this will be a great opportunity to start learning more about the actual design of R2 actuators and why they did things the way they did in the upper body," said Kanelakos. "I also thought it could be a good way for me to bring a fresh perspective because I don't know why things were done the way they were. I asked a lot of questions."

Things just sort of get passed down, she explained. "I'm actually experiencing that right now. We're trying to design



Computer-generated image of R2 working inside of the International Space Station with its climbing legs locked into a track configuration and grasping the hand rails.
Image Credit: NASA/Johnson Space Center

C.J. Kanelakos, mechanical engineer at Johnson Space Center, with the Space Shuttle Endeavour in the background in 2012. Image courtesy of C.J. Kanelakos.

Extra Vehicular Activity (EVA) compatibility into the robot, which means sending it outside the space station. That's a huge challenge in itself. Coming from zero EVA background, I have no experience with spaceflight hardware. Hardware that is outside [the station] goes into vacuum, it's experiencing extreme temperatures, and all of these other factors have a huge impact on your design and your hardware. Where do I even start with all of that?"

Kanelakos says she talks to people to find what she doesn't know. "It pretty much is talking to people," she said. "I need to find someone who can help me find those other resources." Learning conventions and then challenging them is part of the process. "What if we did it this way? What would the impact be? What would be an improvement? I'm just trying to learn from the guys who were there before," she said. "Sometimes you have to dig a little deeper and ask if [a certain way is] still the right way to do it."

Kanelakos also values what she has learned from her leadership and management. Over its 15-year history, the Robonaut program has seen its ups and downs in funding and support. She has taken care to learn how her management has sustained the program through varied levels of support through partnerships and adaptable workflow.

Additionally, spending time with seasoned practitioners has been critical to gaining knowledge about the project. Rob Ambrose, chief of the Software, Robotics, and Simulation Division and lead of the original Robonaut team, takes the time to discuss the project and offer his insight, she explained.

"Even though I'm not working directly with him right now and he's not involved quite as much in the day-to-day activities of Robonaut, it's been great to talk to him just because he has so much experience and so much knowledge in the field of robotics," said Kanelakos. "It's cool to learn things from him. Things we didn't even think about that might have just gotten lost over the years."

Putting One End Effector in Front of Another

With any project attempting to emulate a human capability, there is always the question of whether or not a desired task has to be accomplished the same way a human performs it. In the case of R2's "roving" legs, four wheels were more appropriate than a humanoid bipedal system. In the microgravity environment of ISS, the team had considered just using a single leg (a "tail"), but this wouldn't have provided the desired autonomous mobility. If one leg wasn't enough, then how many would be?

Two fit the bill. More legs introduce increasing complexity, including the need to design a system to keep track of all of R2's appendages. At the end of each leg is an end effector, a sort of clamp for gripping onto a handrail or other surface of the ISS. "If you put all four of your fingers together and then you have your thumb on the other side, that's almost what the gripper is like, except symmetrical," explained Kanelakos.

Telling the end effectors where to go is a something of a beautiful problem. Humans do it every day when we put one foot in front of the other. We (usually) don't need to look at the ground. For R2, it has to look at the ground constantly. For R2's torso, hand movements are driven by a vision system that is still in its development stages. "Integrated cameras in the head and the end effectors will provide vision and software [will] use that to figure out distances and have the robot – long term – be able to…figure out where the next hand rail is, figure out how far it is, and how it needs to move to grab onto that handrail," said Kanelakos.

The team did consider replicating the hands and using them as part of the legs. However, "We knew that the hands themselves were probably not going to be strong enough and the fine dexterity in the hands was not a requirements for the legs, so that's when we started [looking at] the end effector," said Kanelakos. "We needed some extra strength for the robot to be able to hold on tight to the hand rails and climb around the station while leaving the arms free to perform other tasks."

The next step is to translate these hand movements to leg movements. "We can tell the end effector a point in space where we want it to go and so the rest of the joint can figure out how to get there. We know how to do that for the arms right now, so it's basically just transferring that knowledge into the joints for the legs."

"It's not an easy task," said Kanelakos about autonomous robots. "If it was, we would have them all around us already."

Paying it Forward

R2 is scheduled to get its lower half sometime next year. In the two years Kanelakos has been on the project, she has learned volumes. Designs and documentation are stored within CAD models and shared drives. Time spent with seasoned practitioners like Ambrose offers valuable opportunities to gain insight into a career's worth of experience. Open laboratory spaces also enable free and spontaneous opportunities to collaborate.

Kanelakos acknowledges the challenge of sharing what she knows. In an electronic system, "you have to know where to go to find what you don't know," she said. "If you want to find some specific documentation on a shared drive, you [usually] need to ask the person who put it there. You can search, but keywords just don't always come up with what you need."

"I don't really know what the answer is for engineering documentation. I think that's a constant challenge," she said. "Engineers just want to keep doing what they're doing. They don't want to write a book on why they did what they did, but there is a lot to be said about having good documentation and being able to learn from it."

There is a balance that needs to be achieved between capturing enough detail and achieving efficiency, she explained. "Where do you draw the line?"

International Project Management Committee Young Professionals Workshop

October 31, 2012 — Vol. 5, Issue 10

Over forty young professionals from around the world gathered to address the question: What does the next-generation workforce need to be successful?

On Friday, September 28, 2012, forty-plus young professionals from government, academia, and industry from all over the world came together to engage in a workshop about their future. With many challenges facing the next generation—including a looming generation gap that could jeopardize critical knowledge—workshop delegates shared stories, insights, and data about their work experiences and developed recommendations to begin addressing these challenges.

The idea for the workshop stemmed from a meeting convened in late 2011 by the International Project Management Committee (IPMC), an organization of space agencies, companies, and professional organizations dedicated to sharing experiences and best practices with space program/project management practitioners at the global level. One topic of interest was how the IPMC might be able to support the development of the next-generation workforce.

As a result, the IPMC, in collaboration with the International Astronautical Federation, supported the 2012 IPMC Young Professionals Workshop, with the goal of gathering input on what today's space organizations can do to better develop and empower the next generation workforce.

The workshop focused the delegates on discussion topics that covered opportunities and challenges young professionals face, mentors and mentorship programs, exchanges and rotational assignments, motivating factors for young professionals, and the interface between the technical and managerial career paths. In order to capitalize on their limited face-to-face time at the workshop, the delegates participated in pre-workshop sessions through Skype and telecon, and collaborated through a Facebook group.

Young professional delegates from South Africa, Italy, Germany, France, South Korea, and the United States discuss the motivating factors for young professionals in the space industry at the 2012 International Astronautical Congress in Naples, Italy. Image courtesy of Armonica Film.

"I have never met so many young space professionals from all over the world," said Francesca Moretto, who has studied space law and is currently a fellow in the Italian Space Agency's International Relations Unit. "Working together made me realize the deep diversity and cultural approach to young people, but also that we have a common purpose to change things and create new opportunities. I really hope that this effort will continue to develop itself and reach new goals."

The organizing committee for the workshop prepared a presentation for the IPMC to discuss the preliminary findings from the workshop. The delegates reported that some benefit is gained from existing young professional programs, but there is more to accomplish, and they proposed ideas to further explore or add. Some key recommendations included:

- Allow young professionals to participate in high-level meetings (international or not related to their current project), either as observers or in more critical roles
- Consider incorporating online course materials from various institutions into professional development plans
- Facilitate more networking and cross-collaboration opportunities at conferences, meetings, and workshops in physical and/or virtual space
- Reduce administrative barriers to internal, cross-agency, and international exchanges that broaden professional experience and perspective

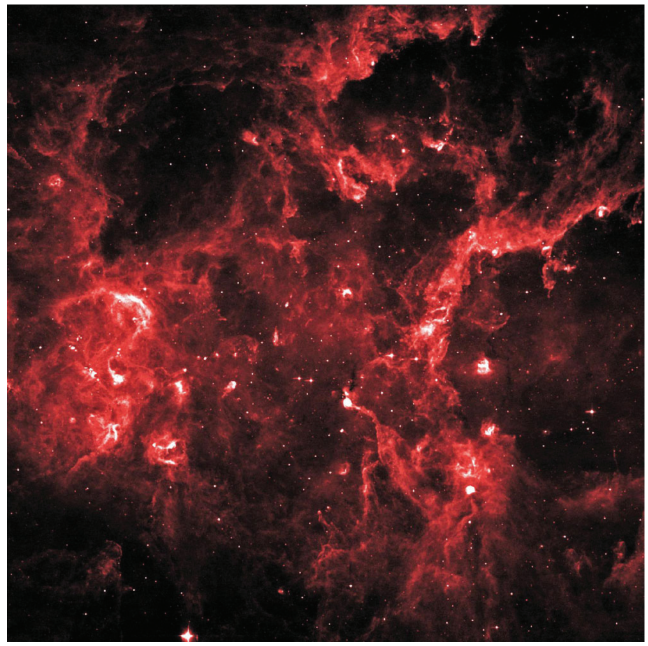
The IPMC, the workshop organizing committee, and delegates from the workshop engaged in an hour-long conversation about the presentation, the final report on the workshop, and next steps for the group as a whole.

"The presentation and discussion on Saturday showed that the IPMC is interested in the opinions of the young professionals and their ideas," said Patrick Hambloch, an operations engineer for the International Space Station at the German Aerospace Center (DLR). "My hope is that this was not a one-off event…. Clearly the ways we work on space projects are changing, and at least a part of the people who participated in the workshop showed interest to continue to work on improving the way we work in space."

Academy Bookshelf

Too Big to Know

March 28, 2012 — Vol. 5, Issue 3



Cygnus X hosts many young stellar groupings. The combined outflows and ultraviolet radiation from the region's numerous massive stars have heated and pushed gas away from the clusters, producing cavities of hot, lower-density gas. Photo Credit: NASA/PAC/MSX

Information overload isn't what it used to be, according to David Weinberg, author of *Too Big to Know.*

There is nothing new about the idea that we are deluged in both information and knowledge. For centuries, people have had to find ways to deal this problem, and in the past, a single strategy sufficed. "Knowledge has been about reducing what we need to know," writes Weinberg, a senior researcher at Harvard University's Berkman Center for the Internet & Society. Editors and other gatekeepers have performed the valuable function of telling us what matters and what we can safely ignore. Encyclopedias catalogued summaries of the world's knowledge from A to Z. Publishers of books and scholarly journals approved a small subset of manuscripts and rejected the rest.

Then the Internet came along. Suddenly everyone with a connection had a means of sharing knowledge and ideas with billions of people instantaneously. To Weinberg, the change from static, paper-based knowledge to electronic formats represents a fundamental shift in knowledge itself. The old strategy of counting on gatekeepers to manage knowledge for the rest of us no longer suffices. "Rather than knowing-by-reducing to what fits in a library or scientific journal, we are now knowing-by-including every draft of every idea in vast, loosely connected webs. And that means knowledge is not the same as it was."

The difference, Weinberg asserts, is the intelligence enabled by networks. "The smartest person in the room is the room itself: the network that joins the people and ideas in the room, and connects those outside it," he writes. "Our task is to learn how to build smart rooms--that is, how to build networks that make us smarter, especially since, when done badly, networks can make us distressingly stupider."

To Forgive Design: Understanding Failure

June 29, 2012 — Vol. 5, Issue 6

Platform supply vessels battle the blazing remnants of the off shore oil rig Deepwater Horizon. A Coast Guard MH-65C dolphin rescue helicopter and crew document the fire aboard the mobile offshore drilling unit Deepwater Horizon, while searching for survivors. Multiple Coast Guard helicopters, planes and cutters responded to rescue the Deepwater Horizon's 126 person crew. Photo Credit: US Coast Guard

When something fails, we are often quick to find fault with the design. It is easy to forget that "the design is us," according to Henry Petroski.

In his new book, *To Forgive Design: Understanding Failure*, Petroski goes beyond the realm of the technical and mechanical complexities of projects explored in his 1992 book *To Engineer is Human* and addresses the human factor that contributes to failure. In this sequel, he revisits classic examples of engineering gone awry such as the *Titanic* and the Tacoma Narrows Bridge, and incorporates more recent events such as the of the *Deepwater Horizon* explosion, the loss of *Columbia*, and the Big Dig to illustrate the intricacies and importance of understanding failure in order to achieve success.

Petroski uses a series of stories to carefully illustrate the relationship among technological complexity, sound design, and, most of all, human fallibility on projects. When something breaks or goes boom, the natural response is to look for a flaw in the design of the system—a misplaced beam or a miscalculation in stress tolerance. Petroski challenges readers to see a bigger picture. Changing technology, optimism, complacency, political complexity, availability for resources, and even an innovative spirit all play a crucial role in the outcome of a project or system. Design is just one component—a component derived from the human mind.

When we do succeed, Petroski explains, it is often not obvious how close we come to failing. Sometimes failing is not only inevitable or inescapable, it's irreplaceable. "A single failure…whether of an airplane or of anything else, is a source of knowledge we might not have gained in any other way," he writes. Failure will always be a part of the process. While no engineer sets out to fail, building in tolerance for failure or having predictable failure modes and breaking points is critical.

Petroski uses examples from ships, bridges, roads, shuttles, eggshells, software, dentistry, tunnels, and towers to illustrate the many facets to understanding failure. This includes the maintenance of a structure or system, the importance of individual engineering integrity, degeneration through repeated use, and the impetus to understand the cause behind a failure.

To Forgive Design encourages readers to grasp the underpinnings of fundamental concepts and practices and to take every opportunity to learn the lessons from past and present projects—successful or otherwise. Failures, Petroski writes, "reveal weaknesses in reasoning, knowledge, and performance that all the successful designs may not even hint at. The successful engineer is the one who knows not only what has worked in the past but also what has failed and why."

Judgment Calls

July 31, 2012 — Vol. 5, Issue 7

Organizations make good decisions in a variety of ways, according to Tom Davenport and Brook Manville.

On November 14, 2008, as Space Shuttle *Endeavor* rocketed skyward on STS-126, flight controllers monitoring data during the ascent noted an unexpected hydrogen flow increase from one of the shuttle's main engines. Despite this in-flight anomaly, the launch proceeded smoothly, but the issue would require immediate attention as soon as *Endeavor* landed safely on November 30.

To ensure the safety of future shuttle missions, management, along with the technical community, needed the best possible analysis to understand what happened on STS-126 and its implications for the next mission, STS-119, and future missions. The formal decision-making processes that followed included three Flight Readiness Reviews, which brought together representatives of the program, engineering, and safety and mission assurance communities to review the data and evaluate the soundness of the flight rationale.

Billows of smoke and the water near Launch Pad 39A at NASA's Kennedy Space Center in Florida capture the brilliant light of space shuttle Discovery's lift-off on the STS-119 mission. Photo Credit: NASA/Sandra Joseph, Kevin O'Connell March 15, 2009.

Davenport and Manville feature the STS-119 launch decision as one of a dozen case studies in *Judgment Calls: 12 Stories of Big Decisions and the Teams that Got Them Right*. (They draw extensively from the Academy's STS-119 case study as well as from interviews with leaders such as NASA Chief Engineer Mike Ryschkewitsch.) Dispelling the myth of the lone leader making the tough call, they focus instead on organizational judgment that involves many parties. As *ASK Magazine* Executive Editor Larry Prusak notes in the foreword, organizational judgment is "the collective capacity to make good calls and wise moves when the need for them exceeds the scope of any single leader's direct control." STS-119 is one of three examples Davenport and Manville offer of a participative problem-solving process. Other cases focus on the uses of technology and analytics, the power of organizational culture, and the importance of leaders setting the context. As they explain:

> *"Good organizational judgment usually involves reframing decisions as a participative process of problem solving. It takes advantage—and often considerable advantage—of the widening array of data now available in the world, and the advancing technological and analytical tools to interpret it. It is shaped by, and often itself shapes, powerful organizational culture based on values such as participation, deliberation, diversity of thought, constructive challenge and debate, and the like. And as our fourth crosscutting theme highlights, good organizational judgment is often created by leaders—not as great "deciders" themselves, but as more egoless developers of the right context and structures to allow their organizations to find solutions more collectively."v*

CKO Corner

KSC's Michael Bell

September 27, 2012 — Vol. 5, Issue 9

Kennedy Space Center's Michael Bell talks about the state of knowledge at his center.

This is the first in a series of interviews that *ASK the Academy* is conducting with chief knowledge officers at NASA's centers and mission directorates. Michael Bell was recently appointed the Chief Knowledge Officer of Kennedy Space Center (KSC). He has also served as program manager of the agency's lessons learned program, and as center data manager for KSC.

***ASK the Academy* (ATA)**: What are some of the most prominent knowledge challenges in your organization?

Michael Bell: I think within Kennedy, probably all the centers, it is just awareness of the various tools and activities. There are so many things going on and people at KSC have been mission focused—I don't know if other centers are different—but we're focused on getting our own work done. I am not going to say we're siloed, we're just focused on what our individual or group task is—if it is facility type stuff, or if it is accounting, or if it is this mission that is going to be launched. So having people understand what's going on across center is a big challenge because people are probably naturally taught to tune other stuff out. I think that is why KSC's Innovation Day is very important in getting to see what else is going on at our own center. And knowing those things can help spark ideas that you can use in your own area.

ATA: Can you tell us about any successful knowledge efforts in your organization that you would like to highlight?

Michael Bell, KSC Chief Knowledge Officer, standing in front of Atlantis before her last launch, STS-135, and the last mission of the Space Shuttle Program. Photo Credit: Kennedy Space Center/ Laura Midulla

Bell: One of the things that I will point to is the Kennedy Engineering Academy. It is useful to more than just the engineering community. Periodically, we have these forums in the training auditorium where everyone across the center is invited and contractors from the various companies who are out here come as well. If it is related to an activity or a specific lab, definitely you tend to get more of the people who work in that lab or work on that contract. But then other people who are just curious, or maybe have a little time on their hands can go and learn about that. I'm happy that this is still going on and it still has a high level of interest and people are able to attend.

ATA: Are there knowledge management efforts, even within NASA or other organizations that you find particularly remarkable or innovative?

Bell: I like the case study activities. I don't know if I can call it innovative, but I think it is just another avenue for sharing knowledge and it is on a different level. It is more of an intimate activity for people to learn and to discuss and to provide feedback. We don't have as much intimate knowledge transfer formalized in case study activity as I think we should have at KSC.

ATA: What is the biggest misunderstanding you think people have about knowledge?

Bell: I think the biggest misunderstanding is that were doing a lot of it and when they hear the term "lessons learned" or "knowledge management," I think most people have a very limited idea of what that that means. So they limit their thinking when they are doing video conferences, they're collaborating across centers, or they're doing a Google search. A lot of people don't realize when they do a Google search, they can actually hit things inside the NASA lessons learned system. They don't realize we have resources like our KSC library and librarians that will do searches for stuff that is going on in other organizations and directorates, which could be useful. So maybe even the opposite is true. If there is stuff that they could be sharing or someone could use that they might not realize, it could help spur innovation and new thoughts on solving a problem.

MSFC's Dale Thomas

October 31, 2012 — Vol. 5, Issue 10

Marshall Space Flight Center's Dale Thomas shares his perspective about the state of knowledge at his center.

Dale Thomas is Associate Center Director, Technical, of Marshall Space Flight Center, supporting the Office of the Center Director. In this capacity he also serves as Chief Knowledge Officer, leading the center's knowledge management effort.

***ASK the Academy* (ATA):** What are some of the most prominent knowledge challenges in your organization?

Dale Thomas: I think our biggest challenge is getting to knowledge domains that are not at Marshall Space Flight

Dr. L. Dale Thomas, Associate Director, Technical, and Chief Knowledge Officer at Marshall Space Flight Center.
Photo Credit: NASA/MSFC Dr. L. Dale Thomas, Associate Director, Technical, and Chief Knowledge Officer at Marshall Space Flight Center

Center. I'll illustrate that with an example. In the area of rocketry, there is a good culture at Marshall, with ready access to retired Marshall veterans, who have Shuttle and Apollo legacies, and the community is pretty tight-knit as well. So that knowledge base is there and it is well used. There are other areas—I will call them transformational areas for Marshall—that are not in rocketry. And for those areas, we don't have the depth of skills and knowledge at Marshall that we do in rocketry, and finding the access to that is much more of a challenge.

ATA: Are there any successful knowledge efforts in your organization that you'd like to highlight?

Thomas: One that comes to mind most easily is the work of (retired Marshall veterans) Bob Ryan, Luke Schutzenhofer, and Jim Blair, in their course on rocketry and space transportation. They have done a great job of capturing not just the technical side of that, but also the teamwork and the human side as well. They illustrate with experience, with case studies, and very practical examples. And the students—I was one who sat through one of the classes—leave there with not just an understanding of the physics involved, but also an understanding that physics doesn't fly. It takes a team to get a rocket flying. Those courses have been very successful and could potentially have broader applicability for knowledge capture, particularly among our aging workforce for the next generation.

A second example is the ExplorNet social media platform that we just tapped into and it's taken off in some novel directions. It's not done morphing and evolving yet, but it seems to be getting a lot of traction.

ATA: Are there knowledge management efforts—either within NASA or other organizations—that you find particularly remarkable or innovative?

Thomas: There are a couple. The shuttle knowledge console at Johnson Space Center appears to be novel, and what we're hearing is that it is very good and we would like to really understand it and see if there are things we could glean from that and try to apply at Marshall. It is my understanding there is also a novel search application at Langley. [Editor's note: Read more about Langley Google.] I don't really know enough about it to even talk too much, but it appears to be getting some good traction. We would like to learn more about it as well.

ATA: What's the biggest misunderstanding that people have about knowledge?

Thomas: I think the biggest misunderstanding is the fact that the knowledge management and lessons learned landscape is littered with past attempts to take a single application and apply it to solve our knowledge and lessons learned issues—one size fits all. After people see two or three attempts at that, it starts tainting the overall field. You see the same thing in medicine. After a given disease is attacked two or three times with no success, people sort of say, hey that can't be cured, quit messing with it. I am talking about the patients, not the researchers. To me, finding some things that are working and building on those and starting to build on success as opposed to getting the quick fix is important. If we can build some successes, we'll change the perception and that will start feeding on itself. So perception is the biggest problem we've got, in my opinion.

LaRC's Manjula Ambur

November 29, 2012 — Vol. 5, Issue 11

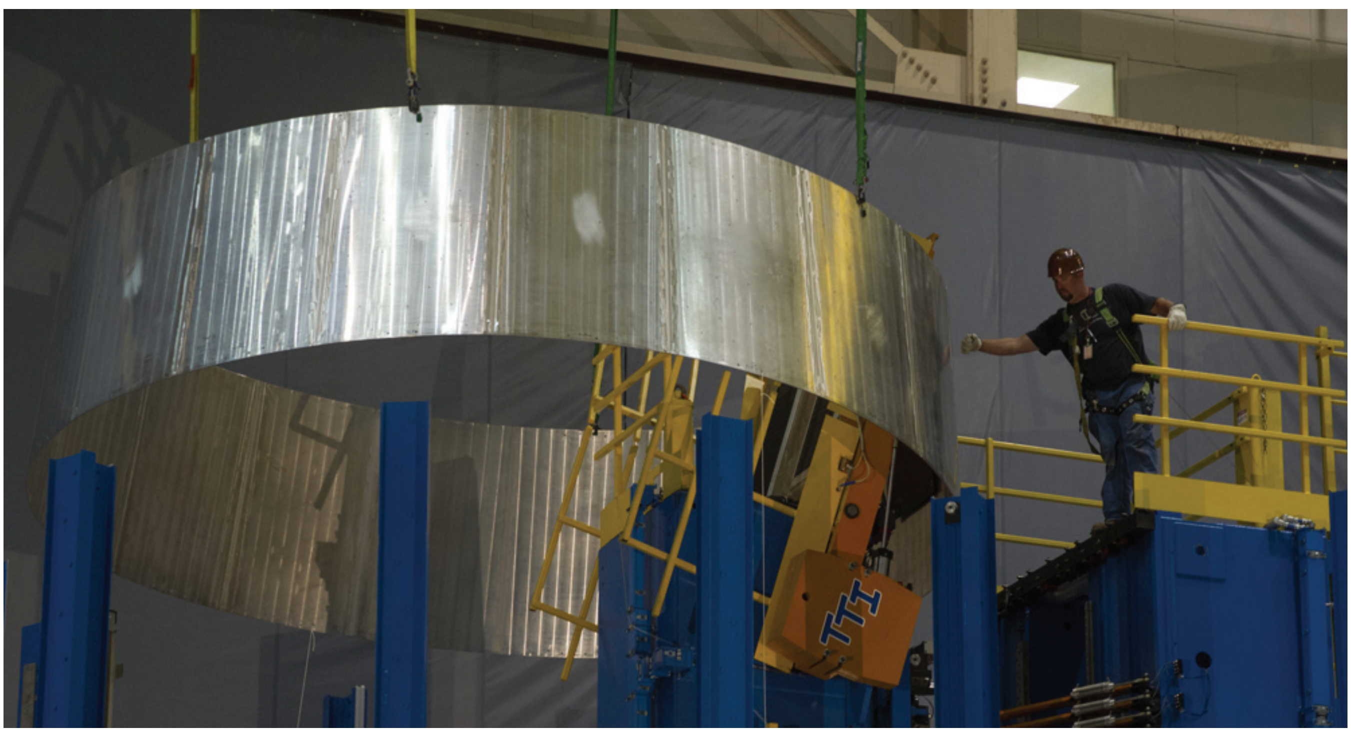
Langley Research Center's Manjula Ambur shares her insights about knowledge management at her center.

Manjula Ambur leads the Information Management Branch within the Office of the Chief Information Officer at Langley Research Center. She also serves as the center Chief Knowledge Officer, leading Langley's knowledge management efforts.

ASK the Academy **(ATA):** What are some of the most prominent knowledge challenges in your organization?

Manjula Ambur: I think one of the biggest challenges for the agency is knowledge retention because of the age of NASA's workforce. Knowledge retention: What does it mean? What do we choose what to retain? How do we retain it? I don't think we're addressing the whole challenge in a very good manner.

The second challenge I would say is knowledge sharing. Knowledge has many dimensions. It is for both now and



Engineers using a state-of-the-art vertical welding tool at the Marshall Space Flight Center in Huntsville, Ala., move a "pathfinder" version of the adapter design that will be used on test flights of the Orion spacecraft and NASA's Space Launch System. The adapter will eventually connect the Orion spacecraft to the SLS. It will be flight tested on Exploration Flight Test-1 in 2014, when it will be used to mate Orion to a Delta IV heavy-lift rocket. The term "pathfinder" refers to an early version of the hardware that is not intended to fly, but to prove the concept and feasibility of manufacturing the design. This pathfinder is 18 feet across and 5 feet tall and will be strengthened in a few weeks when specially machined end rings -- also built at the Marshall Center -- are welded to it. Photo Credit: NASA/MSFC/Emmet Given

Manjula Ambur, Information Management Branch within the Office of the Chief Information Officer at Langley Research Center and Langley Chief Knowledge Officer. Photo Credit: NASA

later use—sometime in the future—for people we don't even know right now, a generation from now. I think it could be done better for both dimensions, for now and later. Knowledge sharing in the short term—which also helps the long term—is one of those challenges. Organizational culture plays a big role here.

The third one is reuse. We do capture a lot of data and information. There are also multi-dimensional and cultural challenges: technology usability, time, and a not-invented-here attitude. People need to take the time to actively seek existing knowledge, and we need to do a better job of improving the usability of systems, especially the integration of multiple data stores and user interfaces. So I would say these are three big challenges.

ATA: Are there any successful knowledge efforts in your organization that you'd like to highlight?

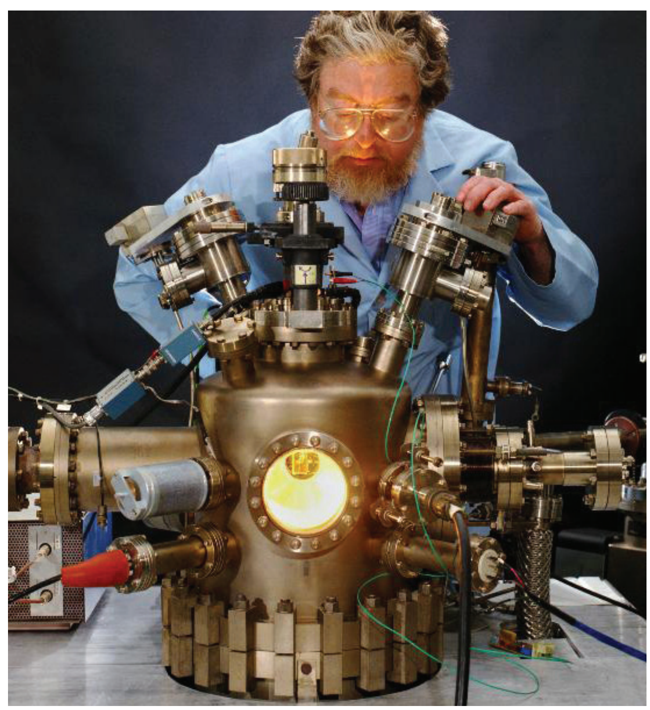
Ambur: I would say the biggest success we have at Langley is the cooperation and partnerships between the mission organizations and the IT organization to work together on projects and initiatives that help with knowledge capture, access, sharing, or archiving. Enterprise search using Google search and the Experts Directory are success stories of these partnerships. Currently, we are working on two other specific initiatives. One is data archival and management of our wind tunnel and computational data sets. We have been working with the Research Directorate and the (Langley) Chief Engineer's office in an active collaboration. We have been working on it for two years, and without a collaboration we would not have succeeded. It's not *our* project or *their* project; it is a combined effort.

Another success is big data mining and deep analytics. We started working on it two months ago with a data analysis proof of concept—again, with a mission organization, Systems Analysis and Concepts Directorate. It's really mining knowledge for insights, trends, and predictions, both internal and external, using IBM Watson technology. Now we are in the pilot phase of working with the Aeronautics Research Directorate and Chief Technologist's office. This is an exciting area that has great potential for machine intelligence augmenting human intelligence, saving time, enhancing productivity, and enabling mission success.

A third one is Langley's Office of the Chief Engineer and I are collaborating on getting together a knowledge sharing workshop at the center with people from all the mission directorates to understand how they are sharing and how it could be improved across organizations and disciplines.

ATA: Are there knowledge management efforts—either within NASA or other organizations—that you find particularly remarkable or innovative?

Ambur: I think what is remarkable is even with all the challenges we have, NASA as a whole does a pretty good job of knowledge management. It is not because of any one group—but because of many efforts. A lot of it is organic and could be more cohesive and more integrated, but I think overall we do a pretty good job. All centers have initiatives that



Looking like a questionable contraption from a science fiction movie—or perhaps a high-tech Reuben 'Rube' Goldberg machine—this March 26, 1991, image features the Surface Analysis System, which used "a pristine ultrahigh vacuum environment to eliminate interference" while performing "qualitative and quantitative evaluation material surfaces at an atomic level." Photo Credit: NASA are suited for their needs, and we can all learn and leverage from each other.

As our knowledge strategy evolves, one thing to think about is that we have to develop and maintain a framework where organizations and experts can integrate their local initiatives into the larger knowledge fabric that encompasses all centers and missions. The people who are closest to the work know what they need to do, we need to help to integrate it. They need the framework so they can belong to a larger connectivity—systems and people. People and organizations want to do a good job and they keep doing work like this; they just may not be calling it knowledge management.

ATA: What's the biggest misunderstanding that people have about knowledge?

Ambur: If we were to specifically ask people about their understanding of knowledge management, I don't know how many would get it. I think a lot of people are using knowledge in their jobs, but they might not be calling it "knowledge management." So they might not even be realizing the value they're getting by doing knowledge management. That is a misunderstanding that I see.

Knowledge doesn't exist on its own; it has to exist as part of the fabric of the organization. I think we do that, but what we don't have is an integrated strategy that makes knowledge a more regular part of everyday work. With a better understanding of the need for cohesive knowledge initiatives and information technology advancements to help make sense of volumes of data and connect ideas and people, we have a greater opportunity to make sure of and share knowledge as a part of daily work and not as an added burden. The agency knowledge management community has an opportunity to make a big contribution to NASA's mission success.

The Way We Work

The Space to Collaborate, the Space to Share

March 28, 2012 — Vol. 5, Issue 3

As NASA quickly approaches a workforce transformation, a movement has surfaced to not only rethink how the agency shares what it knows, but where.

"Knowledge at NASA doesn't only live inside people's heads. It's in the relationships between people, the space between people," said Larry Prusak, Editor-in-Chief of *ASK Magazine*, in 2006. "The architecture of buildings is a great symbol and signal of cooperation and collaboration. When you go into an office and see one hundred closed doors, no open space, no space for talking, no space for meeting, it [sends] a big signal."

The importance of face-to-face collaboration, knowledge transfer, and innovation is the reason why pharmaceutical company Novartis began knocking down and rebuilding nearly twenty of its buildings in 2005. It's why Steve Jobs installed bathrooms in the atrium at Pixar, and why Fuji Xerox has rooms called "The Shipyard" and "The Brain." All these organizations recognized the importance of creating spaces that enable people to collaborate and think creatively.

At NASA, the 2010 Telework Enhancement Act, which provides employees and managers with flexible work arrangements, and recent travel budget cuts are forcing the agency to rethink how people work together, which has added momentum to efforts across the agency to create collaborative work spaces at the centers. These efforts, along with the increasingly collaborative nature of NASA projects and

The sp.ace in Building 29 at Johnson Space Center. Image Credit: NASA JSC / Christopher Gerty distributed teams, indicate a growing interest in work spaces that are accessible, connected, and flexible.

A Burning Platform

Since its inception, Langley Research Center's Navigation Center has grown from 2,500 to 10,000 square feet. It consists of different-sized rooms outfitted with projectors, tables, screens, whiteboards, wireless Internet, and speakers. With trained facilitators available on-site, the space is set up to enable creativity and connectivity. "It's an open environment. We are known for being neutral territory," said Karen Freidt, the team lead at the Navigation Center. "My office space provides a variety of hotelling options [i.e., an unassigned work space] for all. Employees can use the small desk, the treadmill desk, or the air-hockey-combination-conference table as they please. If someone is using a certain space, I just find another spot to work."

The Navigation Center's origin story starts in 1993, when the future of Langley's wind tunnels was threatened. Unless the center found a way to increase efficiency and decrease cost, the tunnels would have to be shut down entirely. The Wind Tunnel Enterprise (WTE), a team dedicated to reinventing how Langley managed its wind tunnels, was created. Senior decision makers—influenced by a five-day facilitated workshop that took place in a collaborative environment—decided to establish a collaborative working space called the Navigation Center to enable the WTE to find a creative solution and save the tunnels.

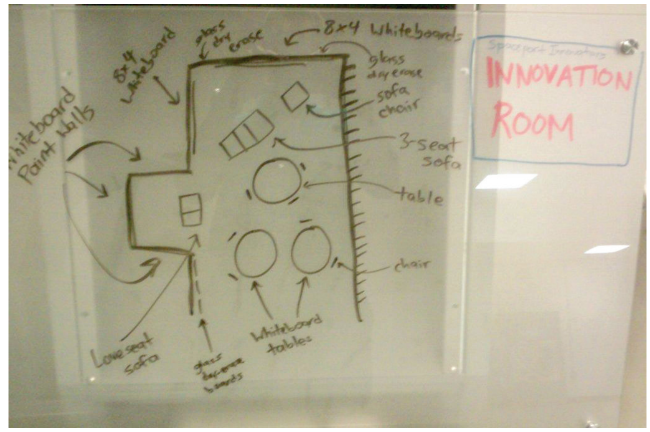
"The Navigation Center is much more than just the space. The employees, especially those who have the expertise in facilitation, creativity and innovation, are the heart and soul of this space." said Freidt.

"When an organization wants to do a major improvement to its processes, it frequently takes a burning platform issue to make it happen," said Charlie Dunton, a senior facilitator at Navigation Center. "The Navigation Center here at Langley formed under exactly those circumstances." If the organization fails to meet the demand in front of it, it will likely crumble. "I think we may be seeing the same thing going on with collaborative spaces at NASA," said Dunton.

Writing on the Wall

Last August, David Miranda, a simulation engineer and in the IT Directorate and member of the Spaceport Innovators at Kennedy Space Center (KSC), got the go-ahead and a bit of funding from Pat Simpkins, KSC Director of Engineering, to find and outfit a space dedicated to innovation at KSC. "What that meant was whiteboards everywhere. Every surface should be a place to share your ideas, which includes the walls and the tables. In the future, we want to find ways to connect with other rooms through video cameras and shared digital whiteboards," said Miranda.

Concurrently, Skip Owens, a systems engineer at KSC, is working with Miranda to develop a space that allows engineers to take the product from Miranda's room (the idea) and then produce a design. NASA is already home to several integrated



Schematic of the Innovation Room at KSC. Image Credit: David Miranda

design centers, places for parallel problem solving. (The center at the Jet Propulsion Laboratory, also called Team X, was recently featured in a Gizmodo story.) Going to the Moon? Get the flight design, thermal, and power engineers all in the same space to crunch the numbers concurrently. Now, imagine if these engineers were capable of doing this easily and effectively in virtual space. "If you're working on a particular design problem, you could bring in an expert at Glenn or Goddard for a project at JPL. You wouldn't have to travel. You could just plug in," said Owens. "It'd be really nice to know that you could always go into a room and interact with your team that is spread out across all of these centers and have that connectivity wherever you go."

The ability to effectively share voice, video, and data is critical, Owens and Miranda explained. The standard methods of collaboration are no longer enough for today's work. "On a telecon, I can't see what you're saying. With video, we can see each other faces, but we can't read each other's minds," said Miranda. "That's where things like shared whiteboards come in. It's a way for me to show you my mind."

Working, Learning, and Sharing Virtually Anywhere

In 2008, an informal, roving collaborative work session called "Co-Lab" emerged at Langley just as the Navigation Center was gathering steam. An individual would send out an email to the group, inviting everyone to a new location each time. They'd eat lunch together and then whip out laptops and paperwork and pick up with business as usual. "I really found a lot of value in Co-Lab," said Eileen Nelson, Executive Liaison to Langley's Chief Strategist and Speakers Bureau Manager at Langley. "It was a great way to meet and network with other people, brainstorm with them, and learn what other people at Langley are doing and how it related to me." The roving Co-Lab meetings lasted for about a year.

Johnson Space Center took a different approach: a fixed physical space with a roving workforce. Located on the second floor of Building 29, the "sp.ace" is outfitted with mobile tables, chairs, and whiteboards to allow users to reconfigure the room to meet their needs. It is a place where the traditional workforce meets the increasingly transient one through the physical space and virtual space via online collaborative tools. “Get out of your office and co-locate to work with your colleagues”, wrote Christopher Gerty, a member of NASA’s Open Government Team, on the open.nasa blog. “Share ideas and help each other look at problems differently, brainstorm solutions, or maybe even just practice that big presentation in front of an unbiased pair of eyes.”

Open, light, and flat, the sp.ace is an environment where people and ideas can connect, collide, and coalesce. “By discussing issues with folks who don’t have your same perspective, it seems easier to be confident in the right solution to problems faster,” said Gerty. “Connecting also seems less deliberate and more natural. It takes full advantage of face-to-face interaction.”

After visiting the sp.ace, William Eshagh, IT Research and Development at Ames Research Center, returned home to California and started writing a proposal for the Ames analog: the “sp.arc.” The space would be reconfigurable like the JSC sp.ace. “Immoveable furniture is an impediment to the creative process,” said Eshagh. “Not being able to write on walls – we’ve been writing on walls since the Stone Age. It’s natural!”

He also proposed the space as a place to prototype new technologies. Eshagh has been working on an initiative to enable agency-wide collaboration through remote whiteboarding capabilities. This capability would allow users from different locations to draw on the same virtual whiteboard. The sp.arc would be a place for employees to test out technologies like this and determine if they found them useful.

Though Eshagh’s proposal has yet to find a home at Ames, another nearby space with a similar purpose just started to gain momentum. Located at the Ames Research Park, “Connect Lab” acts as a place for anyone to work and learn collaboratively across disciplines and to test out new technologies (e.g., iPads).

“I honestly think there’s something to these spaces. I don’t think this is a fad,” said Eshagh. “Ames is surrounded by companies that understand that it’s important to work in a place that fully allows you to be creative. If we can’t attract new talent by demonstrating how forward-leaning we are in the way we think about how we work with one another and how we get things done, we’re going to find that the bright ones will go somewhere else.”

Making It Happen

A major determining factor of the success of collaborative spaces is if they are accessible to everyone. These spaces tend to succeed if they are equipped with the right capability (e.g., wireless Internet capability, electrical outlets, screens, etc.), are easily accessible (e.g., no locked doors, no unnecessary layers of security, and not far removed), and have community buy-in.

“Money,” said Miranda, “isn’t a deal breaker.” For instance, he asked, why buy additional whiteboards if you can use the frosted glass walls in a room? “The whole room can be a canvas for your ideas,” said Miranda. Sometimes all that’s needed is permission to utilize the space and resources that already exist.

Efforts to create collaborative spaces are not confined to Langley, Kennedy, Ames, and Johnson. The next steps involve finding ways for center-based collaborative spaces to work with one another. “We’re paying attention to what each other’s groups are doing,” said Dunton. “As these spaces pop up across the agency, we need think about connectivity.”

The benefits of collaboration include unexpected synergies, diversity of thought, better products, and cross-pollination of ideas. These benefits, while seemingly intangible, are what drive innovation and organizational progress. Creating a space where ideas can thrive is increasingly important in today’s project world.

ISU Space Café: Are We Really Ready for Mars?

March 28, 2012 — Vol. 5, Issue 3

A biomedical knowledge gap stands in the way of successfully sending humans to Mars.

“If we could build the spaceship tomorrow, could we go to Mars?” Dr. Kris Lehnhardt, asked his audience at the March International Space University (ISU) Space Café in Washington, DC. Lehnhardt, an expert in emergency and aerospace medicine at George Washington University, ticked off the challenges of sending humans on a long-duration, long-distance space flight: bone loss, kidney stones, muscle loss, orthostatic intolerance (e.g., similar to standing up too fast and blacking out), neurovestibular instability (e.g., motion sickness and dizziness), psychological factors (e.g., depression, anxiety), and, most challenging of all, radiation.

Lehnhardt readily explained each challenge, engaging with the crowd in a thoughtful discussion about each, but the topic of radiation kept coming up. “You could find solutions and workarounds for just about anything on the list of problems

Dr. Kris Lehnhardt speaks at the International Space University Space Café on March 13, 2012. The event took place at Science Club in Washington, DC. Photo Credit: Image courtesy of Dr. Kris Lehnhardt.

using current technology. Not so for the radiation problem," he said.

The current mission profile to Mars involves a 10-month trip to the surface of the planet. By the time the crew reenters an environment with gravity and has the opportunity to step out onto the surface, any number of things could go wrong: blackouts, dizziness, weakness. If you then were to ask, 'How do we stop that from happening,' I can give you a list of 100 different things you can do," said Lehnhardt, noting that supplements, exercise, patience, and medication are all options. "If you ask me, 'What do we do about galactic cosmic radiation?' I don't really know what we can do about that."

Galactic cosmic radiation (GCR) differs from solar radiation, the kind that comes from stars like our sun. GCR comes from supernovae and contains higher-energy particles that will take an untested toll on organic material. "Most of our radiation knowledge on Earth comes from a few sources: acute radiation exposure (like the atomic bomb or Chernobyl) and long-duration, low-level exposure (people who work around CAT scanners)," Lehnhardt explained. "None of those is an equivocal model to galactic cosmic radiation."

Testing the effects of GCR on biological tissue would require sending (and preferably returning) living biological samples beyond low-Earth orbit, the Van Allen Belt (~4,000 miles from Earth's surface), and the moon—beyond the protection of Earth's magnetosphere—to reach a place where GCR's impact could be tested. So far, no missions have studied this, and the number of people studying it is dwindling. "Many of the flight surgeons, many of the people who have been doing this within recent memory at NASA are getting older. They're going to retire eventually and there are very few new people coming through the pipeline," said Lehnhardt. "The paucity of work in this area over the last ten years has resulted in a dwindling biomedical community."

Lehnhardt engaged the audience in a thoughtful discussion for nearly two hours. "I don't want to discourage anybody and make them think human exploration is impossible because we have all of these questions we need to answer," he said.

"If all you want to do is low-Earth orbit, we can keep people pretty safe in LEO," said Lehnhardt. "But if you truly want to live and work in deep space, we need to have an understanding of how you can do that in an efficient and safe manner."

Balancing Risks for Glory

April 30, 2012 — Vol. 5, Issue 4

The Glory mishap provides a lesson about balancing risks to make the best decision possible.

On March 4, 1999, project manager Bryan Fafaul saw the Wide-field Infrared Explorer (WIRE) primary mission slip away when the instrument cover prematurely ejected, causing the spacecraft to spin out of control and deplete all of its cryogen. Exactly twelve years later, Fafaul watched the Glory mission fail to reach orbit and plunge into the ocean.

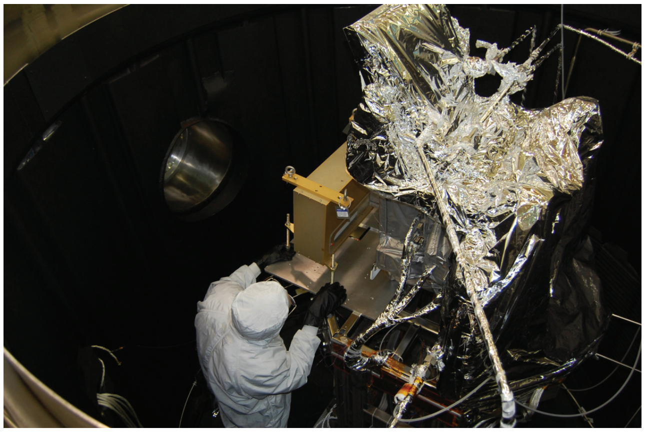
Bryan Fafaul, Glory Project Manager from Goddard Space Flight Center, talks about the launch of the GLORY mission during a news conference at NASA Headquarters, Thursday, Jan. 20, 2011, in Washington. Photo Credit: NASA

Leading up to launch of Glory on March 4, 2011, the three main risks on the Glory project revolved around three pieces of hardware: the Advanced Polarimetry Sensor (APS), the *Taurus XL* launch vehicle, and the spacecraft bus. For Fafaul, the Glory project manager, getting to the launch pad meant having the right people working each issue and gathering the right data in order to mitigate the risk. Unfortunately for Glory, one of the three risks wasn't sufficiently resolved. "You can't recognize everything," Fafaul said during a case study session on Glory at the Goddard Space Flight Center's Masters Forum on April 24, 2012. "That can-do attitude sometimes results in a more optimistic assessment of closing out an issue than what reality will actually dictate to you."

The APS instrument was designed to measure reflected light from aerosols in the atmosphere to help characterize their size, shape, and type, and determine their distribution within the atmosphere. The contractor responsible for building the APS instrument experienced significant delays, and just after the Critical Design Review, Fafaul was informed that the contractor facility would be closing and the work would be relocated. The move resulted in instrument workforce attrition (an initial team of 75 turned into 15, which became 3 in the end). This turn of events cost the Glory project nearly $100 million. "We never really struggled with the technical issues on APS. It was purely execution," said Fafaul.

The most visible issue to work to ground was the launch vehicle. On February 28, 2009, a *Taurus XL* launch vehicle failed to place the Orbiting Carbon Observatory (OCO) into orbit. The vehicle fairing had not detached properly. Initially, Glory was scheduled to fly before OCO, but the delays with the APS instrument pushed their schedule back behind OCO. When OCO plunged into the ocean, Fafaul thought, "I'm not going to have the same problem because there will be enough time to fix it."

Nearly two years after the OCO failure, the Mishap Investigation Board was unable to produce a root cause for why the launch vehicle had failed. The investigation produced a number of possible proximate causes—all of which were



The Advanced Polarimetry Sensor instrument inside the thermal vacuum chamber. Technicians wear garments -- known as "bunny suits" -- to protect the instrument from dust and other contaminants. Photo Credit: Raytheon

logically assessed and addressed—but the "smoking gun" was still at large. All eyes at NASA were on the data. The Glory project team worked closely with Headquarters and the Launch Services Program to gain insight into the launch vehicle return to flight activities. No one took a dissenting opinion that was strong enough to derail the decision to move forward with the launch.

The spacecraft bus also played a role in the decision to proceed with the launch. The bus was originally designed for the Vegetation Canopy Lidar (VCL) mission. After VCL was cancelled in 2000, the decision to use the bus on Glory meant refurbishing it to be flown in a different orbit, launched on a larger rocket, and able to withstand different conditions in space. The adaptation of the VCL bus for the mission invited in a different set of risks to the project, explained Fafaul. The team encountered a number of challenges with keeping the hardware alive and maintaining data and documentation, which were in danger of being eliminated due to seven-year data retention practices. Just over a decade old, the propulsion tank bladders on the bus were approaching end of life. Balancing out the risks, Fafaul determined that the risk of postponing the mission and grounding the spacecraft for two years could actually be a bigger risk than choosing to fly.

When asked what he would do if he were in the same situation all over again, Fafaul replied, "I would not have made a different decision. The decision was a fact-based decision. You make risk decisions every day as a project manager. Hopefully you make the good decisions off the data that you have."

"There will always be the opportunity to get more information," Fafaul added. "There's a chance we could have spent two years on the ground and not found a problem." Discussion about access to the detailed MIB report on the OCO failure brought to light the importance the people doing the work having the ability to learn from such reports. "I think there needs to be better access to them," agreed Fafaul. "There needs to be more exposures of these MIBs back to the people who are going to learn from them. It's closing that loop."

Fafaul now has two pictures that hang across from his desk: one of WIRE and another of Glory. "I think that in every successful mission, you're right on the edge," said Fafaul. "We just happened to be on the wrong side of the line."

How to Create a Conversation with a Mars Mission

June 29, 2012 — Vol. 5, Issue 6

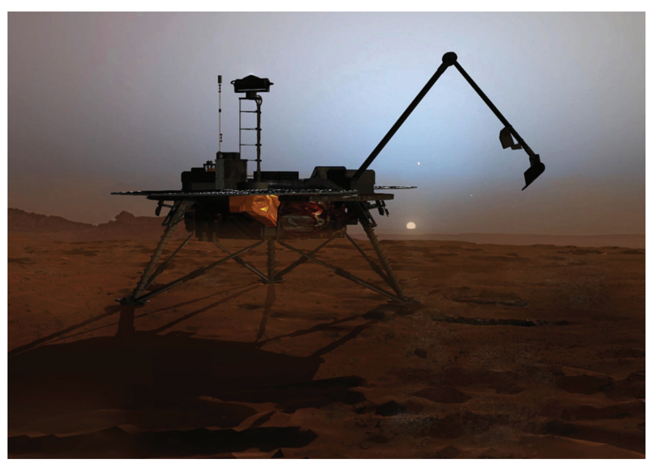
Effectively telling the story of a NASA mission means connecting the audience, the storyteller, and the project team in a conversation.

For the past decade, Veronica McGregor has managed news and, more recently, social media for missions at the Jet Propulsion Laboratory. She was the voice behind the Mars Phoenix Lander, the Mars Exploration Rovers, and eventually the Curiosity mission. *ASK the Academy* caught up with her to gain insights about how project teams can tell the story of their missions through social media.

***ASK the Academy* (ATA):** You made an impact on the way a mission's story got told using social media on the Mars Phoenix Lander mission, specifically through Twitter. Can you tell us how that came about?

Veronica McGregor: We started the [Twitter] account in May 2008, about three weeks before the mission was going to land. The mission was landing on the Sunday of Memorial Day weekend at 5:00 in the evening, and we knew people weren't going to be sitting at home watching the news. We were looking for a way that we could put out the story so that people could get it on their mobile devices. It was an experiment.

Few people were using Twitter back then. I started doing different things with the account to see how people would



In this artist's concept illustration, NASA's Phoenix Mars Lander begins to shut down operations as winter sets in. The far-northern latitudes on Mars experience no sunlight during winter. This will mark the end of the mission because the solar panels can no longer charge the batteries on the lander. Frost covering the region as the atmosphere cools will bury the lander in ice.
Image Credit: NASA/JPL-Caltech/University of Arizona

NASA Administrator Charles Bolden speaks to NASA Twitter followers prior to the launch of the Mars Science Laboratory (MSL), Saturday, Nov. 26, 2011, at Kennedy Space Center in Cape Canaveral, Fla. NASA began a historic voyage to Mars with the launch of the car-sized rover which lifted off at 10:02 a.m. EST. The mission will pioneer precision landing technology and a sky-crane touchdown to place Curiosity near the foot of a mountain inside Gale Crater on Aug. 6, 2012. Photo Credit: NASA/Paul E. Alers

react to it, and it evolved. I found that people responded [better] to the account if it was posted in the first person, as if it were the lander talking. Part of [the benefit to] that was that Twitter limits you to 140 characters and by using the first person it meant I could remove a lot of characters from the post. I also looked at other accounts on Twitter to see how they were posting and I found that most of them sounded like press release headlines. The accounts that were fun to follow were the accounts that were stating facts in the first person. So we adopted the first person for the mission. In the summer of 2008, when that mission was active, it was the fifth most followed account on Twitter. (Barack Obama had the number one account at the time.) Even the Twitter founders said it was one of their favorite accounts. It was one of these unexpected ways they found that people were using Twitter.

ATA: How did you see the interaction between the mission and those following the mission story begin to change?

McGregor: We were posting updates to the mission, I tweeted the landing, and then I started tweeting what the spacecraft what doing every day of the mission. There were two major lessons that came out of that account. One was that there were number of people who wrote back and said that it was the first time they had been able to follow a NASA mission day by day and they had no idea what took place daily on a NASA mission. Most people are only used to reading about a mission when it launches or when it fails.

They were learning from the Twitter account that there were three shifts working 24 hours a day on [the Phoenix] mission. You had a science team analyzing data. They were working with the engineers to develop the next day's activities and what the lander would do the next day, whether it would dig or whether it would be baking samples. We had the software team coming in and writing the commands so those activities could take place, and then the cycle started all over again when the scientists looked at the new data coming in. People had no idea that that's what took place daily on a mission.

There were many unexpected results from our Twitter experiment. Followers loved the tweets coming out of the account, but for me the story was the responses that I was getting back. It was just amazing. I received questions from classrooms. I got replies from people of all ages comparing the excitement of the mission to the Apollo missions. It was really then that we realized there was an untapped audience out there of real space fans, what is now in some aspects the Space Tweeps Society. We could see many people, who were responding frequently or asking questions, started connecting up with each other via social media until they formed this community today of people who are very passionate about space and still in touch with each other.

ATA: And the second observation?

McGregor: The second thing was: that was the summer that many reporters discovered news was getting out around them. When the Phoenix mission found ice on Mars, the tweet [to announce it] went out at the exact same second the news release was posted to nasa.gov. A reporter friend of mine commented later that she realized then that NASA had a new way to release news outside of the old "news release" model. A lot of reporters joined Twitter around that time and started following our accounts. Today, I see many stories that we tweet get picked up by reporters, whether we've done a formal news release or not. But if we had put the same information in a news release, they may not have done the story. Because we are now able to effectively deliver information to the public directly, it's changed the way the reporters look at what story they're going to write about. It turned things around in terms of the flow of information.

NASA Administrator Charles Bolden, center, joins about 150 NASA Twitter followers near the launch clock prior to the launch of the Mars Science Laboratory (MSL), Saturday, Nov. 26, 2011, at Kennedy Space Center in Cape Canaveral, Fla. NASA began a historic voyage to Mars with the launch of the car-sized rover which lifted off at 10:02 a.m. EST. The mission will pioneer precision landing technology and a sky-crane touchdown to place Curiosity near the foot of a mountain inside Gale Crater on Aug. 6, 2012. Photo Credit: NASA/ Paul E. Alers

ATA: The success that you had with Phoenix led to social media strategies for the Mars Exploration Rovers and also Curiosity. How do you typically interface with project teams to tell the story?

McGregor: We started Curiosity back in 2009 when the rover was under construction. It's being done in almost the same way that Phoenix was, in the first person. We're getting a lot of great feedback from people. It's at over 100,000 followers on Twitter right now and it also has a Facebook account. We answer a lot of questions from people and we'll be tweeting the landing for that one as well.

It was really important to me when I started the Phoenix account that people knew I wasn't just some PR person trying to put a spin on things. I was taking in a lot of questions and emailing them to people on the team: for example, the engineer who was controlling the arm and digging, the software code writer, the mission manager, or one of the scientists. I was forwarding a lot of the questions to them and they would write back to me with answers, which I would then have to condense into 140 characters and post.

I also listened to the mission telecons. I would be on the line, take notes, and then I would tweet interesting updates that came out of those meetings. Of course, there is a fine line between not tweeting news that should go out into a news release first. Since I was also involved in the process of writing news releases, I knew exactly when a news release was going to be issued. So the very second that a news release was issued, I could hit the send button on the tweet.

ATA: How have project teams responded to this form of storytelling?

McGregor: We get different kinds of reactions from the missions and projects. Some projects are more attuned to what's going on in social media and how news travels these days. We often provide advice to missions that want to be involved in social media and appoint someone on their team to tweet or post to Facebook. We've found that most people underestimate the time commitment that's required.

I remember starting the Phoenix account and thinking it would only take five minutes a day because I thought I would only be pushing out information. I didn't expect the number of questions and responses that came in, and when you get those, you really are obligated to answer. It turned into hours a day. That's one thing project managers need to be aware of: We have to respond to people, you can't make it a one-way street.

I can think of only a few cases in which scientists are engaging in social media first hand on their missions. One issue is, at the time they're needed most to do postings is when the mission is the busiest and that's when they have the least amount of time. There are some people who tweet when their missions aren't particularly overwhelming. If you don't have a team member you can dedicate to do social media at least a few hours a week, then that's what our office is here to do.

Another thing is that project managers sometimes aren't aware of how their mission team members are using social media. It's definitely a different world out there. If any part of what you're doing is public, you just have to expect that it's going to be in social media very, very quickly. It's very important to understanding the flow of information and the speed at which it happens.

ATA: What contributes to effectively telling a project story through social media?

McGregor: Good lines of communication and finding mission team members who are willing and accessible—and many of them are. A lot of them realize it's too much work to manage the social media accounts on their own, but if we can email them a list of questions and not overwhelm them and split them up among different members of the team, they're more than happy to write down some quick answers and get back to us.

ATA: Twitter aside, what other types of social media have you used to tell a project story?

McGregor: We have Facebook accounts for several of our missions. Whenever we get a really great answer back from the team, we'll post it in its entirety on Facebook (on Twitter we run into the character limitations) and mention, for example, "This response comes from Scott Maxwell, who is a rover driver," so people know exactly where the information is coming from.

We've used USTREAM a lot as well. During the time the Curiosity rover was being built, we had a camera in the clean room that provided a 24/7 live feed and then 2 or 3 hours a day, Monday through Friday, we would open the chat box and do moderated chats. We would also invite mission team members to join us occasionally to be on the chat to answer people's questions. That worked really well. There are so many things that can be done in social media. Now you've got Google+ Hangouts as well.

ATA: What, if anything, has surprised you throughout your experience in communicating NASA missions using social media?

McGregor: The biggest surprise was how well the daily updates were received by the followers. There were a couple of times with the Phoenix mission when the arm was unable to put soil into science instrument where samples were baked and analyzed. The soil was clumpier than they expected and they were having trouble breaking it down into small enough grains so it would enter. If we weren't tweeting the progress of that challenge each day, people probably would have seen news stories saying the mission was in trouble and they'd have a different sense of what was going on. But since were able to keep people updated on a day-to-day basis about how the team was responding to these challenges and creating fixes, we saw a swell of support from our followers. The responses we received were cheering on the team. The best part was seeing people were getting a true understanding of the complexities and difficulties of the mission, and an appreciation for the amazing engineering and science thought that goes into missions like this.

Also, sometimes we would get a string of questions from people and we'd realize that we weren't doing a good job at explaining certain things. Mostly that happened in cases where we assumed the public already knew a certain detail or fact. The result of that assumption is we'd get questions or comments from people questioning why the mission did something a certain way.

It came up a lot with questions and comments about the cameras. They'd write, "We paid millions of dollars for this mission and it has a black and white camera?" We didn't realize that we needed to explain to people ahead of time that the very first images to come back from the [Phoenix] mission would be in black and white and that the mission did have color filters. The first pictures that came back from Mars were of the spacecraft itself and not of Mars and people thought that was a mistake. We realized that we needed to do a better job at telling people that the first images to come down are strictly for the engineers to know whether the spacecraft is in good health.

This feedback from the public was great. Once we saw there was a misunderstanding about any part of the mission we would respond on Twitter, but we would also incorporate the information into the next news release.

That type of feedback didn't exist before and today it happens immediately. It's fantastic.

View from the Outside: Creating Pixar's *La Luna*

June 29, 2012 — Vol. 5, Issue 6

To get to "infinity and beyond," sometimes you have to start at the moon.

One June 22, inside of dark, air-conditioned movie theaters across the country, a new short film premiered in front of Pixar's latest release *Brave*. Called *La Luna*, this Oscar-nominated Pixar 'short' is the latest nugget-sized, computer-animated film to escort viewers into the world of computer animation. Usually enjoyed by moviegoers as comedic appetizers to the full-length film, Pixar's shorts serve a critical behind-the-scenes role for developing its people, honing talent, incubating technology, testing out new ideas, and executing on a tight schedule and unglamorous budget.

The film, written and directed by Italian-born artist Enrico Casarosa, tells the story of a young boy's introduction to his family's unusual line of lunar work. Caught between the practices of his father and grandfather, the boy must navigate generational differences in order to find his footing in the family business. "*La Luna* is sort of this revisionist way, this fantastic way of seeing the moon and what it is to step on the moon," explained Casarosa, who derived inspiration for the story from a compilation of works called *Cosmicomics* by author Italo Calvino. It is also a bit of a dark horse.

Enrico Casarosa, director of the Oscar-nominated Pixar short La Luna, painting in watercolor. Images courtesy of Pixar Animation Studios.

Close up of a model of the main character, a young boy, in the new Pixar short La Luna. Enrico Casarosa, director of the Oscar-nominated film, is painting using watercolor in the background. Images courtesy of Pixar Animation Studios.

"It is something that is a little more slow-paced and poetic, something that makes you smile and think rather than just laughing," said Casarosa. "It is different compared to what we've done in the past with the shorts." Casarosa pitched the idea for the short to Pixar Executive Producer John Lasseter, who appreciated the personality of the story and gave Casarosa the green light to proceed.

Directing a Pixar short was a new experience for Casarosa. His decade-long career at the organization mostly involved working on larger, feature-length films like *Ratatouille*—not leading a team of his own on a yearlong project. "Until I pitched the short, I was really pretty much in story specifically," explained Casarosa. "In directing you learn so much because you see much more of the whole production pipeline."

Being in the director's seat afforded Casarosa the experience of learning how to bring his vision for the story to life by interfacing with the film's producer, Kevin Reher. "As the director, you could argue sometimes that you and the producers are the biggest allies and sometimes you're the biggest enemies," he said. "I think it needs to be that way. The producer is there to try and make sure you end on budget and walk away with something in your hands, not just an idea. It's a struggle. The communication and the relationship are really important. I wanted to be very conscious of that. I didn't want to be 'the creative' that doesn't understand or wants to bend to the rules of the game."

On a film, the producer is the one who assembles the A-Team: the right people for the right job at the right time. Similar to projects at NASA, expertise is a hot commodity and is usually funneled toward high-profile programs or projects. "You're not the first in the pecking order to get a little help from some of the other departments," said Casarosa. "You're a small project…and sometimes it's a real fight for someone to give us this person or that person, and get them at the right time. I have a huge appreciation for that [now]. It really is a big puzzle. When you're in the middle of the trenches, I think it's a lot harder to see."

Throughout the project—long or short—developing, editing, and refining a story is a collaborative process. Screenings regularly bring in a full audience that is made up of anyone including the film crew, seasoned animators, or non-film staff. The culture is one where everyone can "chime in and give their notes about what works and what doesn't," explained Casarosa. "It doesn't matter who you are, it matters what idea you have."

During development, *La Luna* wrestled with several technical challenges that are often a result of working with a small budget, minimal research and development time, and accessibility to the latest and greatest tools. One of their biggest hurdles was something Pixar had yet to tackle in any of its films: facial hair.

"Computers don't naturally do hair," said Casarosa. "There are thousands of hairs and whether they do or don't move isn't easy to control. We've done a lot of that in the past with *Monsters, Inc.* with fur, but we specifically hadn't done the kinds of mustaches and beards that we were looking for, which was something that needed to be animated with the talking."

The *Brave* project team had a similar challenge (the movie features well-bearded and mustached Scotsmen), but they had the advantage of newer software that was more capable of addressing the facial hair challenge. "We didn't [have the same tools] so we kind of had to tell it in our own way," said Casarosa.

Casarosa initially thought including facial hair would save them money, eliminating the cost to model the mouth because it would be covered. They were wrong. "Usually the computer can just figure out how the hair would flow based on what it was attached to, but if we let whatever surface on their faces command the hair it would become this sort of crazy thing, which would move too much," he laughed. "That was a real challenge for the longest time. The hair was just all over the place and their faces looked to be a little too alive."

Casarosa was able to resolve the challenge by giving his animators the right amount of control over the shape of the facial hair. "That was a hard because we hadn't done that before," he said. "We had the limitation of our tools, but we tried to do something different with them."

In a little over a year, *La Luna* was completed. Casarosa is now the head of story on an upcoming feature-length movie called *The Good Dinosaur*, which is expected to premier in 2014. As head of story, Casarosa is leading a team of artists as they draw out and sequence the visual aspects of the movie. Now leading a part of a larger production, he is aware of his role as a mentor. "You try and look for someone who is ready to step up and be the lead," he observed. "So much of what we do as storyboard artists is about cinematography. It's a lot about editing, and from this image you go to that image, and how it's working or supporting our moment, our story. We really think quite minutely about all of those things. That's where a lot is coming to fruition as far as trying to mentor, trying to give opportunities to grow the people around you."

The small-team experience is valued at Pixar, explained Casarosa. It provides an opportunity for people to see a project throughout its entire lifecycle. "It's really wonderful how that becomes a great learning experience for other people. Having smaller teams gives you this wonderful sort of camaraderie—everyone does a little bit more, and everyone is a little closer."

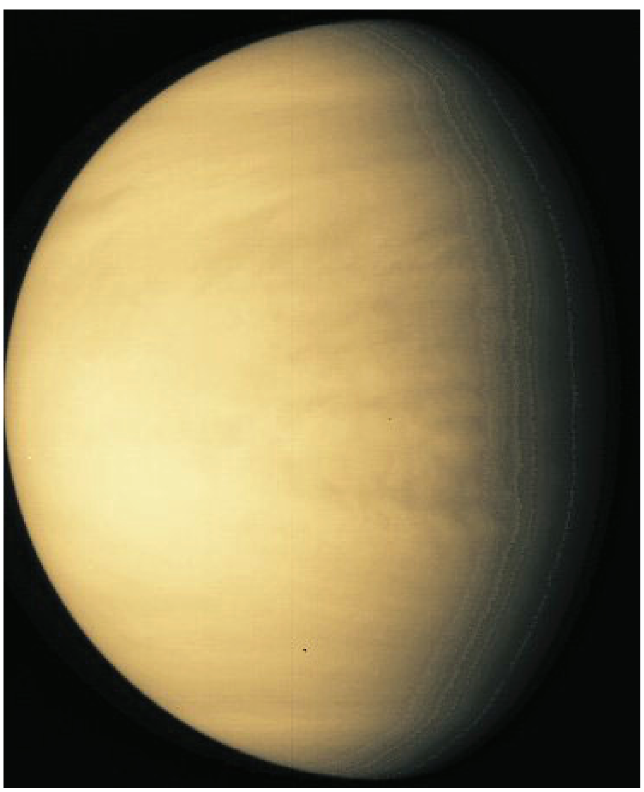
Venus: An Engineering Problem

July 31, 2012 — Vol. 5, Issue 7

Hot, toxic, and murky, Venus serves as an extraordinary engineering challenge, according to Jim Garvin.

Venus is bizarre. One day on Venus is nearly as long as one year on Earth. It rotates about its axis in the opposite direction of all the other planets in our solar system. Venus traps more solar energy than it can release and because it turns so slowly that it's just about as hot on the night side as it is on the day side. As far as science and exploration are concerned, "It makes Mars look so good," says Jim Garvin, Chief Scientist for Goddard Space Flight Center. As the former NASA Chief Scientist for Mars exploration from 2000 to 2004, Garvin is well acquainted with the challenges of Mars exploration, but even he readily admits that Venus is in a league of its own.

The tools for learning more about the surface of Mars—orbiters, landers, and rovers to map, probe, and study the landscape and the compelling rocks—will not work very well for Venus. For one, there's the problem of the atmosphere. It's thick—really thick. "One hundred times the mass of Earth's, it's the biggest atmosphere in the solar system other than Jupiter's," explains Garvin, noting that it's "hot as Hades at the surface and there's toxic chemistry on descent, and that makes it hard to do the science we need in order to understand Venus."



This picture by the Galileo spacecraft shows just how cloudy Venus is. Venus is very similar to Earth in size and mass - and so is sometimes referred to as Earth's sister planet - but Venus has a quite different climate. Photo Credit: Jet Propulsion Laboratory / Galileo spacecraft

To get to the surface, a lander (or rover) must fall through approximately 35km (~100,000ft) of the thick, murky lower atmosphere before the final couple of kilometers where the ground finally becomes visible from above. During descent, the temperature starts at a comfortable 20 degrees Celsius and shoots up to 450 degrees Celsius just before reaching the surface. (A standard kitchen oven runs at about 200 degrees Celsius.) Near the surface, the air is so thick that the lander will settle to the ground much like a stone settles in water—no retrorockets or sky cranes required.

Once on the surface, which is hot enough to melt lead, there is little more than an hour, maybe two, for the lander or rover to do the science it set out to perform. Performing experiments in the comfort of our own planet in only an hour is difficult enough. "On Venus you have every other problem known to woman or man in a hard and unforgiving place," says Garvin.

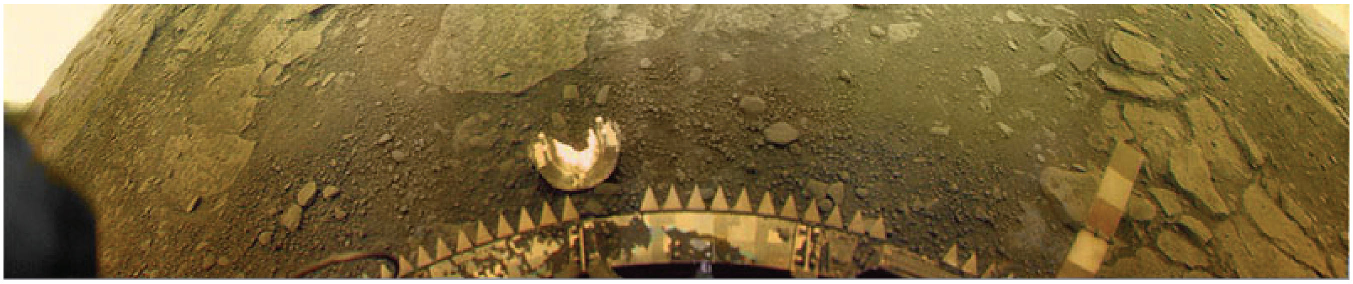
"Venus is an engineering problem. We're not without science questions to ask—there are plenty. But engineering is challenging there," he said. "With an hour or so to do your work, without some other mechanism so you can get rid of heat longer, you have a fundamental problem."

A Few Thousand Words

From 1961 to 1984, the Soviet Union launched a series of probes to Venus. Its Venera program consisted of sixteen massive probes, the first seven of which never reached the surface. Beginning with Venera 8 in 1972, the Soviets succeeded in being the first space agency to perform a soft landing on another planet and the only agency to ever retrieve images from the surface of Venus.

Meanwhile, Garvin was working on his graduate degree from Brown University under Professor James Head. Having spent some time working on Viking Lander images of Mars, Garvin became interested in the results of the Venera missions. "I wrote a couple of little old papers in the early '80s about Venera 9 and 10, comparing it to Mars imagery from Viking," he says. These publications later earned him and his mentor, Head, a trip to Soviet Russia to look over the latest Venera images when a Soviet scientist took interest in Garvin's work and proposed a partnership that was later enabled by means of a scientific relationship through Brown University. Although highly controversial due to the political climate at the time, the payoff was worth it in terms of science.

Garvin and Head visited the Soviet Union several times. Due to a language barrier, some of communications took place in French. "Fortunately I remembered it at the time," Garvin says. Both times they received large facsimile photographs as hardcopies depicting the latest images of the Venusian surface.



Venera 13 landing site panorama, side A (penetrometer side), in original perspective prior to transformation. Image Credit: National Space Science Data Center

"They scanned line by line by line by line. They would go all the way up and all the way back, like an old teletype machine," Garvin said, moving his hand from left to right, explaining how the images were captured by the Venera landers. "The data they gave us when I was finishing up at Brown in the mid-'80s, was stored on tapes that were bit-interleaved, which means there's one bit of data, all this other telemetry, one bit of data, all of this other stuff—not the way we normally encode data from space at NASA."

"Today, we have imaging arrays in our cell phones. 'Click!' We have the whole image in less than one second."

To the untrained eye, the images of the surface of Venus might appear to be unimpressive. Each appears to be taken from a camera roughly waist high that is tilted downward, but still able to capture the ground and the horizon further away. They look like "enigmatic 'slabby' landscapes, which resemble the flagstones we make patios out of," says Garvin. At the bottom of each image, various parts of the lander are visible: a microphone for listening, color palette for color calibration, camera lens cap, etc. Everything appears to be a mostly uniform brownish-orange color.

To a geologist, however, these images are just the beginning of a story about a rather curious planet.

"In geology, we think of three ways of how a surface comes to be," he says. "We have the formation process: Is it volcanic? Did the rocks just fall from the sky or were they formed in place? We have the placement: How did the rocks get there? Did some process bring them in? Were they laid down as a fine bed of dust that then hardened into rock? Was it based on water? Was it wind? And then the final one: modification. As it sits there is it being eaten away by massive chemical weathering? Or other exotic processes as yet unimagined?"

"I calculated that amount of dust," says Garvin, pointing to the toothed lip of the Venera 13 lander visible in the bottom of one image. "When that 500kg lander hit the surface with no rockets firing, it kicked up a cloud of dust that took minutes to settle out on the lander base—which is flat and donut-like and about this wide," Garvin explains, holding his arms out wide. "When you do math to figure out how that works, clearly there's some 'mobilizable' material that's either drifted in from airfall products from volcanoes—volcanoes erupt, they produce dust, it is transported and then deposited some distance from the source—or whether it's just disintegration in place due to weathering, rocks breaking because of thermal and chemical cycles."

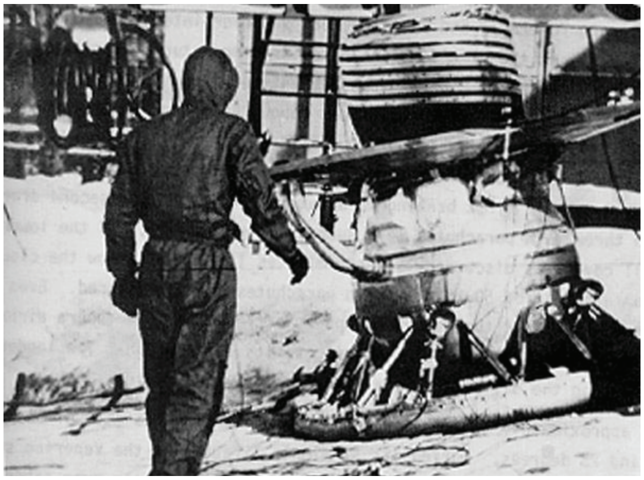
The Soviet-American collaboration on the Venera imagery resulted in several papers published separately by each nation throughout the 1980s. However, even with the same images, their interpretations differed. With so little to go on, the story behind the Venusian landscape was still up for grabs. "Pictures are great," says Garvin. "They're worth a thousand words, but they don't always give us the whole story. As we have learned with Mars, the chemistry and mineralogy of the rocks, soils, and dust is also an essential ingredient."

The Whole Picture – Sort Of

In 1989, NASA launched Magellan, its first orbital mission with the sole purpose of exploring Venus on a global basis. The Magellan spacecraft captured impressive radar images of 98 percent of the planet's surface. The image resolution was 10 times better than the resolution used on the last two Soviet Venera radar missions to Venus. The mission delivered data suggesting Venus might be a very volcanic world.

However, even with the near-global Magellan data, there still isn't enough information to build consensus about Venus today and

Venera 14 landing site panorama, side A, prior to transformation. Image Credit: National Space Science Data Center



A rare picture of Russian engineers testing a Venera Venus lander. This type of lander was used in the Venera 9 and 10 missions to the surface of Venus. Photo Credit: NASA National Space Science Data Center

in the past. "We've gone from swamps and jungles—which isn't astronomically unrealistic—to frighteningly hot, dry forever, to maybe oceans, maybe not, to active volcanoes, maybe not, to spreading center tectonics like the ocean-floors on Earth, maybe not, to an atmosphere that might have fundamentally changed after it was born, to a state where it's now primarily carbon dioxide and not full of these gases that are particularly favorable for life," he says. "But we still just don't know."

Over the past eight years, NASA has collected hundreds of thousands of scientific image of the Martian surface by cruising about the landscape using the orbiters known as Mars Odyssey and Mars Reconnaissance Orbiter. For Venus, there's just the handful of decades-old Venera images of the surface from the Soviet lander cameras.

"That's the sum total of our eyeball view of our sister planet lurking out there only 30 million-odd miles away when she's close. Today, we're still using artist renderings to describe how we think the planet really looks."

Going Back

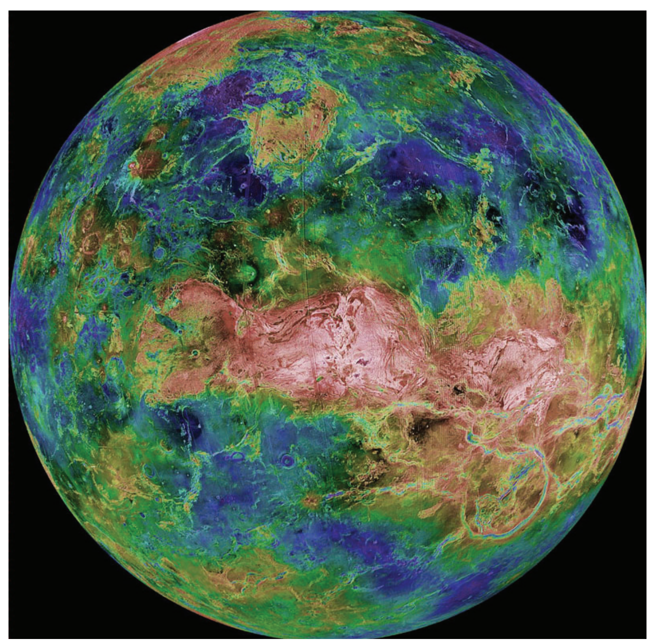
To understand Venus, scientists need more data. To get there, engineers have some problem-solving to do. What's the right first step? What type of mission should it be? Orbiter or lander? If a lander, can the heat factor on the surface be mitigated to allow for more time for data collection? Is it possible to transmit data more effectively through the thick Venusian atmosphere back to Earth?

Most of the lower Venusian atmosphere consists of extremely hot carbon dioxide under tremendous pressures. "The gas near the surface behaves like a supercritical fluid," says Garvin. Prior to the recent development of two test chambers at Goddard Space Flight Center and the Jet Propulsion Laboratory, NASA didn't have a way to test to Venusian conditions. Through a series of fortunate events, a one of several partnerships were established with a New England manufacturing company that required 500-degree-Celsius temperatures at 100 atmospheres pressure for some of its specialty products.

Choosing a place to land is also challenging. Before the Mars Science Laboratory (MSL) and its Curiosity rover, NASA landers and rovers have essentially touched down in the equivalent of parking lots: flat, not too rocky, and relatively safe. MSL will deviate from this paradigm. "Now we're going to the really interesting spots," Garvin says. "Before we couldn't go to these places because we didn't have the engineering and supporting knowledge to get us there. On Venus, we're not even sure where the good stuff is because we can't do the kind of remote sensing we do on Mars because of its big atmosphere. But we know that newly advanced radar methods can give us views of Venus nearly equivalent to those of Mars, perhaps some day."

The interest in Venus is there. In the last round of NASA's openly-competed Discovery missions, seven were bid to study Venus—more than any other planet or celestial body. What is challenging for Venus-hungry explorers is telling a compelling science story. "How do you communicate that? You go to the public and say you want to spend 500 million dollars on Venus sniffing sulfur isotopes, searching for a part per billion of water in a rock, and take a few pictures of rocks. Meanwhile, we're looking for prebiotic chemistry on Mars, or oceans on Europa, or lakes of ethane on Titan," says Garvin. Exploring Venus will hinge on a combination of reality and economics.

"What path can you take on a shrinking budget with lots of



This hemispheric view of Venus, as revealed by more than a decade of radar investigations culminating in the 1990-1994 Magellan mission, is centered at 90 degrees east longitude. The Magellan spacecraft imaged more than 98 percent of Venus at a resolution of about 100 meters; the effective resolution of this image is about 3 kilometers. Photo Credit: NASA/JPL-CalTech other good things to do?" he asks. "Mars? Europa? Titan? That's the challenge we face." Surveying the difficult choices for planetary exploration, he notes that while important to study, Venus isn't going anywhere. "We could be missing parts of the equation," Garvin says. "For now, Venus will wait. The Rolling Stones said, 'Time waits for no one.' But in this case, Venus will wait."

The Sound of Organizational Silence

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"How do we create a culture where the most important thing is to share the expertise and the wisdom that we have?" Ed Hoffman asked the audience at the Goddard Organizational Silence Forum in July.

There are different forms of silence. Goddard Space Flight Center Director Chris Scolese recalled that when he first became a manager, "They took my 'engineer' card away." Things changed. "It's another form of silence," he said. "People don't talk to you the same way they used to." Intimidation and other dynamics also come into play. "How do we get around that?" He said that it was important for forums like the Organizational Silence event at Goddard to discuss the issue and maintain awareness of the agency-wide dissenting opinion process.

"If there are things that we do well, let's talk about them," said Hoffman, NASA Chief Knowledge Officer and Director of the Academy of Program/Project & Engineering Leadership. "If there are things that we need to do better, let's talk about them."

When Bryan O'Connor, former NASA Chief of Safety and Mission Assurance, first arrived at Johnson Space Center in 1980, he recalled seeing the words "In God we trust. All others bring data," written on a wall. He remarked on how this affected him. "If I have an opinion, they won't listen to me. If I bring data, they will," he remembers thinking. How do you build credibility to have your opinion heard if you lack data?

"It's hard to bring data about human issues," said one audience member. When it comes to leadership and management issues, the uncertainty is high and it is difficult to find ways to overcome the hesitation to voice an issue. "How can we overcome that and get over the fear factor?"

"That's a tough question," said O'Connor. He recounted his experience during safety school. The first six weeks was "engineering stuff," he explained. What makes wings come off? How do you investigate an accident? The last four weeks were a different story. The course focused on the human element, which was significantly more complex and uncertain. (Watch video of Bryan O'Connor speaking on this topic.) "A little bit of humility can grease the situation," he said. Acknowledging that you might not have all the data can help temper a sensitive situation. Challenging the value of ideas and not the value of people is also an important distinction to make.

NASA Chief Engineer Mike Rsychkewitsch built off O'Connor's remarks emphasizing the need to build personal credibility. "You want the [right] reputation at the right time," he said, emphasizing the importance of adopting a positive

(Left to right) Bryan O'Connor, Amy Edmondson, Mike Ryschkewitsch, and Robin Dillon share insight into organizational silence on a panel at Goddard Space Flight Center on July 31, 2012. Photo Credit: NASA/Goddard Space Flight Center

Andrew Chaikin, space author and historian, discussed the role of project management during Apollo during the Organizational Silence event at Goddard Space Flight Center on July 31, 2012 Photo Credit: NASA/Goddard Space Flight Center

tone and offering suggestions. "I'm worried about so-and-so. They have done x, y, and z, and normally I wouldn't be worried about it, but this isn't normally how they behave."

O'Connor recalled sitting in meetings when he first joined the agency and hearing people talk past one another. In the wake of *Challenger*, he promised himself that he would never let that happen again. He noted that simply saying, "I'm sorry, I heard two different things come from people who seem to think they are agreeing with one another. Can we go over that again?" can make all the difference.

Amy Edmondson, professor at the Harvard Business School, called this action "speaking up effectively," which requires a balance of advocacy and inquiry. Edmondson, who studies organizational dynamics related to people withholding information rather than sharing it, discussed how not feeling entirely comfortable in their organization can be a hindrance to achieving the mission of an organization successfully.

In the end, it comes down to leadership and setting an example. "If the leader is sitting there and checking emails, then that's what others will take to be the precedent," said Robin Dillon, professor at Georgetown University. "It's not enough to just pause," she said. "You've got to go around and ask for concerns. What are we missing?"

"This is what I think you've told me and this is the conclusion I draw from it," Ryschkewitsch said. "Did I hear what you intended to say?" Sometimes simply asking that question offers the group that one last chance.

The Organizational Silence event featured a number of speakers including Andrew Chaikin, space author and historian, Marsha Coleman-Adebayo, author of the book No Fear, which covers her experience with organizational silence at the Environmental Protection Agency; a Goddard panel featuring Judy Bruner, Director of Safety and Mission Assurance, George Morrow, Director of the Flight Projects Directorate, Dennis Andrucyk, Director of Applied Engineering & Technology Directorate, and Ron Brade, Director of the Office of Human Capital Management.

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