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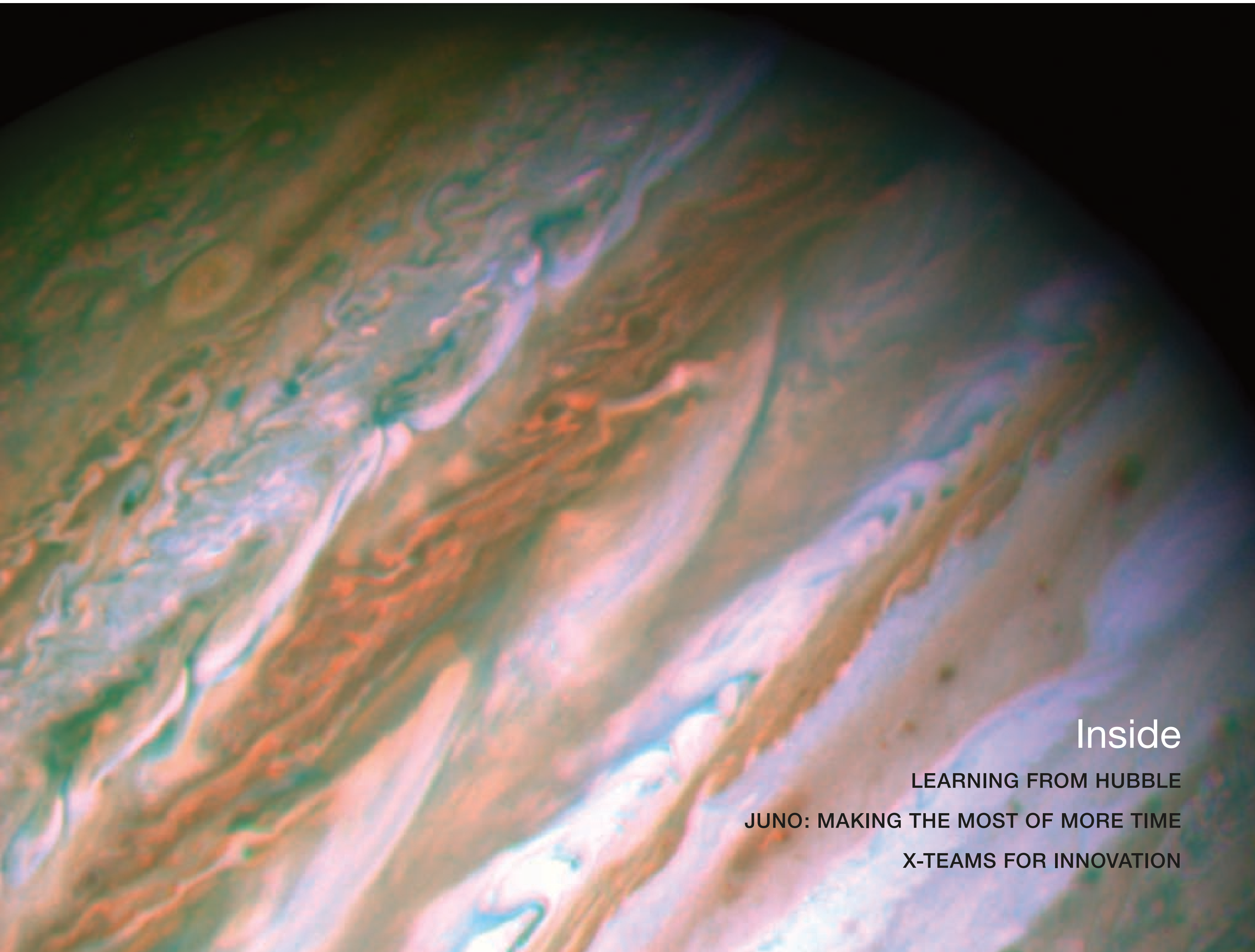

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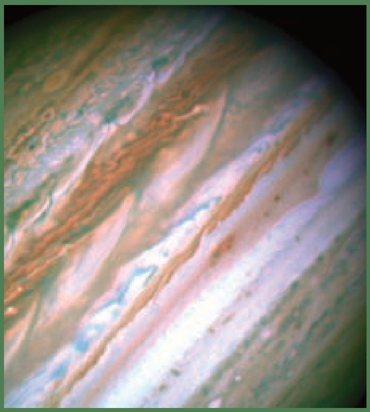

Photo Credit: NASA, ESA, IRTF, and A. Sánchez-Lavega and R. Hueso (Universidad del País Vasco, Spain)

ON THE COVER

This image of Jupiter in visible light from NASA's Hubble Space Telescope shows the turbulent pattern generated by the two plumes at the upper left part of Jupiter. To learn more about how and when Jupiter formed, the Juno spacecraft will reach the planet in 2016 and enter into a highly elliptical polar orbit that skims 5,000 km above the atmosphere. Juno will provide new information to help us understand more about Jupiter's formation, information scientists consider essential for understanding the origin of the solar system itself because Jupiter contains more mass than all the other planets combined.

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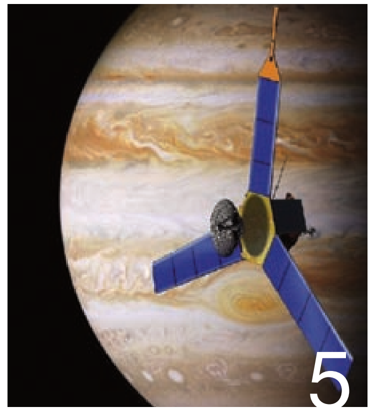

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INSIGHTS

STORIES

ask

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The Academy of Program/Project and Engineering Leadership (APPEL) and *ASK Magazinee* 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*.

You can help *ASK* provide the stories you need and want by letting our editors know what you think about what you read here and by sharing your own stories. To submit stories or ask questions about editorial policy, contact Don Cohen, Managing Editor, doncohen@rcn.com, 781-860-5270.

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In This Issue

At the Academy's Masters Forum in April, the word "risk" turned up in many presentations and discussions: how to anticipate and mitigate risks; how to learn from risks that turn into real problems; how much risk is acceptable in robotic and human space flight. Underlying all that attention was recognition that NASA's missions are inherently risky. Appropriately managing risk is one of project teams' core responsibilities.

Risk is a focus of this issue of *ASK*, too. In "Juno: Making the Most of More Time," Rick Grammier describes how his team has used an unusually long definition and planning phase to evaluate and address risks. Extensive prototyping and testing of instruments and comprehensive discussions between engineers and scientists should, Grammier thinks, reduce risks common in complex science missions.

The problem that nearly turned the Hubble telescope into worthless space junk—an improperly ground primary mirror—was so basic that no one saw it as a likely risk. Frank Cepollina's "Applying the Secrets of Hubble's Success to Constellation" looks at the design for in-orbit servicing that made it possible to rescue Hubble and says that designers of NASA's next generation of launch vehicles and spacecraft should follow Hubble's lead. One of the lessons of Hubble is that unanticipated problems are likely to occur. Counterfactual thinking, recommended by Gerstenmaier, Goodwin, and Keaton, can help predict some of them. Questioning assumptions and analyzing the effect of past decisions are among the techniques that can uncover hidden risks.

Because dealing with risk is central to mission success, Dave Lengyel at the Exploration Systems Mission Directorate has been linking risk management and knowledge sharing to ensure that lessons transferred from one project to another are the ones that really matter and that NASA's knowledge management efforts are not an example of what he calls "collect, store, and ignore." Charles Tucker's related articles ("Fusing Risk Management and Knowledge Management" and "Managing—and Learning from—a Lunar Reconnaissance Orbiter Risk") explain Lengyel's work.

Those articles bring up the other important theme of this issue: devoting your efforts to what really matters, or what we might call "mission pragmatism." Just as Lengyel's knowledge-based risk approach captures lessons that count, the knowledge harvesting process Nancy Dixon and Katrina Pugh describe includes careful determination of which projects will generate knowledge that justifies the effort and expense of identifying and communicating it. "Infusing Operability" shows how practical wisdom gained from Kennedy Space Center's long history of launches is contributing to new vehicle designs that will make ground operations more efficient and reliable. Ancona and Bresman's "X-Teams for Innovation" stresses the importance of project teams that know how to get the external knowledge and support they need to do their work. And articles about the Applied Physics Lab (by Svetlana Shkolyar) and the Applied Meteorology Unit (by Carol Anne Dunn and Francis Merceret) emphasize the importance of the word "applied." Both organizations develop technologies that respond to clear and critical user needs and directly contribute to mission success.

Finally, there is Tony Kim's story of an unmanned aerial vehicle science project ("To Stay or Go?"), which combines the themes of risk and pragmatism. When a range safety officer's aversion to risk makes flight permission unlikely, the team sensibly moves the project elsewhere.

Don Cohen
Managing Editor

From the APPEL Director

Of One Kind

BY ED HOFFMAN

The age of international projects has dawned. Project work is increasingly global. Determining where work happens and how the many, diverse, and widely distributed partners who make up project teams accomplish work together are increasingly part of a project leader's job. One of the benefits of this new age is the opportunity it offers to see the world of project work in innovative ways devised by varied cultures. But we are able to work together across borders because of our essential similarities.

More than 2,000 years ago, Marcus Aurelius wrote, "To see the things of the present moment is to see all that is now, all that has been since time began, and all which shall be unto the world's end, for all things are of one kind, and of one form."

I remember my social studies teacher at Midwood High School saying that in class one day. I laughed. First of all, hearing a middle-aged, Brooklyn high school teacher quoting an ancient Roman philosopher seemed like something from a Mel Brooks movie. And what did it mean? The ensuing discussion informed us that Marcus Aurelius was saying there was nothing new in the world. Things would change, but the nature of human experiences, emotions, thoughts, feelings, and ideas remained limited and constant. This was hard for me to accept. How could a generation that experienced Apollo be essentially the same as our ancestors from the Middle Ages?

Fast-forward a few decades. The idea that humans are interconnected and share the same experiences and lessons was vividly apparent on my recent trip to Japan. I was invited by my friend and colleague Hiro Tanaka to be a keynote speaker at the Project Management Japan Association conference. It was fascinating to listen to different perspectives on project management. Yet, as the trip continued, what most made me smile was the sense that we are all in this together, facing similar problems. The issues we discuss at NASA (like talent management, complex project systems, portfolio management) are the same ones being discussed throughout the project world. Different cultures offer their unique insights about how to deal with them, but our similarities are the essential core.

In Tokyo I was privileged to visit with colleagues from the Japanese Space Exploration Agency (JAXA). During the shuttle mission where the Kibo ("Hope" in Japanese) module was configured to the International Space Station, I talked with the JAXA senior chief engineer, Toshifumi Mukai. Space exploration is now a thoroughly international collaboration.

As I listened to international perspectives on challenges and solutions for a project world, and as I visited with JAXA, I remembered Marcus Aurelius's words about the sameness at the heart of the world's great variety. The human challenges of the future will be met through global project structures. The challenges of exploring space, curing and preventing disease, battling poverty, and supplying the world's energy in environmentally sound ways will be faced through international project partnerships.

The varied perspectives of different cultures will provide a rich variety of insights and innovative concepts; our shared values and aims will unite us in common work. There is no one blueprint for how to make international projects successful, but there are many possibilities. For me, that is the hope for the future. ●

JUNO

MAKING THE MOST OF MORE TIME

BY RICK GRAMMIER

Artist's conception of the Juno spacecraft orbiting Jupiter.

Image Credit: NASA

Juno was selected in 2005 with an initially scheduled launch in 2009. Almost immediately, though, NASA Headquarters warned us that budgetary issues would delay the launch a year or two and asked the project team to prepare a cost assessment for a 2010 launch. We completed that task in November 2005. Six months later, NASA informed us that budget issues would cause a further delay, and the launch date would be in 2011. This required the project team to re-plan yet again.

The schedule change posed challenges for the Juno team. One was dealing with the budgetary implications of delay. Inflation would add cost, as would the personnel and management expenses of a longer project, even with the team size frozen at a low level during the early years. Continuing budgetary concerns also increased pressure to accurately estimate, manage, and minimize the revised budget associated with the launch delay. Another challenge was figuring out how to maintain our heritage designs and retain skilled personnel, making the best use of their expertise during the suddenly extended early stages of the project.

We decided to take advantage of our unusually long Phase B—the definition and planning phase that precedes design and development—to evaluate and address the risks inherent in this complex mission. Part of NASA's New Frontiers program, Juno will enter a polar orbit around Jupiter in 2016 and begin making precise measurements of the planet's gravity, magnetic fields, and atmosphere. The new information the spacecraft acquires about the structure and composition of the giant planet and its atmosphere will vastly increase scientists' understanding of how such planets form, which is key to understanding how the rest of our solar system formed. A typical Phase B for a project of this size lasts about a year; ours would be almost three years long.

We hoped we could use that time to avoid and reduce some familiar perils of science missions—among them incomplete or misunderstood requirements, costly late design changes, communication gaps between scientists and engineers, and the tendency of reality to negate overly optimistic expectations about reusing technology from other missions and reveal mismatches between requirements and capabilities.

Juno's Phase B started in November 2005. We're now only a few months from the end of that planning phase and can look at some of what's been accomplished.

More Time to Talk

One undeniable benefit of the extended Phase B was the time it gave us to unify the team and communicate effectively. We are a diverse, geographically distributed team, with participation from the Jet Propulsion Laboratory (JPL), Lockheed Martin, Goddard Space Flight Center, the University of Wisconsin, the Southwest Research Institute, the Applied Physics Laboratory, University of Iowa, Italian Space Agency, and elsewhere. These groups have different cultures, different expectations, and their own ways of communicating. The English language is imprecise; the same words may have different meanings for the speaker and listener. The more you talk about things together, the more mutual understanding you get—and the more each group grasps and respects the challenges and issues other groups wrestle with. By increasing understanding and trust, those conversations improve the chances of developing solutions that work for everyone.

BEING THERE IN PERSON ENCOURAGES "SIDEBAR" CONVERSATIONS THAT DON'T HAPPEN DURING A TELECONFERENCE.

Among our communication efforts have been workshops to discuss JPL's flight project practices and design principles that have helped identify potential misunderstandings and conflicts. We also had a payload "road show" to conduct in-depth conversations with each instrument provider regarding the project's requirements and expectations in multiple areas (including mission assurance requirements, environmental requirements, design principles, and processes), to identify disconnects and associated risks, and to agree on the path forward. These far-ranging discussions have given us a chance to deal with issues that otherwise would arise one by one in

MORE THAN A YEAR AND A HALF OF FREQUENT IN-PERSON AND PHONE MEETINGS OF SCIENCE, ENGINEERING, AND PAYLOAD PERSONNEL IN SEVEN WORKING GROUPS HELPED THE TEAM WORK OUT THE MISSION'S REQUIREMENTS AND UNDERSTAND THE TRADE-OFFS BETWEEN RESEARCH CAPABILITIES AND ENGINEERING AND BUDGET LIMITATIONS.

later phases, resulting in less than optimal solutions. In order to ensure frequent communication, enhanced team integration, and timely identification and resolution of issues, we have established a robust command, control, and communication structure comprising biweekly integrated management and engineering team meetings, weekly project system engineering team meetings, weekly Juno payload engineering team meetings, and semimonthly management reviews of the entire project, to name a few. These meetings have broad participation from all discipline areas: the science team, systems engineering teams, management teams, and business teams.

JPL people meet in person, with others calling in to the meetings, but we take advantage of chances to get people together. I have set up a standard rotation process among myself, Rick Nybakken (deputy project manager), Doug Bernard (project system engineer), and Sammy Kayali (project mission assurance manager) so that we have a presence at Lockheed Martin, the flight system contractor, each week. A similar process is followed at lower levels as well. Being there in person encourages "sidebar" conversations that don't happen during a teleconference; you see how team members interact outside formal meetings; you get a sense of what's really going on and a better grasp of people's concerns; and you develop a better sense of how people think and talk than you can get at a distance. As Doug Bernard has said, "People need to know each other well enough to interpret remarks made on the phone. In-person meetings give you a better chance to catch their intentions."

More than a year and a half of frequent in-person and phone meetings of science, engineering, and payload personnel in seven working groups helped the team work out the mission's requirements and understand the trade-offs between research capabilities and engineering and budget limitations.

Trade Studies

Every mission involves trade-offs. Our longer Phase B has given us the luxury of taking the time to really understand them, not just choose one option and move on. We have had time to put together explanations of why we made the choices we made, which helps reconcile people to the decisions, even the ones that did not go the way they wanted. And the more extensive study and discussion have led to some solutions that work well for everyone, while decreasing mission risk within our technical, schedule, and budget constraints.

One of these studies focused on the selection of our initial Jupiter orbit. The question was whether we should modify the original plan of going immediately into an eleven-day orbit around Jupiter or go instead into a larger, seventy-seven-day initial orbit, dropping down to the eleven-day orbit later. That change would save fuel (and therefore mass). It would have other advantages, too. The mission's operations people liked the idea of having time in high orbit to prepare for the lower orbit, where the full suite of science instruments would be turned on. The large orbit would also give scientists a good opportunity to study Jupiter's polar magnetosphere, never before visited. On the downside, the higher orbit would change our orbital geometry, slightly increasing the total radiation dose.

The mission design and navigation team studied the options and reported back to the project systems engineering team. That team clarified which options should be studied further. The subsequent trade study of those reduced options led to the high-orbit choice.

Another trade study regarding Juno's spin rate (the spacecraft is spin stabilized) involved the entire science and payload team. The original plan called for a 3 rpm spin rate. The magnetometer principle investigator asked if we needed that high a spin rate, because the magnetometer's star tracker was not certified at 3 rpm. But the microwave radiometer instrument team wanted the higher spin rate, which would give them more measurements since their instrument would more frequently point toward the planet. The microwave radiometer team analyzed in depth the impact of various spin rates on data collection and determined that there was little science opportunity cost as long as the spin rate stayed at 2 rpm or higher. The spacecraft design was also simplified by reducing the spin rate. The full team agreed that 2 rpm would work well for all parties.

More Time to Test and Choose

Our extended Phase B has given us more time to develop and evaluate options for critical mission elements. Juno's Stellar Reference Unit (SRU)—the camera to measure star positions and use them to determine the spacecraft's attitude—is a good example. No one has yet built an SRU guaranteed to tolerate the radiation environment in which Juno operates, in concert with the spacecraft's spin rate. Our extended schedule has allowed us to write Phase B study contracts with two prospective vendors. They will design and test their approaches, including radiation tests. A "shootout" at the preliminary design review—considering technical, schedule, and cost performance—will allow us to determine which is the best choice.

We also have used the additional time to test and analyze the cells of Juno's large solar array in a realistic manner—absolutely critical for the first mission that will be solar powered so far from the sun and in Jupiter's harsh radiation environment.

Our Phase B Benefits

Juno is a demanding mission, with as large a set of instruments as you would expect to see on a more expensive flagship mission and the technical hurdles of providing adequate radiation shielding and deep-space solar power. It has as well the familiar challenges every mission faces: bringing together diverse organizations into a cooperative team, making trade-offs between science and engineering, maintaining budget discipline, and identifying and mitigating risks.

We think our extended Phase B has put us in an excellent position to meet these demands and avoid common problems. Thanks to having scientists and engineers working closely together for so long, we think we have developed a set of realistic requirements that balance science capabilities and engineering realities. Early prototyping of the science instruments should reduce incompatibilities and other glitches when the spacecraft is built. We think we are less likely to confront the unpleasant surprises of requirements changes later on, when they are more costly and difficult to deal with. Having had time to involve mission ops people in our deliberations should help avoid the problem of discovering mismatches between operational requirements and mission design later.

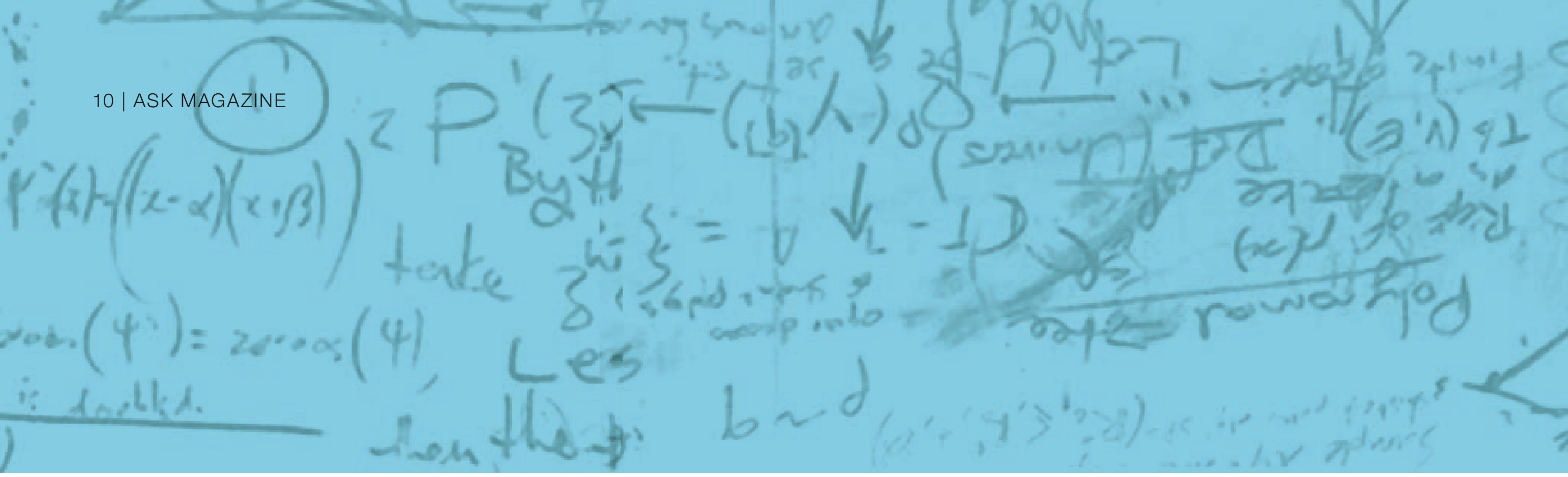
Time will tell how much of this very extensive Phase B work pays off, but we are moving on with a lot of confidence. Members of the project's standing review board agree, citing the cooperation of scientists and engineers and our grasp of critical requirements. One commented, "The project has made excellent use of the additional schedule time in this extended Phase B."

The mission is named after the goddess Juno, the wife of Jupiter. In mythology, she used her powers to peer through the clouds Jupiter was using to hide his activities. In 2016, we expect our Juno to peer at Jupiter and discover many of the giant planet's secrets. ●

RICK GRAMMIER is currently the project manager for the Juno mission in the New Frontiers program. His experience includes previous roles as project manager for Deep Impact, deputy director for Planetary Flight Projects at JPL, manager of JPL's Office of Mission Assurance, and project engineer and deputy project manager for Stardust. He has a BS in engineering from the United States Military Academy and an MS in electrical and computer engineering from California State Polytechnic University.

Seeing Through the Haze: How Counterfactual Thinking Can Help NASA Prepare for the Unexpected

BY WILLIAM H. GERSTENMAIER, SCOTT S. GOODWIN, AND JACOB L. KEATON



Before the English explored Australia in the 1600s, it was held as an indisputable fact in Europe that all swans were white. This "fact" was based on empirical evidence stretching back for thousands of years that grew stronger as each observation of a white swan confirmed the belief that only white swans existed. Yet all that evidence was invalidated by a single observation of a black swan in Australia. In time, the black swan became a metaphor for things that weren't supposed to exist, yet did.

Author Nassim Taleb uses the story of the discovery of the black swan and how it demolished millennia of prior evidence to describe events that were not thought possible:

> A Black Swan event is a highly improbable occurrence with three principal characteristics: It is unpredictable; it carries a massive impact; and, after the fact, we concoct an explanation that makes it appear less random, and more predictable, than it was.

Today, we take black swans for granted and may not grasp why Europeans had such difficulty coming to terms with their existence. We may be more prone to experiencing extreme, unexpected events than the people who lived before us because of the complexity and interconnectedness of the technologies we use, and we can easily find examples of Black Swan events in our time. Such a list would include both the *Challenger* and *Columbia* accidents, the events of 9/11, the collapse of the Interstate 35W bridge in Minnesota, and many of the events that have roiled world financial markets in the past decades. Given our experiences with extreme events, it is natural for us to want to identify them and try to predict when they will happen.

We often attempt to do this by plotting the probability distributions of events along a bell-shaped curve whose narrow "tails" at either end represent outlier events, supposedly rare and unlikely to happen. It is likely these tails are thicker than the typical bell curve would suggest and some of those outlier events are much more prevalent than we imagine. There is also the question of whether a bell curve, or any other distribution model, is appropriate to determine whether an event is likely to occur. The randomness you find in a casino is limited and well understood; the casino knows how many cards are in a deck, how many faces on a die and, because all possible outcomes are known in advance, it can calculate the odds of any particular outcome occurring. In the world outside the casino, we don't know all the possible outcomes, nor do we know precisely how many cards are in the deck. In many cases we may not even know how many decks there are.

When unexpected events do occur, we often dismiss them because they did not have a significant impact and we think the chances that they will occur again are even more remote. Harder to dismiss are outlier events that *almost* occur and that *would* have had a serious impact; these near misses should not be dismissed lightly. Such events are "gifts"—nothing bad really happened, and they provide a tremendous opportunity for learning. We can use these events to brainstorm similar situations in other systems and rethink our assumptions and models, but we must overcome two common biases first.

When an extreme event occurs, an investigation is initiated to determine exactly what happened and why. When you see all the data available to you after the event, you can build a story of how it all fits together and you end up with an explanation that makes complete sense. This leads you to believe the event was predictable—that is "hindsight bias." But it's difficult before the event occurs to be perceptive enough to know this kind of event may be sitting out there and ready to occur and to grasp how it might play out. Once causes are identified and thought to be understood, we conclude that if only we had done x, y, and z, the event wouldn't have occurred. Then we institutionalize x, y, and z in our plans and processes to prevent the same thing

from happening again. Such changes will not protect us from other extreme events, and implementing these changes as rigid procedures inhibits learning, adaptation, and growth. We end up "following the flow chart," and we think less actively about what we're doing and why.

Confirmation bias leads us to form beliefs that are based on repetition, not on analysis or testing. Each recurrence of an event serves to confirm our view that the event will happen again in the same way. Every recurrence that has no serious negative consequences confirms our view that the event is not dangerous and may lull us into accepting it as normal. The Thanksgiving turkey has a thousand days of earned-value metrics behind it; as far as it knows, the day after Thanksgiving will be just like the day before it. Good metrics do not ensure success tomorrow.

These biases cloud our view; we need ways of seeing through the haze. One way of combating our biases and helping defend against potential Black Swan events is through counterfactual thinking. Counterfactual thinking means imagining alternative outcomes to past events. It can be practiced by continuously asking "what if" questions about what might have happened instead of what actually did. It can identify potential risks or solutions to problems that can then be analyzed and tested.

When *Endeavour* suffered tile damage due to a piece of foam breaking away from a bracket on the external tank during launch on August 8, 2007, the common-sense decision was to repair the tile damage in orbit. Instead we made the decision to return with the tile damaged, and a lot of people could not understand why.

What we did was use the Orbiter Boom Sensor System to create a three-dimensional model and then fashion an exact copy of the damaged tile here on the ground. We tested this model analytically and by simulating re-entry using an arcjet and assuming worst-case heating. We saw some tunneling in the tile and some charring of the felt pad, but the structure underneath was undamaged and would withstand re-entry.

This test allowed us to say conclusively that this would be the worst-case result of not repairing the tile. It was a *known* condition, unlike what might happen if we attempted to make the repair. The actual result was not as bad as the worst-case scenarios and testing showed us, so it was a good decision.

We used the same process of asking "what if" questions that is at the heart of counterfactual thinking. And this type of thinking can be applied in all areas of program and project management, including budget processes, property disposal, transition management, and overall decision making.

We manage one-of-a-kind projects that entail significant risks, known and unknown, that can have an enormously adverse impact on our outcomes. As project and program managers, what can we do to prepare for unexpected events? No one can answer that in a definitive way, but there are strategies that will help us prepare for and manage the unexpected.

- Purposely induce a counterfactual mind-set prior to major decisions or significant meetings, perhaps by reviewing past close calls. Actively challenge assumptions to look at high-impact risks that supposedly have a low probability of occurring and brainstorm possible scenarios that could entail those risks. Don't pick sides; let the data drive and flavor the discussion. Then translate the results into productive actions by planning for those risks in your program or project.
- When you do risk management, step back and really brainstorm, pushing the envelope in your risk matrix; ask what else might happen and what effect that might have. But do not become paralyzed by what you discover: risk is real and unavoidable. It is better to discuss and think about it than be totally unprepared for a Black Swan event.
- Even if your project or mission is going well, when earned value looks good, the schedule is being met, and the budget is healthy, ask what could cause a problem that could dramatically change the outcome of your project or mission.
- Recognize that the conventional wisdom of the group is not always correct. We need to guard against groupthink, staying aware of our natural tendency to jump to the same conclusions and move in the same directions. Assign folks

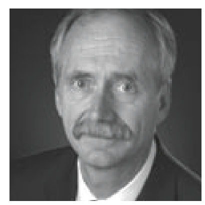
WE MUST BELIEVE IN OUR ABILITIES TO SUCCEED WITH OUR PROJECTS AND MISSIONS AND AT THE SAME TIME DO EVERYTHING WE CAN TO UNCOVER EXTREME NEGATIVE EVENTS THAT CAN CAUSE FAILURE BEFORE THEY HAPPEN.

to look at non-problem areas that are high risk so we aren't all focusing on the "problem of the week." Be creative in thinking of ways to analyze and test possible issues in these high-risk areas to better understand them. Probe the boundaries, test to failure, and know the true margin of the real systems.

- Pay closer attention to anomalies and other unexpected events, not just near misses, and ask what could have happened or what might happen next time. Perhaps we should approach all unexpected and outlier events as near misses, at least initially. Some may be indications of a Black Swan event in the future, and we should treat these as precious learning opportunities.
- When you or others create explanations for events, don't fall in love with the hypotheses and seek out supporting data. Instead, assume that a hypothesis is wrong and look for data to refute it; search for that which is counter to what you want to happen. The goal is to find the best answer with the data available at the decision time, not your answer or the group's answer.
- Improve your predictive and decision-making capabilities by regularly reviewing your past decisions. Capture the data available at the time of the event or decision. Was the information needed to predict the outcome in the available data? Did we fail to collect or analyze it? If the data did not exist, is there a way to create or capture it so it is available next time? Did we capture the proper assumptions we made at the time of the decision? Was the data just not available at the decision time?
- Keep a sense of humor. Always looking for negative consequences and dangers can skew your sense of proportion and balance and will take an emotional toll. Maintain a positive perspective and remember that all problems are positive challenges.

We must believe in our abilities to succeed with our projects and missions and at the same time do everything we can to uncover extreme negative events that can cause failure before they happen. We have to move forward with certainty in what we intend to achieve, and at the same time prepare for the unexpected by doubting everything.

The risks we identify now may not be the risks we need to be the most concerned about, but we can't be honest about risk if we don't accept our fallibility and recognize that we have biases that skew our observations and analyses, or if we suppress dissenting opinions. Acknowledging and talking about these issues openly and directly is a good first step. ●



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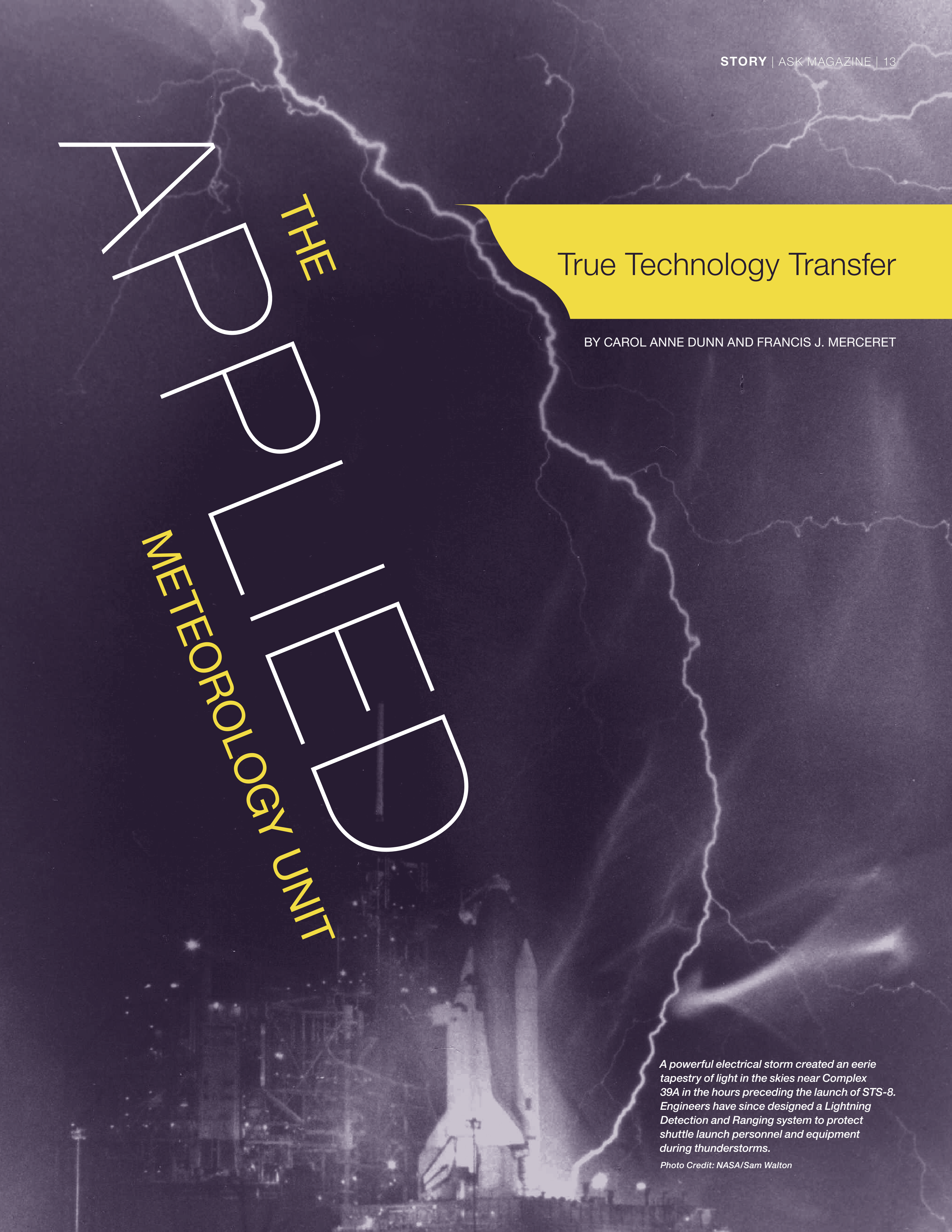


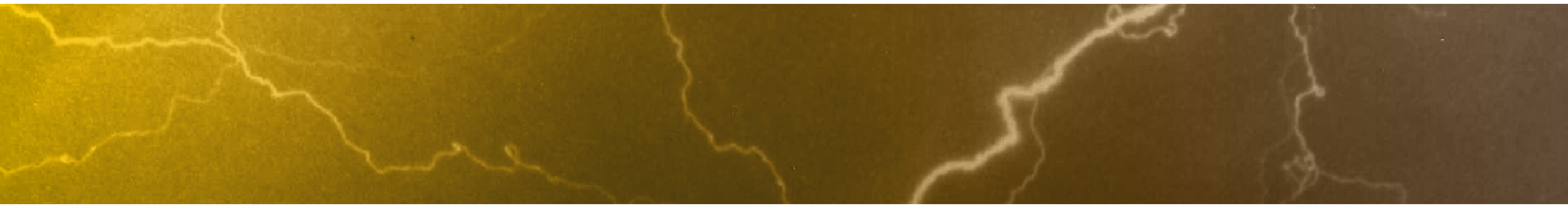
THE APPLIED METEOROLOGY UNIT

True Technology Transfer

BY CAROL ANNE DUNN AND FRANCIS J. MERCERET

A powerful electrical storm created an eerie tapestry of light in the skies near Complex 39A in the hours preceding the launch of STS-8. Engineers have since designed a Lightning Detection and Ranging system to protect shuttle launch personnel and equipment during thunderstorms.

Photo Credit: NASA/Sam Walton



Mark Twain once said, "Everyone talks about the weather but nobody does anything about it." These days we "do" weather forecasting, and it is right far more often than it is wrong, which is fortunate for those of us in Florida and at NASA, since central Florida leads the nation in lightning strikes, and Cape Canaveral Air Force Station and Kennedy Space Center lie within "Lightning Alley." This does not bode well for launching space vehicles. However, thanks to many new or improved technologies, NASA can now launch knowing it has the latest in technological information to keep its personnel, hardware, and facilities safe.

Over the course of its history, NASA has transferred technology using a variety of methods: licensing, partnering with industry, and infusing technology into its missions through the Small Business Innovation Research and Small Business Technology Transfer programs. What we consider the purest form of technology transfer—technology usually published or put on a Web site free of charge—is done by a little known office within the Applied Technology Directorate at Kennedy: the Kennedy Space Center Weather Office. What may not be common knowledge outside the weather community is that NASA, and Kennedy in particular, has made many important discoveries in meteorological science and developed groundbreaking meteorological instrumentation systems.

The ability to apply these discoveries and technologies immediately to operations is due, in no small part, to the Applied Meteorology Unit (AMU), a unique joint venture among NASA, the U.S. Air Force, and the National Weather Service. Originally conceived by a NASA "blue ribbon" advisory panel and the National Research Council, the AMU was established in 1991. The AMU develops and evaluates technology to improve weather support to spaceport operations and its customers and transitions it to operations. Its contract provides for five full-time professionals with degrees in meteorology or related fields.

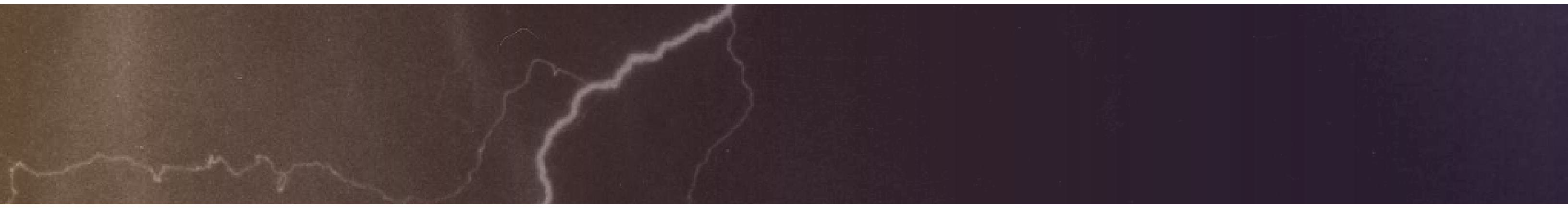
The AMU's effective technology transfer relies on three key elements:

- Tasking is assigned by the customers with input from other stakeholders.
- Performance of each task continuously involves the customers with quarterly in-depth reviews for every project.
- Customers review and test the resulting products before they are delivered.

The AMU projects are chosen through formal prioritized tasking, option hours tasking, and mission immediate tasking. The AMU's tasking process has been listed as a best practice by the U.S. Navy's Best Manufacturing Practices Institute.

Formal prioritized taskings, which account for more than 80 percent of the AMU's workload, are assigned by AMU group consensus, usually reached after several discussion phases. The group consists of representatives from each AMU partner agency. Six weeks prior to the quasi-annual face-to-face tasking meeting, each agency submits proposed tasks for the next twelve to fifteen months. E-mail and telephone discussions lay the groundwork for an efficient and effective meeting. The AMU tasking process has so far always achieved consensus, usually by additional modification or withdrawals of proposals to get within the resource limitation.

Option hours tasking, which accounts for most of the remaining AMU workload, is available for work that was not accepted through the formal prioritized process or which is



proposed between tasking meetings. A customer who is willing to pay for the service may request that the proposed task be undertaken using option hours. Option hours work is subject to some constraints: tasks may not undertake basic research and they must relate to improving shuttle program weather support or national and commercial space program activities at the Eastern Range. The chief of the AMU makes the final decision as to whether a proposed option hours task is appropriate. If it is approved, the proposing organization provides the necessary funding to purchase the additional hours.

On rare occasions, the AMU's special expertise and experience may be needed to assist operational customers with a situation outside their normal experience when there is no time to go through either prioritized or option hours tasking. This may happen, for example, during a launch countdown where unusual radar signatures are seen or remote-sensing and local observations appear inexplicably inconsistent. Resolving the causes of these anomalies needs to be done immediately to assure mission success.

Regardless of how the technology is transferred, AMU products have helped support America's space program. One product, an anvil forecast tool, was developed to display a thunderstorm anvil threat corridor on a satellite image. An anvil is that often wispy, flat, long cloud that blows off the top of thunderstorms at high altitudes. Flying through an anvil can be dangerous because it may contain enough electric charge from the parent thunderstorm to trigger a lightning strike to the vehicle flying through it. The threat corridor is based on observed data from a rawinsonde (a radiosonde probe that measures wind speed and direction along with temperature, pressure, and humidity) or forecast data from a numerical weather prediction model. The tool allows forecasters to generate and display the anvil threat corridor as dotted lines overlaid on the latest satellite picture. If thunderstorms are forecast for the threat corridor, the time until the resulting anvils would approach close enough to violate launch or landing lightning safety constraints can be estimated from the dotted range rings on the overlay. By developing this tool specifically for the operational display system, the AMU enabled the forecasters to use the capability in real time on a system they use routinely in support of daily operations.

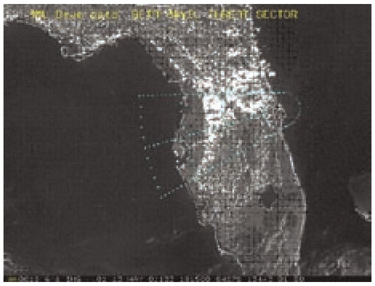
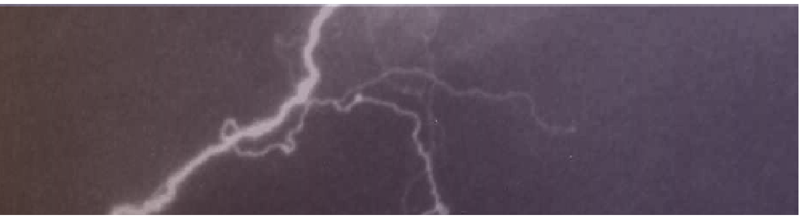


Photo courtesy Francis Merceret

An example of the anvil forecast graphic overlaid on a visible satellite image of the Florida peninsula.

NASA CAN NOW LAUNCH KNOWING IT HAS THE LATEST IN TECHNOLOGICAL INFORMATION TO KEEP ITS PERSONNEL, HARDWARE, AND FACILITIES SAFE.

Upper air wind changes are another major threat to the safety of launch vehicles as they ascend. Marshall Space Flight Center developed a radical improvement to signal processing that allowed those winds to be measured using a radar wind profiler located at Kennedy. The data from the new profiler algorithm was as accurate as the most accurate wind-finding weather balloon and better than any previously available commercial signal-processing methodology. In addition, the new algorithm enabled the profiler to generate complete wind profiles from 6,000 to 60,000 feet in 500-foot intervals every five minutes. The best previously available algorithm required at least thirty minutes per profile. Balloons take an hour to generate a wind profile.



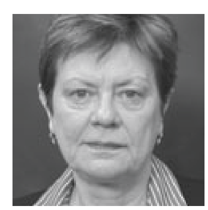
Unfortunately, Marshall's new algorithm required more computing power than was available and could only be used for research purposes because it could not be run in real time. The AMU redesigned the software to run on the operational system in real time, developed a user interface for interactive quality control on the day of launch, and wrote a comprehensive training package to enable operational personnel to effectively use these new tools. Operational use of the Kennedy wind profiler, running the AMU software and quality control interface, has already prevented loss of at least one expendable launch vehicle mission due to last-minute wind changes undetected by weather balloons.

The Kennedy Weather Office and the Applied Meteorology Unit work hand in hand to safeguard our nation's space program from the adverse effects of lightning, tornadoes, and hurricanes. These dedicated individuals—Mr. John Madura, chief of the weather office; Dr. Francis Merceret, AMU chief and director of research for the weather office; and ENSCO/AMU employees Dr. Bill Bauman (AMU program manager), Dr. David Short, Ms. Winnie Lambert, Dr. Leela Watson, and Mr. Joe Barrett—have contributed to advancing the frontiers in the science of meteorological support to space flight and technology transfer in its "purest form."

AMU customers have continued to fully fund and support the AMU for seventeen years despite serious challenges to their available resources. The quality of work has also warranted publication in numerous peer-reviewed journal articles, including a cover article in the *Bulletin of the American Meteorological Society.* ●

For more examples and additional information about the AMU, visit the AMU Web site at http://science.ksc.nasa.gov/amu.

THE AMU REDESIGNED THE SOFTWARE TO RUN ON THE OPERATIONAL SYSTEM IN REAL TIME, DEVELOPED A USER INTERFACE FOR INTERACTIVE QUALITY CONTROL ON THE DAY OF LAUNCH, AND WROTE A COMPREHENSIVE TRAINING PACKAGE TO ENABLE OPERATIONAL PERSONNEL TO EFFECTIVELY USE THESE NEW TOOLS.



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FRANCIS J. MERCERET is chief of the Applied Meteorology Unit (AMU) at Kennedy Space Center, a position he has held since 1991. He is also director of research at the Kennedy Weather Office, where he provides technical expertise in atmospheric physics and meteorological instrumentation, directs research conducted by or for the office, and undertakes scientific investigations.

INTERVIEW WITH

Christyl Johnson

BY DON COHEN

Christyl Johnson has been assistant associate administrator in the Office of the Administrator at NASA since fall of 2005. She joined NASA in 1990, designing and building laser systems for remote sensors at Langley Research Center. She has also been associate director for exploratory missions in the Office of Earth Science and the deputy chief engineer for Program Integration and Operations in the Office of the Chief Engineer. Don Cohen talked to her recently at her office in NASA Headquarters.

COHEN: Tell me about the responsibilities of your current job.

JOHNSON: I am the assistant associate administrator for the Agency, so I am the deputy to the number three person. We are responsible for technical oversight of the Agency's missions.

COHEN: That means, in part, dealing with technical disputes not resolved at a lower level?

JOHNSON: Yes. It has been good to see the technical authority process working the way it was envisioned: to see some real disagreements between the programmatic elements and the institutional elements like safety and mission assurance or engineering get addressed and resolved. These disagreements now have a path of adjudication all the way up to the administrator for a final decision. It's good that the issues are bubbling up and being discussed openly. We are working hard to create an environment in which it is not tolerated, when big problems arise, that the engineer with the concern gets stifled and his concerns are not heard and addressed.

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COHEN: What have been the most challenging cases?

JOHNSON: The engineering issues are probably the easiest. The most difficult decisions are the ones that affect people's lives and are more personal than technical. You can perform calculations and make reasonable trades regarding a specific technical issue, but when it comes to making a decision about moving a program from one Center to another, you have to deal with the political and personal fallout of that decision.

COHEN: Has that happened recently?

JOHNSON: SOFIA [Stratospheric Observatory for Infrared Astronomy] moved from Ames Research Center to Dryden Flight Research Center. In these types of situations you have hurt feelings, not just at the employee level but all the way up through the management chain.

COHEN: What was the rationale for the move?

JOHNSON: The Ames team was experiencing lots of delays due to technical and management problems. Dryden was determined to be better equipped and more experienced to be able to complete the mission successfully, so the decision was made to move it.

COHEN: So it was a technically easy decision, but …

JOHNSON: … but there were political implications associated with moving it from one district to another. Lots of people are affected by these kinds of decisions. There are those that have to uproot their families and follow the aircraft because they're the ones doing the day-in–day-out work. And you have a center director who says, "Believe in me, I have the ability to do this. You hired me to do this job; I've told you how I'm going to get it accomplished. So give me a chance." There's a lot that the engineers never see.

COHEN: Do you see your main role as giving engineering advice, or using your engineering background as a foundation for these human decisions?

JOHNSON: Definitely using my engineering background to make sound, reasoned judgments. It is always better to have someone in a senior leadership position like this one who has experience actually building technical systems. You don't know how long it takes to do thermal vac if you've never done it before; you don't know what a reasonable estimate is if you've never made one. Because I started my career designing and building laser systems, testing them and putting them on aircraft, and doing field measurements in the deserts of New Mexico, I know what it takes to build systems successfully. When they say, "I can get this done in two weeks," you remember what it was like and say, "That doesn't sound right to me."

COHEN: It's wishful thinking.

JOHNSON: Exactly. As a technical manager you make decisions based not just on their assessment but on your experiences, too.

COHEN: You started out as an engineer.

JOHNSON: Yes, I was the lead engineer for the Chromium: LiSAF laser development project at Langley. I designed and built a Chromium: LiSAF laser oscillator that was the first to achieve 33 millijoules in a diode pump scheme. I also established the first stress-optics laboratory at Langley. Universities and other organizations came or sent their crystals to be tested in this lab. I became the program manager for the Differential Absorption Lidar (DIAL) Program, which encompassed all the laser development research projects at Langley.

COHEN: So you combined engineering and management early on.

JOHNSON: Yes, because I had the ability to communicate effectively with both engineers and management.

COHEN: Did you know when you started at NASA that you had those skills, or did you think of yourself as a nerdy engineer?

JOHNSON: I have never viewed myself as a nerdy engineer. I love being able to create things with my own hands—my father and I rebuilt Mustangs together. Math and science came easily for me, but I'm really a people person. I like being in the lab, but I'm more in my element communicating those lab results in international forums or negotiating with the Italians for a spin table for Triana.

COHEN: Were you already thinking in that direction when you started at NASA?

JOHNSON: I have always been a people person and communication came easily, but I never dreamed I would be presenting papers in international forums when I started at NASA. When I first came, the organization I was in was trying to create and discover new laser crystals that could achieve greater efficiencies and greater power output—which we need for remote sensing. It's very difficult to find the combination that gives you high efficiency, great output power, the wavelength that you need, and the right input stimulus. Listening to the discussions in meetings when I first started, I remember thinking, "Oh, my God, this stuff is Greek to me! How am I ever going to get to be as smart about this stuff as a Norm Barnes," who was the guru of the laser design world? As an engineer, I was just focused on this Chromium: LiSAF system and in the laboratory tweaking knobs. When I couldn't get it to work, I would brainstorm with other design engineers to try to figure out what to try next. This was my baby. They had their own research to do, but they'd sit down with me and brainstorm. This was a very helpful practice that we all benefited from.

COHEN: That was your first assignment?

JOHNSON: No, I had been a summer student starting in 1985, so I had numerous smaller assignments prior to that. I also did my master's thesis research at Langley, so I was very much a part of the team before I started working there officially in 1990.

COHEN: The student work wasn't in a co-op program?

JOHNSON: No, the Lincoln AeroSpace Engineering Recruitment (LASER) program that I was selected for required you to work at a NASA Center for one summer. I did that assignment in 1985 and really enjoyed it. The Langley people hired me back the following years as a summer hire so I could continue to do work for them.

COHEN: Were your first months at NASA sink or swim, or did you get guidance and mentoring?

JOHNSON: I got mentoring that was absolutely critical. It is crucial for anyone responsible for a research environment to make sure that they spend that time up front giving new hires some kind of guidance. There were several people who came in and didn't get that kind of mentoring. They sat around and didn't know what to do. They weren't getting much out of the work, and they weren't contributing much to it. Because I had been there those previous summers, I had already established relationships with people in the organization. I could go to them and ask, "What do you think about this?"

COHEN: People who are less outgoing might not be able to do that.

JOHNSON: True. That's why, later, we made sure that anyone who came in did have mentoring. It's critical. You can't just throw people in the water and say "Swim!" if you want them to contribute.

COHEN: What kind of mentoring did you get?

JOHNSON: Some was technical advice, like pointers and guidance in my laser design and development efforts. Other mentoring was of a political nature, like a challenge that I faced as the subsystem manager of the LASE [Lidar Atmospheric Sensing Experiment] program when a person tried to throw a monkey wrench into the laboratory operations. Then there was career advice like what kind of job to take next and what kind of experience I needed before going to the next level.

COHEN: Can you tell me about the problem with LASE?

JOHNSON: I was subsystem manager for the diode-seeding subsystem of the program. We had established an autonomous lab to do characterizations of the diodes that we needed to seed the system. I had engineers and technicians working long hours to address a line-locking problem that was threatening the delivery of this critical system for the mission. The chief engineer of our division would come in the lab and try to take the engineers off task to try his ideas. I went to him and I said, "You cannot redirect these engineers. We have a task plan and a very tight schedule." He wouldn't listen to me because he was a senior-level manager and I was just a program manager.

Finally, I went to my branch manager, who called a meeting with all the senior managers in our division. In the meeting I let them know what was going on, and I asked them to ask the chief engineer to stop interfering with our efforts. The management team asked him to stop going into our lab. He replied, "I can do whatever I want, I'm the chief engineer." The team was outraged by his response and started arguing with him. I interrupted and said, "As long as we know what the rules of the game are, we can play the game. If he wants to redirect the engineers, all we have to do is tell them not to listen to him." We ended up doing just that. The division manager later told me that he had heard of how I handled the situation and that my tact was exactly what was needed in our managers. He also said, "Christyl, that is exactly the approach you need to take. It doesn't have to be a fight. You keep on going down the path you're on." It was good to get that kind of affirmation.

COHEN: You got both advice and support.

JOHNSON: Yes, and it turned out well. We identified the problem, fixed it, and delivered the system on schedule.

COHEN: So that's a case where the problem had more to do with human interaction than technical issues.

JOHNSON: When engineers become frustrated and can't think, that takes away their ability to get the job done quickly. If you want them to focus on the issues, you can't have extraneous stuff interfering.

COHEN: Do you think being black and a woman has influenced your career at NASA?

JOHNSON: I don't view it as a negative. I don't see it as a positive, either. It just is. I've enjoyed being not just the only black female, but the only female in some arenas that I'm in. I have found that most men are comfortable working with me. Sometimes men don't view talented women as a threat like they do their male counterparts. There have been times when I had to deal with people who were not accustomed to women being in

I WOULD NOT HAVE chosen to COME TO NASA IF I'd been told THAT I WAS GOING TO oversee a contract FOR WHICH SOMEONE ELSE WAS DOING THE fun engineering work.

engineering or to having women as their equals or their supervisors. That can cause problems. There have been some guys that really struggle with acknowledging a woman in a prominent role. They won't look at you during discussions at meetings. Even if you are the one that is asking the questions, they'll give the answer to one of the other males at the table. Those things happen. I chalk it up to the guy being ignorant and keep going. It's not personal.

COHEN: You also got mentoring that was career advice?

JOHNSON: When I was program manager for the diode program, the laser engineers did their performance planning through me. Then I would sit down with the deputy branch manager and talk about what each group was going to be doing, and what I thought were their success criteria. He would sign off on them or talk to the branch manager. He was the person I worked most closely with in the management chain. Once, when the branch manager had gone on vacation, an assistant branch head position in the electro-optics and controls branch was advertised. The deputy branch manager said, "Christyl, you are already performing many management functions, and you are good at it. You really should consider applying for the job." The branch manager who was on vacation had been telling me, "It's not good to get out of the laboratory until you've been doing this for fifteen years and establish yourself in the engineering community as an expert in a specific field. Then maybe consider going into management. You'll never be able to succeed if you're not established as an expert first." But the assistant branch head said, "You don't have to be an expert to make progress in your career. Your career path is completely up to you." He wrote my recommendation, and I got the job. That ended up being a really positive experience for me.

COHEN: Is it important for most engineers to develop some of these people skills or does it make sense to say, "We'll let this introverted genius engineer just focus on his own work?"

JOHNSON: I think there's enough room for everyone to be themselves. It's good to give those total introverts some exposure that can help them to grow. If they're comfortable doing things that can stretch them, that's great. Their supervisors should look for opportunities to present to them to give them the choice. Sometimes those introverts come up with the most creative ideas. As an engineer and physicist, I know you need the space to let your mind function the way that it functions. If you try to take a square peg person and force him into a round hole, you're not going to get the best that person has to offer you.

COHEN: How would you describe NASA's challenges today and the challenge of a new administration next year?

JOHNSON: We don't know what's going to happen with the presidential election. That could be a whole new set of challenges we'll have to deal with. As for now, we know that we have lots of challenges making sure that the Ares launch vehicle will be ready for flight in 2014. We know we have a gap between the planned retirement of the shuttle in 2010 and the maiden flight of Ares. There are many hurdles that we need to overcome to meet the milestones before us. In order to maintain support for our mission, we've got to deliver on the first few milestones in the queue for Constellation. We are constantly criticized for schedule slips and cost overruns, so we must be realistic about what we are committing ourselves to and be able to deliver on those promises. That's the only way we'll get the commitment and support we need from the Hill and our other stakeholders.

COHEN: That may involve speaking some hard truths, like saying, "You want us to do this by a certain date but it can't be done with the amount of money you're giving us."

JOHNSON: That's always a challenge, but Mike Griffin is the kind of person who can communicate very bluntly.

COHEN: Does NASA have the skills it needs?

JOHNSON: I think we have a wealth of talent within NASA. As long as we continue to do the things we need to do to fill the pipeline in the STEM fields—science, technology, engineering, and mathematics—we'll continue to have the kind of people we need. It's also a matter of enticing good people in those fields to come to NASA. They won't want to come here if they're going to be contract oversight managers. I know I would not have chosen to come to NASA if I'd been told that I was going to oversee a contract for which someone else was doing the fun engineering work.

COHEN: How do we avoid that?

JOHNSON: We have to strategically assign centers to do in-house work to maintain the competencies we need for the future. We want to develop our engineers with these critical skills and we want to be smart buyers when we contract work out. How can we be smart buyers for procuring systems that we don't have experience building ourselves? How do you have quality engineers if you don't have quality work for them to do? You have to make a conscious decision to ensure a healthy balance between those things you do in house and those things you contract out.

COHEN: Do you think today's engineering students look at NASA as an exciting place?

JOHNSON: It's a mixed bag. There are many students who get excited at the mention of NASA. They are intrigued by space and the research we do. On the other hand, many students have been to career fairs and seen a decline in the hiring opportunities at NASA. We have to make sure that we do a good job establishing the kind of work that would draw good people and then we have to have the flexibility to bring some of them in.

COHEN: Is NASA going out to make the case, to communicate the excitement of the work?

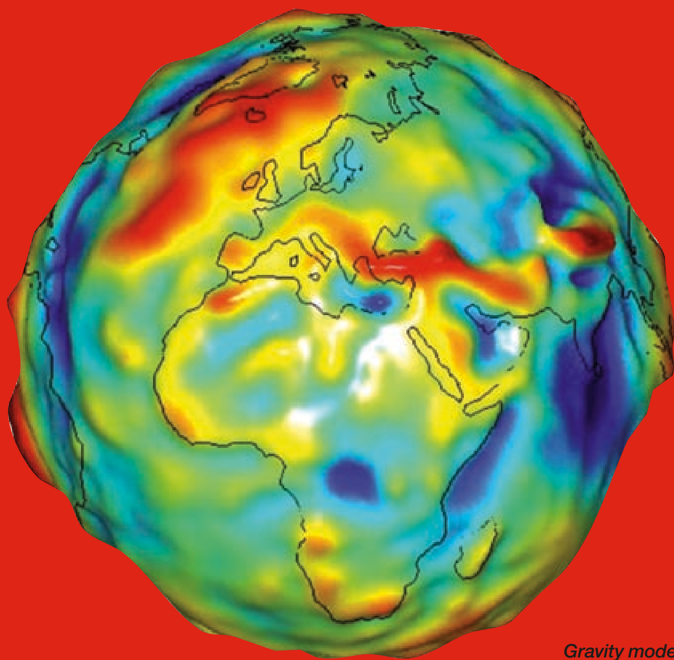
JOHNSON: Yes, we are doing this in many ways. When I do personally, the message is received overwhelmingly well. I have engaged some of the students in dialogue, and I have heard that they are surprised when they visit some of the NASA research facilities. Their school laboratories have the latest equipment so they expect NASA to have at least the same caliber if not better. That is not what they see when they go to some of our facilities. We must do what is necessary to provide them with challenging work and the necessary tools to get the job done. Our laboratory facilities and equipment are important elements for sustaining the capabilities we will need for the future.

COHEN: As a young engineer, your experience with NASA was very positive.

JOHNSON: Yes, the LASER program was designed to give students exposure to engineering in practice. Those kinds of programs are invaluable. When I went to Langley that first summer and got to work side by side with practicing engineers, I was sold. I had opportunities with IBM and others that could offer higher salaries, but I was sold on NASA. After they gave me the exposure and the experience, I didn't want to go anyplace else. I found that once you are on the NASA team, the opportunities are limitless. There are so many parts of NASA, with such a variety of work, that you can move around and have a couple of careers without ever leaving the Agency. ●

The Road to GRACE

BY EDGAR S. (AB) DAVIS



Gravity model figure of Europe and Africa prepared by The University of Texas Center for Space Research as part of a collaborative data analysis effort with the NASA Jet Propulsion Laboratory and the GeoForschungsZentrum Potsdam.

Image Credit: NASA/University of Texas Center for Space Research

On March 17, 2002, twin satellites comprising the flight segment of the Gravity Recovery and Climate Experiment (GRACE) were launched by a Russian Rockot launch vehicle from the Plesetsk Cosmodrome into orbit 300 miles above the earth. The successful launch of that science mission represented not just a technological achievement but years of planning, re-planning, negotiation, and persuasion. The early history of the program suggests some of difficulties and rewards of international cooperation.

LEFT: GRACE launched from the Plesetsk Cosmodrome, a former Intercontinental Ballistic Missile (ICBM) site in northern Russia.

RIGHT: View of the twin satellites in a clean room.

Photo Credits: NASA/University of Texas Center for Space Research

Measuring Earth's Gravitational Field

The aim of the GRACE experiment is to map the strength of Earth's gravity field at given latitudes, longitudes, and times. To measure ocean surface currents using satellite altimetry from TOPEX-Poseidon, oceanographers needed measurements of mean ocean geoid (sea level without the influence of tides and weather) improved by a factor of twenty—from an uncertainty of about 20 cm to about 1 cm. During the concept design phase, it became clear that GRACE could exceed this requirement by more than a factor of twenty-five, and it could do it every month. This remarkable performance extended to the land as well. Among other things, GRACE is now being used to measure both seasonal and year-to-year variations in the storage of water in the world's major watersheds; in the amount of ice stored on Greenland and Antarctica; and the degree to which the sea level is rising due to the addition of water that up to now has been stored on land.

The twin GRACE satellites, separated by 105–165 miles (and by about thirty seconds in time), fly in essentially the same circular orbit under the influence of Earth's total mass. Mass near the earth's surface is not uniformly distributed. The first satellite speeds up along its circular orbit as it approaches a concentration of mass on the surface and slows down after it passes by. Approximately thirty seconds later, the second satellite experiences the same effect. The resulting fluctuation in satellite-to-satellite range is related to the magnitude and extent of mass concentration. A microwave link between the twins measures the ever-changing range with submicron precision. The range measurements and the nongravitational forces on each satellite are recorded ten times per second and sent to the ground twice a day. Every thirty days, the accumulated data is converted to a new mathematical model of the gravity field.

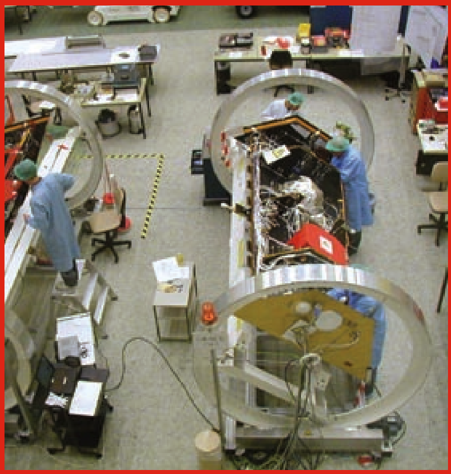
After participating in European Space Agency (ESA)– and NASA-led studies for gravity missions that failed to move out of the study phase, I assumed responsibility for developing the GRACE mission concept into a flight project in 1992. By the summer of 1994, the instrumentation design had taken shape, and we had refined the requirements on twin satellites well enough to begin discussions with potential contractors. I took the requirements on a tour to leading small satellite suppliers in the United States. No one had a design that came close to meeting the mission's requirements for thermal control and structural stability, and no one had experience with the ultra-sensitive accelerometer that we needed to measure the nongravitational forces on the satellite. Furthermore, the United States had given up on developing the kind of accelerometer that was needed.

An International Effort

In the United States we tend to assume that our technologies are the best in the world. This is counterproductive hubris. For GRACE, we used ultra-sensitive accelerometers from France, star cameras from Denmark, custom satellites with an ultra-stable structure from Germany, and a Russian launch vehicle with a custom dual-satellite dispenser. We found it easy to adapt to the Russians' logical and well-defined processes for completely meeting a customer's technical and operational requirements. But it did take long hours to negotiate every point through interpreters and document everything in writing in both Russian and English. It paid off in an efficient six-week launch campaign at Plesetsk with six feet of snow. The Russian-supplied launch vehicle delivered exceptional performance. The Rockot exceeded all GRACE requirements by a factor of three or more.

Our European contractors all worked on fixed-price contracts, so we knew we would get their best people. More importantly, every decision with the European suppliers was made with an accurate assessment of the cost.

The path to international cooperation had its twists and turns as well as opportunities and setbacks. At the July 1995 International Union of Geodesy and Geophysics meeting in Boulder, NASA's John LaBrecque organized a meeting of all the known proponents of various concepts for measuring Earth's gravity field. At that meeting, Dr. Christoph Reigber of GFZ-Potsdam, Germany's geosciences research center, presented the German plans for a single-satellite gravity and magnetic field



mission and expressed interest in the GRACE concept that I presented. LaBrecque suggested that we explore a cooperative U.S.–German mission.

When we took the concept to DARA, the German space agency, the head of DARA's Earth sciences program said a study would be a waste of time because they didn't have the money for the full mission after the approval of CHAMP (CHAllenging Mini-satellite Payload). But DARA had no objection to Reigber using GFZ-Potsdam funds for the study. And we found a potential German ally for our concept at the meeting. Two people introduced themselves as representing DLR's German Space Operations Center, GSOC. I only vaguely knew of its existence, but I made a spur-of-the-moment decision to put my trust in the GSOC and committed to give them responsibility for GRACE mission operations. While the prospects for cooperation looked bleak, we accepted an invitation to visit GSOC the next day. We found a modern but underutilized facility. There were five empty control rooms; in the sixth, a lone operator was monitoring the ten-year-old RoSAT mission, an X-ray observatory. Missions like GRACE were clearly important to their future.

I went on to GFZ-Potsdam with Reigber and drafted an agreement to facilitate NASA sponsorship of the joint feasibility study. In November 1995, I returned to GFZ-Potsdam for six weeks. Reigber arranged for me to share an office with his systems engineering team from Dornier Satellite Systems who were working on CHAMP. I understood that I would be working with this group on the feasibility study, but it soon became clear that my study was not on their radar screen. They were preparing for the CHAMP project's preliminary design review and assumed that I was there for the same purpose. I did help with the systems aspects of hosting the receiver, which NASA had agreed to supply to the CHAMP project. It took some time, but in the process I found that Dornier Satellite Systems had special technical capabilities that were essential to the success of the GRACE mission. Instinctively, Reigber knew that I would connect with the team from Dornier on the GRACE project.

The time at GFZ-Potsdam put me contact with ONERA, the French aerospace lab. The French space agency, CNES, had agreed to supply an accelerometer built by ONERA to CHAMP. In Potsdam, I learned a lot from Bernard Foulon and Pierre Touboul about the limitations and capabilities of their ultra-precise accelerometer. The unit could be easily tailored to the GRACE requirement. The technical competence and integrity of the ONERA team was quickly apparent. They had no peer in the field of ultra-sensitive accelerometers. We needed their device for GRACE.

GFZ-Potsdam planned to use a Russian COSMOS rocket acquired through a German-Russian partnership to launch CHAMP, but a second Russian launch vehicle option was under development by another German-Russian partnership—the Rockot. Both vehicles had the payload capacity and fairing size needed to launch the twin GRACE satellites. I worked out five options for launching the twin GRACE satellites, two on the COSMOS and three on the more capable Rockot.

We still faced serious hurdles. A plan for U.S.–German cooperation on GRACE was shaping up in my study—NASA would supply the GRACE instrumentation and the launch on a Russian launch vehicle, and DARA would supply the satellite and the mission operations—but the plan proved to have a fatal flaw. The Space Transportation Policy of 1994 provided that a NASA payload could only fly on a foreign launch vehicle provided by a foreign government under a no-exchange-of-funds agreement. NASA could not purchase, or contribute to the purchase of, the Russian launch vehicle without a presidential waiver.

Shortly after this problem became apparent, SS/Loral came to the Jet Propulsion Laboratory and described how the GlobalStar satellite bus might be adapted to carry science instruments. The GlobalStar bus didn't come close to meeting the GRACE requirements, but SS/Loral mentioned their corporate connection to Dornier on the GlobalStar project. That suggested a new plan. I saw a way to buy satellites from Dornier through SS/Loral, so NASA could supply the instrumentation and the twin GRACE satellites, and DARA could supply the

IN THE UNITED STATES WE TEND TO ASSUME THAT OUR TECHNOLOGIES ARE THE BEST IN THE WORLD. THIS IS COUNTERPRODUCTIVE HUBRIS.

Russian launch vehicle and the mission operations. SS/Loral and Dornier agreed to pursue the plan. NASA issued the call for a proposal to the Earth System Science Pathfinder program (ESSP). I needed DARA's commitment to the plan.

The timing could not have been worse. The funding for the space program in Germany was being cut by 25 percent and DARA staffing was to be reduced and merged into the DLR. But we needed their signature on a letter supporting our step-one proposal to NASA. We needed to meet with them and negotiate a commitment. Reigber was very concerned and discouraged us from coming to Germany. We took his name off the cover page of our presentation but included him as the proposed co-principle investigator. Trusting us not to embarrass him, he came to our meeting with DARA. GSOC was also represented. Our proposal met with a positive response from DARA management. With Reigber's help, we moved to discussing the content of the supporting letter for the step-one proposal. The new plan was sensitive to German industrial policy regarding reunification, foreign policy regarding strengthening economic ties with Russia, and the reality of a limited budget for space missions. The Germans committed to be part of the step-one proposal. It took similar finesse to get them to be a part of the step-two proposal.

But six months after GRACE was selected for the NASA-ESSP program and two months after JPL received funding for the project, the head of the DLR was planning to tell the NASA administrator that the DLR did not have the funds for GRACE and would not participate in the project. I could only think that he had received bad advice in making this decision. The night before his meeting with the NASA administrator, I obtained the number of the hotel in Washington, D.C., where he was staying and called Reigber in Rio de Janeiro. Reigber awoke the head of DLR at 1:00 a.m. I can only imagine what was said. The next morning, the head of the DLR told the administrator that Germany would cooperate on the GRACE mission. Within a month, the contract between JPL and Dornier was executed. About a year later, NASA and DLR signed the memorandum of understanding, and DLR had selected the Rockot launch vehicle for the mission. The project had a successful mission confirmation review and NASA approved the mission for implementation.

Some Key Points

1. Success stemmed from the essential work of gathering an international team with the skills and capabilities that GRACE required, building relationships, and getting essential commitments.
2. Establishing cooperation with the Germans on GRACE depended on having a respected German scientist, Christoph Reigber, as an advocate for the project. His vision, leadership, and diplomacy with German officials were critical.
3. We created a deal that was sensitive to German policy objectives and a budget crisis in the German space program. In a business-as-usual arrangement, DLR would have purchased the satellites and NASA would have supplied the launch. By reversing responsibility, the DLR's budget for the implementation phase was reduced by about a factor of four.

In the face of long odds, persistence has paid off. For more than five years, GRACE has been measuring and mapping variations in Earth's gravitation. It has shown how much water is used for irrigation in Northern India and near the Aral Sea. It has determined that Greenland's ice is melting much faster than expected, at a rate of 150 to 250 cubic kilometers a year. (One cubic kilometer is about 264 billion gallons of water.) ●

EDGAR S. (AB) DAVIS, an engineer with experience in developing precision optical and RF systems, led the GRACE project through the formulation and proposal phases. He managed the project for the California Institute of Technology's Jet Propulsion Laboratory through the implementation, launch, an early orbit phases. He has a BS in mechanical engineering and an MS in electrical engineering from Carnegie Mellon University. *ab.davis@jpl.nasa.gov*

Fusing Risk Management and Knowledge Management

BY CHARLES TUCKER

An idea had been percolating in Dave Lengyel's mind for some time: how to integrate risk management (RM) and knowledge management (KM) to create a better risk-management approach for the Exploration Systems Mission Directorate (ESMD). How could the wealth of current and future lessons-learned information be fused with RM practices in a dynamic system?

Then, in 2005, came the "Reese's moment," as Lengyel, who had recently joined the Exploration Systems Mission Directorate, calls it—"Hey, you got KM in my RM!" It was the idea of knowledge-based risks, or KBRs, which would couple continuous risk management with lessons learned.

The goal, says Lengyel, was to get away from "a passive collection system" of lessons and into a framework where recognized risks guided knowledge capture and delivery. Rather than introducing new KM tools, a KBR-oriented system would focus on transferring knowledge by infusing it into existing work processes. It would aim to close knowledge gaps by providing broader access to risk information not only relating to NASA legacy programs such as the Space Shuttle and International Space Station but also capturing and transferring what ESMD learns in managing risks along the way.

"A great way to identify risks is through lessons learned, which in many cases were risks that challenged a previous program. KBRs provide that as well as analysis and planning information," says Lengyel, who is now the risk and knowledge management officer at ESMD. "We're just saying, 'Here's what worked or didn't work for this particular risk.' A lot of risk management requires a little bit of art in putting a good plan together."

The timing for launching the KBR effort dovetailed with the cancellation of the Orbital Space Plane, conceived as a crew rescue and transport craft for the space station. There was an abundance of "lessons about lessons" that proved useful in building the KBR construct.

"About that time," recalls Lengyel in an interview in his office at NASA Headquarters, "we started looking at how we were going to do lessons learned differently and more meaningfully than we had in the past." He asked risk and knowledge managers from across the directorate to join a working group that included representatives from NASA's Academy of Program/Project and Engineering Leadership (APPEL) and Office of Safety and Mission Assurance, as well as contractors such as Pratt & Whitney Rocketdyne, Lockheed Martin, the chief knowledge officer at Goddard Space Flight Center, and information technology specialists. "We came up with the concept of knowledge-based risks. We said we were going to capture what worked and what didn't work within the context of risks, put it back into our risk system, and use that knowledge to help us write better risks, identify risks, and have better plans and discrete mitigation steps." The risk database becomes a knowledge base over time—not a separate lessons learned system.

The KM working group began to do benchmarking inside and outside the Agency. It looked at aerospace companies, financial firms, the Department of Defense and the CIA, and a top pharmaceutical company, culling best practices. The initiative began to evolve, taking shape as a four-spoke wheel with KBR as the hub. One of the four practices, called Pause and Learn (PaL) and developed by the Goddard KM officer, was based on the U.S. Army's after-action review; the others are knowledge-sharing forums, experience-based training using case studies, and Web-enabled teams that are growing rapidly. The ESMD's Risk and Knowledge Management portal is located within the Integrated Collaborative Environment (ICE) and already has more than 16,000 registered users. [See accompanying article on how Lengyel's first KBR is displayed on the ICE site.]

At the heart of all this activity was a guiding principle: power to the people. It was a movement away from technology. "A lot of KM effort in the Agency is very IT-centric—what I call the 'IT junkyard' approach to knowledge management," says Lengyel, a former marine aviator and FA-18 and F-15 aircrew training instructor at the McDonnell Aircraft Company before coming to NASA. "We're taking a light-touch approach when it comes to IT tools. Much of what we're doing depends on learning through conversation, people talking to each other, knowledge-sharing forums ranging from brown-bag lunches to more focused workshops and conferences to experience-based training. We wanted to put these things together in a way that would be more closely aligned to process improvement than just strict KM."

The Constellation program provided fertile ground for the new integrative approach. "For Constellation, we looked at requirements-related risks and found that we had 255 risks. Only about a third of them had legitimate mitigation plans. They ranged from 'I'm not going to be able to meet this performance requirement' to 'Given the lack of requirements or immaturity, this risk is going to happen to me.' The fact that they didn't have good mitigation plans was not a good thing for us. So we did some more analysis and found ten things that seem to be working that are reducing risk. Over time what we can do is build templates so we can sit down with risk owners when they come in with a certain type of risk and say, 'Here's a better way to identify the actual root cause, and here are some things to consider in your plan and mitigation steps to really work your plan.'

"One of our challenges two and a half years ago was opening up the risk database. We were told by really experienced risk managers in our directorate that if you open up the database, people will not put risk information in there because they didn't want Ground Ops to look at Capsule to look at Booster, that there would be hesitation to put that information in because we didn't do that before because of different cultures, different centers.

"But you just can't do enterprise risk management if you close the database and partition it off by program and project. We said we've got to get over this structural barrier. So we opened it up and moved on. What helped us immensely during this period was adopting best practices from space station and shuttle and moving it into Constellation, Ares, Orion, and so on."

Lengyel likes to describe RM-KM integration as a "process-improvement approach" that helps the experts—the risk managers—play to their strengths. "People in human space flight understand what risk management is. They understand the foundations, they understand the resource challenges. They also understand why it makes sense to let the risks point you to areas you need help in. I think we do a really good job of risk management. I think we do a lousy job of KM."

As the integration plan is implemented, Lengyel envisions a KBR-capture system built on quality, not quantity. "In the last lessons learned system, there were sixteen hundred–plus lessons. On a good year they collected eighty to a hundred. A lot of that was useless—what I call 'spilled milk' stuff. We want to capture really meaningful information, maybe ten or fifteen KBRs per year."

I DON'T EXPECT RISK OWNERS TO BE DANCING AROUND IN THE DATABASE LOOKING FOR KBRs THAT MIGHT HELP THEM. YOU'VE GOT TO FEED THIS INFORMATION TO THEM, YOU'VE GOT TO DO THE ANALYSIS AND GET IT TO THEM TO HELP THEM DO THEIR WORK MORE EFFECTIVELY.

At ESMD, where the future of U.S. human space flight is being shaped, Lengyel believes merging risk and knowledge management is essential, and that it starts with the practitioners. "It's the risk community, the risk managers, who form the central nervous system for information flowing in our directorate," he says. "I don't expect risk owners to be dancing around in the database looking for KBRs that might help them. You've got to feed this information to them, you've got to do the analysis and get it to them to help them do their work more effectively. Otherwise we're just going to have a fancier lessons-learned system. I call that the 'collect, store, and ignore' approach. Let's stop doing that. Let's make it an active system." ●

MANAGING— AND LEARNING FROM— a Lunar Reconnaissance Orbiter Risk

BY CHARLES TUCKER

Spinning the upper stage of a rocket in flight is one way to stabilize the vehicle, just as a bullet spins to stay on course. But liquid propellant sloshing around in a spacecraft's fuel tanks produces a wobble, or nutation, that can cause instability and alter flight trajectory. The rate of wobble increase is measured by something called nutation time constant (NTC).

In 1994, during its flight, the Clementine spacecraft returned images of the moon. The LRO will travel to the moon in 2008 and map the surface to help pave the way for humans to return.

Photo Credit: NASA/JPL/USGS

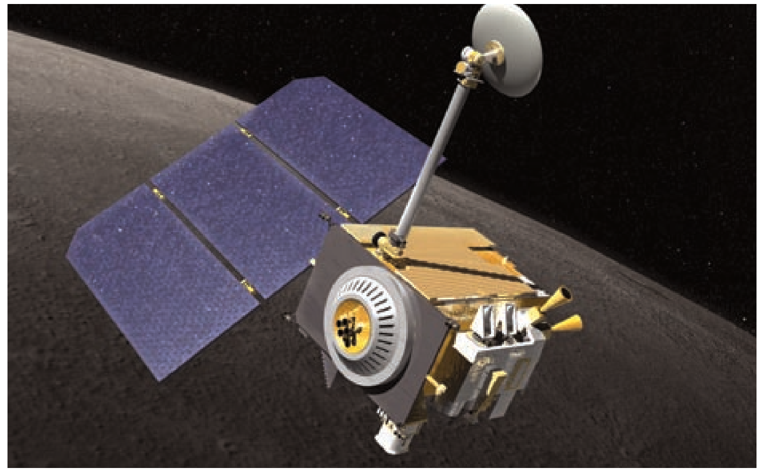
In the case of the Lunar Reconnaissance Orbiter (LRO) with its large propulsion tank, NTC presented a considerable problem. With the moon as LRO's destination, much of the spacecraft's mass had to be fuel—liquid propellant in the mission's initial design. "Driven by the schedule and the hardware availability, we had baselined a large, single tank because that worked well and the design was mass efficient," said Craig Tooley, LRO project manager, in a video interview for the Exploration Systems Mission Directorate (ESMD) Integrated Collaborative Environment (ICE) portal. "With that came uncertainty about the management of the slosh during the spinning phase of the Delta II rocket we were on."

LRO was scheduled for launch in the fall of 2008 for a yearlong mission orbiting the moon as an advance scout for the Constellation program's human space flight missions. In early 2005, with an important design review approaching, consideration of the options for retiring the NTC risk became a paramount issue for the management team.

"As this risk became more and more likely," recalled Tooley, "we were at a juncture where we decided that it was, shall we say, frightening us, and we needed to take it forward with fairly significant mitigations. This meant launching LRO with a solid rocket motor and reducing the need for quantity of fuel or, as ESMD understood the alternative option, launching LRO on a non-spinning vehicle."

It was a daunting challenge at a critical juncture. As Scott Horowitz, associate administrator of ESMD, put it, "This one was so far outside the box that you could just look at it and say this is going to be really hard to solve or you may not be able to solve it without a major redesign of the spacecraft. They were coming into PDR [preliminary design review]. By that time, you want things pretty stable. You don't want a major redesign of the spacecraft—that's the time you don't want to be changing your requirements unless you have to."

How the risk was managed demonstrated a "process working very, very well," said Tooley. Successful mitigation hinged



Artist's concept of the Lunar Reconnaissance Orbiter.

Image Credit: NASA

on open, two-way communication throughout the decision-making process as the risk was escalated from the project to the program level. It required a strategy and plan that reflected an enterprise risk management approach. NTC presented some other characteristics as well of a model "knowledge-based risk," or KBR, the linchpin concept in an initiative at ESMD to integrate risk and knowledge management: communication was critical, analysis of alternatives would lead to opportunity, and the risk appeared late on the project timeline. It was adopted by Dave Lengyel, the directorate's risk and knowledge officer, as the flagship example of a KBR. [See previous article.]

A launch delay for LRO was looming if the NTC problem could not be resolved without redesigning the craft—an option, Tooley said, that simply "wasn't compatible with the time we had." On the other hand, "If we actually went and carried this risk forward unmitigated and launched with a great uncertainty, the risk was the rocket flight wouldn't follow the right trajectory when we got to the moon—and obviously we were never going to go down the path where we launched with that kind of risk."

Carl Walz, a former shuttle astronaut and acting director for ESMD's Advanced Capabilities Division, which oversees LRO as part of the Lunar Precursor Robotic Program, described the pressure on the project. "As the Vision for Space Exploration articulated, this is really our first big mission to the moon. We wanted to make sure we got out of the starting gate on time with a winner. The challenge was the schedule because we were trying to make the end of 2008. It was a very aggressive development schedule.

"We had pulled one of the best project managers in Craig and given him a tough task: have this thing ready to fly, and fast. We were concerned about schedule because when we compared LRO to other projects of about the same magnitude, it was clear that we were bucking a trend, that typically these projects took longer than what we were projecting. We kicked around the options: 'Well, we might be okay, we might be able to solve the nutation time constant [with spacecraft redesign].' But there was significant risk, and there was no confidence that we could find a way to deal with that."

"They were in a bad place time-wise to handle a problem of the magnitude they were facing," Horowitz recalled, "so they either had to make a decision to make a major design change to this vehicle … or they were probably going to not be able to solve this problem in the time that they had to solve it, with the resources they had. In my opinion they couldn't have gotten there from here with all the constraints."

The nature of the risk and the specialized analysis it required made mitigating NTC especially tricky. As Tooley explained in the ICE video interview, "Spinning spacecraft with large volumes of fluid is something that has been tackled, but they're basically unique design problems." LRO consulted the small cadre of experts in the discipline, who recommended a series of scale-model tests and design iterations. But there wasn't time in LRO's schedule to allow for that work.

Horowitz, a former shuttle astronaut like Walz and an aerospace engineer by training, explained the typical process. "The thing you want to do is survey everything that has gone before and at least envelop your problem. So we say, 'Hey, these people had a problem and the mass of their tank was this high and their rotation rate was this high,' and you plot all those points, and if you're somewhere in there, then you have a chance of solving your problem. But if you look at all the work people have done for a similar problem and you're here"—LRO's unique position—"then you've got a real problem on your hands." The LRO mission, Horowitz believed, needed "to find another path" to mitigate its NTC problem—and soon.

"As the nutation time constant risk rose in likelihood," said Tooley, "we decided it warranted, independent of our risk-management process, discussion and decision making at the headquarters/directorate level. We presented the potential mitigation for the risk and the options for what could be done about it, thus enabling Scott Horowitz to make a decision."

The solution—changing launch vehicles from a Delta II to the bigger Atlas V, which didn't have spin stabilization—would not only mitigate the NTC risk, it would provide an unexpected bonus. Tooley explained how the mitigation decision process rippled through spacecraft design considerations, influenced cost, and opened the door for a secondary payload.

"One of the weighting factors was the larger launch vehicle. The fact that it was larger didn't actually matter—it was that it had a guided third stage, not a spinning third stage. That

THEY BASICALLY CAME UP WITH THEIR OWN SOLUTION … BY HAVING THAT OPEN COMMUNICATION AND NOT JUST SAYING, "WE GOT A PROBLEM," BUT "HERE ARE ALL THE POTENTIAL IDEAS WE THINK WE HAVE TO SOLVE THIS RISK."

enabled us to do some simplifications of the design. We said, 'Well, we have a larger fairing now, how could we use this potential decision to mitigate some of the impacts of this redesign we have to do?' [Rather than buying a single large tank that would have needed baffles on a Delta], now we'll use some existing tanks we can get ahold of—there were actually tanks from the cancelled X38 programs—that we couldn't fit in the Delta fairing … and get ahead on that part of the design cycle. That'll make our jump a little easier as we redesign." In addition, the larger fairing allowed for the use of a more traditional panel solar array rather than the originally planned complex folding array. "We exploited all the fringe benefits of going on the larger launch vehicle to help reduce the risk that the redesign itself would impact our schedule," Tooley said.

As the project manager described it, this was all part of the "calculus" done at the associate administrator level. The result of this calculation was not only NTC risk mitigation but the addition of the Lunar Crater Observation and Sensing Satellite (LCROSS), a mission designed to excavate a polar crater on the moon for buried ice. "Our side was fairly constrained by our design, so there was a lot of mass margin going to go to waste. They exploited that opportunity to send a companion secondary payload to the moon to really augment the questions that LRO was addressing. That made the increased cost of the launch vehicle acceptable to ESMD, because they actually fly two missions instead of just one, as well as reducing the risk of the primary mission."

Horowitz concurred on the dual-benefit byproduct: "They didn't have to do any major redesign of the spacecraft, they're on schedule … and we got a whole other spacecraft out of the deal."

The process of retiring the NTC risk on LRO illustrated the importance of an underlying principle of risk and knowledge management integration: communication. As Tooley said, "We were tracking this risk as it elevated in our awareness, until it precipitated the discussion that we should take this forward to an ESMD decision level, and we said, 'Yo, folks, we think this risk warrants some higher-level discussion.'"

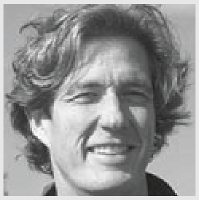
From the ESMD viewpoint, said Walz, the process was paramount. "What really stood out was the ability of the project to go all the way to the top and having the folks at the top be willing to hear the issue and entertain something as radical as going out and getting a brand new launch vehicle. It was the freedom to be able to come forward with potential solutions and then, given the decision-making authority, the latitude to go forward and accommodate another mission."

As Horowitz recalled in the ICE interview, "What I've been real happy with on this project is the fact that the communication is good. People shouldn't be afraid to escalate their risks …. What I have found is that ideas basically generate more ideas …. [That] helps you make connections to other experiences that you might have. By elevating it, with potential different solutions, it wasn't us saying, 'Hey, go stick it on another rocket.' Somebody in the group somewhere had come up with that idea, and so we started probing and asking more questions and asking them to dig deeper, and then they basically came up with their own solution … by having that open communication and not just saying, 'we got a problem,' but 'here are all the potential ideas we think we have to solve this risk.'"

Earlier this year, LRO was in the middle of the integration phase, being prepared for thermal vacuum testing in simulated space conditions. The mission was on schedule for an October launch.

The process of mitigating the NTC risk was ripe for capture in ESMD's knowledge-based risk system, which is why Lengyel, the ESMD risk and knowledge management officer, showcased it on the directorate's ICE portal as the first KBR based on a closed risk. When Constellation Program Manager Jeff Hanley projected NTC on the screen at a review as an exemplar of knowledge-based risk management, Lengyel was satisfied: The integrative approach to addressing risk, based on knowledge sharing, had begun to take flight. ●

CHARLES TUCKER works with Dr. Edward W. Rogers, chief knowledge officer at Goddard Space Flight Center, on organizational learning and knowledge management initiatives using case studies of Goddard and other NASA missions.



Infusing Operability: KSC Launch Experience Helps Shape New Vehicle Design

BY PAT SIMPKINS, ALAN LITTLEFIELD, AND LARRY SCHULTZ

For the designers of a new launch vehicle, reducing mass is a major goal and seems an absolute good—the lower the mass, the less energy needed to put a spacecraft in orbit. Given a choice, for instance, among different temperatures for storing pressurized helium on the vehicle, designers of the Ares 1 upper stage are likely to choose the lowest temperature option to improve performance and save weight. But the effects of that choice on ground operations could be extensive and expensive. The need to supply the extra-cold helium would add complexity and weight to the mobile launcher and crawler-transporter, which carry the launch vehicle from the Vehicle Assembly Building to the launchpad. That change could require a new kind of rock for the crawlerway that the crawler travels on, and that change might have its own further consequences. Looking at the mission as a whole, what seemed like an easy way to save 300 lbs. on the launch vehicle turns into a design choice that would cost $25 million in ground systems modifications.

In fact, many large and small decisions about the design of launch vehicles and spacecraft have profound implications for the speed, reliability, and cost of launch processes and other ground operations. Pat Simpkins, director of engineering at Kennedy Space Center (KSC), describes the consequences of such decisions as being like "the house that Jack built"—the nursery rhyme that describes a long chain of escalating linked actions. ("This is the cow with the crumpled horn,/ That tossed the dog,/ That worried the cat,/ That killed the rat,/ That ate the malt/ That lay in the house that Jack built.") As in the case of the pressurized helium tank options, a single design decision can unleash a cascade of effects that the designer cannot foresee and probably does not even think about. Simpkins talks about the importance of "infusing operability" into the next generation of launch vehicles and crew vehicles by making the knowledge KSC has gained from decades of launch experience an integral part of the design discussion and decision making.

Sometimes a design that improves ground operations does not even require significant trade-offs from launch vehicle or spacecraft designers. Designers may simply not be aware that one of two options they see as essentially equal may in fact be a much better choice in regards to ground systems. For instance, the original design for the Crew Exploration Vehicle (CEV) had access points on different sides of the vehicle, which would require building a second tower. Designing the vehicle with all the access points in one vertical line will save many millions of dollars and reduce complexity. The integrated design team at KSC worked with the CEV designers to relocate the hatch and eliminate the need for the second tower at the launchpad.

Alan Littlefield, chief engineer for the mobile launcher (a transportable launch base), says that KSC has always tried to use what it has learned from decades of launch experience to steer design teams in the right direction, but ground operations rarely played an extensive official role in the design process in the past. That is changing with the Constellation program, adds mobile launcher project manager Larry Schultz. He says that operations' contribution to the design process for the new Ares launch vehicle and Orion crew vehicle is "ten times what it was for the shuttle."

KSC's direct involvement in design discussions and its ability to question design ideas is new and important. The technical

The crawlerway, in the foreground, still bears the tracks of the crawler-transporter that delivered Space Shuttle Endeavour *to Launch Pad 39A, in the background.*

Photo Credit: NASA/Ken Thornsley

THE FUTURE MISSIONS BEING PLANNED NOW WILL CALL FOR QUICK TURNAROUNDS AND BACK-TO-BACK LAUNCHES TO SUPPORT THE IN-ORBIT RENDEZVOUS OF CARGO AND CREW VEHICLES.

An artist's rendition of an Ares I rocket at Launch Pad 39B at Kennedy Space Center. The pad, previously used for Apollo and shuttle launches, will be modified to support future launches of Ares and Orion spacecraft.

and budgetary challenges of the Agency's new space exploration goals make it essential to apply all NASA's best experience-based knowledge to the design of new vehicles and spacecraft. The cost and reliability of the new technology throughout its life cycle—design, manufacture, and many launches—need to be considered up front and inform design choices.

The future missions being planned now will call for quick turnarounds and back-to-back launches to support the in-orbit rendezvous of cargo and crew vehicles. Among the important strategies for improved operability will be designing vehicles that require minimal testing on the launchpad and will be as close as possible to ready to fly when they reach the pad. The Space Shuttle requires six to eight weeks of testing and preparation on the launchpad; the goal for new vehicles would be only a week or two on the pad.

Cutting the current time that dramatically would have several clear advantages. It would mean less exposure to the elements—think of the hail damage that delayed *Atlantis's* STS-117 mission. And, if problems do arise during preparation and testing, they can usually be handled better in the Vehicle Assembly Building, which has better analytical facilities and better access to all parts of the vehicle than the launchpad.

Not all of KSC's recommendations are adopted, of course, but Littlefield says that decisions are at least made with an understanding of the overall economic and operational costs. And sometimes the discussions leading to decisions that go against KSC's recommendations generate new ideas and better designs that help improve performance or reduce costs. The discussion about supplying the Ares 1 upper stage vehicle with helium for pressurization considered, among other things, raising the helium to a higher temperature to reduce the effects of cost and weight on the mobile launcher. Ultimately, that option was not chosen, but the conversation eventually led to a design that provided the lowest practical helium temperature and promised improved performance at reduced cost. ●

PAT SIMPKINS is the director of engineering at Kennedy Space Center.

ALAN LITTLEFIELD is the mobile launcher chief engineer, with twenty-three years of experience designing and testing ground support equipment, launch systems, and test equipment and facilities.

LARRY SCHULTZ is the program manager for the mobile launcher.

Applying the Secrets of Hubble's Success to Constellation

BY FRANK J. CEPOLLINA

From its ignominious beginnings to its triumphant redemption, the story of the Hubble Space Telescope is known around the world. What is less well known is the story behind the story—the elements that made Hubble's ultimate success possible.

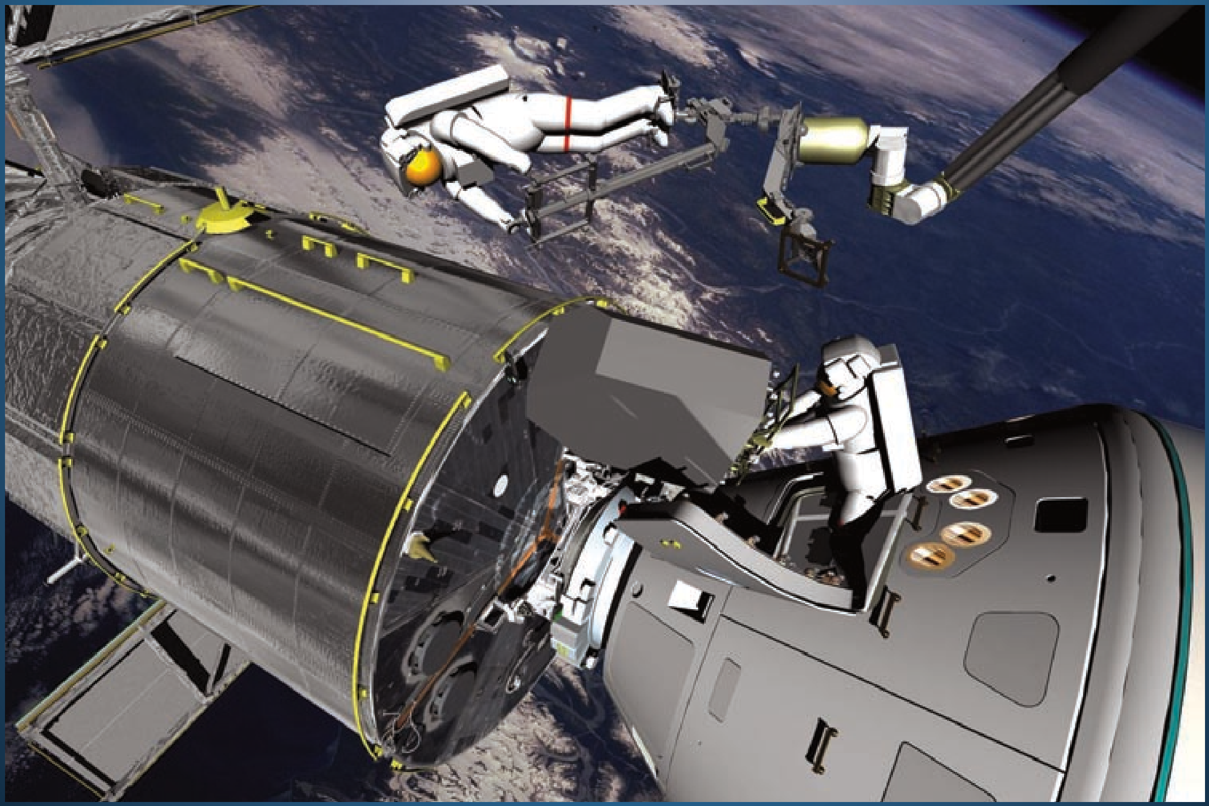


Image Credit: NASA

Artist's conception of astronauts preparing for extravehicular activity from the new Crew Exploration Vehicle.

Astronauts service the Hubble telescope during a spacewalk.

In 1990, I waited impatiently with the rest of NASA for the first images from the marvelous new Hubble Space Telescope to be released. Then came the bad news: spherical aberration. Simply put, the much-touted space telescope had blurry vision. The embarrassment was excruciating as the world came to know Hubble as the $1.6 billion "techno-turkey."

This would have been the end of the story—and possibly the end of NASA as we knew it—had it not been for the forward-thinking designers of both Hubble and the Space Shuttle. You see, Hubble and the Space Shuttle were on the drawing boards at the same time, and managers realized that on-orbit servicing by the Space Shuttle could regularly enhance and upgrade the space telescope.

Fortunately, both Hubble and the shuttle were built with servicing in mind. The shuttle got a robotic arm for rendezvous and capture, and Hubble was built with two grapple fixtures and astronaut-friendly handholds, latches, and modular instruments that could be changed out during spacewalks. These were the features that allowed astronauts to fit the space telescope with the corrective lenses that saved Hubble's vision and NASA's reputation. Since then, Hubble has become a phenomenal scientific success story with major astronomical discoveries being made in rapid succession, servicing mission after servicing mission. The public appreciation of this type of science exploration has also been very gratifying.

Looking back over the past fifteen years, I believe that four major elements made this success possible: developing architecture, bringing fresh technology to orbit, looking toward the future, and collaborating. As we move forward with Constellation, these are the things that should keep NASA on the path to success.

Architecture

I define "architecture" as the collection of hardware, individuals, and facilities needed to achieve major goals. History has taught me that the architecture needs to be developed in conjunction with transportation systems and astronaut capabilities. Trying to retrofit an in-space servicing capability to concepts and hardware for which it was not originally planned costs time, money, heartache, and additional risk.

Modularity is the heart of serviceability and the secret to project cost-effectiveness. When you build subsystems and systems as clean, separate modules with minimal mechanical, electrical, and thermal interfaces between them, you'll see how much more quickly they can be integrated and tested, and how much money that saves. At Goddard Space Flight Center, modular spacecraft were designed and flown on several missions, including Solar Max, Compton Gamma Ray Observatory (GRO), Landsat 4 and 5, Extreme Ultra-Violet Explorer, Upper Atmosphere Research Satellite, Ocean Topography Experiment/Poseidon, and several Department of Defense missions. In these programs, modularity reduced mission integration times by as much as half. Since integration and testing costs account for one-third of program cost, a 50 percent reduction in the integration and testing times results in significant program cost savings.

For most scientific and Earth operational programs, proper architecture is the most significant factor in limiting project costs. Solar Max, Weststar, Palapa, Syncom IV, GRO, and Intelsat VI were all repaired and put back into operation without a separate servicing investment during development. Not one dime was budgeted for satellite servicing.

From time to time as new programs are initiated, study managers comment that incorporating servicing into their design would drive up the design cost. This is because they are working with designs that do not take advantage of modularity. Experience shows that these designs are inherently more expensive, both because of the longer integration and testing times and the fact that they are not easily and quickly repairable on the ground, let alone in orbit.

When we began designing modular, serviceable systems to take advantage of the new shuttle space transportation system way back in the seventies, we kept intensively focused on the shuttle development to make sure it had the scars (mechanical and electrical interfaces) needed for spacecraft servicing. Accommodations for servicing by the transportation system are vitally important. That's why the development of future spacecraft systems—including transportation systems—must maintain coordination and remain conscious of and communicate each other's needs.

Fresh Technology to Orbit

On-orbit servicing of satellites such as Hubble dramatically accelerates the rate of scientific discovery by bringing instruments with the newest and freshest technology to orbit.

As new technology becomes available, spacewalking astronauts fit Hubble with the latest, most advanced instruments and replace components that would otherwise wear out and limit the telescope's life. Each visit increases the telescope's capabilities by at least a factor of ten. On the fourth servicing mission, scheduled for later in 2008, we are taking two instruments to orbit that have twenty to twenty-five times more observing power than the instruments we're bringing back home.

If you have the ability, whether with robots or the Constellation crew vehicle, to carry things to your orbiting facility, you can make changes, upgrade, service, repair, recover, and rescue. And if you manage carefully, you can take brand new technology to orbit on a planned, periodic basis. Things wear out. Technology becomes outdated. The ability to upgrade is a real asset, because technology for items such as detectors, optics, electronics, computers, and communication systems continues to get better exponentially. As we have learned through Hubble and on-orbit servicing, you can keep your astronomical observatory or other satellite at the cutting edge, useful, and relevant, to address the latest scientific questions.

FOR MOST SCIENTIFIC AND EARTH OPERATIONAL PROGRAMS, PROPER ARCHITECTURE IS THE MOST SIGNIFICANT FACTOR IN LIMITING PROJECT COSTS.

The Future

As an agency, we must think ahead. If, as many of us believe, the Constellation architecture is capable of more than just ferrying people from Earth's surface to the International Space Station or the moon, then let's start thinking now about how to modify and augment Orion to make in-space servicing possible. A grapple arm fixture and a storage location to carry reasonably sized instruments can be designed into Orion now. Trying to do it ten years from now, when the hardware is built and moving out to Cape Canaveral, will be too late and too expensive. If the investment is already being made for transportation now, let's make sure the capabilities for servicing are there, too.

Every NASA program and project manager—including those on the Constellation program—must look toward the future as they prepare hardware so they can take advantage of systems as they come online. Think through what you want your systems to be doing ten to twenty years into the future. If you cannot modify the elements of your architecture to achieve all the goals that you want in space, at the very least do not preclude the potential for upgrading later. Allow for expandable architecture.

Although there are no plans for servicing Hubble after the 2008 servicing mission, we're going to be attaching a soft capture mechanism to the aft end of the telescope. At a minimum, this will allow some type of robotic or human rendezvous and docking and for Hubble de-orbiting. A grapple fixture is going to be installed on the James Webb Space Telescope (JWST) even though there are no plans to service or upgrade it. What if our capabilities change ten years into the future and JWST has a problem? At least there will be something onto which a robot or a manned vehicle can connect during a rendezvous docking and repair attempt. Even if we are not going to service these satellites in orbit, we should make them modular so we can replace power systems, communication systems, and detector systems simply during ground integration and testing.

In the case of the Crew Exploration Vehicle, we have been making the point for designers to provide attach points and the capability of controlling robotic systems from the vehicle. Cargo storage provisions need to be added to the service module. If you can't design your architecture with a general-purpose, widely applicable system, at least design it so it can be easily upgraded in the future. Think about the future now and don't make the future hostage to the decisions you make today.

By the same token, observatories need to be designed with higher degrees of modularity. It makes no sense to bury a fine guidance telescope control system in the middle of an instrument or instrument cluster. Think of what that does to program cost when one has to remove and reintegrate the science instrument to repair a failed control system component on the ground, let alone in orbit. NASA Administrator Michael Griffin said, "It's

A soft capture mechanism will allow the new Crew Exploration Vehicle to capture satellites.

Image Credit: NASA

dumb to put big money in big systems that cannot have their lives extended, serviced, and repaired if necessary."

The future has a claim on the present. There's an enormous penalty to be paid for lack of foresight.

Collaboration

The Hubble Space Telescope project, through its engagement with multiple NASA Centers and contractors, has been best served by the "collaborative relationship" and "badgeless society" approaches to project management. In a collaborative relationship, everyone on the team works together in a non-threatening atmosphere. This approach encourages inclusion and the realization that coworkers are all part of one NASA family, and it attracts the best of the best technologists from around the world. In a badgeless society, multimember teams work side by side, and those with the best, most appropriate skill sets lead particular aspects of the job, irrespective of center or company affiliation. These two approaches to project management are particularly equalizing, empowering, and effective.

For example, during the development of new solar arrays for the first servicing mission, the European Space Agency (ESA/Estec) encountered difficulties in testing bi-stem shields to the rigors of solar space environment. To solve the problem, we went to Glenn Research Center to develop a special ultraviolet/free atomic oxygen test facility, and they conducted a series of evaluation tests. Eight years later, when we were developing rigid gallium arsenide arrays for Hubble Servicing Mission 3B, we went to ESA/Estec because they had developed a large-diameter solar-illuminated thermal vacuum facility (the best in the world) to test a new array for thermal-induced jitter.

It is important to avoid the common pitfalls of multicenter participation, with assignments of center efforts based on their technical merits. Partners should coordinate and communicate information and requirements but not direct how the work is to be done. We have to shun short-sighted tendencies, including insisting that "it has to be done my way"—getting hung up on the "how" and losing sight of the "why," the shared goal. Centers have to earn and establish trust in each other, and center directors have to take ownership of the partnering activity.

By forging multicenter strategic alliances, partners gain access to the unique strengths of the centers. These symbiotic relationships offer experience that no one center can achieve. Strategic technologies enable each center to develop and advance unique technologies, so they can be offered to other centers. Communication is the key to collaborative success. Each center needs to communicate its strategic technologies, and through communication and trust, centers must eliminate center-to-center divisiveness and needless competition. In addition, program offices must avoid stovepiping tendencies that further hinder the application and advancement of new technologies across the Agency.

From Hubble to Constellation

Time is running out. Constellation is moving ahead. It's like a train that's moving faster and faster down the track. It's time we hop on and start providing trailblazing missions that demonstrate the usefulness of these new systems. We can and must apply the lessons learned from Hubble to Constellation. This doesn't have to be expensive. For example, a pathfinder can demonstrate that you are adding mechanical bolt-down and electrical interfaces (scars) to Orion so it can be used for repair and servicing in the future.

We did it with shuttle, we can do it with Orion. It's just a question of whether or not we have the willpower, common sense, and foresight. ●

FRANK J. CEPOLLINA serves as deputy associate director for the Hubble Space Telescope Development Project at Goddard Space Flight Center. He is known as the "Father of On-Orbit Servicing" for his decades of leadership in repairing and upgrading satellites in orbit. He has received several awards for his leadership and efforts, including a NASA Exceptional Achievement Award (1985), NASA Outstanding Leadership Medal (1993), the 1994 National Space Club Eagle Manned Mission Success Award, and the Space Logistics Medal (2005) from the International Society of Logistics. In 2003 he was inducted into the National Inventors Hall of Fame.

Harvesting Project Knowledge

BY NANCY M. DIXON AND KATRINA PUGH

"Every time we do something again, we should do it better than the last time" has become a familiar refrain. It means the knowledge gained from experience should be used to improve performance of the next similar task. Why doesn't that happen as often as it should? For one thing, project teams don't always understand what they've done right (or wrong). Teams are often unable to repeat their successes because they have little insight into what worked well the first time. Individual reflection is unlikely to arrive at a full understanding of the team's work, with its multiple interwoven elements. Without time to reflect, teams may repeatedly make the same mistakes and carry them forward as members move on to other projects.

Even when a project team does analyze its processes successfully—maybe through an after-action review, or "hot wash"—the knowledge gained seldom gets to other teams that can use it. Many organizations struggle unsuccessfully to share valuable knowledge between projects. Little-used lessons learned databases and project reports that are filed and forgotten are familiar artifacts of these efforts.

We have developed a process we call "facilitated knowledge harvesting" that we have carried out in a number of organizations. This approach, piloted at a large semiconductor manufacturer, has helped the company speed knowledge collection and transmission and improved the likelihood that it gets productively reused.

The harvesting process involves five important steps (though, as the examples show, two steps may overlap or coincide to some extent):

1. **Select** projects for knowledge harvesting. The selection process is important because only projects that are likely to generate knowledge that can be profitably applied to other valuable projects can justify the investment of time and talent that harvesting requires.
2. **Plan** the harvest cycle from pre-work through capture and reuse. Planning involves both logistics and stakeholder identification. Who should be part of the harvest? When it comes to knowledge originators (those who have gained the knowledge through their work), it's best to have deep subject-matter expertise and comprehensive knowledge across the project, or "big picture" people in the harvest. When it comes to seekers (those who could use the knowledge), the most obvious beneficiaries are a team preparing to do a similar task in a different context or teams encountering a similar context, even when their task is different.
3. **Discover and capture** valuable knowledge. This entails bringing together the knowledge originators and seekers either virtually or in the same room and facilitating a conversation that roughly follows the agenda developed during the plan. Importantly, the facilitator draws out both the seekers, who ask questions, and the knowledge originators. Reflection by the originating team is the first and most significant step in achieving reuse by other teams. Unless the originating team understands the basis for its own successes and failures, it will not be able to provide accurate, clear, and translatable lessons for others.
4. **Broker or transfer** the knowledge through systems and directly to seekers. Tag and publish the knowledge harvest documents in an appropriate knowledge repository. In a study of knowledge transaction costs, Prusak and Jacobson (2006) found that 38 percent of these costs lie in simply eliciting knowledge from experts. Importantly, the harvest process involves facilitating connections between knowledge originators and seekers at the harvest as well as other potential reusers of the harvest insights who may not have been present during the event. These intentional connections greatly reduce time spent eliciting knowledge.
5. **Reuse** the knowledge. Teams engaged in similar tasks, or working in a similar context, use the knowledge to carry out their own work. Prusak and Jacobson found that 46 percent of knowledge transaction costs lie in adaptation, largely because knowledge was "thrown over the wall" with little context added. Knowledge harvesting encourages seekers to reuse the knowledge and help draw out the context from the knowledge originators. Even reusers who do not attend the harvest event get the benefit of rich contextual information that facilitates adaptation.

Based on our research and practice, we found that success in eliciting and reusing knowledge relies on a vital mix of these three ingredients:

1. Facilitating knowledge harvest
2. Engaging knowledge seekers
3. Brokering the knowledge

Facilitating Knowledge Harvest

The facilitator steps in when knowledge originators cannot always see the relevance of their own knowledge. The facilitator helps to identify potential seekers of the originating team's knowledge. Finally, the facilitator helps transport the knowledge to others who could use it.

Facilitation is crucial to bringing important knowledge to the surface, putting it in a meaningful and useful form, and communicating it to potential reusers. An effective harvest event environment encourages participants to speak concretely, avoid blame, withhold judgment, and ground their assumptions in shared meaning. When team members, aided by a skilled facilitator, reflect together on their work experience to derive lessons for themselves, confidence and comprehension both increase.

For example, a semiconductor manufacturer has endeavored to maintain performance standards across fabrication plants. The company deployed veteran managers from an established "fab" to a new plant during its start-up phase. The challenge was to help the new plant operate smoothly when the veterans left. Facilitators conducted a knowledge-transfer event for veterans and new managers. The facilitation elicited a deep discussion about judgment and non-intuitive plant behavior, concepts that were beyond the written manuals.

Engaging Knowledge Seekers

The facilitator guides the conversation, but the seekers have a vested interest in the outcome and a practical understanding of what they need to know. A few prompts from a facilitator can often launch a very effective knowledge transfer. Seekers have the opportunity to focus discussion on the knowledge that matters to them and to explore those ideas until they understand them.

When knowledge seekers are engaged in the harvest, the likelihood of harvesting the most important knowledge and of having that knowledge put to use is increased. At the harvest event, the knowledge originators comprise a "panel," with seekers in the audience. Seekers include members of other project teams, as well as methodology keepers, training developers, and marketing authors. Because seekers are motivated by self-interest, they ask extended questions and think about adaptation costs. The harvesting event brings out important nuances and meanings, not just recitations of "here's what I did." As a result of the harvest, teams are not only emboldened to reuse the knowledge but also more effective at using it.

"LIVE" HARVESTING SESSIONS ZERO IN ON THE KNOWLEDGE PEOPLE REALLY NEED AND ALLOW FOR THE BACK-AND-FORTH CONVERSATION THAT CREATES GENUINE UNDERSTANDING AND HELPS POTENTIAL REUSERS ADAPT THE ORIGINATORS' EXPERTISE TO THEIR OWN NEEDS.

Here's an example. Pharmaceutical companies carry out a multiyear development process that goes from original research through in vitro testing, animal testing, clinical testing, FDA approval, launch, and marketing. At any one time, several teams will be at different phases of that multiyear process. At one large pharmaceutical company, a team that had just completed the FDA approval stage met with a team working on a similar drug category that was preparing to enter that phase. The originating team was able to transfer up-to-date knowledge about the social, political, and regulatory factors they experienced in their review that had implications for the type and detail of the data the approval would require. Bringing together originators and seekers in this knowledge harvest shortened the product development cycle, not only for this phase but for many other phases as well.

Brokering the Knowledge

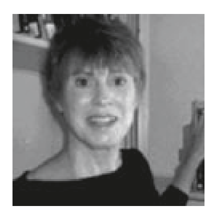
Both the facilitator and the seekers become "brokers" of the knowledge gained in the harvest, acting as intermediaries who bring the knowledge to others. The seekers take knowledge into their worlds—of projects in process, methodologies, training or marketing materials—and transfer it through participation, direct outreach to colleagues, and publishing.

At a technology-consulting firm, a knowledge seeker–turned-broker, who was responsible for project methodology, learned about a new approach to measuring data center power consumption during a harvest. The seeker went beyond the agenda of the harvest and probed the originating team's innovative measurement experience with his questions. What he learned allowed him to package the methodology for subsequent data center power-management projects at different clients, saving considerable time in the assessment phase of subsequent projects.

"Live" harvesting sessions zero in on the knowledge people really need and allow for the back-and-forth conversation that creates genuine understanding and helps potential reusers adapt the originators' expertise to their own needs. It also benefits the expert panel members, who often get insight into their own work in the process of explaining it and also learn from seekers—active knowledge exchange almost always goes in both directions.

The Power of Connection

What makes the harvest better than more familiar efforts to capture knowledge in lessons learned databases or reports is the interpersonal component. By adding adroit facilitation, engaging seekers in the harvest, leading ongoing interpersonal knowledge transfer, or "brokering," knowledge gets into circulation and improves the way we do our work. Knowledge harvesting requires an investment of time and skilled personnel, but it actually works. Knowledge harvesting is less about capture and more connection and conversation. ●



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TO STAY OR

A UAV SCIENCE PROJECT STORY

BY TONY KIM

What would you do if you were a scientist and had just been told by the safety authority that you can only search above the ocean for the science data that you can only get over land?

GO?

Photo Credit: NASA

The Altus in flight.

What would you do as a project manager who has already spent twice the analysis budget when the analyst asks for another chunk of change so he might be able to give you a partial answer to meet requirements that seem to be a moving target?

This was our dilemma in the spring of 2002. I was the project manager of the three-year Altus Cumulous Electrification Study (ACES) from beginning to end. It is rewarding to start and finish a project successfully, but this one could easily have been terminated if back-up plans had not been available and ready for use.

The Mission

ACES was a science experiment to investigate thunderstorms using an unmanned aerial vehicle, or UAV. At the time, the UAV was a new technology that could make a significant and unique contribution to the study of lightning and thunderstorms. Its measurements could be linked to global processes to provide an improved understanding of the total earth system. Part of the NASA-sponsored, UAV-based science demonstration program, the ACES project objectives were

- To conduct high-quality research that exploits a UAV's unique capabilities
- To demonstrate the utility and promise of UAV platforms for earth science
- To build confidence in UAV platforms
- To identify mission planning and operations unique to a UAV
- To advance UAV operations in national air space

BOTH AN EARLY BAD DECISION BASED ON INSUFFICIENT DATA AND A WELL-INFORMED DECISION MADE TOO LATE CAN DAMAGE A PROJECT.

The decision to select the Altus UAV from General Atomics Aeronautical Systems was based on a number of factors, including the maturity of this aircraft system, its performance capabilities and proven flight record, and the successful integration and flight of a developmental version of the ACES payload on Altus in September 2000. In addition, Altus was an electrically quiet platform, ensuring that the thunderstorm measurements could be readily achieved. Slow flight speed coupled with long endurance and high altitude flight gave the Altus aircraft the ability to be maintained continuously near thunderstorms for long periods of time so investigations could be conducted over entire storm life cycles.

The only limitations encountered during the campaign were significant maintenance issues associated with the Altus, arising in large part because it was flown near the edge of its operational limit. The potential for maintenance problems was acknowledged even during the proposal development phase, and some issues did arise during the mission. Clear flight rules defined by General Atomics helped ensure safe operations, though. One rule, for instance, was to maintain altitude so that the UAV could glide back to the runway if it lost engine power.

Seeking Flight Approval

Patrick Air Force Base at Cape Canaveral was the primary deployment site identified in the ACES proposal. It was selected first for the unique ground-based lightning measurement systems located at NASA's Kennedy Space Center. Second, we believed that deploying at Patrick, with easy access to the Eastern Test Range and restricted coastal airspace, would ease the FAA approval process. We didn't foresee the problems that ultimately led to a "no-fly" decision from Patrick.

Predeployment planning and activities (extending back to the proposal development stage) progressed smoothly. From its inception, ACES closely coordinated with the Joint Planning Customer Service Office (JPCSO) and followed its procedures. JPCSO was established in concert with Spaceport Florida Authority, Patrick, and Kennedy as a "one-stop shop" for Cape Canaveral Spaceport services. Since the office was new, though, the working relationships between the various Patrick and Kennedy organizations that it represented were not always well established. In fact, this new model for working with customers may have been a source of animosity or conflict between some of those organizations.

Initially, JPCSO believed that the Altus could be treated like a conventional aircraft with respect to airfield operations and control. They thought the Eastern and Western Range (EWR 127-1) Safety Requirements for rockets would not be applied and the role of the Patrick Range Safety Office would be minimal. However, range safety interest and involvement in the project increased steadily following ACES selection and authority to proceed. Ultimately, the difference in views between range safety and JPCSO led to our making a presentation to the Patrick commanding officer in December 2001. A major factor in the commanding officer's decision was a suggestion by the judge advocate general that the commanding officer of the airfield was responsible for the UAV while it was on the base and during all phases of flight.

As a result of this meeting, the commanding officer commissioned range safety to "make this mission safe." If he had said, "make this mission work and keep it safe," the final result might have been different. I feel that mission success must always be mentioned along with safety. If safety is the only objective in the challenging type of work that NASA does, we might as well just stay home.

This decision placed the ACES project under EWR 127-1 requirements that the Altus could not fully satisfy. Discussion about tailoring requirements to suit the ACES project did not lead to substantive negotiations. Patrick Range Safety believed there was not enough data to make those changes and remained most comfortable viewing the UAV within the rocket paradigm they knew well. A number of issues made it difficult or impossible to get beyond this impasse:

- The project could not meet the level of aircraft documentation EWR 127-1 required. The fact that General Atomics was at first reluctant to reveal that they did not have some of the information we requested compounded the problem.
- The Altus had a number of single-point failures that could not be easily or acceptably remedied. At the top of the list was not having a fully redundant and adequately documented flight termination system.
- Patrick Range Safety lacked knowledge and experience about the turbulent and electrical thunderstorm environment and failed to consult experts in aircraft flights in and around thunderstorms.

Some suggestions for mission operations that proved unfeasible emerged during the discussions with range safety. One, ocean-only flights, was scientifically unacceptable. The installation of a redundant flight termination system (FTS) or a fully qualified FTS was technically feasible, but cost and schedule prohibitive. It also became clear that the activation and coordination of the Range Operations Control Center or an independent range operations center would be imposed on ACES operations, a scientifically, operationally, and financially impractical requirement. The open-ended discussions, with no clear indication of convergence, tended toward "paralysis by analysis."

Seeing "the writing on the wall" at Patrick, we investigated a number of alternate deployment locations that would satisfy a reduced set of science goals: other commercial Florida airports, Eglin Air Force Base, Mayport Naval Air Station, and Naval Air Facility Key West (NAFKW). The likely availability of other sites and the lack of progress in our discussions at Patrick made it fairly easy to request a final decision from Patrick Range Safety, although the principal investigator was initially reluctant, not wanting to give up the highly desirable ground-based lightning imaging system available at Kennedy. (ACES was run in PI mode, giving the principal investigator ultimate authority on major project decisions.) But the many restrictions to flight operations being levied on the mission convinced the principal investigator that a decision should be made by Patrick Range Safety without further analysis. The ACES project sought a final decision from Patrick and received a definitive no-fly decision in April 2002.

Our experience at Patrick taught us some important lessons:

- **Establish responsibility and liability early.** In the case of ACES, had General Atomics Aeronautical Systems been considered responsible and liable for operations in National Air Space, the Patrick approval process might have been eased (particularly if it was determined that EWR 127-1 need not be applied).
- **Document the aircraft system as well as possible.** Possessing redundant systems as well as key safety features such as collision avoidance systems also imparts obvious advantages, particularly in having the UAV aircraft treated more like a conventional aircraft. On this point, schedule and funding limited ACES's options.
- **Obtain an on-site advocate at the appropriate level to serve as a spokesman and represent the interests of the project.** The JPCSO could conceivably serve in this capacity (and probably will do better in the future as this organization matures). For ACES, a Kennedy co-investigator with a stake in the project and a working knowledge of the local organizations would have proved beneficial.
- **Attempt to obtain direct access to the decision makers.** One problem ACES encountered at Patrick was having few opportunities to deal directly with the individuals making the key decisions. This made it very difficult to present our case and more directly participate in the decision-making process. This was probably the most frustrating part of our experience at Patrick.

A New Deployment Site

The no-fly decision allowed the ACES project to focus its full attention and resources on obtaining an acceptable alternate deployment site. Steve Wegener, the UAV science demonstration program manager who had oversight of ACES and another UAV

Photo Credit: NASA

The ACES UAV is worked on before flight.

project, suggested we investigate the Naval Air Facility Key West. It provided the best science opportunity in Florida outside the Kennedy area, with excellent weather and ground-based instrumentation infrastructure. It offered the best opportunity for project success, since the FAA felt that it would be the easiest place for them to give us a certificate of authorization approval for flight. It also helped that the NASA-sponsored Crystal-Face project to investigate cirrus clouds had established contacts there and was planning to conduct their campaign from NAFKW in July. Exemplifying the "OneNASA" principle, Crystal-Face helped ACES slide in behind its campaign.

NAFKW treated the Altus UAV like any other aircraft flown from their facility. The Marshall Space Flight Center aircraft safety officer contacted his counterpart at NAFKW and addressed safety issues in one phone call. The NAFKW aviation safety officer was satisfied on the condition that an FAA certificate of authorization would be established prior to flight. This interaction typified our relationship with NAFKW. The distribution of responsibility and authority to the chief officers and on-site contractors made it easy to get things done. We readily developed a memorandum of agreement (MOA) with NAFKW for the ACES project using the Crystal-Face MOA as a model. Good communication among all parties involved made a huge difference.

ACES's well-defined project and implementation planning had been the basis of its competitive selection. Our final proposal included a detailed implementation plan, work breakdown structure, and schedule. Throughout development execution, the project team maintained a clear understanding of the facilities, logistics, expendables, and schedule required for success. When unexpected and ultimately insurmountable problems developed at the proposed primary deployment site, our comprehensive plan and schedule gave us the flexibility, time, resources, and clarity of purpose needed to make a successful transition to a scientifically acceptable alternative deployment site.

The critical point in the project was our request for a final decision by Patrick Range Safety. It is obviously not desirable to base important decisions on insufficient data, but acquiring information takes time and resources—not making a decision because you think you don't know enough has its own costs and consequences. Both an early bad decision based on insufficient data and a well-informed decision made too late can damage a project. Given our difficulties at Patrick, our decision was fairly clear-cut, but it did take time to get buy-in from all interested parties. Fortunately, we made a decision early enough to allow us to recover to a site that was not as scientifically desirable as Patrick but was good enough to accomplish most of our science objectives. We all have to make such decisions in a project, assessing risk, resources, and schedule in light of project goals. Knowing when to make key decisions is part of what makes project management as much an art as a science. ●

TONY KIM has worked at the Marshall Space Flight Center for eighteen years. He is currently responsible for the advance capability and technology development for the Deep Throttling Engine, a liquid oxygen and hydrogen expander closed cycle rocket engine with throttling capability for safe and soft landing on the moon.

Technological Progress from User Necessity

BY SVETLANA SHKOLYAR

New specialized tools that improve existing processes or address new issues can make space launch preparations more effective. Developing those innovative technologies is the mission of the Applied Physics Lab (APL) at NASA's Kennedy Space Center, but users influence the design of the tools and decide which ones will actually be used.

Photo courtesy Svetlana Shkolyar

One example is the external tank (ET) vent hood alignment tool, used to align the vent positioned on the ET tip. This "beanie cap" prevents ice that might damage the orbiter during launch from forming on the vent. Engineer Jorge Rivera enthusiastically accepted it for use because he recognized that it would align the vent more safely and quickly than the existing process. Before the tool was available, technicians worked while strapped inside the hood—a hazardous operation that took as long as eighty hours. With the tool, alignment can be quickly and safely performed from outside the hood, not only before external tank propellant loading, but also with a loaded tank when a launch is scrubbed. Despite management's concern that it needed additional capabilities, Rivera immediately saw its value.

A tool that aids the crucial task of leveling an orbiter in the orbiter processing facilities after missions was also in demand because the access platform system could damage a vehicle that is not perfectly level. The user, a NASA contractor from the United Space Alliance named Mike McClure, recognized the need for an improved leveling tool.

This improved orbiter jack and leveling system is memorable because, when funding was tight, the users and APL took the idea to the Kennedy shuttle processing chief, Michael Wetmore, and fought for it together. "Development of the improved orbiter jack and leveling system is an outstanding example of how groups from different organizations with different responsibilities can work together to achieve a goal even in times of tight funding," remembers Charles Stevenson of the Shuttle Chief Engineers

Technician Steve Parks of Arctic Slope Regional Corporation is testing the vacuum of the WET tool. This Plexiglas sheet has holes drilled into it to simulate the waterproofing holes on the shuttle tiles.

Office. McClure worked "hand in hand" with the lab to develop it, remembers Dr. Robert Youngquist, who got the APL running in 1989. Without McClure's support, technically and politically, the system would never have been built.

"The idea for such a system came about many years ago, but no one was willing to champion it until I came into the group," said McClure. "That is usually what makes or breaks a good project: a champion. You have to be willing to keep pushing."

It is clear why he was so determined. The orbiter needs to be raised accurately to the height of the servicing platforms by jacks installed forward and aft, an operation that requires precision within one-eighth inch. The previous method of using calibrated measuring sticks consumed time, cost, and labor, and it was hazardous to tile safety. "It took 25 percent longer than with either of our laser systems," recalls McClure. "From a time-saving standpoint, the laser systems were significant, especially when you add up the number of technicians and quality control inspectors involved with our operations."

The system uses Leica laser rangefinders positioned at the four corners under the jacks and transmits the height readings to a central computer. It is a vital tool for the orbiter's safety that would not have come about without the push from McClure's group.

The water extraction tool (WET), a vacuum system for drying multiple orbiter tiles, is "a case where hardware is needed for contingencies," said Dr. Youngquist. The tool was designed to remove water from orbiter tiles after the March 2001 *Atlantis* orbiter mission, which was rained on after landing at Edwards Air Force Base in California. WET is five times faster than the method used for *Atlantis*, which was dried by heating it with infrared lamps. It efficiently prevents launch delays and tile damage during ascent to the 20,000 tiles covering more than 180 square meters on the orbiter. The tool now dries 150 tiles in two hours, not days as before, by vacuuming water out through the needle holes in each tile that are used to inject a waterproofing compound.

The vacuum system also makes use of the facility's vacuum cleaning system instead of using extra power for heat lamps. It allows faster temperature recovery, easier tile access, and clearer water flow visibility. "The Thermal Protection System team laughed when we first demonstrated the system; it was so much easier to use," recalls APL physicist Stan Starr.

ACCORDING TO YOUNGQUIST, "THE BEST CASE IS WHEN THE END USER WANTS TO WORK WITH YOU AND DEVELOPS A VESTED INTEREST" IN MAKING A TOOL.

Quality assurance inspector James Allen Atwell is using the fuel hole inspection device to look into a nozzle in the Orbiter Processing Facility bay 2.

Photo courtesy Svetlana Shkolyar

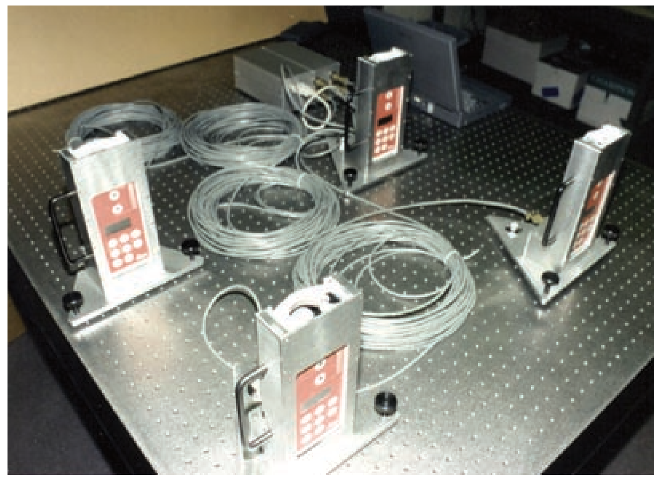

Photo courtesy Svetlana Shkolyar

Four Leica laser rangefinders for the Improved Orbiter Jack and Leveling System.

The team approved of the tool, but after it was developed, tested, and delivered, they "kindly asked us to keep our hardware," recalled Youngquist, because shuttles are rarely rained upon. But in August 2005, *Discovery* landed at Edwards and encountered almost two inches of rain. "When users want something, things can move very quickly," said Youngquist. A request for the tool was sent to the lab; within two weeks, WET was being used in the field.

Another APL technology that would not have made it into the field without the user's active involvement was the Reaction Control System, or RCS, nozzle inspection tool. This checks the RCS for defects, which cost millions of dollars to remake and repair. The tools are made of Teflon to limit damage to the orbiter surface. "We worked closely with the inspectors and gave them a machined Teflon glove and a Teflon mirror tool with a mirror and eyepiece. It went through a few versions until they were satisfied that it met all their needs," said Youngquist.

The RCS nozzle inspection tool replaced a flashlight and a boroscope tool, which were time consuming to use and failed to meet the desired capability. Today, three RCS tools are used at four sites, including the White Sands Test Facility that refurbishes thrusters.

Just as NASA Orbiter Maneuvering System engineer John Peters "took a hands-on interest" in the RCS project, Robin Floyd, lead window inspector, took a similar interest in developing the surface light optimizing tool (SLOT). SLOT saves money and time by efficiently highlighting tiny defects on orbiter windows. It took the lab only a few days to make a small plastic tool that attaches to the window via a suction cup and uses total internal light reflection with a prism to trap light in the glass. The light escapes at defects, showing the smallest damages to the windows, caused by micro-meteors, as bright points. Developing a tool with a large mirror makes the inspection "like looking through a big picture window," recalled SLOT quality inspector James Atwell.

Floyd conceived the idea for SLOT independently but had no means of fabricating it on his own; he teamed up with APL and jointly produced the tool when a "meeting of the minds occurred," said Youngquist.

As a result, fourteen SLOT devices were delivered during the 2005 fiscal year and hundreds of potentially risky defects that the previous approach did not find were located. The SLOT will soon be adapted for use on the International Space Station and the Constellation project, which hopes to send the Ares I and V crew and cargo launch vehicles to the moon and Mars. It is now in its fourth generation.

In all, more than forty pieces of hardware have been developed at APL to assist shuttle program operations in the nineteen years of the lab's operation. According to Youngquist, "the best case is when the end user wants to work with you and develops a vested interest" in making a tool. He adds, "Technology is a function of how ardent the customer is on getting the product; it is need and personality driven." No one knows better than the user whether a particular tool will make his work easier and better. Listening to the customer is one important secret of successful technology development. ●

Some of this content was originally published on Space.com, for the Institute of Engineering Technology, and in NASA Kennedy Space Center's Spaceport News.

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X-Teams for Innovation

BY DEBORAH ANCONA AND HENRIK BRESMAN

For more and more companies in today's hypercompetitive business environment, success depends on the ability to innovate and put innovations to productive and profitable use. For those companies—and for government agencies, nonprofits, school systems, and other organizations facing their own innovation challenges—the question is how do you actually create an infrastructure of innovation? How do you establish the conditions that produce breakthrough innovation—not just once, but again and again?

Years of research (ours and others') show that the real action takes place at the team level. This realization is not new. The hard part is to put in place teams that emerge as reliable engines of innovation. How do you actually do it? We offer one eminently practical answer: X-teams.

Fact: Especially in large, complex organizations, the most important work—including the critical work of generating new products and services—is done in teams. That will not change anytime soon.

Fact: Most of our thinking about what makes a team successful is focused on internal dynamics; for instance, on how team members interact, how they structure their work, how they resolve their differences.

Fact: Some of the most provocative research on team performance indicates clearly that a team can work well "on the inside" and still not deliver results. In other words, in the real world, "good" teams often fail.

What Is an X-Team and What Makes It Special?

Numerous research studies comparing high- and low-performing teams—including sales teams, product development teams, and consulting teams in the computer, software, pharmaceutical, and financial services industries—enabled us to develop the X-team model of high-performing teams.

An X-team combines and integrates high levels of **external activity** with **extreme execution** inside the team, hence the name. While most teams engage in some degree of external activity, X-teams view such activity as central to their mission, their mind-set, and their modus operandi. "Going outside" is a top priority from the day the team comes together. Like other project team members, members of an X-team are selected because they have the necessary content expertise, process skills, personality, and motivation to work together "on the inside." But they are also chosen for their ties to other individuals and groups that can help the team achieve its goals, whether inside or outside the company.

X-team external behaviors are illustrated by the Razr team at Motorola. By the late nineties, Motorola, the communications industry juggernaut, had fallen off track. The former cell phone industry trailblazer was lagging behind more nimble Scandinavian companies like Ericsson and Nokia, and even Korean players like Samsung and LG. The problem was that, like many of its historically successful peers, Motorola had grown into a giant and had become, as Yankee Group analyst John Jackson put it, "the stodgy, engineering-driven, Midwestern company that was Motorola." Meanwhile, the competition had become exponentially smarter and more aggressive. Motorola's future looked bleak.

Along came the Razr team. Razr was a team on a mission: it would develop a cooler and sleeker phone than anything the world had seen. Cool and sleek was nothing new, but this team planned to produce a phone that would surpass anything that had come before, a veritable "razor" of a phone. Adding to the technical challenge, the team faced a competitive climate in which so-called smartphones—offering a multitude of functions such as e-mail and Internet browsing—were all the rage.

The challenge of bucking industry trends was matched with what the team was up against at Motorola itself. As other teams had discovered, Razr found that the team's great ideas, vision, and engineering brilliance was not enough. Somehow the team had to find a way to get the resources it needed to push through a big, unorthodox, and expensive project in a large, orthodox, cash-strapped organization. The answer? The team engaged in three core external activities: scouting, ambassadorship, and task coordination.

An X-team's external activity takes the form of scouting for new ideas, opportunities, and resources. This might mean conducting a survey, hiring a consultant, interviewing customers, spending a day "googling" the competition, or just having coffee with an old college professor. The Razr team faced real technical challenges. A complex design required complicated technological footwork. Team members started by looking at what other teams had done before them. They looked not only at what had worked and what had not worked but also at what had been discarded. The team solved a number of technological challenges, like mounting a camera on a tiny phone and

HOW TO MAKE X-TEAMS WORK: 5 SUCCESS FACTORS

1. Choose team members for their networks as well as their personality, skills, and compatibility with others.
2. Make external outreach a mind-set and modus operandi from day one.
3. Provide tools, such as checklists, to help teams focus on external activities as well as the internal process.
4. Set milestones and deliverables to keep teams moving through exploration, exploitation, and exportation.
5. Work with top management to get their commitment to work as a partner to help establish a context to make X-teams work.

developing a keypad that was etched directly onto the phone, by repackaging existing technologies developed—and sometimes discarded—by other teams. Furthermore, scouting the market convinced them that simple functionality and cool design, very different from the smartphones of many competitors, was a niche that was waiting to be filled.

Another critical external activity is ambassadorship, meeting with management to gain support, sponsorship, and protection from potential internal opponents; to acquire funding and other resources; and to keep the team's work tightly connected to the company's strategic imperatives. The Razr team engaged in ambassadorial activity by finding a match between its product idea and top management's desire to shift Motorola's stodgy image. They also worked with top management to "gain air cover" for the team and its program so it could short-cut bureaucratic procedures, eliminate political interference, and move quickly through product development.

Finally, working externally involves task coordination, engaging with other individuals and groups inside and outside the company to get feedback, identify critical resources, and convince or cajole others to help get the task done. Razr had to engage in task coordination. Finding a home in the system of manufacturing and marketing set up for very different kinds of phones was not an easy feat. Nevertheless, by working with other teams, figuring out the interdependencies, and making some compromises (while refusing others), Razr pulled it off.

The end result? The Razr design became the best-selling cell phone in the world. With its killer margins, the product was credited with turning around Motorola at a crucial time. Unfortunately, circumstances unrelated to the Razr project prevented the company from diffusing X-team practices into its culture.

X-teams blend high levels of external activity with "extreme execution" inside. They follow well-established guidelines for building the collaborative culture, a transparent decision-making structure, and open information processing/communication systems necessary to make full use of outside ideas and resources, and they keep the work moving forward.

An X-team's external and internal activities go on concurrently, with changing emphases, through a series of flexible phases that shift with the work requirements. An X-team initially **explores the environment** to figure out what customers want, what the competition is doing, what top management will support, and where resources can be found. By going outside from the very beginning, the team establishes the critical importance of an external focus and innovation begins by bringing new eyes to a problem. For example, when an IDEO design team was redesigning an emergency room, they put a camera on a patient's head for ten hours. After watching ten hours of ceiling they realized that their design would need to expand to the ceiling.

Acting on the results of its initial exploration, and placing somewhat greater emphasis on internal activities, the team then moves quickly to prototype, test, and modify an innovative new product or service that will exploit the most promising opportunity. For example, when a team at Microsoft decided to create new software for the Internet generation, they tested multiple prototypes with potential customers and redesigned multiple times based on their feedback. They worked quickly to get other parts of Microsoft to help them in the redesigns. Finally, the team shifts operating mode again, this time to **export the innovation** to the larger organization for full-scale implementation. The same Microsoft team spent a great deal of time getting others at Microsoft Messenger excited about their software approach.

ANOTHER CRITICAL EXTERNAL ACTIVITY IS AMBASSADORSHIP, MEETING WITH MANAGEMENT TO GAIN SUPPORT, SPONSORSHIP, AND PROTECTION FROM POTENTIAL INTERNAL OPPONENTS; TO ACQUIRE FUNDING AND OTHER RESOURCES; AND TO KEEP THE TEAM'S WORK TIGHTLY CONNECTED TO THE COMPANY'S STRATEGIC IMPERATIVES.

As an X-team moves through these cycles of activity, its members move across the team's core, operational, and outer-net tiers, changing roles as needed. The team also periodically adds and subtracts members as new linkage and/or expertise is needed. This **exchangeable membership**—along with such activities as scouting, ambassadorship, and task coordination—has the added result of simultaneously reinforcing the team's connection to the larger organization and extending the reach of the team's innovative thinking. Thus, the Microsoft X-team not only created a new social networking product for "netgen" users but also became the driving force behind a new model for customer-inspired software development.

In other words, X-teams are not only highly successful at achieving their own task, they are also highly effective agents of change and innovation across the larger organization.

Making It Happen: Putting X-Teams to Work in the Real World

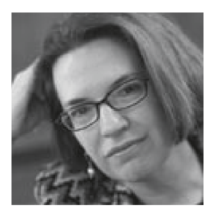
X-teams can be systematically set up, trained, coached, and replicated. In all, around 100 X-teams have been trained at MIT Sloan's Executive Education program with input from the MIT Leadership Center.

At BP, for example, X-teams have delivered a variety of breakthroughs, including new ways to manage the company's huge oil/gas exploration projects across the world. At Merrill Lynch, X-teams have produced everything from new interest rate volatility indexes to a foreign exchange hedge fund index to an entirely new and very successful distressed equity business. At Vale, the Brazilian mining company, X-teams have been trained to play a key role in taking the company global and integrating newly acquired companies.

These are examples of real success. Before setting up a comprehensive X-team program, however, it is important to recognize the careful planning and substantial support it requires. Important success factors include consistent commitment from top management and a solid launch, ensuring that everyone involved at all levels of the organization commits to the goal of the program and the work needed to get there. Another critical factor is ensuring that team efforts are celebrated and that all the X-teams' hard work is put to good use.

In *X-Teams: How to Build Teams That Lead, Innovate, and Succeed* (Harvard Business School Press, 2007), we detail how X-teams have driven innovation at companies as diverse as Microsoft, BP, Merrill Lynch, Vale, Procter & Gamble, and Southwest Airlines. Extrapolating from these examples, we also provide detailed guidelines for managers who want to set up an X-team, for X-team leaders themselves, and for senior executives who want to use X-teams as a powerful tool to establish a distributed leadership model companywide.

There is no doubt that X-teams work. There is also no doubt that making them work can be complicated for senior management and taxing for team members. In deciding whether the potential benefits justify the effort, consider the words of Margaret Mead: "Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it is the only thing that ever has." That is the essential message and truth behind X-teams. ●



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The Knowledge Notebook

Authors Who Make a Difference

BY LAURENCE PRUSAK

When I was twelve or so I fell in love with science fiction. It was a short but intense love affair lasting about three years, but its consequences are still very much alive within me. I was brought back to this early passion recently by reading some of the many obituaries for Arthur C. Clarke, certainly one of the mainstays of my science fiction reading agenda, and also the one author among the many that I read who had, and will continue to have, a lasting effect on our collective imaginations. Let me elaborate a bit.

It is now established that there was a "golden age" of science fiction that lasted from the years of the early cold-war period to, ironically, the launching of Sputnik and the creation of NASA. This period saw the transition of the genre from a mainly lowbrow fixation on "bems" (bug-eyed monsters to all you non-aficionados), published in rags such as *Weird Tales*, to stories of real sophistication and philosophical impact. This was the glory period of Isaac Asimov, Robert Heinlein, Theodore Sturgeon, and many others who wrote for Galaxy and began to publish their books with more mainstream publishers.

Their wide-ranging influence was facilitated by the arrival of the paperback book—cheap editions, often with elegant covers, that brought to the masses (and the young) the works of these wonderful writers, including the last them to die—at 90: Arthur C. Clarke.

Fifty years after the fact I can still recall the pleasure and stimulation (are they different phenomena?) I received when for a mere quarter I could buy a spanking new edition of Clarke's *Childhood's End*—a book still very much worth reading. I was not alone in this love. I had several friends who were equally transfixed. We even went to conferences in New York devoted to science fiction. We were real fans. The science fiction fandom, along with the writers and publishers, formed a community of interest—sort of an early blogging community without the technology. And this brings me to the major point I want to stress.

What was being created, absorbed, and disseminated in those golden days was an overall narrative consisting of many stories that revolved around the belief that science and technology were not only inherently fascinating but would one day bring spectacular changes in all the ways we live, work, and think. Some of the specific developments they imagined have come about. Clarke himself was the first to describe the possibility of communication satellites in geosynchronous orbits—the basis of global communication that we almost take for granted today. Some developments they missed entirely: no one predicted the small, ubiquitous computers that are such an integral part of contemporary life. Some of their imaginings—bubble-covered cities, high-speed moving sidewalks, robots indistinguishable from humans—are still in the realm of science fiction. But underlying all those particular stories was the narrative of technological transformation.

Clarke formulated three laws of prediction that expressed his belief in the almost unlimited potential for technological innovation:

1. When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong.

2. The only way of discovering the limits of the possible is to venture a little way past them into the impossible.
3. Any sufficiently advanced technology is indistinguishable from magic.

Even in retrospect we can't measure the impact of this narrative in any exact way. Yet I think we'd all agree that this belief had a huge influence on my life, yours, and many other lives, including people of power who have acted on these beliefs in the policy arena. Some of you may have come to work for NASA or other aerospace organizations in part because science fiction inspired a love of space flight and space exploration. The Apollo astronauts' landings on the moon and NASA's robotic exploration of other planets in the solar system are realizations of dreams dreamt by those science fiction writers. The impact of stories can be more wide-ranging than their authors imagine. Those cheap paperbacks had far more influence than many hardcover books that climbed the best-seller lists of those years and many weighty tomes of academic research and opinion.

My love affair ended as abruptly as it began. I began to read what I was led to believe was more "serious" literature and began to take a strong interest in history and the more human of the social sciences. Reading science fiction would have been considered "uncool" among my college and grad school friends, to say nothing of those professors whom we looked up to as role models. I can see now how much fluctuating fashion plays a role in what ideas get taken up and how ideas and the narratives that carry them along are subject to all sorts of forces that have little to do with their intrinsic merits. All those wonderful sci-fi authors from the golden age surely have the last laugh as we live at least some aspects of the life they foresaw—some of the wonders they described and some of the evils they warned us about. How wonderful that at least Clarke lived long enough to see it happen. ●

THE IMPACT OF STORIES CAN BE MORE WIDE-RANGING THAN THEIR AUTHORS IMAGINE. THOSE CHEAP PAPERBACKS HAD FAR MORE INFLUENCE THAN MANY HARDCOVER BOOKS THAT CLIMBED THE BEST-SELLER LISTS OF THOSE YEARS AND MANY WEIGHTY TOMES OF ACADEMIC RESEARCH AND OPINION.

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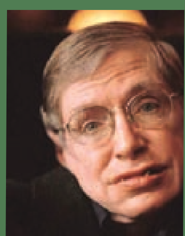

NASA in the News

In April, Professor Stephen Hawking, one of the world's foremost cosmologists and astrophysicists, spoke about "Why We Should Go Into Space" as part of NASA's 50th anniversary lecture series. "What is the justification for spending all that effort and money on getting a few lumps of moon rock? Aren't there better causes here on Earth? In a way, the situation was like that in Europe before 1492," said Hawking. "People might well have argued that it was a waste of money to send Columbus on a wild goose chase. Yet, the discovery of the new world made a profound difference to the old. … Spreading out into space will have an even greater effect. It will completely change the future of the human race and maybe determine whether we have any future at all." The talk included a segment from his daughter Lucy Hawking, who is a journalist and novelist. For a full transcript of Professor Hawking's talk, visit http://www.nasa.gov/pdf/223968main_HAWKING.pdf. You may also watch a video of his presentation at http://mfile.akamai.com/18566/wmv/etouchsyst2.download.akamai.com/18355/wm.nasa-global/Future_Forum/hq_stephen_hawking.asx.

Learning and Exploration

Learn about NASA's past and future projects with NASA 101, an online interactive Flash module that takes you through the journey of space flight NASA has embarked on for the past fifty years. Summaries of past and future missions, centers, and directorates as well as the inspiration, innovation, and discovery NASA has stimulated are all available in one visually stunning package that includes movies, short film clips, and interactive models of space and flight vehicles. Visit NASA 101 and learn more about the Agency and its achievements and aspirations at http://www.nasa.gov/externalflash/nasa101/index.html.

Web of Knowledge

NASA's Science Mission Directorate recently launched a new Web site that provides enhanced and engaging information about NASA's scientific endeavors and achievements. The site will provide in-depth coverage of NASA's past, present, and future science missions with features that include the following:

- Interactive tables and searches for Earth, heliophysics, planetary and astrophysics missions
- Insight into dark matter and dark energy, planets around other stars, climate change, Mars, and space weather
- Resources for researchers, including links to upcoming science solicitations and opportunities
- A citizen-scientist page with access to resources that equip the public to engage in scientific investigation

Visit the new NASA science Web site at http://nasascience.nasa.gov.

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