National Aeronautics and Space Administration

Academy Sharing Knowledge

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Inside

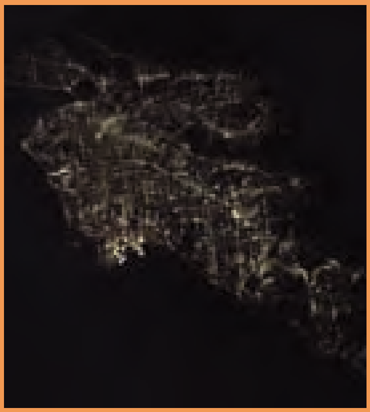

Photo Credit: Image Science and Analysis Laboratory, NASA Johnson Space Center/Donald Pettit

ON THE COVER

This space-station view of Los Angeles was taken by Astronaut Donald Pettit, who lived aboard the International Space Station for five and a half months. The city is defined by yellow-orange, sodium-vapor-lit streets in north–south, east–west grids. In between the main streets it is relatively dark due to the design of street lighting that minimizes stray light. Geographic features of coastlines and mountains remain dark. At the edge of town, the lights abruptly fade into the surrounding desert.

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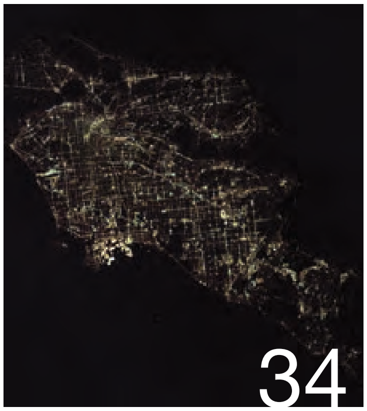

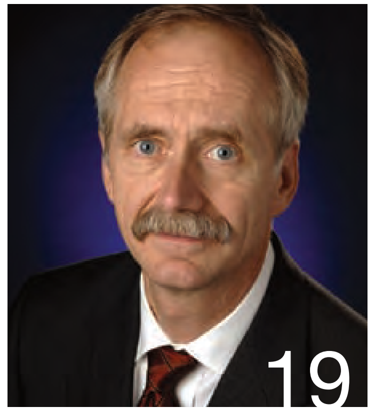

ask

Issue No. 38

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

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

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In This Issue

At the NASA Project Management Challenge in Galveston, Texas, this past February, Jean-Jacques Dordain, director general of the European Space Agency, predicted that global collaboration will define future space exploration. Only a joint effort can tackle the immense technical and economic challenges of extending our reach in space. Part of Dordain's speech appears in this issue of *ASK* ("Space Exploration in the 21st Century"), and other articles here deal directly with international cooperation or with the related issues of broadening the search for critical expertise and building the trust and understanding diverse teams need to work together successfully.

In the interview, William Gerstenmaier reflects on the development of the International Space Station, the premier example of multination collaboration in space. He talks about the long working relationship that has made it possible for the United States and Russia to cooperate effectively in times of crisis and of the value of partners taking different approaches to the same technical challenge. These different ways of looking at a problem help create the "requisite variety" that Laurence Prusak identifies as essential to a robust organization or project in "The Knowledge Notebook." Prusak argues strenuously against "going it alone." He says that organizations can thrive in this complex, changing world only by welcoming knowledge from many sources.

Ed Hoffman's "From the APPEL Director" column brings together the themes of international cooperation and trends in project management. He emphasizes the importance of cognitive, cultural, and geographic diversity in carrying out demanding projects. NASA's Astrobiology Institute ("Are We Alone?") is an outstanding example. The study of potential extraterrestrial life necessarily involves many scientific disciplines. The institute uses cross-training classes, face-to-face conferences, strategic-planning workshops, and videoconferencing technology to support worldwide astrobiology collaboration and provides grants to help educate the next generation of astrobiologists. The challenge in creating the kinds of teams that Hoffman describes, and the astrobiology work exemplifies, is to develop teams that have enough cohesion to work well together without undermining the diversity of perspective and experience that makes them creative and flexible.

In "Petrobras and the Power of Stories," Alexandre Korowajczuk and Andrea Coelho Farias Almeida look at the issue of creating cohesion and sharing rich knowledge from a somewhat different angle. The Brazilian energy company is carrying out a major storytelling initiative to teach thousands of new employees about the organization's values and culture as well as the real-life expertise needed to carry out the company's operations. Hearing the stories—usually in the presence of veterans who lived them—communicates subtle knowledge that could never be conveyed through manuals or memos.

One way NASA has sought new ideas from diverse sources in recent years is by sponsoring the Centennial Challenges program, which offers an open invitation to individuals and groups to undertake technical challenges ranging from designing a better spacesuit glove to building a robotic lunar-soil excavator ("Open-Door Innovation," by Andrew Petro). Even the entries that do not win prizes sometimes demonstrate surprising, potentially valuable new technologies. Many of the competitions—the glove and excavator, and the lunar lander and power-beaming challenges—are inspiring new ideas that will undoubtedly contribute to future space exploration.

Don Cohen
Managing Editor

From the APPEL Director

Project Management Trends and Future Reality

BY ED HOFFMAN

Space exploration has always been international. NASA's first international mission dates back nearly fifty years, and the agency has had more than three thousand agreements with over one hundred countries in its history. What has changed is the complexity of our projects, our partners' capabilities, and the number of spacefaring nations. How we work together has also evolved. Over the past year, as I reviewed current project management thinking with colleagues at NASA and around the world, five themes kept surfacing: team diversity, virtual work, sustainability, innovation, and portfolio management.

Team diversity—cognitive, cultural, and geographic—has increased as projects become more complex, technically challenging, and global. Cognitive diversity refers to varying perspectives based on expertise, education, experience, age, training, and professional background. Cultural diversity manifests itself through different languages as well as less obvious elements including goals, politics, budgets, and national security concerns. Geographic diversity continues to grow as projects involve multiple partners from government, industry, academia, and nonprofit organizations.

Virtual work attracts talent and facilitates relationships that might otherwise be unavailable. Companies like IBM, Procter and Gamble, and AT&T have partially or fully eliminated traditional offices. NASA and IBM host meetings on "islands" in Second Life. Project managers are still trying to understand ways to remedy challenges like isolation, performance measurement, and the blurry line between work and personal life, but virtual work is here to stay.

More than a synonym for "environmentally friendly," *sustainability* includes principles and practices that enable mission success and long-term societal health and progress. Sustainability is a systems-thinking challenge; it tackles questions of life-cycle impact, which can extend far beyond the duration of a project. To help address this challenge, NASA held its first Green Engineering Masters Forum in 2009.

Innovation in products and processes is a constant in the world of complex projects, shifting demographics, public–private collaboration, and the need for more sustainable practices. Projects demand adaptive thinking to adjust to changing requirements, budgets, and resources. Technology development is also essential.

Managing one project successfully is not enough. The larger challenge is managing a *portfolio* of programs and projects. NASA's mission directorates function as its portfolio management organizations. Portfolio management will continue to increase in importance.

Complex international projects shape the context for these trends. For me, the highlight of PM Challenge 2010 was the first-ever international track, which explored the international dimensions of NASA's missions. The day after that meeting, I met with counterparts from other space agencies and representatives of organizations, including the Project Management Institute and the International Astronautical Federation (IAF), to share ideas about professional development and explore avenues for future collaborations. There was strong agreement about the potential benefits of finding more ways to work together. Many colleagues expressed interest in establishing an International Project Management Committee under the auspices of the IAF.

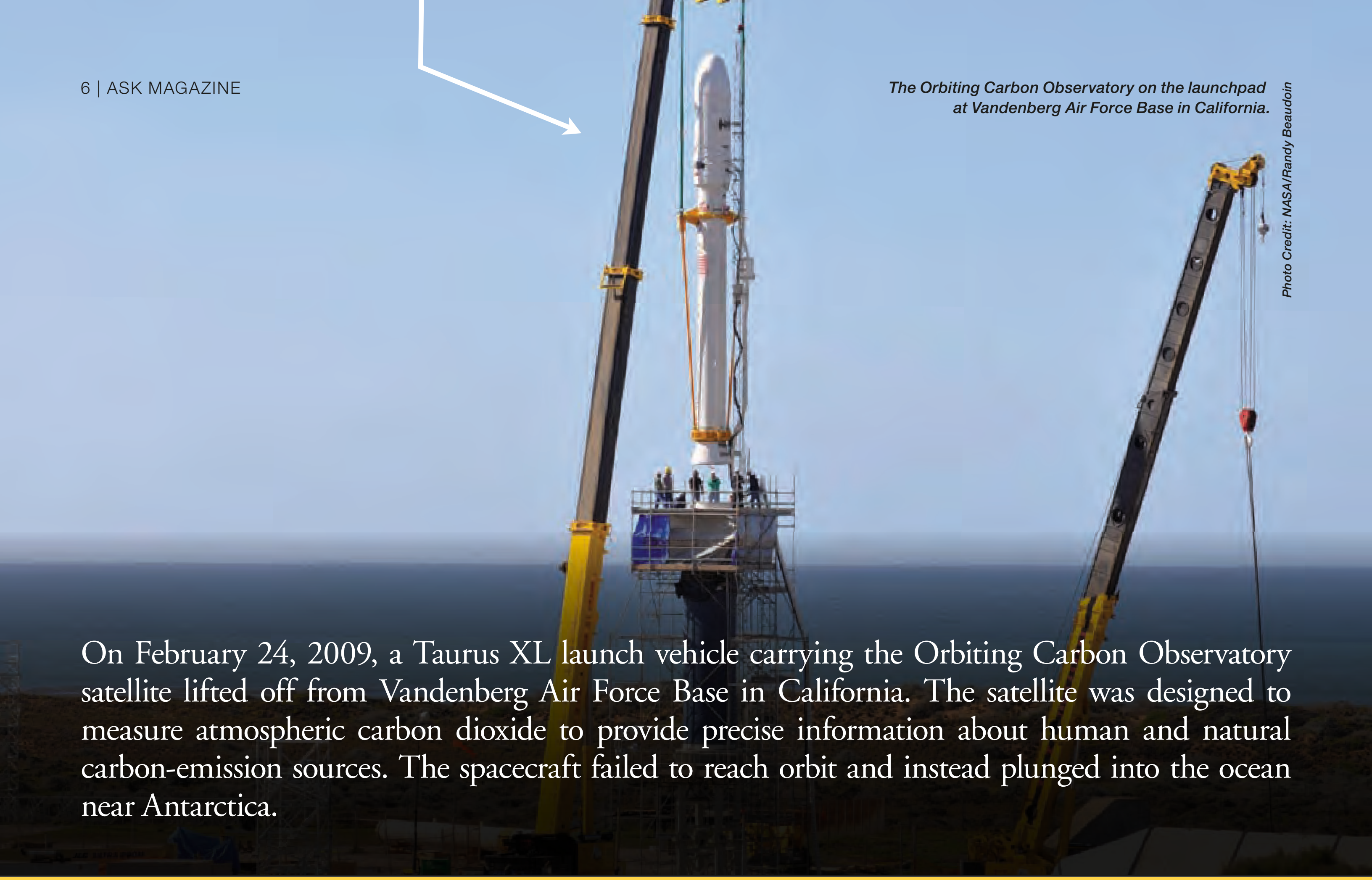
One thing seems clear: in the years ahead, the trend toward greater collaboration in space exploration will continue. Getting into space is expensive, and no single organization has all the answers. European Space Agency Director General Jean-Jacques Dordain summed up the imperative for international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

ANATOMY of a Mishap Investigation

BY RICK OBENSCHAIN

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

Photo Credit: Orbital Sciences Corporation



The Orbiting Carbon Observatory on the launchpad at Vandenberg Air Force Base in California.

Photo Credit: NASA/Randy Beaudoin

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

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

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

The MIB Team

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

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

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

Looking for the Root Cause

Our job was to try to discover both the *intermediate* cause or causes of the fairing separation malfunction—the particular component or components that failed to function as expected—and the *root* cause of those failures: the organizational behaviors, conditions, or practices that ultimately led to the production and acceptance of what proved to be faulty mechanisms. If you

Inside Building 1032 at Vandenberg Air Force Base, technicians install the Orbiting Carbon Observatory spacecraft inside the payload fairing.

Photo Credit: NASA

find and fix the intermediate, technical problems but ignore the underlying sources of those problems, they are likely to persist and lead to other failures, so identifying the root cause is important.

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

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

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

… WHAT INITIALLY LOOKED LIKE A PROCESS THAT MIGHT BE TOO RIGID TURNED OUT TO BE USEFULLY RIGOROUS.

The MIB Report

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

recommendations for how to ensure that they would not pose a risk on future missions. Briefly, these are the possible causes the board identified and our recommendations for improvement.

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

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

Electrical subsystem may have failed.

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

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

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

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

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

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

A Valuable Investigation

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

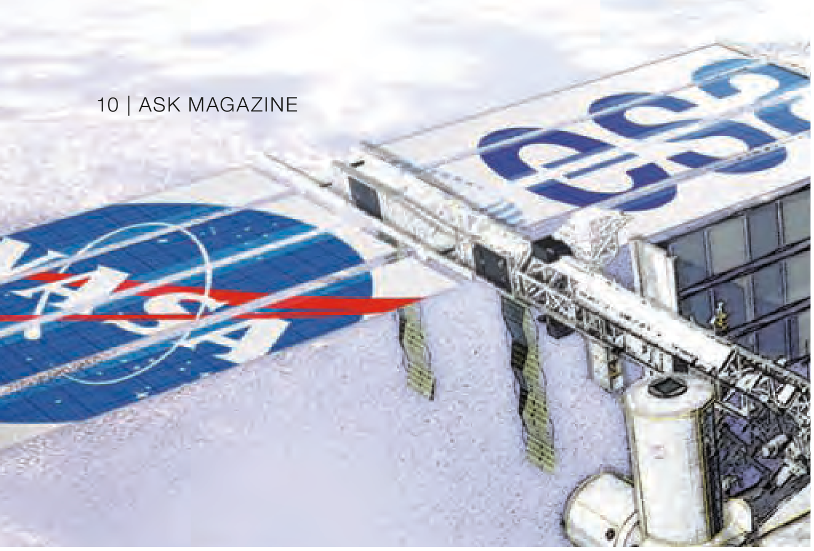
One general conclusion that our work supports is the importance of rigorously adhering to the procedures designed to eliminate and minimize as much risk as possible. This is especially true when the project team has only sporadic experience with a particular vehicle, as was the case with the Taurus XL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

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

Space Exploration in the 21st Century: Global Opportunities and Challenges

BY JEAN-JACQUES DORDAIN

Forty years after the first landing on the moon by two American astronauts, the significance of that historical step of human exploration is very different from what it was at that time. Then, it was a clear demonstration of the supremacy of U.S. technology over the world, and a symbol of the U.S. identity. Forty years later, it is not anymore a matter of the moon and the United States, but rather of planet Earth and humankind; twenty-seven astronauts have seen planet Earth as a small and fragile golf ball floating in the universe and, as a result, helped develop the understanding that our future can only be global.



Thanks to that first landing on the moon, we have witnessed two paradigm shifts. The first is about the objective, which has shifted from space to planet Earth. The compelling urge of man to explore and discover is not enough to justify engaging in long-term exploration. There is a need, at least in Europe—it may be different in other societies—to identify benefits of space exploration able to generate a resilient political and public support, which is a condition for space exploration to be sustainable over the years. The benefits must be measurable on Earth: economic growth, technological innovation, scientific information, international cooperation, education, all of which can contribute to solving problems here. Exploration addresses the future of planet Earth.

The second paradigm shift is about the process, which has moved from competition to cooperation. We have started with one flag on the moon, then two flags for the Apollo Soyuz mission, then four with Space Station Freedom, and now five flags for the International Space Station (ISS). The cooperative process may be much slower than the competitive race, but it is also much more robust and sustainable.

Future space exploration can indeed only be global, and it will require us to assemble the nations that explored individually in the past to explore collectively in the future. This is not easy. It will be the most difficult part of exploration, much more difficult than any required technological development, but it is necessary. There is no alternative. We shall have to invent the future together.

Because it will not be easy, we will have to go there in steps. I see three major steps: make the utilization of the ISS a success for exploration, develop robotic exploration plans, and define a human exploration scenario.

Make ISS Utilization a Success

The recent decision taken by President Obama to extend the operation of ISS to 2020 and beyond is very good news for all partners. As NASA Administrator Charlie Bolden has said, we were waiting for that decision and even asking for that decision.

These next ten years are necessary to make ISS utilization a success, to demonstrate to the public and governments that they were right to invest in it. Also, we need time to reap the benefits, be it for science, for technologies, or for new partnerships. As I said to the Augustine Committee, we shall not build exploration on the failure of the ISS. So our first priority shall be to ensure the success of ISS.

These next ten years will provide time and perspective to improve the ISS and make it a concrete step toward exploration. The decision not only represents five additional years of exploitation, it also provides a perspective long enough for all partners to think about new ideas, new approaches, and new hardware. The two questions we should now ask ourselves are how to increase the benefits of the ISS, and how to decrease the costs of using it.

How can we increase the benefits of the ISS? These are some of the possibilities:

- Increasing capabilities, not by adding new labs, but by reducing bottlenecks such as storage, communications, or download;
- Extending the range of scientific utilization toward new fields such as Earth observation, monitoring of natural disasters, climate change;
- Improving operations, for instance through a common transportation policy or a common operations policy—that is, defining common interfaces between each htpartner's elements;
- Testing new systems and technologies, for instance in the fields of life support or resources recycling;
- Extending the partnership to other partners, on conditions to be defined. To be sustainable, the space station partnership cannot be closed.

How can we decrease the costs of ISS utilization?

The objective is to decrease the costs of production and operations in order to rebalance development and production activities. The use of commercial services is one interesting track—not the only one, but a track that requires the space agencies to think and to adapt.

My biggest fear as the director general of the European Space Agency (ESA) is that ESA could become a dinosaur, no longer adapted to its environment. We have to change, continuously.

FUTURE SPACE EXPLORATION CAN INDEED ONLY BE GLOBAL, AND IT WILL REQUIRE US TO ASSEMBLE THE NATIONS THAT EXPLORED INDIVIDUALLY IN THE PAST TO EXPLORE COLLECTIVELY IN THE FUTURE.

This is not easy, in particular because we are a successful agency, and it is easy to keep doing what has made us successful. But the future will not be made with the recipes of the past.

Commercial services may indeed be one way. We have already experienced that in Europe, by creating the commercial operator Arianespace for launch services, but that was thirty years ago. Reflections are ongoing to see how we can adapt this scenario for the future.

We should not forget, however, that the customer for the ISS and exploration is and will remain governments, not private organizations. I refuse the much too simple statement that agencies are expensive and industry is cheap. The reality is as usual much more complex: agencies work under substantial constraints imposed by their governments, such as distribution of activities, but agencies can also be cheaper, and we in ESA shall work together with the other agencies to reduce significantly utilization costs. Agencies cannot do without industry, but industry also cannot do without agencies.

Any progress made for the utilization of the ISS will be a progress made for exploration. The ISS will be valued also by its capacity to support exploration.

The space station is the first step in human exploration beyond low-Earth orbit!

Develop Robotic Exploration Plans

Last year, ESA and NASA made a significant step by taking a joint initiative for a systematic robotic exploration of Mars; we have decided to use every opportunity to go to Mars together, and we have already defined joint missions that will be launched in 2016 and 2018. The ultimate goal is a joint Mars sample return in the mid-2020s. There, also, the partnership is not closed and must be open to other partners.

Beyond this Mars robotic exploration plan, other robotic missions should be planned as precursors to human exploration, around or on the surface of other destinations such as the moon or asteroids. Such missions should provide detailed information on the topography and geochemical properties of the surface of these destinations, and allow the testing of possibilities and techniques for "living off the land."

A major interest of robotic investigation is to involve industrial expertise outside the traditional space industry and, therefore, to widen the base of stakeholders and increase the synergy between space-bound and Earth-bound interests.

Define a Human Space Exploration Scenario

As Administrator Bolden has noted, there is no common vision among international partners about a human space-exploration scenario beyond the exploitation of the ISS. The U.S. Constellation program is being terminated, though the United States remains committed to explore beyond low-Earth orbit. In Europe we are currently reflecting on our future human-exploration plans. Other partners may have plans, but they are individual plans rather than a contribution to a global scenario.

A global exploration strategy has been developed by fourteen space agencies, including ESA. But this global exploration strategy has not been addressed at a political level and does not represent a political strategy shared by an enlarged community of international partners.

A high-level political forum, including current partners as well as potential new partners of the ISS, should be set up with the objectives of developing a common vision for exploration. At the space-agency level, we can develop a common architecture for human space exploration. But we can't develop the political vision. We are waiting for someone to take the initiative.

Which partner in the world has the willingness and credibility to propose such a political forum? I am convinced that the United States is the best suited to take such an initiative … but when?

As the French author and aviator Saint-Exupéry said, "… the question about the future is not to predict it, but to make it possible." So let us work together to make it possible. ●

JEAN-JACQUES DORDAIN is the director general of the European Space Agency.

Are We

An image of a nebula is displayed on a hyperwall at the California Institute for Telecommunications and Information Technology.

Photo Credit: Lockheed Martin/Estelle Dodson

Alone?

Answering This Question Is Not a Lone Venture

BY WENDY DOLCI, ED GOOLISH, AND CARL PILCHER

How does life begin and evolve? Is there life elsewhere in the universe? What is the future of life on Earth and beyond? The NASA Astrobiology Institute (NAI) was founded in 1998 as part of NASA's long-term quest to explore these fundamental questions. The NAI is one of four elements of NASA's Astrobiology Program, which has its roots in the agency's Exobiology Program established in 1960.

This artist's concept illustrates the connection between life and space exploration, both of which are key for astrobiology.

The field of astrobiology developed rapidly during the mid-1990s as several threads of scientific investigation came together. Scientists were recognizing the great diversity of life on Earth and life's ability to survive in extreme conditions. At the same time, the diversity of solar-system environments and their potential to harbor life were increasingly understood, and extrasolar planets were first detected. The NAI was born amid this convergence of discoveries and new ideas.

Capitalizing on advances in information technology that had begun to make remote collaboration practical, the NAI was designed as a nontraditional "institute without walls" with researchers distributed across the United States. Currently, fourteen interdisciplinary teams—encompassing about six hundred researchers at more than one hundred institutions—compose the core of the Institute. The teams work under competitively awarded cooperative agreements with five-year terms. A small management office at Ames Research Center administers the Institute and provides leadership to make the whole more than the sum of its parts.

Although basic and applied research in astrobiology is the Institute's first priority, NASA also envisioned that the NAI would test a new paradigm in science management, bringing scientists together across disciplinary, geographic, and organizational boundaries. The institute is further charged with playing a leading role in shaping space missions, making innovative use of information technologies, nourishing public interest in astrobiology through a strong education and outreach program, and training new generations of astrobiologists. This broad charter is a distinguishing characteristic of the NAI that puts the Institute and its science teams front and center in cultivating the field of astrobiology.

Developing a Field, Creating a Community

Creating a community of scientists with diverse backgrounds is a multifaceted process. Astrobiology requires collaboration between researchers from the geo-, bio-, astro-, and other sciences. Of course, this expertise is not limited to one or even a few nations. With the founding of the NAI, NASA's long-term commitment to astrobiology catalyzed a global astrobiology community. Partnership with the NAI lent weight to the establishment of organizations abroad such as the Centro de Astrobiología in Spain and the Australian Centre for Astrobiology. The NAI maintains these early partnerships and today also has partnerships with astrobiology organizations in Britain, France, and Russia as well as with the European Astrobiology Network Association.

The NAI links national and global networks of astrobiologists through technology and a range of activities and funded programs. The Institute funds workshops and conference sessions, and it designed and operates the Astrobiology Program Web site for NASA Headquarters. It brings program news and activities together in one place online. Broad participation in NAI science is made possible through programs such as the Director's Discretionary Fund, which awards small grants each year for seeding new ideas; a Minority Institution Research Support program; and NAI focus groups that advance specific topics of community interest.

Addressing the questions of astrobiology will take a sustained effort over generations. Current scientific investigations and space missions will, in many cases, be brought to fruition by today's students. Recognizing that students need a stable environment to thrive, the NAI actively supports a growing network of early-career researchers in astrobiology. A key example is the NAI Postdoctoral Fellowship Program that has funded fifty-four postdoctoral fellows to date, with many of the earliest NAI fellows now in faculty positions and advising a new generation. An additional five hundred or so postdocs have been supported directly by NAI teams.

A critical aspect of training the next generation of astrobiologists is preserving continuity in the face of budget fluctuations and turnover in grants. When astrobiology budget cuts occurred during the mid-2000s, student support remained a top priority for the NAI. And in 2008, NAI provided "continuity funding" for students who faced potential loss of funds when team grants ended their five-year terms.

From Competitors to Collaborators

A central management challenge for the NAI is balancing healthy competition with collaboration. Selected teams must make the transition from the highly competitive proposal process to the collaborative environment of the NAI. Five years later they may again be competitors. Despite this, collaboration flourishes across the Institute.

In the Institute's early years, biennial general meetings drawing about five hundred scientists provided opportunities to meet, present research, and discuss potential collaboration. In recent years, strategic-planning workshops focused on particular goals, and topic-based "virtual meetings," have replaced large, general meetings. For example, addressing the issue of competition versus collaboration head-on, a workshop was held immediately following the selection of ten new teams in 2009 to identify common research threads. The premise was, "Okay, now the competition is over and we have fourteen NAI teams—let's see what we can accomplish together." Such an approach is unusual; research teams typically go their own way once grants are awarded. The result was a suite of cross-institute initiatives and a new network of connections among researchers.

One of these new initiatives became the subject of a "Workshop Without Walls" conducted in March 2010 using the NAI's advanced collaborative technologies. The workshop, on "The Organic Continuum from the Interstellar Medium to the Early Earth," was international, with more than 170 registrants from twenty-one U.S. states and sixteen other countries. Thirty-three scientific talks were presented over two days, with the vast majority of participants remaining at their home institutions—or in some cases, at home! The ease of joining the workshop

THE VIRTUAL PLANETARY LAB

How do you get fifty-five scientists with diverse science backgrounds from five countries and twenty-three organizations to work together? By posing questions that are so big that they force interdisciplinary collaboration, says Vikki Meadows, head of the NAI's Virtual Planetary Lab (VPL) team at the University of Washington. The major question that drives Vikki and her team is this: Were we to find a rocky world orbiting another star, how would we know if that planet could or did support life? To help answer this question, the VPL team constructs models that simulate the planet's interaction with its parent star, and the resulting environments and spectral signatures of Earth-like planets. These models help us understand what "the fingerprints" of life look like—so that we might recognize life on distant planets when we see it.

The VPL team draws together scientists from more than fifteen disciplines, from biometeorologists to stellar spectroscopists—there is some truth to the inside joke that "it takes a planet to model a planet." Team members live across the United States and in a handful of other countries, including Australia, Mexico, and France. They use a mix of videoconferences, teleconferences, Web sites, and online meeting tools and workspaces for communication and remote interactions. In-person meetings also play an important role.

Developing a large team that works well together takes time. The five-year duration of NAI grants (and VPL's selection in two separate competitions) has provided time for the team to gel and produce truly interdisciplinary research, and to attract and support a cadre of young researchers launching their astrobiology careers. The distributed nature of the team has encouraged its members to stay involved over the long term. Colleagues who no longer have a formal role still connect from far-flung places for team meetings and contribute to VPL research.

Former NAI Director Baruch Blumberg and members of the NAI Executive Council view an image of Mars on the NASA hyperwall at Ames Research Center.

Photo Credit: NASA/Wendy Dolci

remotely made a great diversity of participants and increased interactions possible.

Bringing people from different disciplines together is not all that's required. Having a common language and a common understanding of multiple fields are key to working on interdisciplinary teams. The NAI has experimented with various ways to share knowledge across disciplinary boundaries. "Primer sessions"—an astronomy class for biologists, for example—have been held prior to astrobiology conferences to introduce multidisciplinary concepts and terminology.

Natural cross-training occurs when researchers from various disciplines work together, resulting in a new breed of individuals who are themselves interdisciplinary. Surveys conducted by NAI soon after its formation and again in 2007, asking scientists to identify their areas of expertise, show an increasing number of scientists calling themselves "astrobiologists." Furthermore, the 2007 survey, which asked for identification of primary, secondary, and tertiary disciplines, showed that many NAI scientists indicate expertise in multiple fields.

Working Together Across Distances

The basic NAI tools for remote communication include high-definition videoconferencing, teleconferences, Web sites, Web-meeting software, online recordings and podcasts, online workgroup software, social networking sites, and online office tools. In addition, the NAI experiments with hyperwall technology, high-speed networks, virtual worlds, and other leading-edge technologies to enhance research.

Shadows of future astrobiologists.

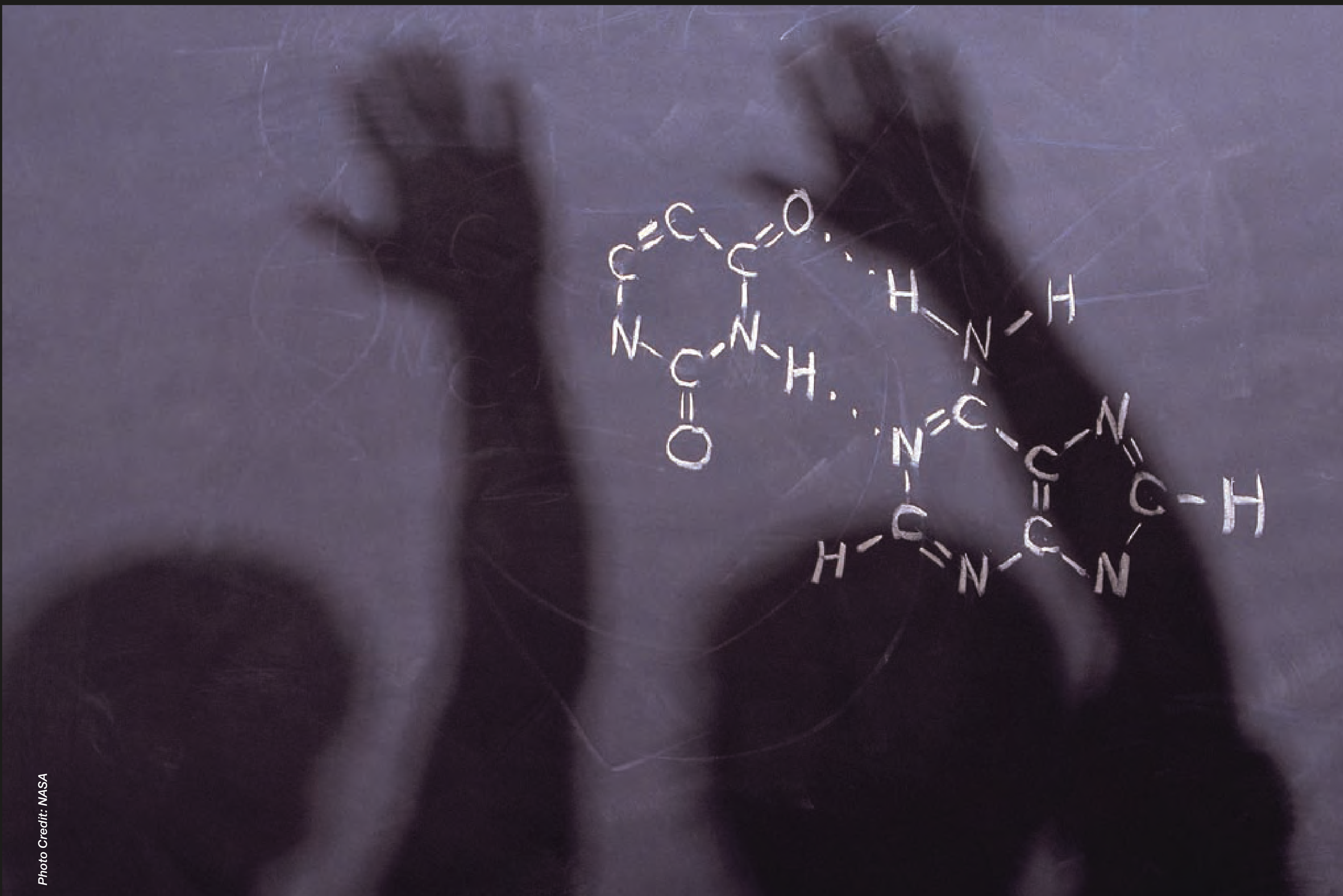


Photo Credit: NASA

Students in many cases are leaders in the use of information technology for science communication, reflecting their ease with social networking and other forms of remote communication. As part of the 2009 Astrobiology Graduate Student Conference, students held a mixed-reality event that took place simultaneously in person and in the virtual world Second Life. Students gathered in Seattle were able to interact with students from Portugal, Greece, Australia, Uruguay, and across the United States who otherwise would not have been able to participate.

A few management philosophies guide the NAI in its use of information technology. One is to offer a suite of tools and the expertise in how to use them, and support flexible solutions as teams create collaborative environments that suit their particular needs. Another is for the NAI's central office to be the first line of support for teams. Problems such as a forgotten password or a technical glitch can be barriers to success. Having a known and trusted point of contact for immediate resolution of problems is critical.

Videoconferencing in particular has seen much improvement since the late 1990s, when multipoint videoconferencing was fraught with problems and required racks of equipment. Today's videoconferencing solutions are reliable, much easier to use, and smaller; the NAI's high-definition multipoint controller (used for conferences that connect more than a handful of sites) is jokingly referred to as "the pizza box" because of its size and shape. Even more importantly, modern multipoint controllers come with a Web

HIGH-DEFINITION VIDEOCONFERENCING IMPROVES THE EXPERIENCE, AS FACIAL EXPRESSIONS AND BODY LANGUAGE THAT ARE KEY TO EFFECTIVE COMMUNICATION ARE MUCH MORE DISCERNABLE.

interface that allows users to schedule and manage their own conferences. High-definition videoconferencing improves the experience, as facial expressions and body language that are key to effective communication are much more discernable.

Space, Slime, and Dinosaurs

Astrobiology has caught on as a way for science educators worldwide to engage their learners. Spanning many disciplines, it can be applied in many types of classrooms and facilitates teaming and problem solving. It is especially relevant to middle school–integrated science courses, positively affecting a critical age group at risk of turning away from science. Incorporating the natural affinity kids have for space, "slime," and dinosaurs, astrobiology has the added appeal of "aliens."

When the NAI was founded there were scant educational programs and materials to draw from; it had to bootstrap a program more or less from scratch. In the early years, the staff of the NAI central office took to the road, exhibiting at major education and scientific conferences to help educators understand the educational value of astrobiology. More recently, education and outreach activities have been conducted by the science teams, with coordination by the NAI central office. Having a close-knit community of science educators that work together as a team enables innovation and encourages individuals to draw on one another's expertise and experiences.

On the Horizon

In the past ten years, tantalizing clues about the potential for life in the solar system have been uncovered. NASA missions to Mars have found extensive alteration of minerals by liquid water, indicating that one essential ingredient for life has been present on the red planet. Ground-based observations by NAI scientists and their colleagues have revealed that methane gas is being generated on Mars and may vary with the season. Since methane can be a byproduct of life or be produced by chemical means, scientists are hot on the trail of what accounts for it on Mars. Farther out in our solar system, liquid water exists under the icy crust of Jupiter's moon Europa and several other satellites. Looking beyond our solar system, the current count of extrasolar planets is well over four hundred. None of the known planets are Earth-like, but the Kepler mission is likely to change that. Launched in 2009, Kepler is designed to detect Earth-like planets around other stars. It is poised to tell us whether planets like ours are run-of-the-mill or rare. So, are we alone? Stay tuned. Astrobiologists are working hard to find out. ●

Learn more at astrobiology.nasa.gov/nai.

WENDY DOLCI is the NASA Astrobiology Institute (NAI) associate director for operations and has been with the NAI for seven years. Previously, she was a mission director for airborne science operations at Ames Research Center. In her current position she is responsible for the Institute's technology infrastructure, including Web and collaborative tools.

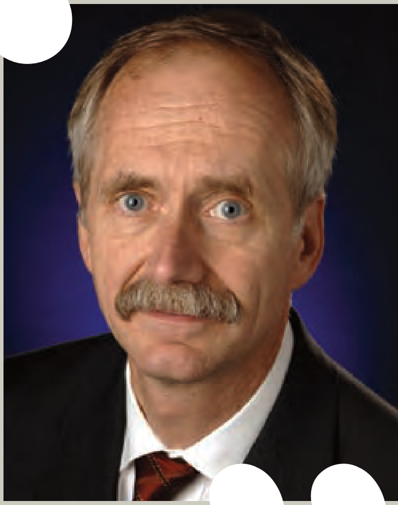
ED GOOLISH, deputy director of NAI, has been with the NAI since 2000. Prior to that he conducted research at Ames on the biological effects of gravity, contributed to the design and development of biological research facilities for the International Space Station, and was involved in several life-science space missions.

CARL PILCHER has been director of NAI since 2006. He was a professor of astronomy and planetary science at the University of Hawaii before moving to NASA Headquarters in 1988, where he held a number of management positions in human and robotic solar-system exploration and astronomical research.

INTERVIEW WITH

William Gerstenmaier

BY DON COHEN



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

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

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

They assigned me to start doing wind-tunnel tests right away. I had just come out of college and now I'm in charge of a multimillion-dollar test facility, with maybe seven technicians. For two nights I sat with someone else watching them do tunnel activities, then I was on my own. It was a tremendous responsibility, but a tremendously nurturing environment. I couldn't think of a greater place to start my career. The folks wanted to make sure I really understood; they really challenged me. They gave me top-notch tough jobs to do and let me work as hard as I wanted to. Also, being in testing was very good. When you put something in the wind tunnel, you did your own analysis, putting the probe in if you're going to measure the flow behind the model, for example. You had to do your own stress calculations, your own safety report. That was a scary experience because if this little probe breaks off and goes into the turbine

IN DIVERSE CULTURAL ENVIRONMENTS, demonstrating a capability IS MORE EFFECTIVE THAN academic proof THAT A CONCEPT OR A DEVICE WORKS.

at the end of the tunnel, I'll have caused a multimillion-dollar mishap. I would do all the calculations, then I'd find three or four engineers who had done this before and say, "Would you make sure that I really did this right because I don't want to mess something up?" I had lots of responsibility, yet I could really learn. So I gained a ton of firsthand experience, a lot of detailed engineering stuff, and even management skills, managing these technicians in the evenings when we were running the tunnel, keeping people on schedule, keeping things moving.

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

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

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

GERSTENMAIER: At the research center, the focus was on technical excellence. Managing and project management skills at that time were not stressed. We were pushing the state of the art of technology; we were writing peer-reviewed papers.

The things that were really valued were technical excellence and the research side. I had a new employee individual development plan, much like we do today. Each year I got reviewed to make sure I was moving forward. I think what was even more valuable than the plan was the fact that the personnel there took an unbelievable amount of time to help me learn.

COHEN: What came next in your career?

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

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

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

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

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

COHEN: This was before the Russian involvement?

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

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

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

COHEN: Was that a hard negotiation?

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

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

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

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

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

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

COHEN: For instance?

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

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

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

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

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

Also, dependence drives learning: I need you to do this component because

… WHEN YOU THINK ABOUT doing a project, WHERE YOU choose somebody TO BE IN THE CRITICAL PATH OR WHERE YOU'RE GOING TO be dependent upon them NEEDS TO BE A very strong STRATEGIC DECISION BECAUSE THAT WILL drive learning and technology.

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

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

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

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

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

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

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

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

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

NASA PAST AND FUTURE: A PERSONAL MEMOIR

BY KEN RANDLE

When I was working for the Sperry Corporation in the sixties, we submitted a proposal to the Jet Propulsion Laboratory (JPL) to provide support for their unmanned space exploration programs. Our proposal won and, in July 1966, I took a team of twenty-three engineers to JPL. I had two responsibilities: manage the team and provide the configuration design of spacecraft for the Future Projects Study team.

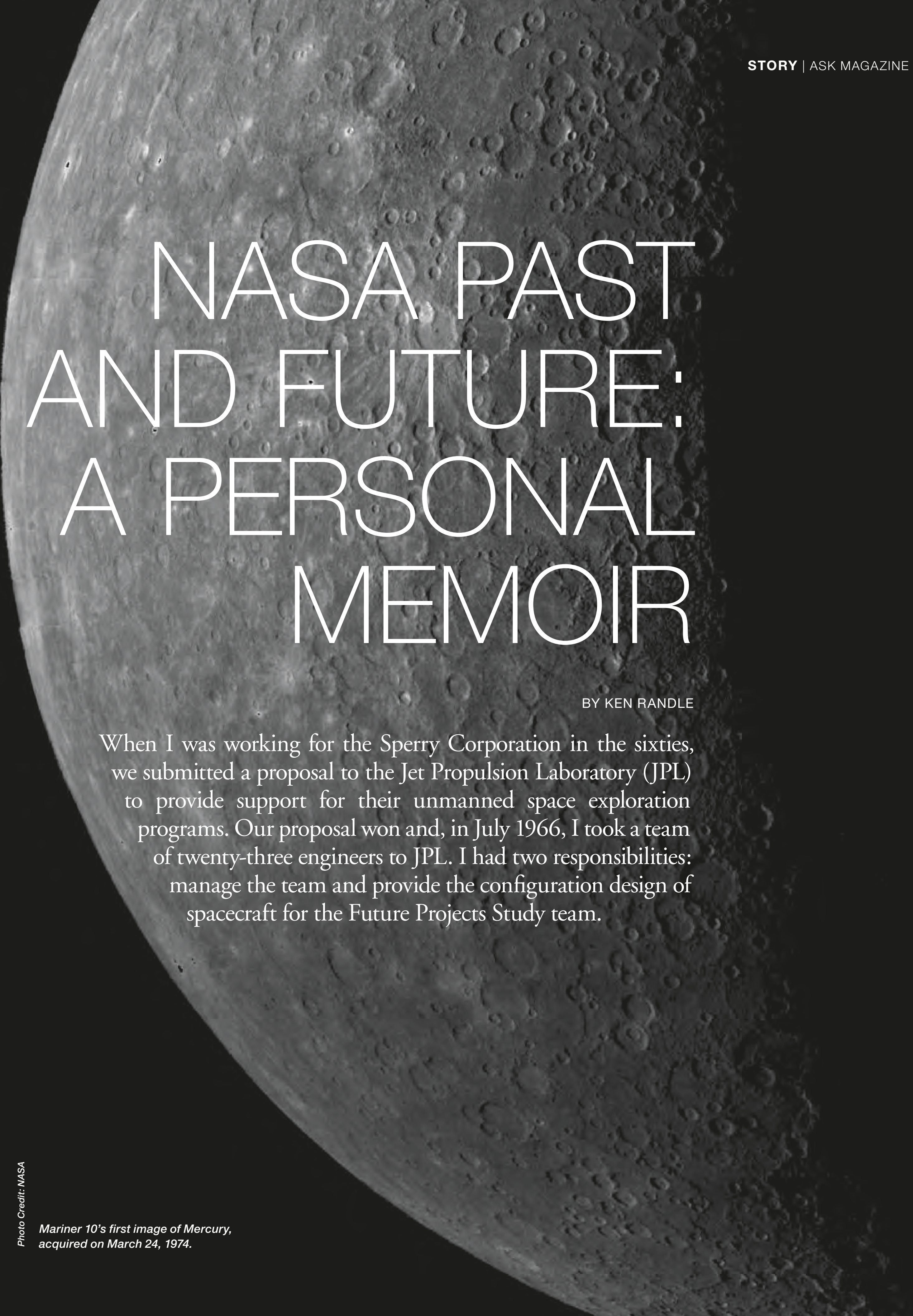


Photo Credit: NASA

Mariner 10's first image of Mercury, acquired on March 24, 1974.

Exploring the Solar System

The Future Projects Study team, under JPL's direction, performed four six-month feasibility studies for NASA's consideration. Two of them became successful missions—a pretty good record. The first study was for a mission to Venus with the release of a capsule to the surface before going on to a flyby of Mercury. This became the Mariner 10 mission, the first mission to use the gravity assist of one planet to reach another planet. This was before powerful computers were available, so the trajectory analysis was very laborious. I worked on the configuration design of the spacecraft, and this work became the basis of my master's thesis at the University of Utah. I had to coordinate the different disciplines of propulsion and science, figuring out where to place the instruments that would focus on Venus and Mercury, plus planning for backup equipment. NASA accepted the recommendations of the Future Projects Study team's feasibility study. Mariner 10 was launched on November 3, 1973, and crossed Mercury's orbit in March 1974. We didn't know a lot about Mercury then, but we learned fast.

Next, we did a feasibility study of a Venus lander. We enclosed a capsule in balsa wood and carried out a successful landing test in the Mojave Desert, but the Soviet Union launched the Venera 7 spacecraft on August 17, 1970, and landed a capsule on Venus on December 15, 1970, which transmitted data for twenty-three minutes. So NASA gave up on the idea of funding our proposal. The next six-month feasibility study for a project that didn't happen was a plan to send a solar-electric spacecraft to Jupiter. The challenge was to fold 1,500 square feet of solar panels and package the spacecraft into a Centaur nose cone. We made a one-tenth scale model of the solar-electric spacecraft, and a picture of the model made the cover of the June 1968 issue of *Aeronautics and Astronautics* magazine, published by the American Institute of Aeronautics and Astronautics (AIAA). It was a worthy project, but it wasn't funded.

The Future Projects Study team's next feasibility study was for a grand tour of the outer planets, an ambitious idea that became the Voyager mission. Back in the sixties, Gary Flandro, a JPL employee on the study team, discovered that the alignment of the outer planets would make it possible to use a gravity assist from Jupiter to go to Saturn and on to Uranus and Neptune. The launch had to take place between 1976 and 1979 to take advantage of an alignment that occurs only once every 175 years.

For this discovery, Flandro received an award from the British Interplanetary Society. The grand tour missions would require an entirely new kind of spacecraft, a design with capabilities far beyond those of the simple machines that had reached the moon, Venus, and Mars. At the time, Voyager was the most complex unmanned machine ever designed. There had to be a boom for the radioisotope thermoelectric generator, another boom for the magnetometer, a planetary astronomy plasma-wave antenna, high-gain antenna, location for a plasma detector, cosmic-ray detector, low-energy-charged-particle detector, infrared interferometer spectrometer and radiometer, and cameras. Voyager would have to survive the intense radiation at Jupiter and operate almost flawlessly for more than a decade. The new spacecraft would need the decision-making capability to detect and react to a variety of internal problems, since command times from Earth would stretch to hours during the long flight. The reliability challenges were far greater than for any other spacecraft ever designed. We succeeded even better than we expected. In fact, the two Voyager spacecraft are still transmitting data from the outer edge of the solar system today, more than three decades after launch.

Space Exploration Day

To help recognize and celebrate these and other space exploration achievements, for the past thirty-five years I have been working with J. David Baxter, president of the Utah Space Association, to promote Space Exploration Day (July 20) and U.S. Space Observance Week (July 16–24), which coincide with the dates of the historic liftoff, landing, and return of Apollo 11 in 1969. Baxter conceived the idea of a celebration on the anniversary of the Apollo 11 mission while he was a junior at East High School in Salt Lake City. In 1972, Flandro and I served as advisors to help Baxter form the Utah Space Association.

Senator Frank E. (Ted) Moss of Utah introduced the Senate Joint Resolution in Congress in 1976. The Space Exploration Day Resolution passed in the Senate as an annual observation, but it was amended in the House of Representatives to apply for only one year. For my efforts in pushing for recognition of the first landing of men on the moon by Apollo 11 and other AIAA activities, I was given the Distinguished Service Award by AIAA in January 1977.

In 1984, Senator E. J. (Jake) Garn of Utah introduced a Senate Joint Resolution for Space Exploration Day to celebrate

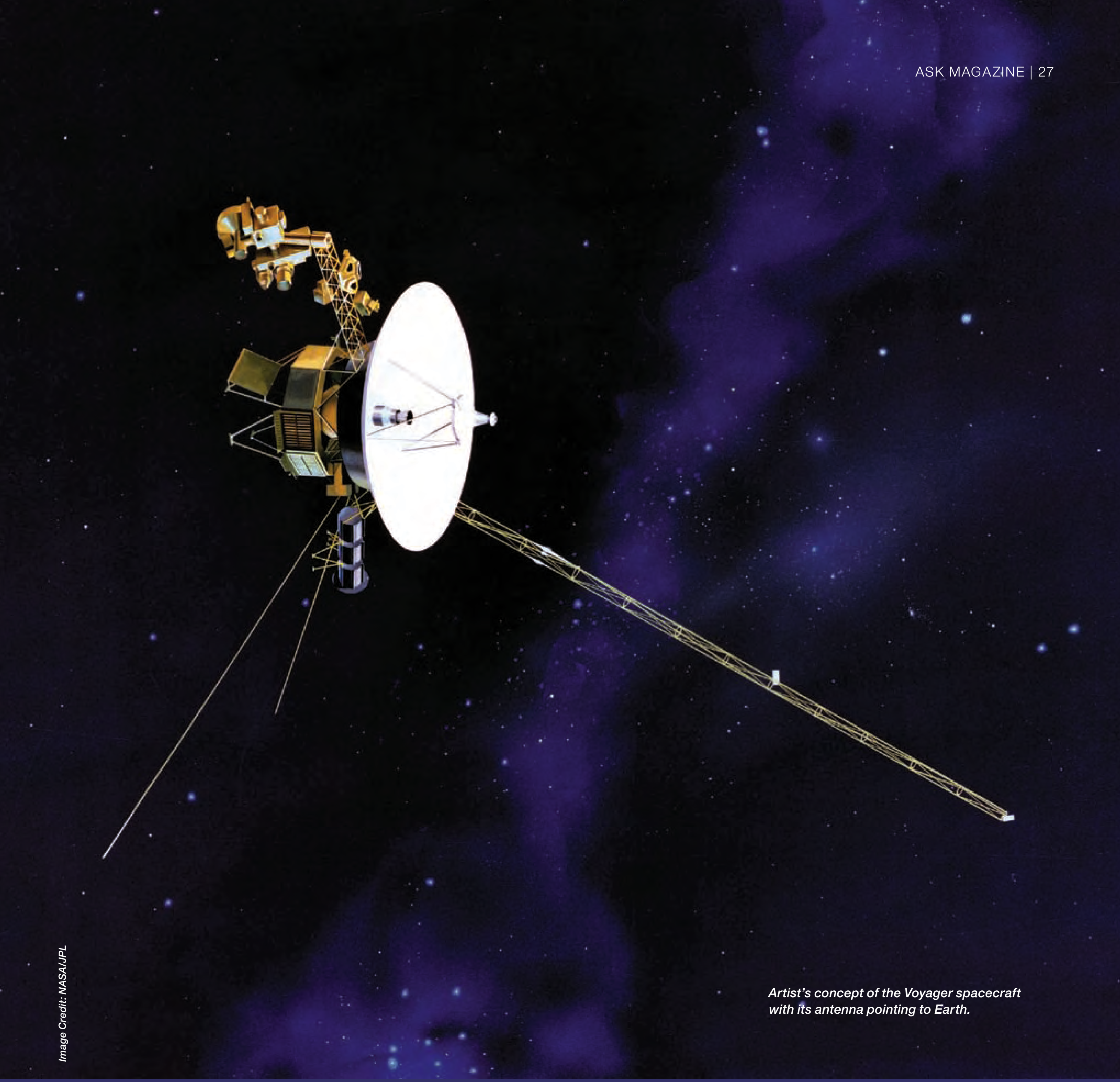


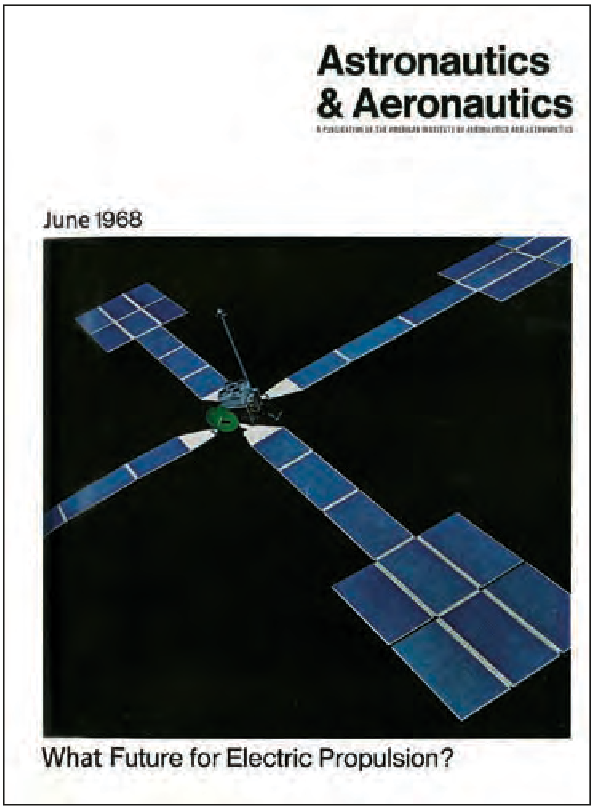
Image Credit: NASA/JPL

Artist's concept of the Voyager spacecraft with its antenna pointing to Earth.

THE GRAND TOUR MISSIONS WOULD REQUIRE AN ENTIRELY NEW KIND OF SPACECRAFT, A DESIGN WITH CAPABILITIES FAR BEYOND THOSE OF THE SIMPLE MACHINES THAT HAD REACHED THE MOON, VENUS, AND MARS. AT THE TIME, VOYAGER WAS THE MOST COMPLEX UNMANNED MACHINE EVER DESIGNED.

the fifteenth anniversary of Apollo 11 landing on the moon. It passed both the Senate and House of Representatives unanimously. President Reagan invited all the Apollo astronauts for a reception at the White House. I also received an invitation. It was an exciting opportunity to meet the Apollo 11 astronauts as well as many others. After the reception, we were invited into the East Room of the White House, where President Reagan sat down and signed the Space Exploration Day Proclamation, which I had helped get through Congress. It wasn't easy, as we had to get the majority of the Senate and the House as co-sponsors. The Apollo 11 astronauts and James Beggs (then NASA Administrator) stood behind President Reagan as he signed the proclamation. Then, President Reagan gave a talk on the importance of space commercialization. From 1981 through 1989, I had gotten proclamations or Statements of Support from all fifty governors plus Puerto Rico as a result of many phone calls and letters. Presidential proclamations were obtained starting with President Nixon on the fifth anniversary of Apollo 11 through President Clinton. The power to declare holidays and commemorations now lies with the president. Our goal is for a presidential order that will permanently establish Space Exploration Day as a nonpaid commemorative holiday.

My related efforts over the years have included taking four high school students (including Baxter) to the Apollo 17 launch—the first Apollo night launch. On September 14, 1971, as program chair of the Utah section of AIAA, I organized a dinner meeting to host the Apollo 15 astronauts, their wives, and Dr. James Fletcher (then NASA Administrator). There were 786 people in attendance. In October of 1975, as chair of the Utah Engineers Council, I coordinated a gathering of Apollo and Soyuz astronauts, cosmonauts, and their wives at the Hotel Utah in Salt Lake City. My goal has been and is to increase public understanding of the value of human spaceflight and support for future exploration. The Apollo program was expensive, but it has been estimated that, for every dollar spent on the Apollo program, the nation has received nine dollars in benefits from new technologies. ●


Astronautics & Aeronautics

June 1968

What Future for Electric Propulsion?

Image Credit: American Institute of Aeronautics and Astronautics

June 1968 cover of Aeronautics and Astronautics *magazine showing a one-tenth-scale model of a solar-electric spacecraft that was never funded.*

KEN RANDLE graduated from the University of Michigan with a BS in aeronautical engineering, after which he worked at Douglas Aircraft and then the Sperry Corporation. He spent his first year at the Jet Propulsion Laboratory (JPL) working on the airframe design of the Sergeant Missile System and later helped create a proposal to support JPL's unmanned space programs. Later, he was the engineering manager of the Shrike Missile System and held various engineering management positions until he retired in December 1986.

THE NEXT BIG THING IS SMALL

BY HALEY STEPHENSON

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

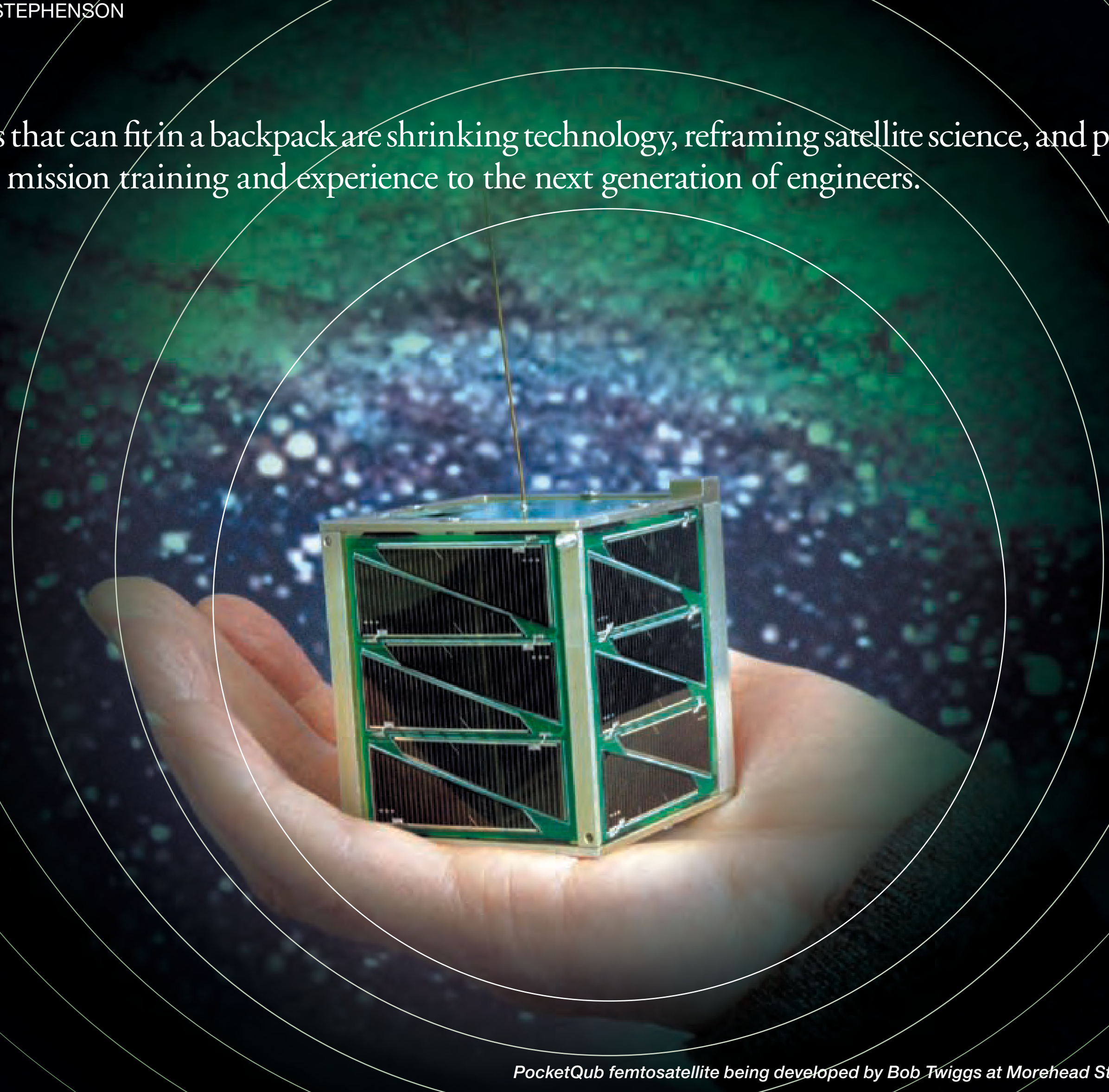


Photo Courtesy Bob Twiggs

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

Chris Beasley, NASA Ames mechanical engineer, places the PRESat payload into a gold press vessel.

Photo Credit: NASA Ames Research Center/Matt Piccini

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

CubeSat, Meet NASA

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

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

Twiggs's group at Stanford started developing a satellite bus—the subsystems that support the satellite—to house the picosatellite payload while Puig-Suari's group at CalPoly went about developing a deployment mechanism called the Poly Picosatellite Orbital Deployer (P-POD). The result was CubeSat, a 10 cm^3 picosatellite weighing 1 kg. Three fully autonomous CubeSats can be configured together to form a nanosat no larger than a loaf of bread. (Nanosatellites are those that are less than 10 kg.)

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

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

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

Nanosats: Not Toys

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

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

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

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

Puig-Suari said that the biggest constraint in the field is mind-set, not resources. "People are trying to shrink a big spacecraft," he said, "but if you do it that way, it's not going to work." He believes the way people think about the capabilities of nanosats is shifting. "People will initially say, 'I cannot put my component on that box because my component was designed for a big spacecraft,'" explained Puig-Suari, "but now we're starting to have people say, 'Okay, what can I put inside that box?'"

Early versions of nanosatellites included Bio NanoSat and GeneBox, which carried a variety of organisms and molecules such as genes, bacteria, and yeast cells. These nanosatellites paved the way for the development of NASA's first deployable, autonomous nanosatellite, GeneSat. "We started to miniaturize something that we already thought was impossibly small into

GeneSat 1 payload assembly with Chris Beasley in GeneSat Test and Integration Lab N 240.

Photo Credit: NASA

WITH THEIR LOW COST, RISK, AND VISIBILITY, SMALL SATELLITES CAN OFFER AN EXCELLENT TRAINING OPPORTUNITY FOR HANDS-ON LEARNING.

something even smaller," said Hines. GeneSat launched in December 2006, taking nanosatellite experiments to a new level of visibility in the aerospace community.

Prepping Gen Y

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

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

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

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

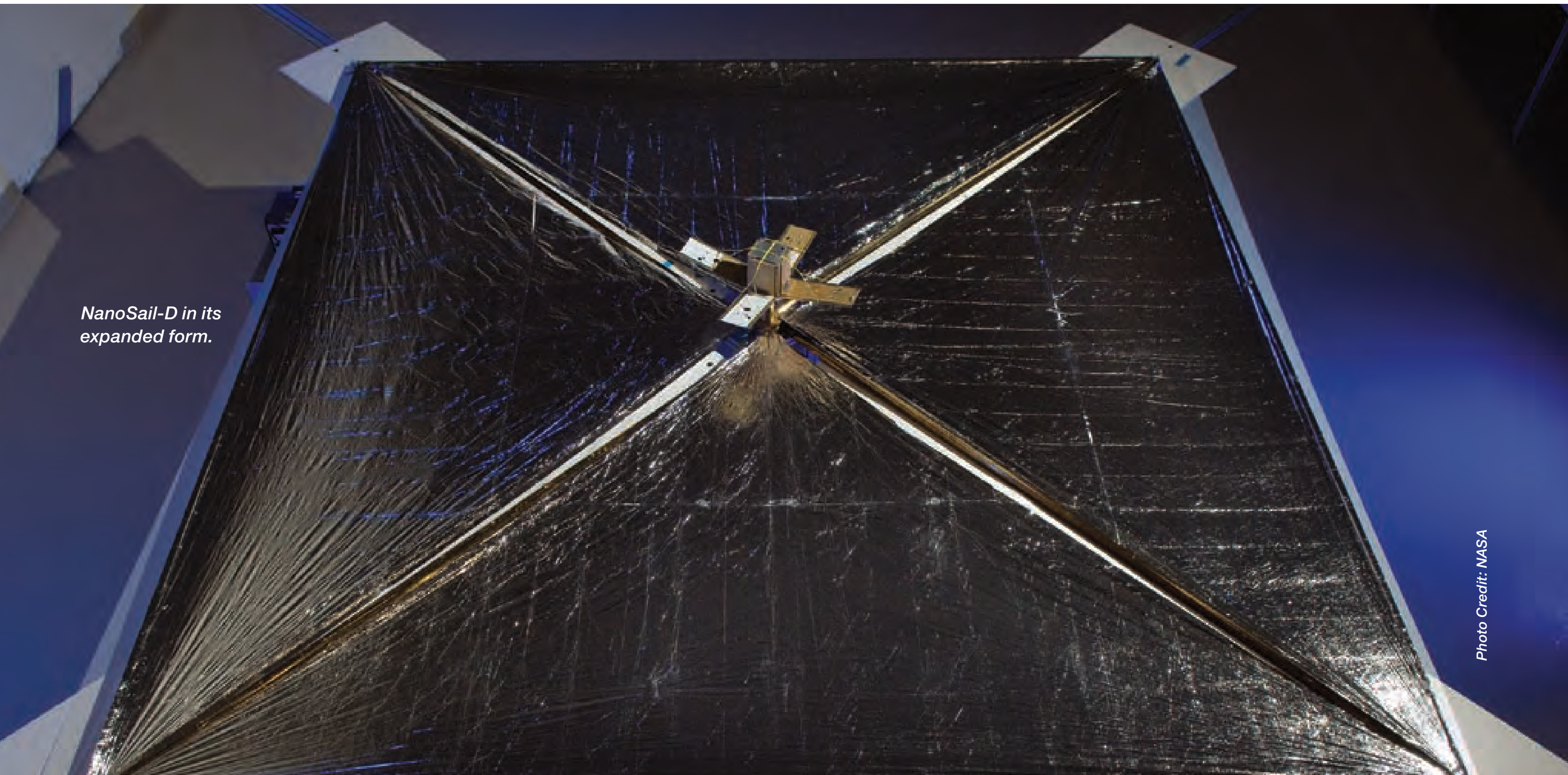
At the university level, Puig-Suari sees a noticeable change in how students approach their projects. "Interacting with industry really puts them in the right mind-set as far as the quality levels, level of seriousness, and documentation," he said. "You need to prove that it works, write it up, and show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

Learning from NanoSats

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

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

"We were able to look at different launch-integration capabilities, different launch sites, different launch operations, different mission and range considerations, as well as [gain experience in] deploying a spacecraft and payload to a very, very remote launch site," said Hines. The remote location of the SpaceX Falcon launch site tested NASA's ability to react to a launch delay. The launch vehicle was grounded long enough for the specimen to expire and forced NASA to replace the living specimen inside PRESat. "We got a big operational logistics effort under our belt with that as well," Hines said.



NanoSail-D in its expanded form.

Photo Credit: NASA

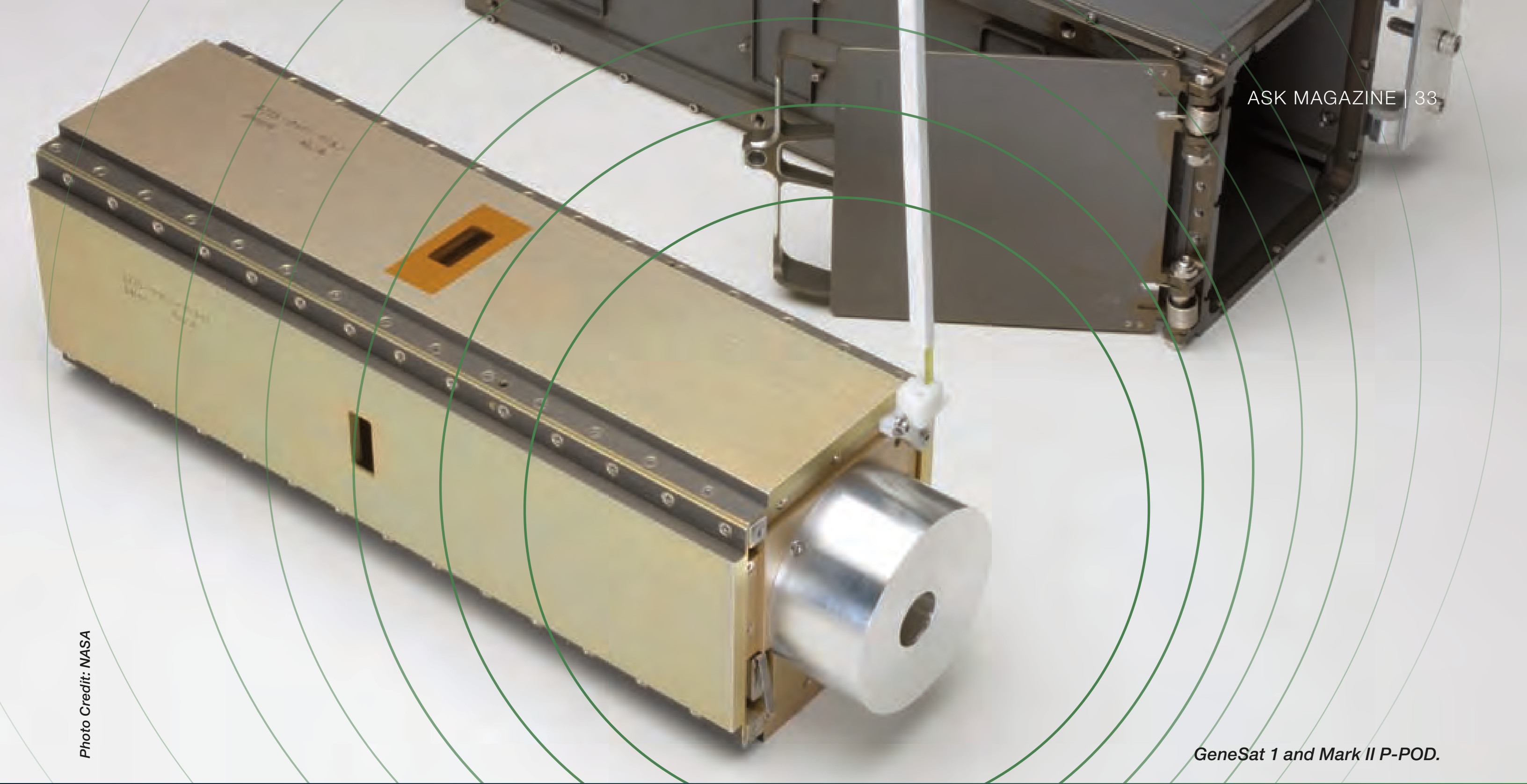


Photo Credit: NASA

GeneSat 1 and Mark II P-POD.

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

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

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

Leveling the Playing Field

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

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

The Next Wave

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

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

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

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

CITIES AT NIGHT: AN ORBITAL PERSPECTIVE

BY DONALD PETTIT

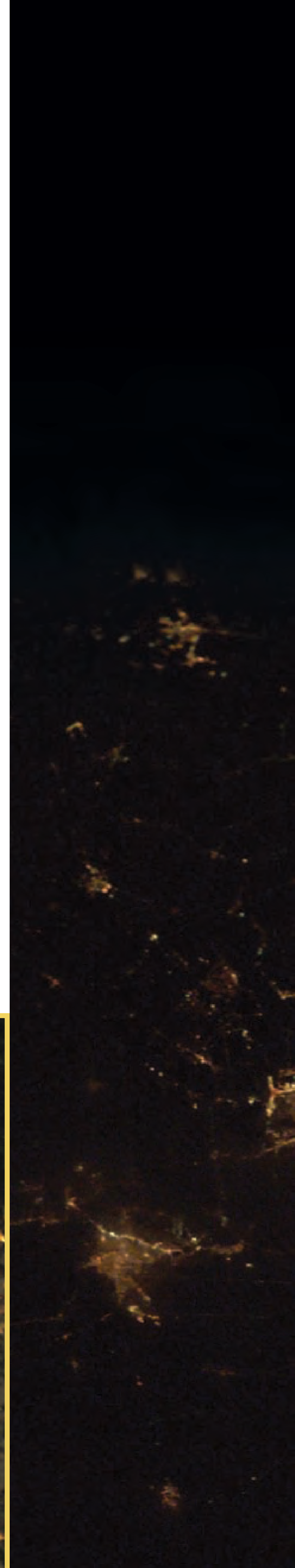
Cities at night, when viewed from orbit, offer a spectacular display. Although this light is a form of pollution that masks our earthly views of starry nights, from orbit it is an amazing display that radiates something about who we are into space. As crewmembers on the International Space Station, we now have the opportunity to observe and study these patterns of light and record what they have to tell us in ways that satellites currently cannot. The patterns that surface when viewed from orbit show the intersection among geography, technology, and culture and are worthy of recording for scientific study as well as for their beauty. Perhaps what we learn can even help us minimize these displays and once again give us back our starry nights.

Typical western U.S. cities, Las Vegas (left) and Los Angeles, are defined by yellow-orange sodium vapor–lit streets in grids. Airport runways stand out as dark lines where, surprisingly, it is better to land an airplane on a dark runway than a well-lit one. At the edge of town, the lights abruptly fade into the surrounding desert. The "Strip" in Las Vegas is probably the brightest spot on Earth.

From orbit, the unaided eye sees incredible detail when looking at cities at night. But capturing clear images of cities at night on film has eluded the best efforts of astronauts for years. Details on Earth scoot by at an amazing speed of 4.4 miles per second due to orbital motion. Getting a daytime picture is hard enough. And to obtain truly sharp images, even during the daytime, the camera must be panned to cancel out orbital motion while using the fastest possible shutter speed. During an exposure of 1/1000th of a second, 7 meters of Earth motion occurs; the resulting image will be less than optimum without this compensating motion.

Obtaining good images of cities at night requires exposures as long as one or two seconds, which, with uncompensated orbital motion, would show city lights as streaks. Obtaining reasonable images requires one to float over the window and slowly pan the camera while looking through the viewfinder to cancel out orbital motion, while to the best of one's ability, holding the camera still in all other axes. Any jitters during this process result in a blurry image. Not surprisingly, images of cities at night have been disappointing to those who have taken them since they know that they are only a blurry approximation of what is actually seen.

Living in a space laboratory for six months, you have the time to think about such problems and look for solutions. So during my off-duty time, I built an orbital tracking system from spare parts found in various nooks on the space station. In one stowage area, I found the old and now unused IMAX camera mount (used to film the IMAX movie *Space Station*) and used it as a framework for my tracking system. We no longer had either film or an IMAX camera on station, so no one minded my pressing this mount into a different kind of service. The mount's precision gimbal motions could be used to eliminate the effects of orbital motion only if a precise and smooth method of panning could be improvised. I mounted a long, threaded bolt on the IMAX platform so that it pushed against a plate and smoothly moved the platform in one direction when it was rotated. This direction of motion was then aligned with that of orbital motion so the mount would pan and cancel out the effects of orbital motion, at least long enough for a few exposures. A variable-speed drill driver was used to rotate the bolt; the rotation speed, and hence pan rate, could be varied by how far the drill drive's trigger was pulled. I then attached two cameras to the mount, one with a long telephoto lens to act as a spotting scope and one with a medium-focal-length lens to take the photograph. Orbital



Two images of Montreal, Canada, taken from the International Space Station. The best handheld image is shown on the left, and on the right is an image taken with the improvised barn-door tracker. Once this technique of operating the barn-door tracker was refined, astronauts used it to take images all over Earth. The resolution of ground objects in these new images is about 60 meters, and the current database of cities at night is now at about eight thousand, gathered by many crews.

Chicago (left) and Tel Aviv with Jerusalem in Israel (facing page, bottom). A grid of north–south, east–west streets typifies U.S. cities, whereas Europe and the Middle East show a tangled pattern of lighting.

São Paulo, Brazil (facing page, top left), a major urban area, shows blue-green (mercury-vapor lighting) in the older original town center and yellow-orange (sodium vapor) in its newly growing borders.

Tokyo (facing page, top right) typifies the blue-green lighting of Japan's major cities. The dark spot in the center of town is the Emperor's Palace; Narita Airport terminal is the bright spot to the east.

motion was canceled by first looking through the spotting-scope camera and varying the rate of bolt rotation by squeezing the trigger until the image of the city below stood stationary on the camera's focusing screen. Then I took an image with the second camera using a cable release.

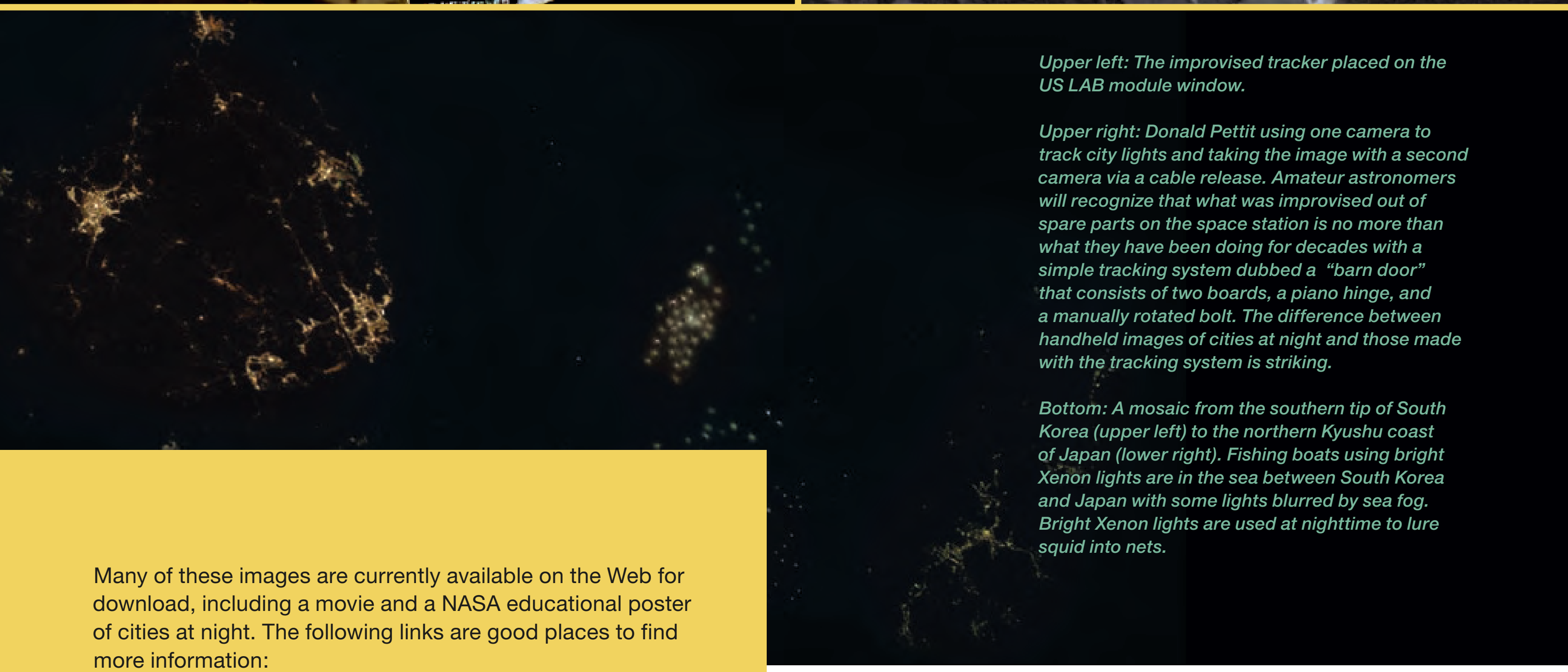
We are in the process of merging these astronaut-taken images of cities at night with the popular nighttime Earth images from the Defense Meteorological Satellite Program (DMSP). The DMSP images have near-world coverage but at a much lower resolution (about 3 kilometers in black and white) than the astronaut images now coming from the space station. A joint NOAA–NASA satellite under development will be optimized to take full-color, high-resolution images of nighttime Earth and eventually render this initial astronaut effort obsolete. Such is often the course with exploring a frontier. The special eye of humans pioneers the initial phase of discovery followed by the development of highly specialized machines that result in a more complete and better set of collected data.

The richness of how humanity sprinkles lights across the nightscape is striking from orbit. Colored patterns, caught in a triangle between technology, geography, and culture, radiate into space something about who we are. If the lights are mercury vapor, the cities will appear blue-green, while sodium vapor will yield yellow-orange. Some cities are dark with bright main arteries while others illuminate the whole urban area to an extent that matches the "yellow zone" printed on an atlas. After living in space for a while, one can quickly tell what part of the world one is over simply from the patterns of city lights. While considered a form of light pollution and a display that can and should be minimized, their orbital appearance is spectacular. Cities at night may very well be one of the most beautiful unintentional consequences of civilization.

Antwerp, Belgium (bottom), with Brussels at the bottom edge and Milan, Italy (top). Spider-web networks of streets typify the older European cities.

El Paso, Texas (facing page, left), bordering Juarez, Mexico. El Paso appears with a grid of illuminated streets with relatively dark areas in between. Juarez displays scattered light in an area defining the city limits, matching the urban area "yellow zone" printed on an atlas.

The square of the District of Columbia (facing page, right) is clearly defined with an east–west dark line identifying the National Mall with the Capitol seen as a bright spot on the east end and the Lincoln Memorial on the west. Center is the Washington Monument, and the Jefferson Memorial is seen as a spot of light on the south side of the bay.



Upper left: The improvised tracker placed on the US LAB module window.

Upper right: Donald Pettit using one camera to track city lights and taking the image with a second camera via a cable release. Amateur astronomers will recognize that what was improvised out of spare parts on the space station is no more than what they have been doing for decades with a simple tracking system dubbed a "barn door" that consists of two boards, a piano hinge, and a manually rotated bolt. The difference between handheld images of cities at night and those made with the tracking system is striking.

Bottom: A mosaic from the southern tip of South Korea (upper left) to the northern Kyushu coast of Japan (lower right). Fishing boats using bright Xenon lights are in the sea between South Korea and Japan with some lights blurred by sea fog. Bright Xenon lights are used at nighttime to lure squid into nets.

Many of these images are currently available on the Web for download, including a movie and a NASA educational poster of cities at night. The following links are good places to find more information:

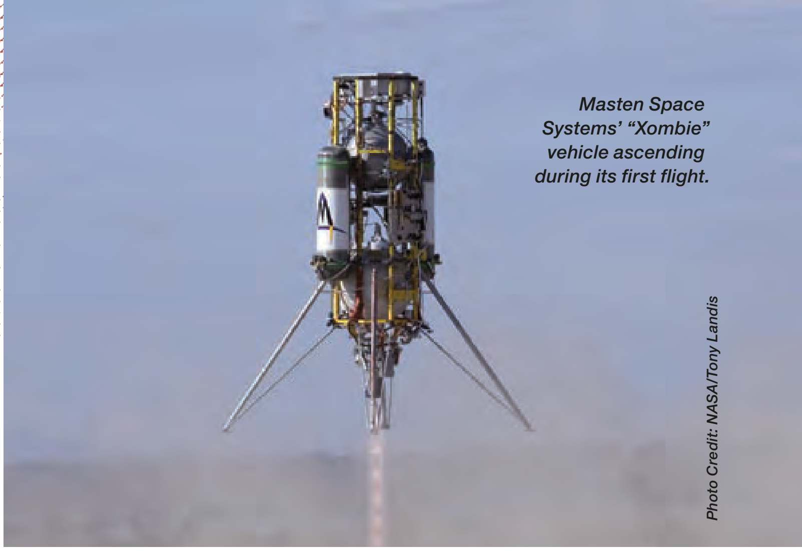
- earthobservatory.nasa.gov/Features/CitiesAtNight/page1.php
- earthobservatory.nasa.gov/IOTD/view.php?id=870
- www.airspacemag.com/space-exploration/Cities_at_Night_An_Astronauts_View.html
- www.youtube.com/watch?v=eEiy4zepuVE
- hsfa.jsc.nasa.gov/MISSIONPOSTERS/misc/Cities%20at%20Night%20%20Front%20Final%20graphics%203-4-09.jpg
- sfa.jsc.nasa.gov/MISSIONPOSTERS/misc/Cities%20at%20Night%20Poster%20Back%20Final%203-4-09.jpg

DONALD PETTIT has logged more than 176 days in space and over 13 extravehicular activity hours. He lived aboard the International Space Station for five and a half months in 2002–2003 and, in 2008, was a member of the STS-126 crew.

OPEN-DOOR INNOVATION

BY ANDREW PETRO

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



Masten Space Systems' "Xombie" vehicle ascending during its first flight.

Photo Credit: NASA/Tony Landis

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

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

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

Defining the Challenges

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

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

In the 2009 Power Beaming Challenge, creating the competition venue was as much of a technical challenge as the competition itself. The contest requirement was to drive a robot climber up a vertical cable using only power transmitted from the ground. In previous years of the competition, a cable was suspended from a crane, but that became impractical when the target height rose from 100 meters to 1,000 meters. The solution was to connect a cable from the ground to a helicopter 1,300 meters overhead, something that had never been done before. After several unsuccessful tests, a scheme was found for safely maintaining cable tension, and the result was a stable vertical racetrack into the sky. In the end, LaserMotive, a team from Seattle, Washington, drove their climber to the top at a speed of almost 4 meters per second.

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

Innovation from Anywhere

The winners of the challenges show that innovation comes from diverse and sometimes unexpected sources. The first Astronaut Glove Challenge was won by Peter Homer, who developed his

The team from Worcester Polytechnic Institute stands with their excavator Moonraker, which won them $500,000 in the Regolith Excavation Challenge.

Photo Credit: California Space Authority/Jamie Foster design working alone at his dining room table in Maine. Homer conducted dozens of failed experiments that helped him arrive at the winning design. After winning the prize he formed his own company to manufacture pressure-suit gloves and related products. Another competitor in that challenge, Ted Southern, is a costume designer from New York who partnered with a former rival and won the second-place prize in the latest astronaut glove competition.

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

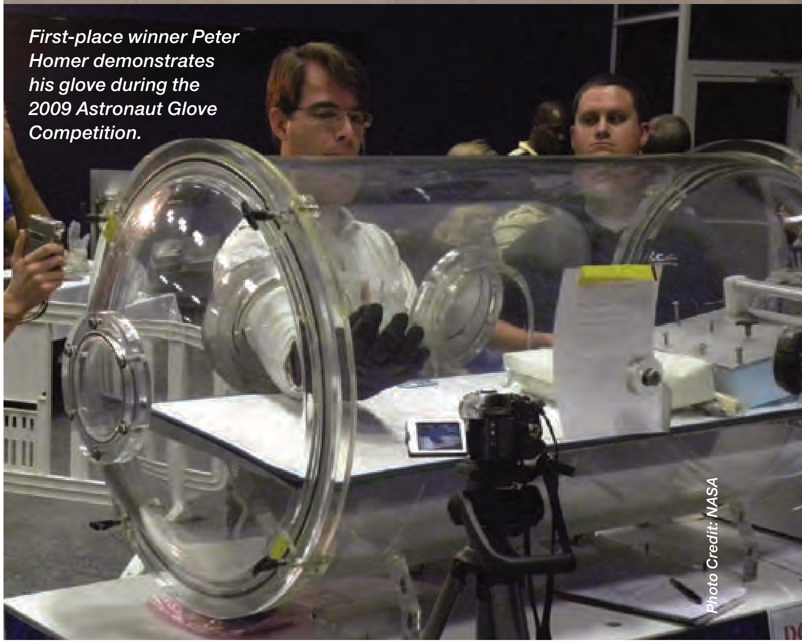
Many prize competitors are existing small businesses; these small companies find that the prize competitions allow them to focus their efforts and provide them with visibility and credibility not easily attained in fields that are often dominated by large corporations. That was the outcome for Armadillo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

The Citizen-Inventor

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

The LaserMotive team prepares their climber prior to launching on their prize-winning climb.

Photo Credit: NASA



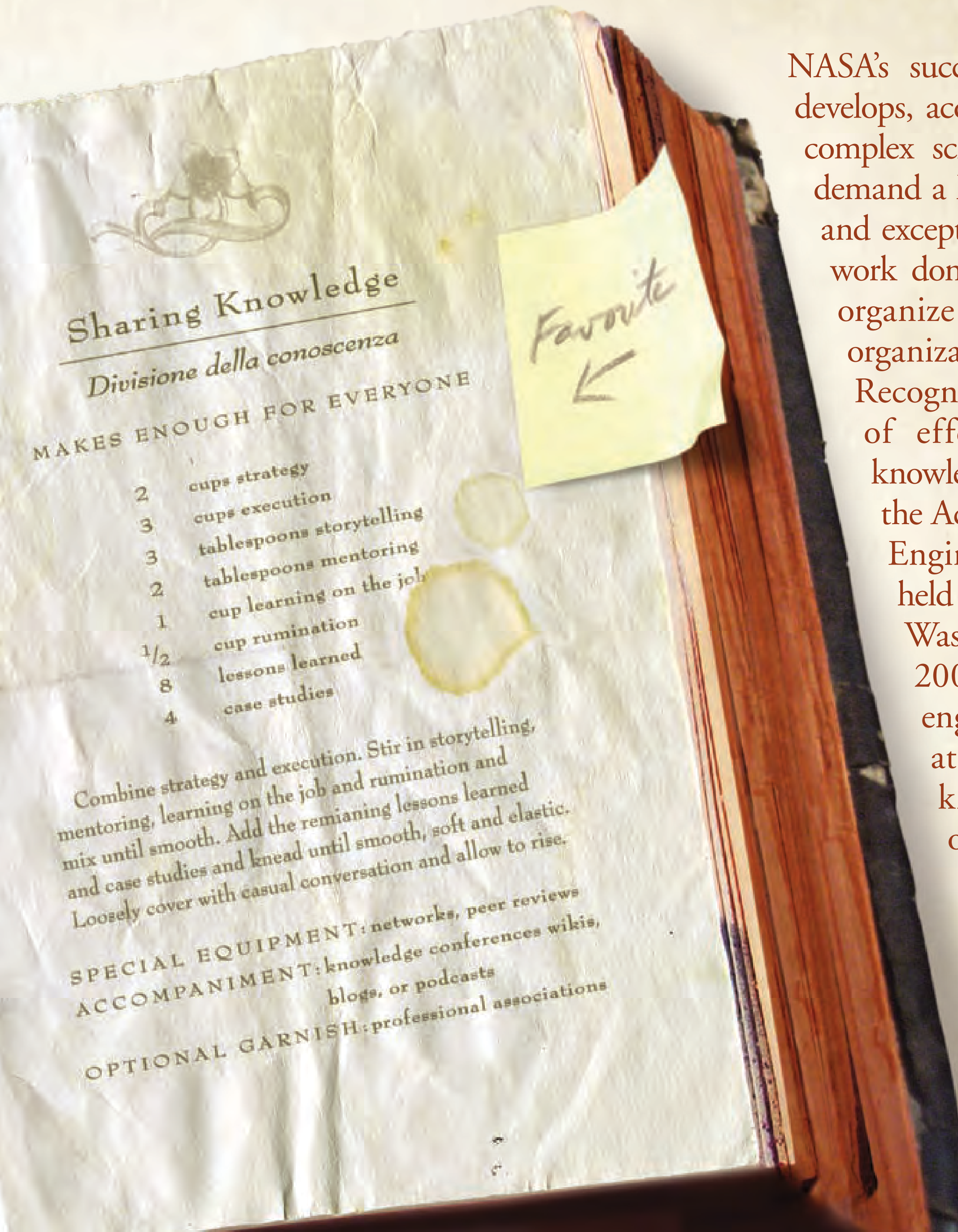
First-place winner Peter Homer demonstrates his glove during the 2009 Astronaut Glove Competition.

Photo Credit: NASA

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

Sharing Knowledge About Knowledge

BY DON COHEN AND MATTHEW KOHUT



NASA's success depends on how well it develops, acquires, and uses knowledge. Its complex science and exploration projects demand a high level of technical expertise and exceptional knowledge of how to get work done—that is, how to direct and organize the efforts of the people and organizations that execute its projects. Recognizing the central importance of effective knowledge use and knowledge sharing across the agency, the Academy of Program/Project and Engineering Leadership (APPEL) held its first knowledge forum in Washington, D.C., on October 15, 2009, bringing together people engaged in knowledge work at several NASA centers and knowledge experts from other organizations including MITRE, the World Bank, Educational Testing Service (ETS), Fluor, the Department of Energy, Petrobras, and the International Centre for Complex Project Management.

The daylong discussion was organized around three panels that explored, respectively, knowledge strategy, knowledge effectiveness, and knowledge at NASA. Panelists' presentations were limited to fifteen minutes each to ensure time for knowledge-sharing conversations.

Knowledge Strategy: Doing the Right Thing

Northeastern University Professor Michael Zack, moderator of the first panel, defined knowledge strategy as "doing the right thing." In the early days of knowledge management, many organizations tried to make as much knowledge as possible available to as many people as possible, but that kind of broad approach rarely, if ever, produced the hoped-for benefits. A knowledge strategy identifies the particular areas of knowledge needed to help the organization reach specific goals and sometimes defines new goals that the organization's knowledge makes achievable. (Zack used the Polaroid Corporation as an example of a company that failed to capitalize on knowledge that could have led it in a new, profitable direction: the knowledge of the people at Polaroid who understood digital imaging was never put to use.) The SWOT strategic-planning method (analyzing strengths, weaknesses, opportunities, and threats) can be applied to organizational knowledge to determine the kinds of knowledge the organization should acquire, strengthen, share, and use.

T. J. Elliott of ETS reinforced the importance of what he called "knowledge intention"—having clear, convincing goals for knowledge efforts. Without a specific purpose, he said, online communities designed to share knowledge become "ghost towns."

Klaus Tilmes, advisor to the World Bank's Knowledge Strategy Group, agreed that the key question is "what knowledge do we need to achieve our goals?" One of the ways to answer the question, he suggested, was to look at levels of dissatisfaction among knowledge workers. The aspects of their work that thwarted or frustrated them were likely targets of efforts to make needed knowledge available. According to Tilmes, organizations need both good internal networks (to understand what knowledge resources exist) and external networks (to understand opportunities and threats) to be able to define valuable new goals. He cautioned, though, that gaining understanding is only half the battle. What leaders and decision makers listen to—and act on—is obviously critical, and they sometimes fail to heed important knowledge. It may be true that, in some circumstances, knowledge is power, but too often power trumps knowledge.

Knowledge Effectiveness: Doing Things Right

Moderating the second panel, Laurence Prusak, editor-in-chief of *ASK Magazine*, emphasized the complexity of knowledge, which, unlike data and information, cannot be readily packaged and shipped. Understanding that fact is critical to understanding how to create, exchange, and use knowledge effectively. The knowledge strategy discussion made clear the close connection between a sound knowledge strategy and knowledge effectiveness: having a clear, productive purpose is one of the essential elements of an effective knowledge program. People share and seek knowledge only when they see the value of doing so. Even with a clear knowledge strategy in place, however, other factors influence the effectiveness of knowledge work.

Jean Tatalias, director of Knowledge Services at MITRE, talked about the key role "connectedness" plays in successful knowledge work. The powerful, often informal social connections among people in organizations are an essential mechanism for knowledge exchange. The trust, understanding, and mutual goodwill that characterize these relationships make the sharing of expertise possible. MITRE supports various kinds of connectedness. An information-technology system that includes documents and contact information about experts increases the "findability" of knowledge. Frequent technical-exchange meetings and collaboration on projects foster knowledge sharing and strengthen personal networks.

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Tatalias also mentioned the relationship between organizational culture and knowledge effectiveness. She believes that MITRE's mission-oriented, not-for-profit culture encourages people to share what they know and seek the knowledge they need.

To carry out its large engineering and construction projects, Fluor works to share knowledge across projects as well as within large, often geographically dispersed project teams. John McQuary, vice president of the Technologies and Strategies Organization at Fluor, described the company's investment in communities of practice and other knowledge endeavors to ensure that the knowledge of some 3,500 subject-matter experts in 1,000 areas is preserved and made available when and where it is needed. The company's leadership actively supports the communities and their Web sites with resources and public recognition of outstanding contributions to knowledge sharing. McQuary says that Fluor also "puts people side by side for a number of years" to ensure the transfer of expertise. A subject-matter-expert protégé program has a similar goal. Typically, the protégés are not immediate successors in a given role, but younger employees who will carry the expertise into the future.

Alexandre Korowajczuk, corporate knowledge manager for Petrobras, described how the Brazilian oil company uses storytelling to communicate the organization's values to its flood of new hires. The storytelling sessions that bring together veterans and newcomers convey some "how-to" knowledge about oil exploration and drilling, but their most important content is emotional, expressing the commitment and determination of Petrobras employees. Like MITRE (and NASA), knowledge sharing at Petrobras benefits from a sense of mission, in this case an awareness of the importance of the company to Brazil's economic, social, and environmental well-being. (See "Petrobras and the Power of Stories," p. 54.)

Knowledge at NASA

Don Cohen, managing editor of *ASK Magazine*, moderated a panel of practitioners engaged in knowledge work at NASA. He noted that no large organization is one thing—it has different kinds of characteristics in different places—and asked if NASA's centers can be expected to foster knowledge development and sharing in the same ways despite differences in culture, organization, and technical expertise.

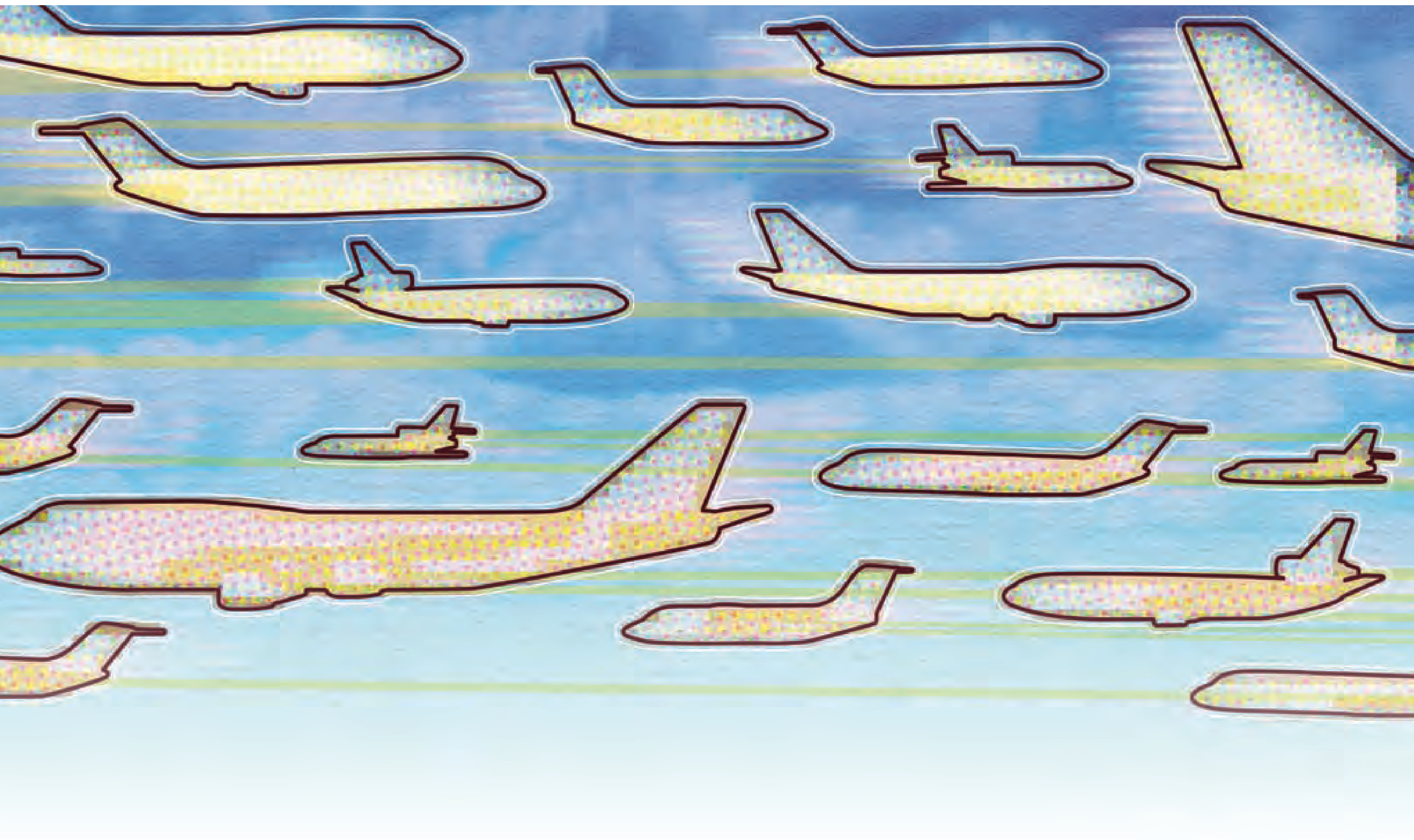
Manson Yew, manager of the NASA Engineering Network (NEN), discussed efforts to build online communities of practice for engineering discipline areas that connect engineers across the agency who would not necessarily work together. The NEN focuses on twenty-five key engineering disciplines with the goal of connecting engineers to sources of both explicit and tacit knowledge across the agency.

Dave Lengyel, risk and knowledge management officer for the NASA Exploration Systems Mission Directorate, said that technology is not the problem with knowledge sharing. Like MITRE's Tatalias and Fluor's McQuary, he believes the key is building a community. He discussed the DART (Demonstration of Autonomous Rendezvous Technology) mission as a NASA case study of a knowledge and communication failure.

APPEL Director Ed Hoffman noted that APPEL addresses the question of how to develop competence, particularly in the absence of certainty. He pointed out that performance happens at the team level in a project-based organization like NASA, and said that organizational sustainability was a large focus of APPEL's knowledge-sharing effort since project teams often don't have the time or resources to connect with one another. Given the unique nature of NASA's missions, knowledge sharing is also a means of preserving the agency's legacy. ●

NextGen: Preparing for More Crowded Skies

BY KERRY ELLIS



There's one word travelers never want to hear when checking in for their flights: delayed. "Delayed" can cause frequent flyers to clench their suitcase handles that much tighter, because it can lead to the even more treacherous "canceled." Air travel delays are common these days, but we might have it better than we realize. The Federal Aviation Administration (FAA) has forecast that airspace operations could triple in the next two decades. If delays are bad now, how much worse will they be in 2025? Maybe not at all, if NASA succeeds in helping the Interagency Joint Planning Development Office (JPDO) prepare for the Next Generation (NextGen) Air Transportation System.

After the JPDO defined more than one hundred research objectives that would help handle increased airspace operations, NASA's Aeronautics Research Mission Directorate identified areas where the agency's expertise and facilities could contribute. NASA is working alongside the FAA, Department of Transportation, Department of Defense, Department of Homeland Security, Department of Commerce, the White House Office of Science and Technology Policy, and the Office of the Director of National Intelligence to prepare the airspace transportation system for the anticipated future demands.

One of the research activities NASA is heading is the NextGen Concepts and Technology Development (previously known as NextGen Airspace), which is looking into how, when, and to what extent automation can be applied to moving aircraft within the national airspace. Currently, the system relies on manual monitoring, with air traffic controllers on the ground analyzing displays and directing pilots to make flight-path adjustments through radio systems. According to NASA's NextGen Plan, human controllers' cognitive ability limits their capability to handle more than about fifteen aircraft. Ames Research Center and Langley Research Center are working together and with industry and university researchers to develop, test, and demonstrate techniques and technologies that will introduce some automation to areas such as trajectory prediction, traffic flow management, and separation assurance in an effort to increase this capacity as well as reduce the time it takes to safely move aircraft through the system.

Managing a research effort this large and long-running comes with unique challenges. Setting milestones, determining and reducing risks, and tracking progress entail different approaches than NASA projects that have a predetermined launch window or require building a physical piece of hardware that can be handed off after completion.

Managing Research

Instead of a launch project's satellite or rover, NASA research projects may deliver an algorithm, a user interface or display, or software. Even thinking in terms of an "end product" can be deceptive, as a resulting bit of software can always be changed or updated. "No researcher ever thinks their work is done. Period," said Harry Swenson, who was the principal investigator for NextGen until 2008.

"That causes its own problems when trying to obtain progress reports on milestones," explained Mike Landis, who was the project manager for NextGen until his retirement in January 2010.

"You put out milestones and markers and ask someone to report, and they say, 'I'm not done yet,'" Swenson said. "What you're reporting on in research is progress. But researchers think if they report on it, it's done, and it isn't done. I've learned from project management principles that sometimes good enough is good enough. And that's a continuous challenge in project management of research and development activities," he added. It takes convincing to assure those conducting the research that delivering a status report does not mean what they're working on is finished.

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Managing the cost for research projects can also present challenges. Ensuring that people are available in time for testing new displays, for example, can pose a risk to the timeline that then impacts the budget. Instead of worrying about pieces of hardware fitting together and operating correctly—an inflexible requirement—project managers of research efforts have more

flexibility in moving resources around to avoid risk, and the ultimate result can be different from the original plan.

"If we see that our hypothesis is not going to give us the data that we need, and the simulation proves that our hypothesis, in fact, was not correct, that's just part of the process," explained Landis. "That doesn't mean that we failed; it means that we just need to look at a different way of creating a display, or a different procedure that is less labor intensive for a flight crew or an air traffic controller. With the research work that we're doing, we have more flexibility in our milestone schedule, among other things," he said.

"There are risks and trades you have to make, but there aren't as many hard schedule items," added Swenson. "A lot of the work you're doing is breaking down the barriers of knowledge in a continuous fashion."

The human interaction element is more dynamic in research, as the way data is input or displayed is determined by how well people can understand and use the resulting interface. Introducing more automation into air traffic management does not eliminate human flight controllers from the system, so ensuring that people can successfully use and adapt to new displays and ways of inputting data is crucial.

"What's the best way to ensure that you capture input from the users who are going to use a particular display in air traffic control? They have to understand what the objective is of a particular display that they're going to see on their console, or a procedure that they are going to use in concert with the procedure that a flight crew is going to use," said Landis.

While research goals can be more flexible, milestones are still set and worked toward. For example, if a research goal is to improve the merging and spacing of aircraft during final approach to an airport, one milestone might be to perform final-approach simulations with active pilots and controllers in 2011. But to achieve that milestone, the scenarios for the simulation need to be developed well ahead of time. Part of the project manager's role is ensuring the scenario development work begins early enough, which could be years in advance.

There's still a risk that trained pilots and controllers will be unavailable on planned testing days. "They may not be available," explained Landis, "so we may need to use retired controllers, and that reduces the level of fidelity and reliability because the retired controller may not have managed or done air traffic controlling for four or five years." Risk mitigation, in this case, could include slipping the milestone a few months until FAA controllers are available, or reducing the technology requirement level of that milestone because the input won't be from an active controller.

"There's just more flexibility in this type of research than, say, NASA needing a satellite that will orbit Mars for two years and then release a probe that will land on the Martian surface and collect a sample and analyze it, then through telemetry send data back up to the orbiting satellite, which in turn will then send the data down to the station at Johnson Space Center, or Goddard," said Landis. "For that, you've got very rigid specs that you have to follow. You've got a very structured and rigid schedule. Fortunately, we don't have to worry about that."

For all their complexity, NASA flight projects at least have the clear goal of producing hardware for a specific purpose. Research projects are more amorphous. And a research project like NextGen must continually adapt to essential elements not under its control, like changes in flight-controller display hardware and the work schedules of active FAA flight controllers needed to test equipment.

Sharing What's Learned

With efforts such as NextGen taking five, ten, or fifteen years, constant communication among everyone involved—including repeatedly defending a proof of concept to stakeholders—is crucial. According to Landis, "Real estate agents talk about location, location, location. From a project manager's perspective, it's communicate, communicate, communicate. It's not just sending an e-mail out, it's sitting down with the line management and researchers, understanding their requirements, and ensuring they have the resources they need to execute our plan." Because the researchers are not collocated, communication includes daily phone calls, face-to-face meetings weekly and sometimes daily, and annual technical-interchange meetings.

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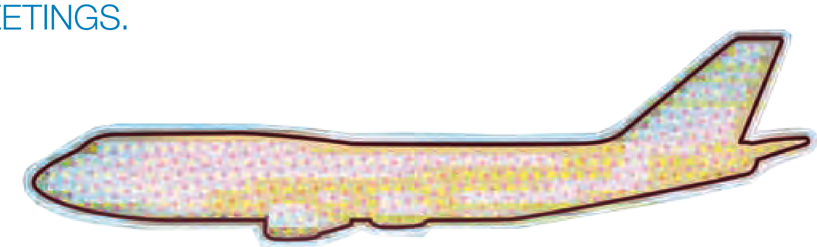


"At our most recent technical-interchange meeting, we had roughly 250 people in attendance and about eighty research papers presented on around twenty themes," said Landis.

The research and understanding gained by these efforts doesn't end at an internal meeting.

NASA has a responsibility, determined by the Space Act of 1958, to disseminate information about its activities and any associated results. The NextGen project takes this to heart, publishing research papers, technical reports, and peer-reviewed journal articles. Researchers from the project also present what they've learned at forums, such as those hosted by the American Institute of Aeronautics and Astronautics.

"Knowledge dissemination is one of our number-one requirements," said Landis. "The past three years, we've published more than one hundred research papers on average annually, and we publish a CD with those reports at the end of each year." The project is also in the process of creating a Web site to make the reports more readily available to the public.

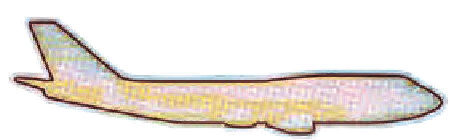
With so much information about NASA research available, it might be tough to imagine how any of it makes the transition from pure research to something that's deployed on a national level. "The hard part, as a researcher or scientist," said Swenson, "is going from trying to figure out principles to helping develop a product. It's a big transition. Your basic mathematical ideas have now turned into software, that software turns into an interface, and it takes in data. You assume one thing of the data, and it changes, so you have to redesign, implement, and deploy while adding other 'ilities': maintainability, survivability; the functions that make it easy to maintain long after the researcher has left."

Flexibility and adaptability are among those functions, allowing different stakeholders to implement the same research in different ways. The possibilities of what NASA's research can do for the future of aeronautics seem nearly endless because one piece of research can be adapted to several different environments. It's up to the stakeholders to determine how they'd like to use and implement it, or change it to fit their needs.

"We work with our stakeholders and we show them these great things, and they say, can I have two?" said Swenson. "That's often a challenge for those of us who are in research. Communicating that our real product is the generation of knowledge and reducing technological risks through research results and technical papers is key so major system developers can actually implement these concepts, ideas, algorithms, software, or technology in the real system. But still the pressure is there that unless it is actually operating in the air traffic control system or on a fleet of commercial aircraft that you are not successful."

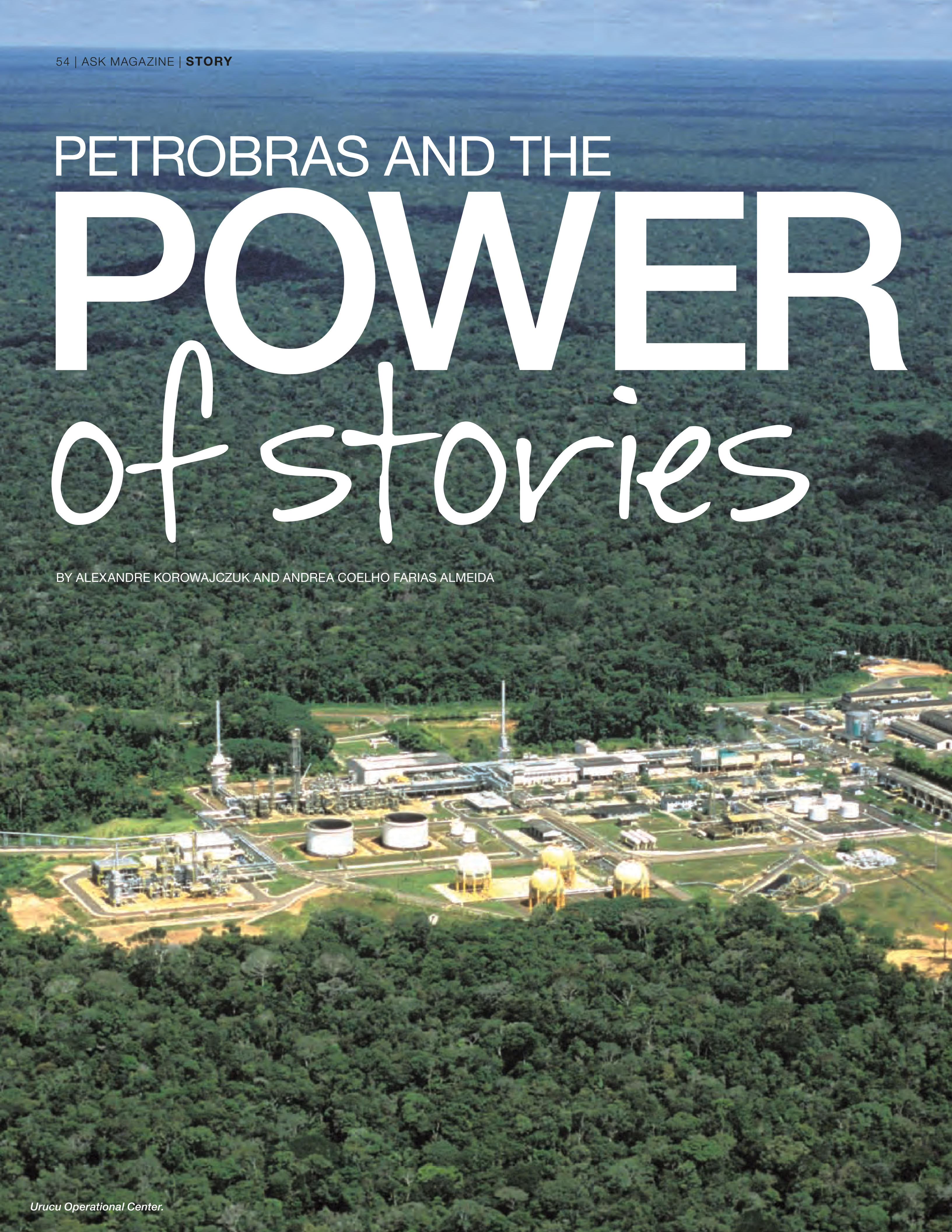
NASA has been very successful in its research, and the agency has helped implement its research into stakeholders' systems. It takes time to transition from a well-tested idea to a fully deployable product, which is why the NextGen project is already under way. To be ready to contribute to the NextGen Air Transportation System in 2025, a lot needs to be accomplished now so the ideas can evolve and be embodied in technology and practice.

"This work is something that just about anyone can relate to. Anyone that's ever gotten on a flight from Dulles to San Francisco, or flown out on vacation or work, you've probably experienced flight delays," said Landis. "You can relate to what we're doing and the problems that we're trying to solve. And it's very human-focused because you've got air traffic controllers that safely manage aircraft, you've got flight crews that safely fly aircraft, you've got people and cargo flying on these airplanes, and just about anyone can relate to what we are doing. Obviously it's a challenge, but it's very rewarding work." ●



PETROBRAS AND THE POWER of stories

BY ALEXANDRE KOROWAJCZUK AND ANDREA COELHO FARIAS ALMEIDA



Urucu Operational Center.

Photo courtesy Petrobras

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

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

The objective of this robot is to collect environmental information from a wide range of complex Amazon regions, technology developed by the Petrobras robotics laboratory (CENPES).

Photo courtesy Petrobras

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

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

Petrobras

Petrobras is a Brazilian integrated-energy company operating in more than twenty-seven countries. It has a tradition of overcoming project challenges. Its project environments have become more technically complex, from exploring and producing oil and gas onshore and in shallow waters, to deep water (2,000 meters) and now ultra-deep water (7,000 meters), with the pre-salt layer discoveries. These high-risk projects demand innovative solutions using leading-edge technology. The projects have to consider not only the proximal environment but also the social impact on communities—those near the production facilities and those along the pipeline infrastructure. All this complexity demands project team excellence at a time when we face the imminent retirement of our most experienced staff and the recruitment of about 25,000 new employees. In addition, our strategic plan foresees doubling our oil and gas production capacity and a major investment in alternative energy, such as biofuels, over the next ten years.

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

The Hidden Objective of Lessons Learned

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

During an oil refinery major-revamp project, some unpredicted events affected the cost and project schedule. To identify the causes, a lessons-learned workshop was organized with the main project participants, most of whom had coincidently worked on its original construction twenty years earlier. The knowledge management manager related to this project asked why no new employees had been invited and was told none of them had participated in

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the project and they had no practical experience. But he insisted and two new employees were invited, on the condition they would be only spectators. After several meetings over the course of two weeks, the main conclusions about the causes of the cost and schedule problems were presented at the final meeting. Because the reasons were already known in some way by the experts, they felt the workshop had been a waste of their time.

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

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

Building the "Petrobras Challenges" Program

In 2003, the "Memories of Petrobras" project was launched as part of Petrobras's fiftieth anniversary celebration. The objective was to recover company history from the employees' point of view, hearing their career stories and stories of their families and the communities that interacted with the company. This project gave voice to the "other side of the story"—not just the company's view. This project helped veteran employees recover the memory of their work experience and gave new employees a sense of the real-life challenges of project work and a better understanding of company culture. "Memories of Petrobras" helped shape what became the "Petrobras Challenges" program to use storytelling to communicate essential knowledge to new employees.

We initially defined three aims for this new program:

1. Develop a systemic vision of the studied project to focus on events that presented important moments of reflection and changes to solve problems.

2. Use interaction among employees who worked on the project and employees who are studying the project.
3. Prepare new project managers for decision making in complex environments.

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

To record and disseminate knowledge about an important project, we developed this methodology:

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

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

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

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

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

The Power of Stories

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

Right from the start, our objective was to contribute to the decision-making quality of Petrobras leadership in an environment marked by profound changes, including the increasing

importance of sustainability. The thought that we could contribute to a more effective decision-making process, enabling our leaders to anticipate new business needs, preparing Petrobras for the future, affected me strongly.

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

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

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

ASK Reader Response

In the fall 2009 issue of ASK, *Ed Hoffman wrote that the excessive optimism or pessimism of project teams can obscure the realities they need to understand to carry out their projects successfully. David T. Hulett, of Hulett & Associates, offers this reflection on Hoffman's remarks.*

I am a project risk analyst/manager with experience analyzing the cost and schedule risk of large, complex projects in many industries. My associates and I have been assigned to do the risk analysis in support of the solid rocket booster for the Ares launch vehicle and support Constellation risk analysis by NASA's Independent Program Assessment Office. Perhaps my experience in these engagements and other industries (oil and gas, construction) can help put the issues you raise in a positive context.

I often see what you describe. Project teams may develop a plan early on with incomplete information; then that plan becomes engraved in stone. Alternatively, the team is given parameters by management that force the team to come up with a plan they do not believe in. At some point, a risk analysis may reveal the plan's flaws.

What can be done when an honest analysis predicts an overrun of months or years over the (unrealistic) baseline schedule if the project continues its plan and cost, related to schedule, is also driven up?

Project managers react to this "bad news" in several ways, some productive and some not:

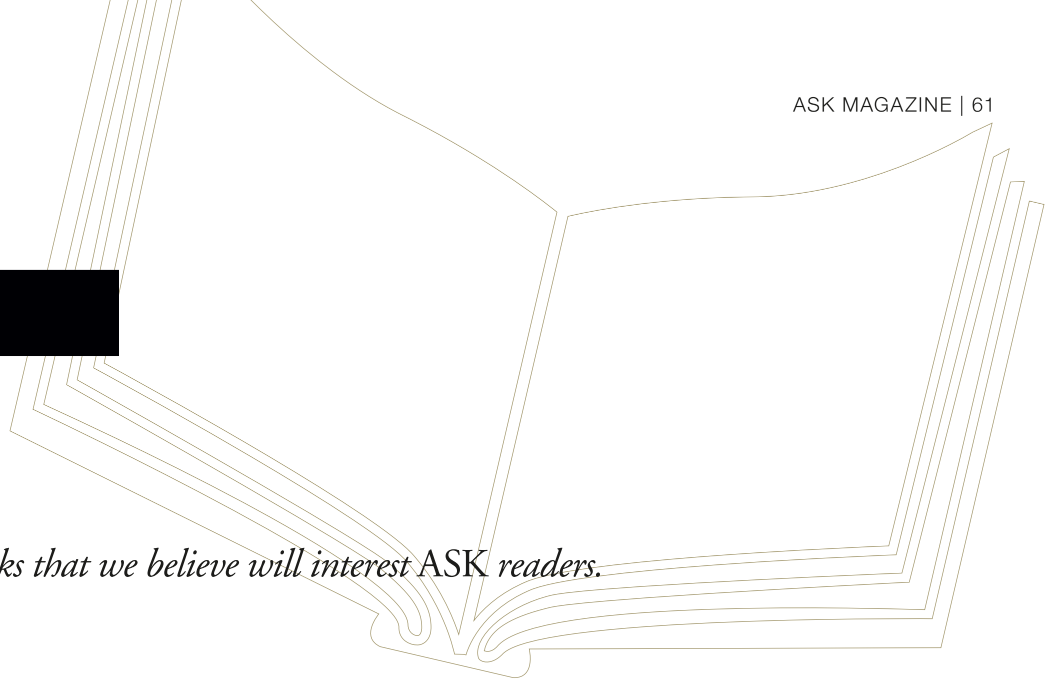
- The results must be incorrect. We cannot possibly be that far off our target schedule. We will thank the analyst but toss the report into the trash and stick to our plan.
- The results may be correct, but we cannot do anything about it. The plan has been accepted and any deviation will not be welcomed by management. We should inform management of the new targets from the risk analysis and work to those.
- The results are correct and show two things: how much we will be late and overbudget if we continue on our current path, and which risks are most responsible for driving us off our target. The project team should use the results as a tool and conduct risk-mitigation exercises, improving the project plan by attacking the high-priority risks first.

This last is the most mature and productive approach, but I have certainly experienced all three.

Mitigating schedule risk often costs money, and NASA management needs to be willing to trade off these two important objectives. Fully mitigating risk is usually not possible, but I have seen projects bring a predicted twelve-month slip back to a two- to three-month slip when schedule risk-mitigation actions are approved and implemented. This schedule saving may actually reduce contingency costs that were driven up by the initial schedule slip.

Pessimism about the current plan may be quite realistic, but the best, most mature response is to address the sources of that pessimism head-on in a constructive way. Project teams that embrace risk mitigation as the response to a realistic assessment of the project risk, rather than succumb to pessimism or unrealistic optimism, will have more success in their projects. ●

We welcome your comments on what you've read in this issue of *ASK* and your suggestions for articles you would like to see in future issues. Have a brief comment, a long letter, or your own project experience you'd like to share? Send it to us at ASKmagazine@asrcms.com. We look forward to hearing from you.



ASK Bookshelf

Here are descriptions of two books that we believe will interest ASK *readers.*

How NASA Builds Teams: Mission Critical Soft Skills for Scientists, Engineers, and Project Teams, by Charles J. Pellerin (Hoboken, NJ: Wiley, 2009)

Since 2003, roughly two thousand NASA personnel and contractors have used the NASA Academy for Program/Project and Engineering Leadership's team-building support services. In *How NASA Builds Teams: Mission Critical Soft Skills for Scientists, Engineers, and Project Teams,* Charles Pellerin details the method he and his colleagues have developed for helping to improve the effectiveness of teams at NASA.

The heart of *How NASA Builds Teams* deals with assessing and understanding healthy and unhealthy team contexts. Pellerin begins with the story of his tenure as director of astrophysics at NASA at the time of the Hubble Space Telescope launch. He recounts the pain of discovering shortly after launch that the telescope had a spherical aberration, and his astonishment at learning that the technical problem had a basis in the organizational cultures of NASA and its contractor. "It took me several years to realize that I was as culpable as the technician who spaced the null corrector incorrectly," he writes. "I was in charge of NASA Astrophysics during the period when P-E [the contractor] withheld measurements that suggested we had a mirror problem. I was a full party to creating Hubble's flawed social context."

This communication breakdown led to what Pellerin calls a "red storyline"—the sum of the negative thoughts and expressions that team members shared. Healthy, or "green," storylines are a sum of mostly positive shared views. Although storylines seem true to the participants, he cautions that they should not be mistaken for truths because they are not indisputable.

The key to improving a negative context, he writes, is cultivating eight behaviors that healthy teams practice: expressing authentic appreciation, addressing shared interests, appropriately including others, keeping your agreements, expressing reality-based optimism and being 100 percent committed, resisting blaming and complaining, and clarifying roles and responsibilities. The transformations necessary to cultivate these behaviors do not take place overnight, and they typically require skilled facilitation through a combination of team workshops and individual coaching and mentoring.

This methodology relies on short, individual assessments online to determine the extent to which these behaviors are present. A picture of the team's health emerges from the composite of individual assessments. After workshops or coaching, follow-up assessments measure progress on the eight behaviors.

The good news for people who find themselves operating on project teams with red storylines is that they can overcome negative contexts with effort and commitment. "You have several options to change your culture," Pellerin writes.

Games at Work: How to Recognize and Reduce Office Politics, by Mauricio Goldstein and Philip Read (San Francisco: Jossey-Bass, 2009)

Goldstein and Read analyze the all-too-common games that undermine the morale and effectiveness of organizations. "Gotcha" (identifying and communicating other people's mistakes), "Marginalize" (exiling people who don't "fit"), and "No Bad News" (suppressing negative information) are among the interpersonal games they consider. They also describe games played by leaders, including "Kill the Messenger" (blaming the person who brings you bad news) and "Token Involvement" (pretending to consult with people after you've made up your mind).

The authors know how hard it is to stop game playing once it becomes part of an organizational culture, but they offer solid advice on how to try. Recognizing which game is being played is key. That makes it possible to short-circuit the game by calling attention to it or choosing not to play the expected "role."

Anyone who has spent time in organizations will be familiar with some of these games. *Games at Work* is a helpful guide to countering their destructive power. ●

The Knowledge Notebook

On Not Going It Alone: No Organization Is an Island

BY LAURENCE PRUSAK

One of my father's heroes—and he didn't have many—was Albert Einstein. He often regaled me with stories of the great physicist. He especially liked to dwell on how Einstein, working in solitude in Zurich, wrote five equations that revolutionized physics as it was then understood. Now, much of what he described is true. One of the words he used is less than accurate, though, and that word is "solitude." When I got older, I was also intrigued by Einstein and read a few biographies written after his death. It turns out that he didn't really work alone. He knew the work of most of the leading physicists in Central and Western Europe and was in communication with many of them. When you think about it, this is not the least bit surprising. Einstein was both sociable and highly ambitious, and he loved talking about the latest theories. And, no matter how brilliant and revolutionary he was, his ideas were part of an ongoing, shared process of wrestling with problems in physics.

What is surprising is the persistence of the myth of the solitary genius—the isolated individual who, entirely by his own efforts, comes up with something new and remarkable that transforms the world. It may be an attractive, heroic-sounding story, but it generally is not the case in real life. All geniuses know what their predecessors have done and what their contemporaries are doing; the most successful of them are consummate networkers, talkers, sharers, and correspondents. No genius is an island! Even Isaac Newton, Einstein's predecessor in discovering important truths about how the universe works, was connected with the ideas and thinkers of his time, though he was far less sociable and socially skilled than Einstein.

I have no idea why so many of us still seem to believe in the myth of purely individual brilliance and accomplishment. It clearly has deep cultural roots in western stories of mavericks, pioneers, and lonely heroes. The myth has far less potency, for example, in Asia. In the West, it seems to defy any attempt to eradicate it with facts and historical examples. The myth underlies (and is reinforced by) the adoration we give to executives of large corporations and sports superstars. It makes some of us swallow the absurd idea of the "self-made man," which suggests that there are people whose success owes nothing to parents, teachers, colleagues, and the whole social infrastructure of health, education, and public safety.

Acceptance of this myth is a danger to organizations of all kinds. In our very complex, interrelated, and volatile world, any firm, agency, or non-governmental organization that consciously or unconsciously acts on the belief that an individual or organization can "go it alone" is sure to fail. Like the geniuses of science, they need to learn from and collaborate with the outside world, because no single entity can know everything that needs to be known to accomplish work or deal with the challenges and surprises of the world it operates in.

There is a term in cybernetics known as "requisite variety"—the idea that a complex system can only sustain itself if its internal variety is equal to that of the environment it operates in. What is true of cybernetics is also true of organizations. Organizations cannot achieve that variety on their own. They need to develop processes for working with potential allies outside their own systems and official channels. Equally important, they need to promote the idea that connecting and collaborating are *the* way to work—that no one is an island. Smart organizations like Procter and Gamble (P&G) are doing just that. P&G mandates that half its new products come from outside the firm itself. The consulting firm McKinsey, the World Bank, and Netflix, to name just a few, have all recently begun to organize their work so that they are much more open to ideas from outside their own borders. NASA has always collaborated with industry and other agencies, and now increasingly with governments of other spacefaring nations. The trend must continue.

For some, this increasing emphasis on collaboration is not a welcome trend. Myths of self-sufficiency die hard. Admitting that others have valuable knowledge we do not possess is not pleasant, and we have not seen the end of ideas rejected because they were "not invented here." Many of us still have to learn how to learn from others.

Yet there will be little cognitive or material progress without increasingly coordinated, interactive learning and collaborative work. To understand the rich complexity of today's knowledge environment and act effectively, we must reach out to whoever has ideas of value that we can use. We have no alternative but to do it—and do it soon. ●

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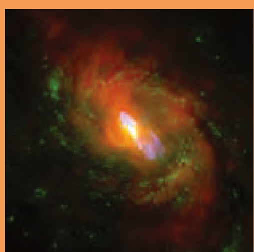

NASA in the News

New observations from NASA's Chandra X-ray Observatory provide evidence for powerful "winds" blowing away from the vicinity of a supermassive black hole in a nearby galaxy. This discovery indicates that "average" supermassive black holes may play an important role in the evolution of the galaxies in which they reside. It has long been suspected that material blown away from a black hole—as opposed to the material that falls into it—alters the evolution of its host galaxy. The X-ray images and spectra obtained using Chandra's High-Energy Transmission Grating Spectrometer showed that material is being driven away from the center of galaxy NGC 1068 at about a million miles per hour. Further studies of nearby galaxies will examine the impact of other active galactic nuclei winds, leading to improvements in our understanding of the evolution of both galaxies and black holes. More information, including images and other multimedia, can be found at chandra.harvard.edu.

Learning and Development

The European Space Agency (ESA) is an international organization of eighteen member states. By coordinating the financial and intellectual resources of its members, it undertakes programs and activities far beyond the scope of any single European country. To read about ESA's missions, view their gallery of spectacular space and Earth images, and track their satellites in real time, visit www.esa.int. Also check out their YouTube page at www.youtube.com/esa to watch astronauts answer questions and learn more about ESA's activities in space.

Web of Knowledge

How often can you say that you've seen the components of a space telescope being worked on at NASA? Web cameras in Goddard Space Flight Center's largest clean room are now providing daily, live coverage of work on components of the upcoming James Webb Space Telescope. They provide one image per minute so people can see what happens behind the scenes. Of course, the work happens during regular working hours, so there may not be action on screen all the time. To watch the "Webb cams," visit www.jwst.nasa.gov/webcam.html.

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