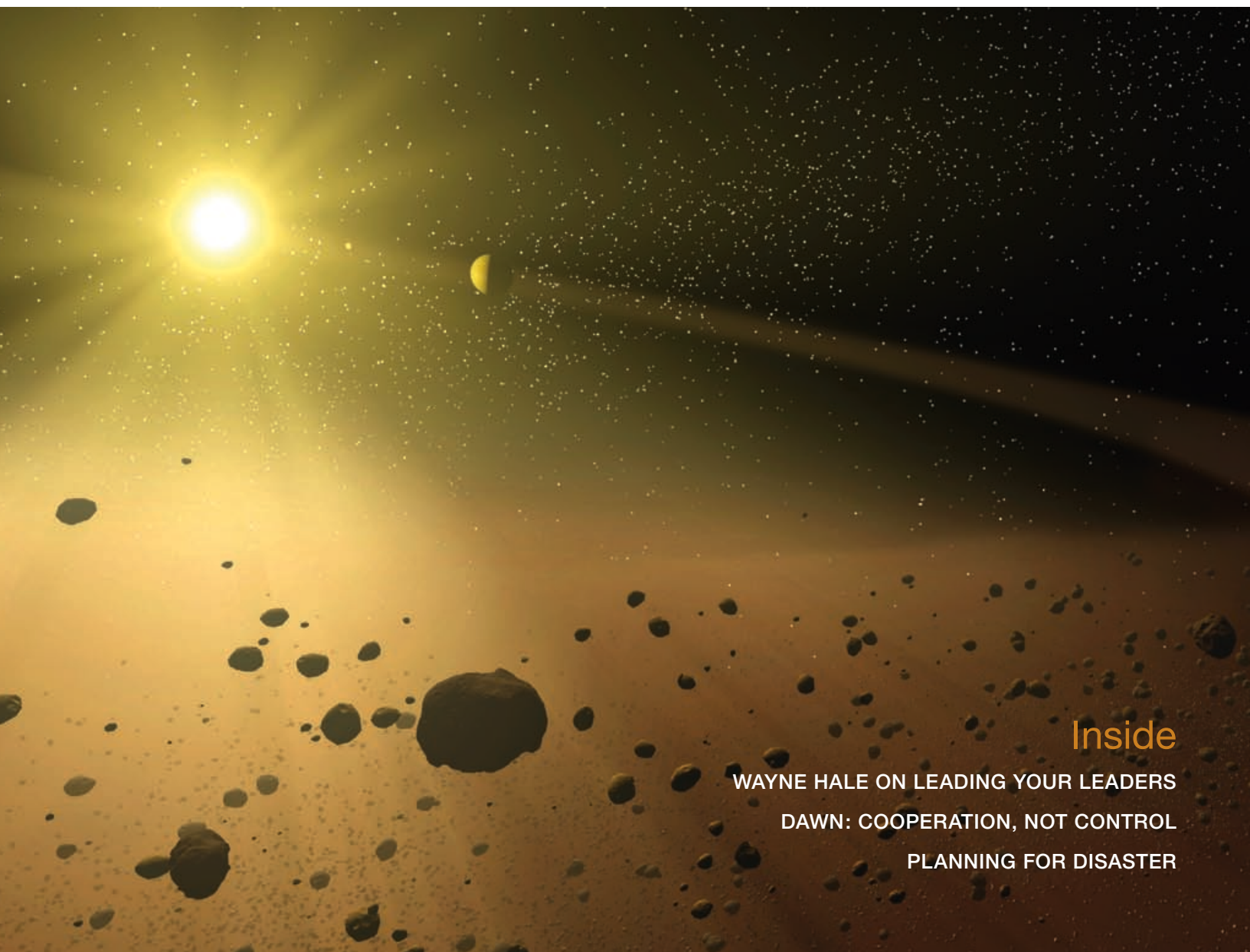


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WINTER | 2008



Inside

WAYNE HALE ON LEADING YOUR LEADERS

DAWN: COOPERATION, NOT CONTROL

PLANNING FOR DISASTER

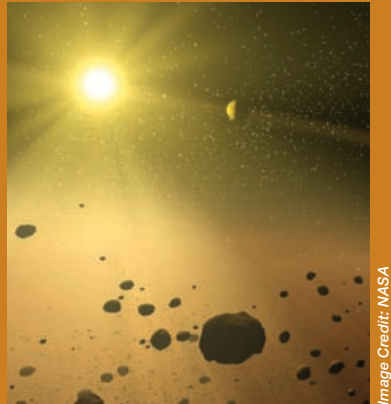


Image Credit: NASA

ON THE COVER

In this artist's rendering, a narrow asteroid belt filled with rocks and dusty debris orbits a star similar to our own sun when it was approximately 30 million years old (about the time Earth formed). During a nearly decade-long mission, Dawn will study the asteroid Vesta and dwarf planet Ceres, celestial bodies believed to have accreted early in the history of the solar system. The mission will characterize the early solar system and the processes that dominated its formation.

Contents



DEPARTMENTS

- 3**
In This Issue
BY DON COHEN
- 4**
From the APPEL Director
BY ED HOFFMAN
- 48**
Knowledge in Brief
- 49**
ASK Bookshelf
- 50**
The Knowledge Notebook
BY LAURENCE PRUSAK
- 52**
ASK Interactive

INSIGHTS

- 8**
Leading Your Leaders
BY N. WAYNE HALE, JR. To make well-informed decisions, leaders need to be guided by the knowledge and judgment of those who do the hands-on work.
- 24**
Using the Space Glove to Teach Spatial Thinking
BY PETER LORD The head of the Island Astronomy Institute enlisted the aid of the astronaut glove inventor to teach space science to schoolchildren.
- 27**
The Power of Story
BY JESSICA FOX AND DON COHEN Narratives can communicate ideas, values, and emotions—and inspire action.
- 29**
Interview with Jay O'Callahan
BY DON COHEN The well-known storyteller talks about the power of stories to explain and inspire, and the essential contribution of story listeners.
- 40**
Reaching for the APEX at Ames
BY MATTHEW KOHUT Structured mentoring and on-the-job training help Ames project managers and systems engineers develop the skills they need.
- 42**
The Project Manager Who Saved His Country
BY JOHN BANISZEWSKI A project completed more than 150 years ago affords lessons for today's project managers.
- 46**
Choosing and Developing the Right Leadership Styles for Projects
BY DR. RALF MÜLLER Because different kinds of projects require different emotional, managerial, and intellectual skills, success depends on carefully matching the leader to the task.

STORIES

- 5**
The Summer of Hydrogen
BY PHILIP WEBER The Kennedy Space Center ground crew dedicated months of effort and ingenuity to finding and fixing a puzzling hydrogen leak.
- 12**
Dawn: Cooperation, Not Control
BY TODD MAY The Discovery and New Frontiers Program Office at Marshall had to earn the trust of the Dawn team by proving that it wanted to contribute to the mission, not control it.
- 16**
Best Buy: Planning for Disaster
BY ADAM SACHS AND KERRY ELLIS Rising to the challenge of a summer of hurricanes in Florida, the retailer shaped an effective disaster-response plan.
- 20**
The Astronaut Glove Challenge: Big Innovation from a (Very) Small Team
BY PETER HOMER Learning from incremental failure, the author-inventor built a better astronaut glove.
- 33**
Learning from Space Entrepreneurs
BY WILLIAM POMERANTZ Small, passionate, resourceful teams of space flight entrepreneurs compete—and cooperate—in X PRIZE Foundation competitions.
- 38**
Featured Invention: Laser Scaling Device
BY CAROL ANNE DUNN AND GINY CHEONG A device developed by the Applied Physics Lab to aid shuttle repair is adopted by crime scene investigators.



Issue No. 29

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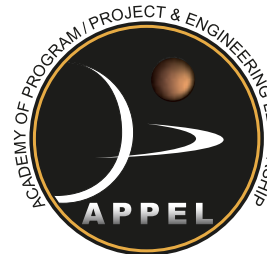
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The Academy of Program/Project and Engineering Leadership (APPEL) and *ASK Magazine* help NASA managers and project teams accomplish today's missions and meet tomorrow's challenges by sponsoring knowledge-sharing events and publications, providing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

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

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In This Issue



The success of complex project work depends on good communication. That's such an obvious truth, it may hardly seem worth mentioning: if the many people building a spacecraft or pursuing some other ambitious goal can't understand one another and coordinate their efforts, the project will fail. But knowing that communication matters doesn't tell you how it works. Several articles here take a close look at both the *what* and *how* of communication.

One way people communicate is through story. "The Power of Story" notes that stories excel at communicating norms, values, relationships, and emotions—essential elements of teamwork and project success that cannot be evoked by the content or language of technical documents. Stories also draw listeners into the action, offering a vicarious experience of what life or work is really like, as opposed to the theorist's description of what it should be like. Because stories are such potent communicators, we decided to interview a master storyteller in this issue of ASK rather than a manager, engineer, or scientist directly involved in the space program. One surprising point storyteller Jay O'Callahan makes is that the listener plays an active, creative role in storytelling: that effective listening is also a skill.

The importance of listening is implicit in the argument of Wayne Hale's "Leading Your Leaders." Hale writes about how and what people doing hands-on work should communicate to the leaders who make decisions about that work. He stresses the importance of clarity, of providing context and describing solutions as well as problems. But the leaders being led by that information have an essential role to play as open, intelligent listeners. Real communication is always a partnership between speakers and listeners. Other articles that are less directly about communication—"Best Buy: Planning for Disaster," "The Project Manager Who Saved His Country," and "Dawn: Cooperation, Not Control"—all touch on the importance of listening and being open to learning from what you hear.

Innovation is another of this issue's themes. The innovation articles hinge on a different kind of "listening"—that is, paying attention to what experimentation and failure tell you. Peter Homer won NASA's Astronaut Glove Challenge by quickly turning dozens of ideas into prototype glove fingers and learning something from each failure that pointed the way to a better idea. Homer considers *awareness* a vital contributor to innovation. His solitary achievement is the exception rather than the rule. As Ed Hoffman says in his "From the APPEL Director" column, most innovation arises from groups whose members communicate well, combining their "old" ideas to make something new.

Philip Weber's "The Summer of Hydrogen" and William Pomerantz's "Learning from Space Entrepreneurs" offer other examples of learning from trial and error or rapid prototyping—of listening to experience. Both articles also affirm the importance of communication among the people striving to build something new or solve a difficult problem. The Kennedy ground crew eventually fixed the Space Shuttle's hydrogen leak by working closely with the contractor who built the faulty seal. The space entrepreneurs competing for X PRIZE Foundation prizes frequently share experiences and information, recognizing that they get as much as they give from that open conversation. There's also the fact that they are too passionate about their work to keep quiet about it.

Don Cohen
Managing Editor

From the APPEL Director

Innovation: Burning Bridges or Building Them?

BY ED HOFFMAN



"I can only talk about what has moved me or intrigued me. I can't really be objective here."

—Martin Scorsese, from *A Personal Journey with Martin Scorsese Through American Movies*

I love movies. What does that have to do with *ASK* and NASA? My love of movies recently led me to purchase a DVD set called *A Personal Journey with Martin Scorsese Through American Movies*. Scorsese is a great director. Among his forty films are *Taxi Driver*, *Raging Bull*, *Goodfellas*, and *The Departed*. Buying and watching the documentary crystallized for me concepts about innovation—an issue that is critically important to NASA and this magazine.

Until now, I accepted the notion that innovation was about destruction: breaking away from the past, blowing up the old, changing everything. Burn your ships when you get to a new place so there's no going back. (According to legend, Spaniard Hernándo Cortés did that on the coast of Mexico to make retreat impossible.)

I think that view is wrong. In reality, innovation brings the old and new together, both in what it creates and how the creative process happens. It doesn't burn bridges; it builds them.

I first saw the Scorsese documentary years ago when I checked out a beaten-up set of VHS tapes from my local library. I loved every minute of it. Scorsese communicated his passion and devotion to great movies and vividly evoked the challenge movie artists face in bringing their unique visions to the screen. Those individual visions can only be made real through the competence and cooperation of a whole community of reflective practitioners. And however brilliant and "new" they may be, they will only matter to audiences if they connect with fundamental human experiences and feelings that are very old.

I never expected to see this documentary again. But after watching the recent Kennedy Center Honors that included Scorsese, I typed

"Martin Scorsese" into Amazon's search field and was ecstatic to find the documentary had been put on DVD in 2000.

The relatively new experience of online purchasing is amazing. The Amazon site offers reviews, search capabilities, communities, buying options, and links to other sites. It is successful not only because of shopping convenience but because its technology makes a large, like-minded social community instantly accessible. It helps you do old things—buy something you want and connect with other people—in a new way.

By definition, innovation means something new, but the best innovations of the Internet—Google, Amazon, eBay, Second Life—are powerful because they build on exactly the things that are most useful and valuable from the past. Instead of the new overthrowing the old, the new strengthens and extends proven ideas and capabilities. The ease and power of its social connections has made the Internet a ubiquitous tool, as common as driving a car or turning on the television. From games to shopping to information exchange to influence networks, it has wrought a tremendous transformation thanks especially to the vast potential for collaboration it has opened up. The Internet is an innovation in how we collaborate that I believe will lead to even greater innovation.

So both Scorsese's understanding of how great movies are made and my experience of buying the DVDs on which he shared his wisdom tell me that community is an essential part of innovation. Humans have always needed to communicate, collaborate, and share with other humans, and great innovations spring from our communal experience. Innovation is more about connection than destruction. ●

THE SUMMER H of Hydro H gen

BY PHILIP WEBER



On August 9, 1990, Columbia (left) rolls out to the pad while Atlantis rolls back to the Vehicle Assembly Building.

Photo Credit: NASA



Ground crew veterans at Kennedy Space Center still talk about what they call “the summer of hydrogen”—the long, frustrating months in 1990 when the shuttle fleet was grounded by an elusive hydrogen leak that foiled our efforts to fill the orbiter’s external fuel tank.

I was the external tank/solid rocket booster project engineer on the ground crew during that painful stretch of mainly trial-and-error efforts to locate and solve the problem. It drove us crazy for more than six months—a Florida-length summer. As painful as it was, the experience demonstrated the incredible dedication and persistence of the workforce and, we eventually discovered, showed the importance of designing tests that match flight conditions as exactly as possible.

Columbia (STS-35) was on Launch Pad A for a scheduled May 30 launch when we discovered the hydrogen leak during tanking. The external fuel tank is loaded through the orbiter. Liquid hydrogen flows through a 17-inch umbilical between the orbiter and the tank. During fueling, we purge the aft fuselage with gaseous nitrogen to reduce the risk of fire, and we have a leak-detection system in the mobile launch platform, which samples (via tygon tubing) the atmosphere in and around the vehicle, drawing it down to a mass spectrometer that analyzes its composition. When we progressed to the stage of tanking where liquid hydrogen flows through the vehicle, the concentration of hydrogen approached four percent—the limit above which it would be dangerously flammable. We had a leak.

We did everything we could think of to find it, and the contractor who supplied the flight hardware was there every day, working alongside us. We did tanking tests, which involved instrumenting the suspected leak sources, and cryo-loaded the external tank to try to isolate precisely where the leak originated. We switched out umbilicals; we replaced the seals between the umbilical and the orbiter. We inspected the seals microscopically and found no flaws. We replaced the recirculation pumps, and we found and replaced a damaged teflon seal in a main

propulsion system detent cover, which holds the pre valve—the main valve supplying hydrogen to Space Shuttle Main Engine 3—in the open position. The seal passed leak tests at ambient temperature but leaked when cryogenic temperatures were

ONE MEMBER OF THE GROUND CREW EVEN VOLUNTEERED TO SIT IN THE AFT FUSELAGE DURING FUELING WEARING AN OXYGEN SUPPLY SO HE COULD CARRY A SENSOR AROUND FROM POINT TO POINT UNTIL HE FOUND THE LEAK. IT’S NO SURPRISE THAT HIS PROPOSAL WAS VETOED ON SAFETY GROUNDS, BUT HE WAS READY TO DO IT—THAT’S HOW FRUSTRATED AND DETERMINED WE WERE.

applied. We added new leak sensors—up to twenty at a time—and tried to be methodical in our placements to narrow down the possible sources of the problem. We even switched orbiters,



sending *Columbia* back to the Vehicle Assembly Building and bringing out *Atlantis*, scheduled to fly as STS-38. Two shuttles on their mobile launchers passing in the night was a majestic sight, but not one you want to see if you're trying to get an orbiter launched. None of this told us where the leak was, or if we were dealing with more than one leak source.

One member of the ground crew even volunteered to sit in the aft fuselage during fueling wearing an oxygen supply so he could carry a sensor around from point to point until he found the leak. It's no surprise that his proposal was vetoed on safety grounds, but he was ready to do it—that's how frustrated and determined we were.

Eventually, since nothing else had worked, we put a series of leak detectors outside the orbiter, near where the umbilical connected with the external tank. We found the greatest concentration of hydrogen there, so we knew, finally, that the leak had to be at the seal we had changed out and so rigorously inspected. Now that we *knew* the leak was there, we were able to figure out what was happening. We knew from the testing that the leak would appear when the liquid hydrogen, which is much colder than the gaseous hydrogen used to chill the system, was flowing through the vehicle. The extremely cold liquid hydrogen made the metal of the joint contract unevenly, creating small gaps that the hydrogen escaped through. The fix seems counterintuitive: we added spacers outboard of the bolts in the umbilical flange; when the bolts were tightened, the inside diameter of the flange squeezed down tighter on the seal. We also slowed the loading sequence to reduce the cold shock created when the liquid arrived at the joint.

But how had the seal passed all its tests at the contractor? Why didn't they see the leak then? Since they were working so closely with us, they were able to supply the answers as soon as we understood the problem. They had tested the seals with liquid nitrogen, not liquid hydrogen. They had a good reason for that choice. Their facility in Downey, once fairly isolated, had seen Los Angeles grow around it. With schools and offices

nearby, testing with hydrogen had become too dangerous. Liquid nitrogen was the safe alternative. But liquid hydrogen, at about -253°C , is much colder than liquid nitrogen, which liquefies at about -196°C . Also, hydrogen atoms are many times smaller than nitrogen atoms. So the seal worked fine with liquid nitrogen, but liquid hydrogen created gaps it could slip through. (Hydrogen atoms are so small, they can even escape through a weld.)

The lessons we took from this experience, in addition to seeing that persistence and dedication eventually pay off, are these:

- Don't take anything for granted.
- Stay in constant communication with the hardware manufacturer.
- Test as you fly.

On October 6, 1990, *Discovery* took off from Launch Pad 39B, the first launch since April. Other successful launches would occur in November and December. The summer of hydrogen was over. ●

PHILIP WEBER has worked at the Kennedy Space Center for twenty-two years. He worked on shuttle processing/engineering up until 2000, at which time he began working on future launch systems. He currently serves as the technical integration manager for the Constellation Ground Operations Project Office at Kennedy.



Leading Your Leaders

BY N. WAYNE HALE, JR.



When I was a new NASA employee, my branch chief put together a training class that has been on my mind recently. Among the other things he taught us new employees was that we had to lead our leaders. That has always been good advice. I'd like to share some of those thoughts and expand on them.

First of all, remember that your leaders are not very smart. Once upon a time some of us might have been smart in certain subjects, but that was long ago. Being a manager dulls your technical skills.

So who is smart? The smartest guy is the person with his hand on the tool, running the test or doing the analysis. That person has all the information. He or she understands all the limitations of the test or analysis. The smart guy knows how the part or test or analysis fits in the context of its surroundings.

Unfortunately for us managers, the smart guy is almost always so intimately connected with the hardware/analysis/test that it is hard for him to explain to the rest of us just how it works. It is hard for an expert to communicate to a layman, especially with all the connotations that give meaning to the subject. But the guy doing the work is still the smartest person in the world on what the work means.

In between that smart guy and the upper management bosses live the dreaded middle managers. These folks are semi-smart: they have some recent experience, they understand part of the data, they have gotten the verbal reports unfiltered, and they can sometimes go see the test rig or the flight hardware. But these middle managers are subject to pressures from the personnel department, the "budgeteers," the schedulers, and the paperwork bureaucrats who are so prevalent in our system. This causes smart technical folks to lose their technical abilities when they become middle managers. So the middle managers are only semi-smart, and, worse, they control the communication chain—the middle managers determine what gets told and to whom.

The top leaders are supposedly the decision makers, but they are *really* not smart. Once they were real workers and perhaps were really smart, but that was so long ago that they most likely used slide rules. (I sure did.) They haven't solved an integral equation in twenty years nor have they used a torque wrench in decades (except to break the lawnmower last summer, like I did). Meanwhile, senior leaders spend most of their waking hours thinking deep thoughts, subjects like what are the goals

of the Agency for the next twenty-five years, how should the governance model work (and what the heck it's about), and how should we deal with congressional staffers or the White House? Brain-numbing stuff.

So how do the smart guys get the decision makers to make the right decisions? Simple: The smart guys have to lead their leaders.

Don't be mistaken: everybody I have met in this outfit has their heart in the right place. Everybody wants the mission to succeed and the crew to come home safely. But sometimes the right way to reach those goals is complicated.

To make it easier, here are some tips on how to lead your leaders:

1. REMEMBER TO EXPLAIN THE PROBLEM.

Even though working on a problem has been your primary effort for the past year, your leadership may have heard about this once in a briefing a decade ago. Now they are basically clueless. Pretend that you are talking to your daughter's fifth-grade class. Explain how your complicated gizmo works. If possible, do not use acronyms. Define your terms. Put your work in context. Assume your leader has no idea what you do, who you work for, or what your gizmo does. That is a good place to start.

2. TELL YOUR LEADER HOW THIS PROBLEM SHOULD BE SOLVED.

Remember, taking the next century to study the problem or spending the Gross National Product to invent a new solution are probably not going to be acceptable solutions. Real engineers and technicians build real hardware that works in the real world in a reasonable manner within a reasonable time at a reasonable cost. True, skimping on time or money can cause mistakes, but folks whose gizmos are delayed unreasonably or cost more than is practical get their programs canceled, force the business into bankruptcy, or give the market over to

the competition. Real engineers and technicians always consider cost and schedule in their work.

3. DON'T CRY WOLF.

If you repeatedly tell top management the world is going to end, and then it doesn't end, your credibility will suffer. Worst-case analysis or worst-on-worst tests are mandatory and results from them must be reported, but these tests and analyses don't represent what *will* happen. It is not enough to demonstrate how badly things might turn out; it is important to show how the hardware will most likely perform and put the really bad outcomes in the right context.

4. SOLVE THE PROBLEM.

Raising questions is important. However, we are in the business of doing things. Engineers and technicians are paid to get things done. Yes, you have to identify the problem, frame the design, identify the tests, perform the analysis, and assemble the hardware. But the goal is to *solve the problem*. Nobody ever said flying in space was easy. We make it look easy the same way that an Olympic champion makes her sport look easy: by working hard at improving performance every day.

5. MIKE GRIFFIN HAS SAID, "NOBODY GETS TO DO HOMEWORK PROBLEMS AND PUSH THE PAPER UNDER THE DOOR."

What that means is that we all have to understand the risk relative to the bigger picture. No matter where you are on the org chart, you have to understand the context, be able to place the risk involved in relation to the risk of the alternatives. You don't understand the risk (or cost, schedule, or performance) of the alternatives? Then you have homework to do. Be prepared to put your recommended solution in relation to the alternatives.

6. BANISH THE WORDS "WE JUST DON'T KNOW" FROM YOUR VOCABULARY.

When you say those words, you empower dumb upper-level managers to make a decision based on their inadequate understanding of the problem and on other factors (like cost and schedule). Do you really think

the guy at the end of the table who just came from the budget meeting is a better expert than you are on your gizmo? No. It is important to say how you are going to find out those things you don't know. If you are the smartest guy and you don't know, at least provide a plan on how we will get to a good solution. As a famous astronomer once noted, "We don't know one-tenth of one percent about anything." That's true, but it doesn't stop us from trying to build things that work. So we do what they still teach in engineering school: make some reasonable approximations. Neglect the terms that provide a relatively small contribution to the answer. Give it the best you've got. Instead of saying, "we just don't know," tell your leader what you *can* do and what approach you are going to take, and include a description of the variations that may result from your work.

You can also use some elements of good flight rationale to provide to your not-so-smart leaders.

First, use expert judgment. After flying this equipment for years, hands-on experts have learned a great deal. Judgment, honed over a long period from observation of many space flights and the operation of our hardware, is valuable. When faced with a problem, it is imperative to review the previous history and

TRUE, SKIMPING ON TIME OR MONEY
CAN CAUSE MISTAKES, BUT FOLKS
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performance of the hardware. And the opinion of the engineers and technicians who have worked with the equipment for many years is of incalculable value. On the other hand, using everyday experience or the “logic” of folks who are not familiar with the specifics of the way the hardware works is worse than useless in our business and can lead to the wrong conclusions.

Next, use analysis. A good analytical tool—verified against real-world performance (including all variables), peer reviewed, and operated within the limits for which it was intended—is a powerful way to understand what could happen. However, the output of analysis always contains an error or level of uncertainty, and the validity of the analysis output always depends on the inputs and assumptions. Assume a worst case and you will get one answer. Assume a nominal case and you get a different answer. It is important to report all these results along with the basic accuracy of the analysis. To conduct an analysis without understanding limitations and uncertainties is an incomplete analysis. An analysis not anchored in testing or an analysis tool used in ways for which it was not designed can lead to inaccurate conclusions. A “back of the envelope” analysis based on first principles can also be terribly misleading in our line of work, where we deal with extreme environments and complex mechanisms.

Better are the results of a well-defined test. Remember that a test on a laboratory bench is always an approximation of reality, and rules similar to those for good analysis also apply. One should always be mindful of Mechelay’s rule: “It is better to be stupid than to run a stupid test.” Often we try to overtest. If a piece of hardware passes an unbelievably difficult test, then life is good. More often when an unbelievably difficult test fails, we are left with a very long discussion of why and what was wrong in the design or execution of the test. Make sure that the test is well defined. Even then, it is important to explain to your leaders what inherent accuracy (or error) the test conditions or equipment have and what the assumptions or initial conditions were for the test. Test results without a good understanding of the test’s accuracy or the pedigree of the test assumptions are worth very little.

Finally, there is flight test data. Always limited, never at the edge of the envelope, it still shows how the real hardware works in a real and combined environment. Flight experience is dangerous because it typically doesn’t show how close to

the edge of the cliff the equipment is operating, but it does demonstrate how the hardware really works. A flight test is the ultimate test, again taken with the knowledge that it is probably not the extreme but something more like the middle of the environmental and systems performance.

Good understanding of a problem and its solution always relies on a combination of all these methods. Be sure to lead your leaders by using all the tools you have at your disposal.

At the end of the day, decisions in space flight always come down to a risk trade. Our business is not remotely safe, not in the sense that the public, the media, or our legislators use the term. Everything we do has a risk, cost, schedule, or performance trade-off. For your leaders to make an appropriate decision, you need to educate them, lead them, talk with them, and engage them in the discussion until full understanding takes place.

It’s your job. ●

N. WAYNE HALE, JR., is the manager of the Space Shuttle Program for NASA at Johnson Space Center, a position he has held since September 2005. In this capacity, he is responsible for overall management, integration, and operations of the Space Shuttle Program. He also served as a shuttle flight director for forty flights from 1988 to 2002.



DAWN:

COOPERATION, NOT CONTROL

BY TODD MAY



Photo Credit: NASA/Troy Cryder

On September 27, 2007, a Delta II rocket carrying the Dawn spacecraft lifted off from Kennedy Space Center. Part of NASA's Discovery program, the \$370 million Dawn mission began its three-billion-mile voyage to the asteroid belt to study the asteroid Vesta and Ceres, a dwarf planet. The spacecraft is scheduled to reach Vesta in 2011. After spending nine months measuring the composition, shape, and topography of that body, it will travel a billion miles to carry out a similar analysis of Ceres in 2015.

As manager of NASA's Discovery and New Frontiers program at Marshall Space Flight Center, I had oversight responsibility for Dawn, which the Jet Propulsion Laboratory (JPL) was managing while developing the spacecraft with Orbital Sciences Corporation. Over the years, Marshall has had a reputation for taking a command-and-control approach to program and project management: tell the project institutions or contractors

what to do and, to a large extent, how to do it—end of story. When we formulated the Discovery and New Frontiers program, however, we decided to take a different tack. All our projects were developed either by JPL or Johns Hopkins University's Applied Physics Laboratory (APL). We knew these organizations actually knew what to do and how to do it. While the responsibility for mission development lies squarely with the

project, we in the program office could make real contributions to problem solving and decision making, and we could bring technical expertise to bear when needed. We would not impose Marshall's specific set of "how-to" rules on them. Instead, we wanted to focus our energies almost entirely on enabling and supporting the success of these project teams.

We strove for trust and mutual respect, not control. It was an uphill battle at first, and there were some folks who frankly just didn't trust our intentions. It took six months of demonstrating by our actions that we really were committed to this approach and were there to help. We had to earn their trust. I distinctly remember the day I knew the approach had worked. I walked into my office and found a yellow sticky note on my desk: Charles Elachi, director of JPL, wanted to talk to me. I picked up the phone and returned his call. He explained he had been a skeptic about the Discovery Program Office, but he had been won over by numerous reports from his staff and project managers that the office had helped them in some way.

Trust and cooperation build on each other; genuine cooperation creates more trust, which leads to more cooperation. Several months after that conversation, when APL ran into a late-breaking problem with their autonomy system on the New Horizons project (the onboard system for handling anomalies independent of instructions from mission operations), JPL offered up one of their most senior directors to lend a hand. He traveled to APL and stayed there for three weeks, rolled up his sleeves, and helped them solve the problem.

Ion Propulsion

Dawn's long, complex journey is made possible by the spacecraft's extremely efficient, futuristic ion propulsion system. Xenon ions expelled at high speed provide thrust. Their speed is high—about 25 miles per second—but their mass is low, so the amount of thrust is miniscule compared with conventional rocket engines. It is about the same force as that applied by a single sheet of typing paper resting on your hand. At full throttle, it would take one of Dawn's three ion engines four days to accelerate the spacecraft from 0 to 60 miles per hour. But the engines can operate for extremely long periods of time. (They are expected to fire for more than five years over the course of the mission.) One of Dawn's engines operating continuously for one year uses only fifteen gallons of fuel to increase the spacecraft's speed by 5,500 miles per hour.



In a clean room at Astrotech, workers begin black light testing on the solar panels of the Dawn spacecraft.



Image Credit: NASA/JPL

Artist concept of the Dawn spacecraft after launch.

Deep Space 1, launched in 1998, was the first and only other NASA mission to use ion propulsion, so there were still technological and developmental hurdles to overcome for Dawn. Developing the system presented several engineering challenges that were also management challenges. One of the engineering challenges facing the JPL engineers working on Dawn was to understand the behavior of the nearly 1,000 pounds of xenon the engines required when the Delta II rocket's third stage spun.

Most spacecraft do not have difficulty sensing post-separation spin rates while the propellant and spacecraft are exchanging angular momentum. For Dawn, however, the heritage gyros of the spacecraft attitude control system saturated at too low a spin rate for this problem. Since a significant fraction of the flight system's moment of inertia was in the xenon propellant, and given the low-saturation rate of the gyros, it was critical to mission success to understand the xenon spin behavior. If the attitude control system was activated while the gyros were saturated, the hydrazine propellant needed for the mission would have been expended in the first minutes of the mission, resulting in mission failure.

JPL engineers had no previous relevant experience to help them understand the potential problem. Success came from not simply identifying and assigning blame for the problem or taking control of it away from the group trying to solve it, but instead from focusing on how to help them succeed. The Discovery Program Office immediately offered engineers at Marshall a number of lessons about propellant slosh dynamics of superfluid helium learned while working on the Gravity Probe B project. This gave JPL engineers the support they needed to develop analysis and test techniques to resolve the problem.

Later, the xenon tank failed during qualification testing. The failure occurred just below the qualifying pressure, though—significantly higher than the nominal operating pressure. Focusing on the goal of mission success rather than the letter of the law of requirements, the Discovery Program Office grabbed pressure vessel experts and worked alongside the project to develop the recommendations and rationale to lower the operating pressure while maintaining mission performance



requirements. This avoided the significant delay and expense redesigning, rebuilding, and requalifying the tank, which was already installed on the vehicle, would have caused.

Launch Delays

After a couple other assignments, I rejoined Dawn as deputy associate administrator for programs in NASA Headquarters' Science Mission Directorate. In this role, I chaired the Program Management Council (PMC) that provided the recommendation to the associate administrator to proceed with final launch preparations. Dawn was scheduled for launch between June 20 and July 10, 2007, which, from four months out, seemed a reasonably generous launch window. Consequently, I was bullish on our ability to launch in this timeframe. After the PMC, I put out a press release announcing that we were "full steam ahead." But as always seems to be the case, Murphy was right, and we learned the hard way how seemingly minor circumstances and delays can cascade into major problems. It's like the old saying: "For want of a nail, the shoe was lost; for want of a shoe, the horse was lost; for want of a horse, the rider was lost ..." and so on.

In Dawn's case, what seemed like a relatively benign ten-day slip in the delivery of the second stage fuel tank cascaded into what Steve Francois, the Launch Services Program manager at Kennedy Space Center, called "the perfect storm." What happened? Here's a sampling.

The P3 Orion surveillance aircraft, which was ready to provide telemetry during the original launch period, had another commitment during the new launch window dates. We purchased the services of a navy ship that could sail to the eastern Atlantic to receive the telemetry, but it had mechanical problems, ran into twelve-foot sea swells and unfavorable ocean currents, and failed to get to the location on schedule. We ordered up yet another telemetry aircraft, Big Crow, which also developed mechanical problems and could not get to its deployment station. We encountered a crane failure from a simple bearing that cost another week. Then there was the weather.

In July at the Cape it's common for afternoon thunderstorms to develop and force transportation and fueling delays. We

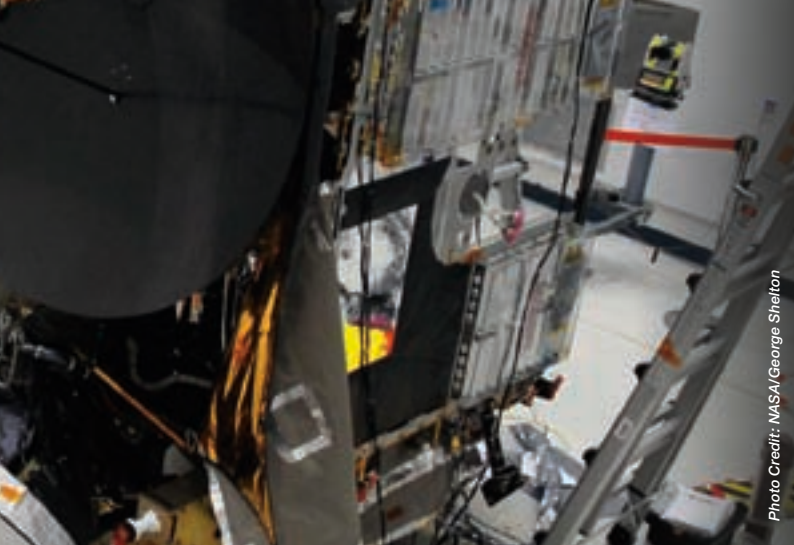


Photo Credit: NASA/George Shelton

At Astrotech, workers check the Dawn spacecraft after testing the deployment of its more than 32-foot-long solar panels on one side.

encountered a stationary weather front that sat on us for several weeks. Our slipping schedule began to impinge on the planned launch date for Phoenix, cutting into the time required between launches. Since Phoenix was a Mars mission, missing their launch window would cause an unacceptable two-year delay and cost hundreds of millions of dollars, so their schedule needed to take priority over ours. As we neared the fish-or-cut-bait point, the frequency and intensity of discussions increased dramatically. The odds were increasingly against successfully launching both Dawn and Phoenix within their windows. Discussions were elevated to the highest levels in the Agency, and our governance model was once again tested when there was disagreement as to whether the requirements for telemetry could be waived entirely. The right decision was made in the end, but it was a tough call. When the dust from “the perfect storm” settled, we ended up slipping the launch to a new window several months down the road at a cost of more than \$25 million.

I drew two conclusions from this experience. One is a reinforcement of the need to maintain vigilance in examining the potential downstream repercussions of seemingly small issues. The other is that it is important to know when to fold 'em. You need to look at your situation realistically and objectively assess the risks without personal bias. When circumstances demand it, give up the effort to launch at the earliest possible date, as hard as that is to do and as much as that may feel like a failure. Temporarily standing down the Dawn launch was a tough decision, but it was the right one.

The Important Lessons

The demands of Dawn and other challenging missions I've been involved with have taught me some important lessons for successful program and project management. As far as I'm concerned, these are the main ones:

- Program management, particularly of uncoupled and loosely coupled projects, should be more about enabling than controlling. You're working with motivated, high-performing teams and institutions with a track record of

quality and success. Emphasize commander's intent over rudder control; let them know where you want to go and when you want to be there, then let them figure out how to get there.

- Open and honest discussion of issues is essential. People fill the void of the unknown with their worst fears. Get folks around the table and have open, honest, and frank dialogue. I've seldom seen this fail to get to the root of issues.
- You have to earn your seat at the table, proving that you are competent, trustworthy, and dedicated to the success of the mission.
- Know when to fold 'em. Your pride can get rolled up in making a milestone or launch date, but you have to make a judgment based on the realities of the situation and not wear down the team trying to meet an increasingly impossible deadline.
- The NASA governance model that gives a voice to the concerns of engineers and safety experts works—trust it and use it.

Successful Launch

Dawn finally launched successfully—at dawn—on September 27, 2007. By November 14, while the spacecraft traveled away from Earth, controllers at JPL completed testing the ion propulsion system. The craft began long-term thrusting for its interplanetary travels in mid-December and will reach Vesta in a little fewer than four years. ●

TODD MAY is the deputy associate administrator of the Science Mission Directorate, located at NASA Headquarters. He is responsible for the efficient and effective execution of NASA's vast portfolio of robotic programs and projects, including more than 100 spacecraft in various stages of formulation, development, and operation.



BEST BUY: **PLANNING FOR DISASTER**

BY ADAM SACHS AND KERRY ELLIS



When a 1981 tornado in Minnesota revolutionized the retail approach of Sound of Music, which later changed its name to the now very familiar Best Buy, those who founded the company never imagined that a series of hurricanes twenty years later would also help give it a cutting-edge lead in customer service and disaster planning. That original “Tornado Sale” introduced low prices in a “no-frills” environment that gave the company higher sales than the industry average and paved the way to a new business model. But before Best Buy could find the silver lining of these new storm clouds, it needed to survive them by planning for the destructive weather that plagued Florida during the summer of 2004.

Having corporate headquarters in the Midwest gave Best Buy little experience with hurricanes after it expanded nationally and opened stores in Florida in 1994. By then, Hurricane Andrew had already run its course in 1992, and Minnesota had seen few tornadoes since the early eighties. When Adam Sachs, regional merchandising manager for Best Buy at the time, was called into his supervisor’s office in August 2004 and asked to present a plan for preparation and recovery for a hurricane forecast to brush the Florida coast, he found little to support his efforts. Best Buy had disaster plans, but nothing detailed or specific enough to handle what might be headed its way.

Knowing he didn’t have all the answers to help the more than 38 stores and 5,000 employees that could be affected, Sachs reached out to those who could help find them: the facilities manager, the operations manager, and others with relevant expertise within the company. A week before the hurricane was forecast to hit their region, those involved scheduled conference calls twice daily to update needs and recommendations as well as seek resolutions and answers.

The group did well with what they considered “prework”—preparations for taking care of their employees and facilities. Their facilities manager had arranged for local contractors to be on call for roof repairs, water extraction, glass repair, electrical needs, and HVAC issues. Their operations manager had plans in place to help with payroll, store closings, and point-of-sale systems. District managers printed lists of all store employees and their phone numbers so they could track their safety and the well-being of their families. Sachs led the command center, facilitated the conference calls, coordinated plans to properly secure stores if and when evacuations were ordered, arranged

guards to protect and secure the properties, and rescheduled with logistics partners for product deliveries.

When Hurricane Charley made landfall August 13, 2004, it took a few unexpected turns and cut through Orlando, which hadn’t been directly hit by a hurricane for more than forty years. The plans Sachs had helped pull together still worked, and Best Buy was able to locate all its employees, ensure their families were safe, and open most of its stores the next day. However, many area residents and customers were unprepared for the storm. Best Buy stores were able to help by providing batteries, power inverters, portable DVD players, flashlights, radios, and portable battery-operated televisions, but they did not anticipate requests for emergency supplies like gas generators and water. And power outages meant their normal sales equipment didn’t work.

Thanks to the creativity of Best Buy employees, the stores were able to jury-rig a solution by setting up tables outside and using runners. Customers could walk up to a table, ask if the store had a battery in stock, and those outside would radio an employee in the store to grab the battery. Most customers paid cash, but Best Buy did process credit cards they verified through cell phones. Though they were able to meet these immediate needs, Sachs and his planning team realized they had overlooked some aspects of taking care of their customers, and they set out to remedy this before another storm hit the area. Key to improving the customer experience was getting feedback from the customers themselves and from the employees who were working in the affected areas.

People often share their stories in times of crisis, so the information the managers and directors needed steadily poured

in. During a call after the first storm, the leadership team freely communicated what their customers had said they needed. Taking this information to heart, Best Buy worked out a deal with Pepsi, their beverage vendor at the time, to bring in ample amounts of bottled water. “We hadn’t specialized in water,” said Sachs. “No one thinks, ‘I need water, I’ll go to Best Buy,’ but our customers were asking for it. So five to seven days before the next storm was supposed to roll through, we called Pepsi to get cases of water.” They also sought out gas generators and still carry them in their stores today. Every time they were able to communicate with their customers, they learned more.

Store leaders and employees also helped identify additional processes, partners, and even product needs that could help for future storms. Sachs and his team of experts took all the ideas and needs and wrote them out on a whiteboard in order to break them out by discipline and areas of responsibility. Then everyone took charge of their areas of responsibility and tried to find solutions. The first storm response was mainly about the company’s facilities and employees. “For the second, third, and fourth storms, we knew it had to be ‘and’—employees *and* families *and* customers,” said Sachs. As a result of these efforts, Best Buy created Web sites and provided BlackBerries

to help with communication, expanded their mix of battery-operated products, improved facility maintenance, and built processes around asset recovery and insurance claims.

They also refined processes that were good in theory but proved difficult to execute. The list of store employees and their phone numbers is one example. “We realized that was a great idea,” said Sachs, “but we didn’t have a way to call some of those people because their phones didn’t work. Some of our store leaders drove out to find their employees, and it was much more tedious than we anticipated.” For the second storm, Best Buy set up voicemail in another market that would be unaffected by the hurricane and gave the number to its employees. “Instead of us calling them, we had them call us. The message would tell our employees when we planned to open and when they could come back to work. If their family had any needs, they could let us know at this number and we’d help them.” And it worked.

The company also looked to improve things it already did well. Though it carries batteries for radios, appliances, and toys, that stock usually



HAVING SEEN THE POWER OF LISTENING TO ITS EMPLOYEES AND CUSTOMERS, BEST BUY NOW SEEKS TO CAPTURE THEIR THOUGHTS AND FEEDBACK ABOUT OTHER ELEMENTS OF THE BUSINESS.

numbers in the hundreds. During a power outage, company officials realized they could use thousands, so they called their battery vendors. “Energizer and Duracell partnered with us to get products our competitors didn’t have,” explained Sachs. “We were the first retailer to get a flashlight that took any kind of battery. We also started carrying crank flashlights.”

After the second hurricane hit less than a month later, several of the regional leaders drove to the hardest-hit stores and visited with the employees to thank them and hear their stories. “We were shocked to see how appreciative they were of our efforts and concerns over their well-being. They thanked us for the water, food, and ice,” said Sachs. From that day on, Best Buy added store visits to its standard operating procedure for disaster recovery. “After one of the storms, one of our managers hooked up a generator to his house and had twenty-two employees staying there. We didn’t realize the emotional impact it would have on our employees and their families. We knew some of these employees had no intention of working at Best Buy as a career, but their families would say our company would always be a part of their lives. We knew Best Buy was us. We knew we represented the brand. So it was very important to us, and it was life-changing.” They drove thousands of miles to accomplish this outreach, through Orlando, Punta Gorda, Miami, Pensacola, and several places in between.

By the end of the summer, three hurricanes had devastated Florida with the last, Hurricane Jeanne, making landfall twice. The storms hit in such quick succession that the regional leaders and employees had little time to do more than refine their disaster planning. Execution improved each time, and they enhanced a few elements of the process. For example, instead of writing down the voicemail number they created for the second storm and handing it out, they began printing up business cards with the emergency information.

After each storm, Best Buy would ask its employees and customers, “What do you need?” In response, they added more products. Between the second and third storms, the planning team realized their customers’ insurance adjusters wanted pictures. They knew disposable cameras and digital cameras were important for accomplishing this, so they increased their stock.

Many of the items they began to stock for these emergencies became a permanent part of their stores. Best Buy originally

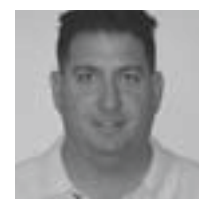
stocked power inverters, which allow you to use a regular plug in the cigarette lighter jack in your car, only in disaster-prone areas. “We soon realized there were other needs for this item,” said Sachs. “Do you need a hurricane to lose power? No. You can lose power anywhere for any reason for an extended time.” Power inverters are now in stock at all their stores. Gas generators are sold in all coastal and hurricane-area stores.

The plans Sachs and his team developed for one of Florida’s toughest summers are the foundation of Best Buy’s current disaster response procedures, and they were used when Katrina struck New Orleans one year later. Thanks to those plans, it took Best Buy only thirteen days to find every employee that worked in the New Orleans market.

Having seen the power of listening to its employees and customers, Best Buy now seeks to capture their thoughts and feedback about other elements of the business. To help unleash that power, Best Buy offers immense recognition for employee ideas. They distribute certificates, plaques, and trophies, and they invite contributing employees to leadership meetings to see how their ideas will be implemented. If an idea is accepted by the company everywhere, the employees are recognized nationally.

What Sachs took most from the experience was realizing that many voices can be better than one. “If you have a map, throw it out the window and unleash the power of the people who are involved,” he said. “They will know more than anybody else what their needs are. Take every one of their needs to heart, no matter whether you think they’re serious or not, to really value the unique ideas of the employees. At the end of the day, your plan will be better because of it. One little idea from an employee on the journey, which is continuous, enhances and morphs itself into something more than the original idea was or could hope to be. Unleash the power of the people; value their ideas and experiences.” ●

ADAM SACHS has worked at Best Buy for fifteen years and still resides in Florida. He is currently the director of store operating model capabilities, where he and his team focus on store support to improve the employee and customer experience and drive shareholder value.



THE ASTRONAUT GLOVE CHALLENGE:

BIG Innovation from



Photo Credit: Matthew Z. Homer

Several versions of Homer's glove show his idea's progress.

How does one guy in Maine transform a pile of failures sitting on his dining room table into one of the biggest innovations in spacesuit glove technology since the beginning of human space flight? This is a story about what it took to compete in and win the 2007 Astronaut Glove Challenge, one of seven competitions organized under NASA's Centennial Challenges program.

a (Very) Small Team

BY PETER HOMER



I learned about the competition by accident, browsing the Web. The Astronaut Glove Challenge was designed to promote the development of a highly dexterous and flexible glove that could be used by astronauts over long periods of time for space or planetary surface excursions. It brought competitors to a single location for a head-to-head competition using gloves they designed and fabricated themselves. Each team was required to perform a variety of tasks with their gloves and was scored on glove performance against each other and the current NASA Phase VI glove. One of the things that interested me was that competitors had to build the hardware; this wasn't just a design competition. At the time, I was heading up a medium-sized nonprofit and had been away from aerospace engineering for a while, so this was to be strictly a personal challenge, a "science project" to pursue in my spare time. Creating a better astronaut glove appealed to me because it would be a good test of my skills and was a small enough project to do in my garage. As it turned out, the bulk of the fabrication took place on my dining room table.

At the kickoff meeting held a year before the competition, I learned about pressure suits and got my first (and only) look at the Phase VI glove. A 4.3 psi pressure differential between the inside and outside of the glove didn't seem to be a big deal to me, but when I had the opportunity to try the Phase VI out for a few minutes in a depressurized glove box, and heard astronaut Carl Walz describe the problems that he and others had with spacesuit gloves while performing extravehicular activities, or EVAs, I was surprised at how stiff the glove became and how difficult it was to use. I had a decade and a half of experience designing satellites, but I had never worked in human space

flight and had no knowledge of spacesuit design. I wasn't able to find much useful information and found nothing specifically about how to fabricate and test a pressurized glove. I had to learn or invent everything from scratch.

My hope was to come up with a new and radically different approach to spacesuit glove design. I spent the first nine months after the kickoff meeting just thinking about ideas and sketching them out. Rather than copy the two-layer approach of the current design, I thought it would be better to combine the restraint and air-containing "bladder" layers into a single, reinforced rubber layer. Once I began to make and test prototypes, however, I discovered that my new "great idea" was an utter failure. With less than two months to go before the competition, I was starting all over! But something good came out of that catastrophic failure. It forced me to look for a new way to attack the problem—there wasn't enough time for the usual design/analyze/validate/build approach. Instead, I decided to use "incremental" failure as a tool to learn rapidly. Had I not taken this path, I believe I would not have finished in time.

I decided to focus all my effort on just the finger element. If I couldn't come up with a more flexible finger, there was no point in spending time on the rest of the glove, I reasoned. So I devised a simple test fixture that allowed me to build and pressurize finger elements in about twenty minutes, and I spent the next few weeks designing and making glove fingers. A lot of fingers. Probably three dozen in all. Every one of those fingers (except the last) was a little failure, but every one taught me something about what did and didn't flex easily, or about how to streamline the fabrication process, or what materials and design elements were or were not important.

About six weeks before the competition date, I had a breakthrough “Aha!” moment. I knew I needed to constrain the pressure inside the glove’s finger but at the same time allow it to flex. Late one night I came up with the idea of creating a “linkage” across the joint of the finger, but I was struggling with how to do it. I was applying strips of tape to my fingers in an attempt to simulate links when I came up with the “X” design

that allowed me to make a fist without feeling any resistance from the tape. I knew I had a winner, and after a few more iterations, I had created a working flexible finger design. The next task was to join four of these fingers to a palm and to develop a functional metacarpal (knuckle) joint. It took quite a few tries to figure this part out, not just the mobility element, but also the patterning and fabrication sequence. I followed the same process of incremental failure to learn and ultimately to come up with a flexible metacarpal joint.

I followed the same process for the thumb articulation, and finally the wrist joints, with less time available for each. The final step was putting all the elements together into a complete glove. I only had one day to accomplish this, but, because I knew each element worked and I had refined the patterning and fabrication sequence (and my fabrication skills) through all that repetition, I was confident I could pull it off. As it turned out, I was only able to test the first glove in my homemade glove box for about an hour because I had to get back to work fabricating the second, identical glove the rules required. That marathon build session lasted until it was time to leave for the event, so I first tried out the second glove during the actual competition.

Once the event began, I learned that five teams had registered to compete—four individuals like myself, and Team MDLH, which included spacesuit mobility expert Gary Harris, aerospace engineer Pablo de Leon of the University of North Dakota, and Nik Moiseev, who until 2005 was an engineer with the Russian firm Zvezda that designed that country’s current and Soviet-era spacesuits. Two teams dropped out before the competition started because they had not finished their gloves in time. So the official lineup was myself; Ted Southern, a graduate art student from Pratt Institute in New York; and Team MDLH. And of course the “house glove,” NASA’s Phase VI glove.

After going over some preliminaries, the competitors were asked to bring out their gloves. This was the first opportunity to see each other’s work, and it was immediately apparent that there were three very different designs. Aside from some initial “acceptance” testing (length, weight, leak check), there were



Photo Credit: Matthew Z. Homer

FAILURE FORCED ME TO LOOK OUTSIDE CONVENTIONAL THINKING AND OPENED THE DOOR TO INNOVATION. CHOOSING TO MAKE INCREMENTAL FAILURES ENABLED ME TO RAPIDLY CLIMB THE LEARNING CURVE.



Photo Credit: Matthew Z. Homer

Homer sews his glove concept.

three major components to the scoring: strength, flexibility, and comfort/dexterity. The first challenge was a burst test to evaluate overall strength. Each competitor chose one glove to be slowly pressurized until it failed. The higher the pressure before failure, the higher the score. I chose my first glove, the one I had tested, because I was afraid that it didn't have enough "life" left in it to get through the thirty-minute dexterity test. I was relieved to see it go to almost 22 psi before failing, well over the 13 psi qualifying minimum. Unfortunately, Ted Southern's entry didn't reach the minimum required pressure, which disqualified him from the remainder of the competition. It was now down to me, Team MDLH, and the Phase VI glove. Team MDLH's glove survived to more than 29 psi, putting them in an early lead.

The next day began with finger flexibility measurements using a force gauge on the pressurized gloves, including the Phase VI glove. Many measurements were taken by test engineers from Hamilton Sundstrand, the prime contractor for the current EVA suit. Because the raw measurements needed to be converted to torques and combined into a final score, it was impossible to keep track of who was ahead in this phase. The final comfort and dexterity test was performed in a depressurized glove box to simulate real on-orbit conditions. Each competitor was required to exercise the glove through a defined set of finger, thumb, and wrist motions without any sign of abrasion or bruising of the competitor's hand. I learned a lot about arm fatigue! This was a pass-fail event, and both of the remaining competitors came through intact. After taking what seemed like an eternity to tally the final scores, the judges announced that I had won the competition. My glove was the only one to have achieved lower finger-bending torques than the Phase VI glove.

Looking back, I see three sources of the success of this project that I believe also operate in other programs where small teams have broken new ground in aerospace technologies. These are awareness, failure, and trust. By remaining aware of the big picture, continuously asking myself, "Am I converging on a solution?" and "Am I converging fast enough?" I was

able to see that my original design was not going to succeed, leading to the decision to start over. I was also aware that, had I lingered over this choice or taken time to analyze it, I would not have been ready on the first day of competition. Failure forced me to look outside conventional thinking and opened the door to innovation. Choosing to make incremental failures enabled me to rapidly climb the learning curve. Trusting my "gut" feelings—which are really an internalized accumulation of experiences—and my newly acquired skills allowed me to devise new technologies rapidly and complete both gloves just in time. Awareness, failure, and trust are intertwined: failure provides experiences that inform awareness and provide decision-making opportunities that build trust among team members and managers while opening minds to new pathways for development. All three are necessary for teams—large or small—to achieve big innovation. ●

This story was told as part of a broader presentation on how small teams achieve big innovation, delivered at NASA APPEL Masters Forum 15 on October 16, 2007, in Phoenix, Arizona. For more information about the Centennial Challenges, visit <http://centennialchallenges.nasa.gov>.

PETER HOMER has ten patents related to space structures, thermal control, and deployables. His career in aerospace spans more than two decades, most recently developing commercial communications satellites for Lockheed Martin Space Systems (formerly GE Astro Space) and leading configuration and design of the A2100 spacecraft bus structure. His experience also includes systems engineering and engineering management for software giants SDRC, Netscape, AOL, and Sun Microsystems and organizational leadership in the nonprofit world.



Using the Space Glove to Teach Spatial Thinking

BY PETER LORD

I was standing in the dining room of a rambling white Victorian on Mount Desert Island, home to Maine's Acadia National Park. Arrayed before me on a massive wooden table lay an antique sewing machine, an improvised pressure test stand, a glass vacuum chamber, and an immense collection of gloves and fingers. I had driven across this mountainous island as an engineer and curious educator hoping to get my hands on Peter Homer's Centennial Challenge–winning astronaut glove.



Alexis of Pemetic Elementary School tries on one of Peter Homer's "failed" glove designs.

I'd come to Mount Desert Island to found the Island Astronomy Institute, in part to fill the space sciences gap in the island's schools with a grant from NASA's Maine Space Grant Consortium. News of Peter's prize-winning astronaut glove had spread across the island's towns like wildfire, in part because this type of engineering simply does not happen here.

My own experiences designing and building commercial spacecraft, including the three satellites of the Sirius Satellite Radio constellation, made it easy to admire Peter's mechanical aptitude. My first patent grew out of multiple failures. I was one of three engineers assigned to solve a high-profile, on-orbit performance issue. Fabricated with our own hands from custom composite materials, our first full-scale engineering model of a 2.4-meter "self-supporting aperture cover" was a total failure. The second model was almost a complete failure, but we were fast learners. Our third attempt is now used on dozens of satellites.

As Peter unfolded his story, I couldn't help but smile. Here was a road I had traveled many times but had never seen portrayed with such clarity. Each piece of glove Peter picked up spoke volumes about the creative process of planned failure and incremental success. On the table lay the physical evidence of insight, perseverance, and, perhaps more than anything else, the ability to visualize precisely what was required to arrive at a winning design by the competition deadline. I was impressed and excited about the educational possibilities.

The way of thinking that Peter so clearly embodies is reflected in the Institute's mission to promote astronomy as a stimulating educational and cultural activity for people of all ages. The full significance of this way of thinking was brought to my attention in 2006 by a National Academy of Sciences report called *Learning to Think Spatially*. The report recognizes the ability to visualize and manipulate objects in space as a poorly understood, previously unrecognized "blind spot" in the nation's educational system. It describes spatial thinking as a fundamental cognitive process "integral to the everyday work of scientists and engineers that has underpinned many scientific and technical breakthroughs." I knew from my own experience that this was a nonverbal skill, a unique kind of knowledge that,

once grasped in a flash of understanding, becomes as natural as riding a bike.

The Island Astronomy Institute was founded on the proposition that astronomy provides an efficient, engaging way to teach advanced forms of thinking now characterized by the National Academy of Sciences as enabling deep understanding across the wide spectrum of knowledge-intensive fields. Advanced spatial thinking allows experts to conceive of and express highly abstract concepts through a language of spatially conceived analogies and metaphors.

THE CHALLENGE OF EXTENDING STUDENTS' SKILLS IN SPATIAL THINKING TO ASTRONOMICAL SCALES WAS THE CENTRAL FOCUS OF OUR K-8 CURRICULUM DEVELOPMENT.

The ability to envision a physical perspective outside our own bodies comes into play when we recognize our own image in a mirror. Expanding this spatial skill across broader dimensions of time and space is essential to developing deep astronomical knowledge. It is one thing to state that Earth revolves around the sun; it is quite another to stand under a noon-day sun and point to where the earth you are standing on will be in three months.

Ironically, attention to these critical spatial skills is usually limited to the first years of elementary school. Some people have the ability to mentally rotate our sense of physical orientation to the East, West, North, and South without thinking, but many don't. The process is so instinctive in those who possess it, we describe it as a "sense" of direction. Spatial concepts are deeply

rooted in our most basic perception of our physical surroundings. Several college students in our philosophy of astronomy class reported feeling the earth move under their feet as they repeated Galileo's observations through a telescope; was Jupiter moving, or was it Earth?

The challenge of extending students' skills in spatial thinking to astronomical scales was the central focus of our K–8 curriculum development. When the project's lead teacher requested a curriculum that cumulatively built on each prior year's learning in a spiral fashion, I knew exactly what the school was asking for. Second and third graders began by noticing the cyclical patterns that the sun, moon, and stars make in the sky. Fourth graders explored the phases of the moon by taking turns modeling and sketching them in their classroom and then comparing them to the real sky. Sixth graders used real telescopes to observe a moving model of our solar system and walked a scale model of the planets' orbits. The curriculum is designed to expand students' capacity to visualize space in a hierarchical fashion that asks them to imagine themselves from a broader number of spatial perspectives through hands-on activities.

The "situational awareness" Peter's story describes is a hallmark of high-performance engineering and innovation. Keeping in mind the potential outcomes of multiple paths of pursuit from multiple perspectives while keeping track of their relative merits and performance requirements is a demanding spatial task.

What made it possible for Peter to transform the failure of his first glove into triumph was the mental space in which that failure provided exactly the information needed for a new breakthrough. In at least two cases, Peter could immediately "see" the full implications of what his hands were telling him. He tells the story of how putting his hands in a Phase VI astronaut glove instantly transformed his understanding of the glove challenge. Six months into his development, the failure of circumferentially wrapped cords to produce a sufficiently flexible glove again forced him to abandon his assumptions. His situational awareness was so clear and compelling it became a gut-level response. Peter's finely developed spatial skills enabled

him to almost instinctively focus his full energy on a carefully constructed set of experiments. The finger's ability to sense pressure, force, and work gave him the immediate feedback required to solve this one central problem. Once properly understood, his failure quickly led to the magical "Aha!" moment of discovery; the rest is history.

Peter worked in the kind of information-rich, hands-on environment so essential to science education. At the request of local teachers, Peter and I hauled his collection into class to test my belief in the glove's educational potential. Peter and I shared his engineering process, complete with failures and the principles of pressure, force, and work at play in the successful design. Then we gave students the chance to get their hands on it all, letting them develop their own spatial understanding. The feedback from the students and teachers was that the glove was an instant hit: they really "got" it.

Just as children need opportunities to develop hands-on understanding, engineers need to explore new possibilities through incremental hands-on failure. High-performance innovation is all about learning to make maximum use of thinking spatially to direct this process. Peter Homer's glove also reminds us that efficient engineering decisions need to be made as close to the hardware as possible. Whether we're doing hands-on education or hands-on engineering, it is when we trust in our ability to "feel our way" through failure that we reach our highest potential. ●



PETER LORD is executive director of the Island Astronomy Institute and a consulting senior satellite systems engineer with Stellar Solutions.

The Power of Story

BY JESSICA FOX AND DON COHEN

“I know what I have given you. I do not know what you received.”

When he wrote these words, Antonio Porchia, an Argentinean printing press owner in the 1930s, wasn't thinking about project management. But he articulated a major knowledge-sharing issue that is the source of many project problems: how to communicate our intentions so that the information received is the same as the information given.

One answer is conversation—the back-and-forth of statement, question, and response that gradually brings talkers and listeners to a shared understanding. Stories also offer a way to share knowledge effectively. While the storyteller's intent and the listener's interpretation will not be identical, a good story reliably communicates essential knowledge so it is not only understood but absorbed and embraced.

Narrative is one of the oldest knowledge-transfer systems in the world. Religion knows it. Politicians know it. Fairytales know it. Now, knowledge management practitioners are coming to know it, too. But why are stories such a powerful knowledge-transfer tool? And what kinds of knowledge do they transfer?

Joseph Campbell, the mythologist, defined stories as serving four major functions: the mystical, the cosmological, the sociological, and the pedagogical. The mystical function of narrative lies in its ability to open up emotional realization that often connects with a transcendent idea such as love or forgiveness. He calls this realization “mystical” because it connects the self with the universal.

What Campbell calls the cosmological function of stories relates the self to the outside world, focusing on action, on understanding cause and effect and our role in it. For the cosmological function of stories “to be up to date and really to work in the minds of people who are living in the modern scientific world,” Campbell notes, “it must incorporate the modern scientific world.”* We must continually tell stories that demonstrate our current vision of the world.

The sociological function of stories, Campbell explains, helps maintain and validate the social order of a society. Stories pass on information about power relationships, taboos, laws, and the inner workings of communities. Countries and religions have stories that serve this function and so do organizations and project teams, where stories about project work communicate information about behaviors and attitudes that are expected and rewarded or frowned upon and penalized.

BECAUSE STORIES ALMOST ALWAYS TELL ABOUT A HERO OR GROUP OF PEOPLE FACING A CHALLENGE, LISTENERS SEE THE EVENTS OF THE STORY THROUGH THOSE INDIVIDUALS' THOUGHTS AND FEELINGS.

Functioning pedagogically, says Campbell, narratives guide individuals harmoniously through the stages of life in terms of their world today, with its current goods, values, and dangers. These are stories that deal with life transitions and guide us from one stage to another.

Stories powerfully serve these functions partly because of two great strengths: their ability to engage listeners personally and emotionally and their use of metaphor. And it turns out that these two things are related.

METAPHOR FREES US TO INTERPRET STORIES INDIVIDUALLY. STORIES, METAPHOR, AND NARRATIVE ACTIVATE OUR INNATE IMPULSE TO SEARCH FOR MEANING. AS LISTENERS, WE PLAY WITH THEM LIKE KIDS ON WELL-CONSTRUCTED JUNGLE GYMS.

Because stories almost always tell about a hero or group of people facing a challenge, listeners see the events of the story through those individuals' thoughts and feelings. We tend to identify with the hero and live the story through him or her. Think about the tragedy of the Apollo 1 fire. A lot of essential technical information about what happened was captured in reports that followed the accident. But the *story* of what happened communicates the sorrow, pain, and guilt of the accident, the human failings that contributed to it, the passionate determination of the survivors to do better and to go on. Hearing the story today helps NASA engineers understand their limitations and what's at stake in their work, and it inspires them to work harder and better. Stories get us as close as we can to learning from experience without actually having the experience.

As the interview with storyteller Jay O'Callahan in this issue of *ASK* makes clear, metaphor—images that suggest a range of meaning—makes stories powerful and rich. Metaphor is part of what makes listeners active participants in stories, and they must engage with and interpret these images that work on the show-don't-tell principle. An image that has to be explained, Campbell says, is not working. You would never say, "He was a deer in headlights, and what I mean by that is that he was stunned, scared, and caught unaware."

Metaphor frees us to interpret stories individually. Stories, metaphor, and narrative activate our innate impulse to search

for meaning. As listeners, we play with them like kids on well-constructed jungle gyms. We feel as if we are extracting meaning ourselves, and we are—stories don't force a single, simple conclusion on us. But a good story guides us, so that what we learn is what the story wants to tell us, but adapted to our own needs and interests.

Charles Dickens's *A Christmas Carol* demonstrates the transformative power of living through a story. Ebenezer Scrooge's nephew, Fred, and his employee, Bob Cratchit, try to talk him out of his stinginess to no avail. Even the ghost of his former partner, Jacob Marley, can't convince him to change his ways. Only directly witnessing the drama of his past, present, and future gives Scrooge an emotional understanding of the meaning of his life powerful enough to change him.

Although we are not all so fortunate to have the ghosts of our past, present, and future create a personal holodeck for us to journey through, a good story can come close to giving us a sense of lived experience. The technical information we need to do our work probably comes from other sources, but stories tell us how we work and—even more important—why we work. ●

* Joseph Campbell, *Mythos*, DVD, Directed by Robert Walter (New York, NY: Wellspring, 2002).

INTERVIEW WITH

Jay O'Callahan

BY DON COHEN

Jay O'Callahan is one of the world's best-known storytellers. He has performed at Lincoln Center, at the Abbey Theatre in Dublin and other theatres around the world, at the Olympics, and with the Boston Symphony Orchestra. His work appears regularly on National Public Radio. In addition to creating and performing stories, he leads workshops on storytelling and writing. Don Cohen talked to him at his home in Marshfield, Massachusetts.

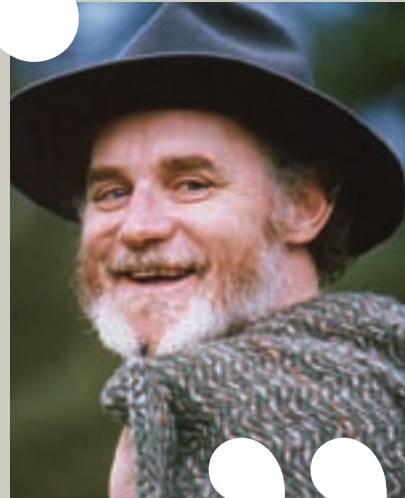
COHEN: At NASA, we've been talking about the value of storytelling for knowledge sharing. Why are stories important? What do we get from them?

O'CALLAHAN: Stories draw you into the experience and imagination of the storyteller. Reading one of your *ASK* interviews, I was intrigued with astronaut Eileen Collins saying that in space she looked down and thought, "The earth is round." Then she said, "Of course I knew that, but I was seeing it with my own eyes!" Eileen's words were so simple and direct; I could feel her excitement in the

simplicity of her words. Her excitement was such that I imagined that if Einstein and a kindergartener were with Eileen Collins, they might have all shouted, "The earth is round."

Storytelling knits images together and those images touch on something deeper than themselves. They touch on mystery. Think of the image of the Statue of Liberty.

The job of the storyteller is to invite the listener into the world of the story. The storyteller uses events and images to capture beauty, fun, struggle, characters—all in an accessible way.



“

... I THINK PEOPLE ARE **distracted**. THEY ARE ALMOST **too busy** TO FOCUS ON ANYTHING, BUT **space exploration** IS SO **extraordinary** I THINK OUR IMAGINATIONS CAN **catch fire** AGAIN. AFTER **millions of years** WE'RE ABLE TO LEAVE THIS EARTH AND **explore what's beyond.**"

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COHEN: When we think about stories, we usually think about events more than images, about how a character deals with a problem or a challenge. Isn't wondering about what's going to happen an important part of stories?

O'CALLAHAN: Astronaut Gene Cernan, speaking at Acton High School in Massachusetts, said walking on the moon was like dreaming or like hearing a story before bedtime. I think he meant the experience was full of mystery. Only a word like dream could communicate how unusual the experience was. The deepest stories, like *Moby Dick*, touch on mystery, and there is something mysterious, bravely wild, and joyous about exploring the universe.

A friend of mine, Gail Gutrad, is writing a work in progress about her volunteer work with children who have AIDS in Cambodia. Gail was speaking to a seventeen-year-old boy, Samorn, who hopes to be a doctor. He asked Gail if it were true men had walked on the moon.

She said yes, and he asked if they'd been to the sun. "Too hot," Gail said. Samorn mused then brightened, saying, "Maybe they could fly in a rocket made of ice." It's Samorn's journey, too.

Astronaut John Young said after he commanded the *Columbia* shuttle, "We're really not too far, the human race, from going to the stars." We humans are sticking our big toe into the universe.

COHEN: There's a good bit of danger and uncertainty in that adventure. I think those things are often part of compelling stories.

O'CALLAHAN: Usually stories have elements of risk, trouble, challenge, adventure. These elements are universal because they're part of life. A story gets exciting when someone takes a risk. With risk there's tension and with tension there's energy, and the energy draws us into the story. NASA's work involves great risk. Sometimes, as with *Challenger* and *Columbia*, the result is tragedy.

COHEN: It's interesting that the Apollo missions to the moon, which were extremely risky, were presented to the public in dull language, almost as if they were routine.

O'CALLAHAN: I lived through that time. I had a sense the astronauts were invulnerable. They were so well trained, and the engineers behind them were superb. Nothing was going to go wrong. That's one of the reasons the *Challenger* crew's death moved people so deeply. Christa McAuliffe was not an engineer; she was a teacher and she died, and the whole space enterprise became very human. The *Challenger* lifted off and in seventy-three seconds the Space Shuttle disintegrated. Seventy-three seconds. That's a day I'll remember, like the day of Kennedy's death. The danger was there, but we were lulled into thinking the space flight was routine.

COHEN: You also experienced the Sputnik era. Sputnik went up almost exactly fifty years ago. What impression did that make on you?

O'CALLAHAN: Sputnik made a huge impression on my high school, the country, and me. People were frightened that the Russians were getting ahead of us. The Cold War was oppressive in high school. There was no sense of wonder in our chemistry class. It was all: Sputnik! Learn! We had a math teacher who said, "X! Why can't you find X!? The Russians have Sputnik. They're watching us. Find X or we'll all be speaking Russian!"

COHEN: Can people be taught how to tell stories?

O'CALLAHAN: In workshops I draw stories out of people. Everyone is filled with stories. Flannery O'Connor says if you get through childhood you have enough stories for a lifetime.

I use simple suggestions that I call "sparks" to elicit stories. I might say, "Can you recall a moment in your life when a shoe was important?" Then I give people a couple of minutes to tell their memory to a partner, after which I have the partner appreciate what was alive in the story. The appreciations are information which the storyteller builds on. The appreciations can be about language, character, detail, expressions, sound of the voice, gesture, and emotion—anything that's alive.

There was a doctor in one of my workshops who talked about having marvelous handmade shoes when he was a freshman at the University of Chicago. He often noticed a pretty girl he wanted to ask out and finally got the courage. On the third or fourth date he asked, "Why did you say yes when I asked you out?" She said, "I thought anybody who would wear shoes like that must be very interesting." They've been married thirty years. His story was fresh and told with great warmth.

COHEN: The emotion comes from the fascinating detail, rather than, say, training in vocal expression?

O'CALLAHAN: The emotion comes from a hundred places. There is a universe within each of us: family characters, friends, enemies, and fictional characters. And so many moments. It's the job of the workshop leader to bring the moments

out so the storyteller is more aware of the gold mine within and aware of his or her strengths. By strengths I mean a sense of humor, enthusiasm, a presence, a way of using language, a sense of beauty. I've found most people are not aware of their strengths. That's why appreciations are important.

Professor Talbot Page, an environmental economics professor who's just retired from Brown University, took my workshops in order to find new ways to stimulate his students. Professor Page began using this method of appreciations and found his students responded well and wrote better papers.

COHEN: So if you did a storytelling workshop for NASA project managers and engineers, you'd listen for the interesting details?

O'CALLAHAN: I would start with little things, like the shoe spark, just to be playful and build up trust. Then I would ask: what are some wonderful moments in your work? What are some hard moments?

COHEN: I think you've had the experience of creating stories about the history of a place or an organization. What is that process like?

O'CALLAHAN: I was commissioned to create a story about the steel-making community of Bethlehem, Pennsylvania. *Pouring the Sun*, the story, took three years to create. Steel-making was not my world. I was compiling what I call the "compost heap," talking to salesmen, steel workers, foremen, community people, managers, historians, and union representatives.

“LISTENING IS A **creative process**. IT TAKES **attention**—THAT’S CRUCIAL—AND IT TAKES A **generosity** OF SPIRIT.”

The information I gathered became the compost pile. It heated up, and the story came alive. As I gathered the information, it was important to be in the city of Bethlehem, to be in the steel plant, to know the place. I’ve learned that place is very important.

COHEN: Why?

O’CALLAHAN: Place becomes a character in every story. It’s so obvious, it’s invisible to us, but place shapes us. A lot of my stories are about growing up in a place called Pill Hill, a predominately wealthy neighborhood in Brookline, Massachusetts. Pill Hill shaped me. The trees there, the neighbors, the political and religious conflicts that were going on which seemed electric to me as a boy.

When I’m commissioned to do a story, I need to be part of the place. I need to talk to the people who live and work there. I need to walk the streets. In the city of Bethlehem, I met one family, the Waldonys, and I centered the whole Bethlehem Steel story on Ludvika Waldony. Ludvika was eighteen when she came from Poland on a ship by herself in 1907 with very little education and almost no money. The story is told through her eyes. I hope Ludvika’s story captures the experience of hundreds of thousands of immigrants who came from all over the world to work in the steel-making city of Bethlehem.

COHEN: If you were telling a story about NASA, do you have a sense of what it might be about?

O’CALLAHAN: My first job would be to talk with NASA people—scientists, engineers, astronauts. I’m sure that underneath the whole NASA enterprise there is a sense of wonder. Perhaps science and myth are coming together in NASA. The myths of old were often stories about the sun, the stars, and the moon. Now with NASA, we’re going out there. NASA is turning our eyes heavenward just as the ancients did.

COHEN: I remember the excitement of the first moon landing, and Walter Cronkite presenting it as a world-changing event, but then the world didn’t seem to change all that much. I think many people were disappointed.

O’CALLAHAN: Rather than disappointed, I think people are distracted. They are almost too busy to focus on anything, but space exploration is so extraordinary I think our imaginations can catch fire again. After millions of years we’re able to leave this earth and explore what’s beyond. That’s amazing. If people can take this in they’ll realize how astonishing it is. There are rovers on Mars and now we’re headed toward sending a manned spacecraft to Mars.

In another *ASK* interview, Michael Coats says, “When I look down, I’m no

longer a Texan or an American; I’m part of the human race.” In time we may all see through the eyes of Michael Coats and realize we can find ways to live and work in greater harmony.

COHEN: Do stories need to be told face to face?

O’CALLAHAN: I think that’s best. Radio, DVD, and print are wonderful, but when I read Eileen Collins’ *ASK* interview, I was so moved I wanted to meet her, I wanted to hear her voice. Storytelling is a fundamental way of communicating. Ideally a story is told directly to another person or a group of people.

COHEN: When story listeners and storytellers are together, I think they affect each other.

O’CALLAHAN: Listeners mysteriously have the power to draw out details, images, and memories. Listeners can inspire the storyteller. Becoming a good listener takes a lifetime. Listening is a creative process. It takes attention—that’s crucial—and it takes a generosity of spirit. My children listened me into being a storyteller. Listening is key.

NASA’s work is thrilling. They’re exploring the universe. We haven’t taken in the wonder of it, but one day we’ll wake up astonished. ●

LEARNING FROM SPACE ENTREPRENEURS

BY WILLIAM POMERANTZ

On October 4, 2004, Brian Binnie piloted SpaceShipOne above 100 km, marking the third time ever—and the second time in as many weeks—that a civilian astronaut had taken a privately built craft to outer space. In doing so, Binnie and SpaceShipOne captured the \$10 million Ansari X PRIZE for Mojave Aerospace Ventures—a small, cutting-edge private enterprise led by legendary aerospace designer Burt Rutan and financed by Microsoft co-founder Paul Allen. Amazingly, this small team, operating only for a short amount of time and spending an incredibly small amount of money, had joined the United States, the USSR/Russia, and China in the exclusive ranks of human space flight powers.



Pixel, a rocket designed, tested, and flown by Armadillo Aerospace in less than six months, flies at the 2006 X PRIZE Cup. The vehicle broke several world records but failed to win the Northrop Grumman Lunar Lander Challenge.

THEY OFTEN GO FROM DRAWING ON THE BACK OF A NAPKIN TO FIRING ENGINES OR EVEN FLYING VEHICLES IN A MATTER OF WEEKS OR MONTHS, LEARNING VALUABLE LESSONS ALONG THE WAY.

Prizes like the Ansari X PRIZE and later efforts like the NASA-funded Northrop Grumman Lunar Lander Challenge and the recently announced \$30 million Google Lunar X PRIZE exist to focus public attention and apply innovative new ideas to targeted technical problems. Many of the new ideas are elegant technical solutions, like Burt Rutan's use of feathered wings on SpaceShipOne. Equally, if not more, important are the innovative program management practices that come into play when extremely small and motivated teams put their own money on the line to win a prize. Just as SpaceShipOne is not a replacement for the Space Shuttle or other governmental human space flight programs, prizes like those offered by the nonprofit X PRIZE Foundation will not, and likely cannot, replace government design, development, or procurement methods. But just as SpaceShipOne and its counterparts in the private sector can provide effective lessons and practical applications for government programs, so too can program managers at NASA and other government agencies take important cues from the teams competing for prizes.

In my two and a half years at the X PRIZE Foundation, I've had the enormous pleasure of working with several such teams. The experience gives me a front-row seat from which to observe breathtaking innovation. The individuals and groups that are attracted to these prize competitions are a particularly fascinating subset of the human species: passionate, strong-willed, risk-taking, and imaginative.

The space industry would benefit from the involvement and enthusiasm of any one of this new class of steely-eyed missile men and women. On their own initiative and with their own funding, these pioneers put an enormous variety of concepts through the tests needed to expose each as a useful tool or a dead end.

With one of our space prizes successfully claimed, another—the Lunar Lander Challenge—just shy of being won, and the Google Lunar X PRIZE recently announced, we can already begin to look at the progress of the teams and draw important

conclusions. I won't presume to call them "lessons learned" as the lessons from each still need to permeate the industry and inform decision making across the sector. Instead, I think the struggles of each team have revealed some important lessons that we need to learn.

Build, Test, Fly, Destroy, Repeat

The early days of rocketry and space exploration in the United States were marked by incredibly rapid progress: a seemingly endless parade of firsts. Not coincidentally, this period also saw more than its fair share of failure, especially in the infamous "kaputnik" days prior to the successful launch of Explorer. Without a standard canon of known quantities to turn to, the early pioneers of rocketry and space flight were forced to dream up new ideas that ranged from the elegant to the bizarre and to accept the fact that the price of radical progress is occasional failure.

Nowadays, rapid prototyping and testing have slowed, as we rely more and more on the extensive knowledge gained by our predecessors and on the embarrassment of riches modern engineers get from computational modeling and computer-assisted design. In many cases, this leads to much improved or phenomenally more efficient designs. It also, however, fosters a culture so terrified of failure that we over-engineer and overanalyze everything, often tweaking designs for decades before a new system takes flight. (This is not a problem unique to rockets; the same phenomenon seems to have occurred in high-performance jets.) This is one reason why it was possible for President Kennedy to dream of the completion of the Mercury and Gemini missions and a successful landing on the moon in under a decade, while returning to the moon may take nearly twice as long.

Lacking access to the tremendous computational resources of the national space program—and, just as importantly, removed from the harsh judgment of public shareholders or congressional appropriations committees—the hungry entrepreneurs who



High above the Mojave desert, White Knight carries SpaceShipOne aloft for the first of its two Ansari X PRIZE-winning flights.

compete for our prizes tend not to display such fear of failure. Instead, most of them follow a rapid “build, test, fly” program. They are willing to throw a handful of concepts against the wall and see what sticks. They often go from drawing on the back of a napkin to firing engines or even flying vehicles in a matter of weeks or months, learning valuable lessons along the way. Indeed, our teams have repeatedly learned many of the most valuable lessons after only a few moments of working with real hardware—lessons that could never have been learned from a CAD drawing, like finding the failure modes of different welding practices or tracking down the interference between an onboard camera and a GPS unit. As Paul Breed, the leader of a Northrop Grumman Lunar Lander Challenge team (playfully called Unreasonable Rocket), is fond of saying, “In computer simulations the plumbing never leaks. In real life, it always does.”

“Not Invented Here” Leads to “Not Invented”

Aerospace engineers and professionals from other disciplines involved in this sector may be endowed with above-average intelligence—after all, what they do *is* rocket science. But they are still human and still liable to succumb to vanity and pride. This can lead to a variety of actions that, while understandable, slow progress. All too often, members of this industry ignore solutions provided by other sectors of the industry owing to ignorance of those solutions, mistrust of their quality, or a simple desire to promote their own handiwork over that of others.

Though there are exceptions, the new class of entrepreneurial companies that compete for our prizes have thrown “not invented here” out the window. Given that they directly compete for millions of dollars in prize money and usually wager their personal fortunes to fund their entries, one would expect them to guard their own products and ideas jealously, limiting the exchange of ideas.

Instead, though, our teams consistently advise their competitors or distribute labor when teams share common requirements. Many of the contestants in the Northrop

Grumman Lunar Lander Challenge, for example, use a public e-mail list called aRocket to share test information on everything from onboard cameras or guidance systems to specific parts or propellant combinations to the complex and detailed mathematics required to, say, characterize the moment of inertia of their rockets. The “build, test, fly” strategy these teams follow generally leads to a lot of new systems being tested to the point of failure; oftentimes, a team posts test results to this public list within the hour, inviting others to share in the analysis and benefit from their results.

Similarly, most of our teams have, by necessity, vigorously pursued commercial off-the-shelf products. Lacking the time, budget, or facilities to reinvent the wheel, they scour scrap yards, commercial retailers, and even their fellow teams’ shops for parts that can be slotted into their design. They also show a refreshing willingness to look outside the aerospace industry for solutions. Teams have used off-the-shelf products like irrigation tubing or automotive parts as the basis for important components of their vehicles. Parts and systems slated to go into high-performance racing cars or mass produced for consumers have gone through impeccable design and quality assurance processes and offer economies of scale never before seen in the commercial rocket industry. The massive catalog of a universal industrial parts supplier like McMaster-Carr, whose Web page is bursting with valves, piping, and other parts, practically makes these rocketeers giddy. After all, says Breed, the manufacture of rockets boils down to “just tanks and plumbing.”

Size Matters

NASA and the traditional aerospace contractors generally work in teams that number in the hundreds, if not the thousands. Since the days of Kelly Johnson’s Skunk Works, though, the industry has recognized the advantage of small groups of exceptionally talented engineers working with minimal oversight.

Regardless of how intelligent and innovative a manager is, it seems unlikely that any group of hundreds of contributors

Speed-Up, a team in the \$2 million Northrop Grumman Lunar Lander Challenge, watches the show at the 2007 X PRIZE Cup.



ON TEAMS THAT OFTEN NUMBER TEN OR FEWER, THE PEOPLE COMPETING FOR OUR PRIZES ARE ALL CONSTANTLY AWARE OF HOW CRITICAL THEY ARE TO THEIR TEAM.

could ever function as efficiently as a group like Armadillo Aerospace—eight close friends who have worked side by side for years and can practically finish each other's sentences. Such a group can spend most of its time on engineering or production, and little in meetings or coordinating labor.

There Is No Substitute for Passion

Working with teams seeking these prizes, I am struck by one almost overwhelming advantage they have over many traditional aerospace workers: incredible passion. For many of them, the prize entries are the fulfillment of lifelong dreams. Their vehicles are their hobbies, their keys to wealth, and their children, all wrapped into one. Team members as a rule cannot stop talking about their entries—and cannot stop working on them. They dream about their rockets. They talk to their friends and coworkers about them. They blog about them. They happily give up weekends and use up vacation days to find even more time to work. “We’re standing on the threshold of a dream,” says Neil Milburn, vice president of Armadillo Aerospace. There is not a 9-to-5 worker among them. Of course, NASA has its fair share of motivated employees as well. But the commitment of these entrepreneurs, with so much of their personal lives wrapped up in their projects, borders on obsession.

Some of this enthusiasm and passion comes from the lofty goals of the prize requirements; some, no doubt, comes from the thrill of competition. But I suspect their unbridled obsession comes mainly from the high degree of personal involvement and ownership each team member feels. In an era when the smaller aerospace boutiques of the 1960s have merged into a few massive corporate giants, it is too easy for engineers, especially younger engineers, to feel like a small cog in a massive machine. On teams that often number ten or fewer, the people competing for our prizes are all constantly aware of how critical they are to their teams. They are intensely and deservedly proud of this and work on their machines as though their lives depended on it. Their confidence in themselves frees

them to borrow solutions from others and leads to progress at incredible speeds.

We’re Entrepreneurial Space, and We’re Here to Help

The creative, small, privately funded groups that find themselves called to our competitions possess, by necessity, a number of advantages that allow them to function on infinitesimal budgets, by industry standards. Many of these advantages are probably impossible to translate to efforts being undertaken by the traditional members of the aerospace community. The good news is that, despite the occasional playful bravado of some of the more colorful characters involved in these competitions, all our teams are die-hard supporters of a robust space exploration program and will gladly do their parts. As such, they can function as highly specialized components of the greater aerospace workforce. These small, innovative teams can quickly and cheaply provide services to their larger brethren. Whether it is a Northrop Grumman Lunar Lander Challenge team providing a flying platform capable of carrying experimental sensors on dozens of flights a week, or Ansari X PRIZE competitors carrying scientific payloads and their human operators into the blackness of space, or the eventual Google Lunar X PRIZE winners testing systems and returning data that will support NASA’s return to the moon, the entrepreneurial community is poised to help the national space program like never before. ●

WILLIAM POMERANTZ has been the director of space projects at the X PRIZE Foundation since 2005. He currently manages the Northrop Grumman Lunar Lander Challenge, a \$2 million, NASA-funded prize competition, and he was one of the primary authors of the Google Lunar X PRIZE. He lives and works in Washington, D.C.



Featured Invention:

Laser Scaling Device

BY CAROL ANNE DUNN AND GINY CHEONG

When the Applied Physics Laboratory (APL) at Kennedy Space Center developed the laser scaling device for the Space Shuttle program, the inventors had no idea that the invention would become commercially successful with law enforcement and crime scene investigation teams.

After a storm caused extensive hail damage to the shuttle's external tank, NASA Space Shuttle operations personnel wanted to measure the extent of the damage. Although telephoto lenses clearly showed the damage to the external tank, the image contained no reference objects to determine the exact size of the dents. In many photographic situations an object such as a ruler is placed within the frame so the viewer will have a visual indication of the scale of the other objects in it. This procedure was not possible in this situation, however, as several areas were physically inaccessible. Personnel needed to know the scale of the damage to determine whether repairs would be necessary, so the operations team called on APL's innovative problem-solving abilities to help.

Dr. Robert Youngquist, the lead inventor, explained, "Our lab is unique here at Kennedy, and there aren't any other labs that do what we do. When problems arise that aren't specific to any lab, for example corrosion or chemistry, or when strange problems arrive, they are brought to our lab. Historically, we've fallen into the role as a catchall to solve problems that don't fit or aren't supported by the more specific labs."

Two shuttle engineers, Charles Stevenson and Jorge Rivera, came to Dr. Youngquist and APL with the idea for the laser scaling device. Dr. Youngquist recalled, "They hadn't thought it all through very well, but they had realized that by using laser beams, they could get some kind of scaling information. They posed the problem and suggested laser beams as a solution. I built the system in my lab using lab parts and verified that it met the requirements [one-sixteenth-inch resolution at 80 feet]." William Haskell and Robert Cox built the first prototype while Dr. John Lane, Kim Ballard, and Dr. Youngquist created the

software, which converts the pattern in the image and computes the distance scale for the entire image.

The resulting device attached directly onto a camera or any other observation instrument to project parallel laser lines into the camera's field of view. The lines indicated a known distance and generated a set of evenly spaced laser spots on the object being photographed. The resulting image projected a built-in scale to show the size of the object being seen. The accompanying software converted the pattern in the photo and computed the distance scale, saving valuable time in establishing and documenting measurements. The laser scaling device essentially placed a virtual ruler in the field of view that allowed the operations personnel to determine the scale of the object and measure the extent of the external tank's hail damage with more than one-sixteenth-inch accuracy.

The Kennedy APL team also tested several other design prototypes, including multiple lasers versus a single laser sent through beam-splitting optics and plastic versus metallic housings for the battery. The experimentation resulted in a multilaser assembly that used four lasers, as requested by shuttle operations personnel, and subsequent versions that used two lasers. Dr. Youngquist said, "We always try to find simple solutions. A lot of the hardware that we build, a lot of the reason people like us, is because we find simple solutions."

Dr. Youngquist also cited several factors for his laboratory's success: "Ingenuity and mechanical design as well as our breadth of background and years of experience are vast here. We also provide a strong customer experience—we listen to them and the problems that they bring to us. Other labs fix things by using what they know, while we will learn things



The laser scaling device.

Photo courtesy KSC Technology Transfer Office

or bring problems to other labs when it's outside our realm of expertise."

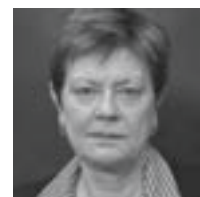
In September 2003, NASA signed a nonexclusive license agreement with Armor Forensics, a subsidiary of Armor Holdings, Inc., for the laser scaling device under the Innovative Partnerships Program. Coupled with a measuring program, also developed by NASA, the unit provides crime scene investigators with the ability to shoot photographs at scale without having to physically enter the scene, analyzing details such as blood-spatter patterns and graffiti. This ability keeps the scene's components intact and pristine for the collection of information and evidence.

The laser scaling device elegantly solved a pressing problem for NASA's shuttle operations team and also provided industry with a useful tool. For NASA, the laser scaling device is still used to measure divots or damage to the shuttle's external tank and other structures around the launchpad. When the invention also met similar needs within industry, the Innovative Partnerships Program provided information to Armor Forensics for licensing and marketing the laser scaling device. Jeff Kohler, technology transfer agent at Kennedy, added, "We also invited a representative from the FBI's special photography unit to Kennedy to meet with Armor Forensics and the innovator. Eventually the FBI ended up purchasing some units. Armor Forensics is also beginning to receive interest from DoD [Department of Defense] for use in military crime scene investigations overseas." ●

For information regarding the laser scaling device, please call Jeff Kohler, Technology Transfer Agent, at 321-861-7158.

THE LASER SCALING DEVICE
ELEGANTLY SOLVED A PRESSING
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CAROL ANNE DUNN currently works as a project specialist in the Technology Transfer Office at Kennedy Space Center. She is also the awards liaison officer for the Inventions and Contributions Board.



Reaching for the APEX at Ames

BY MATTHEW KOHUT

“Every manager has the same complaint, regardless of his or her level,” says Dr. Jeffrey McCandless, strategic advisor for the Human Systems Integration Division at Ames Research Center. “We all say it all the time: ‘My subordinates don’t understand the big picture, and they don’t understand all the relationships that I, the manager, need to build.’”

As one of the first graduates of the Ames Project Excellence (APEX) development program, McCandless has been trying to keep his eye on the big picture. He was one of twenty participants selected to go through the pilot year of APEX, a professional development program for project managers and systems engineers. “APEX gave me a much broader perspective about the center,” he says. “I realized that I have to make sure I don’t just focus on my own division here.”

Pete Zell, another member of the APEX class of 2006, found a different kind of focus in the program. “APEX allows you to turn down the volume and concentrate on improving key project management skills more deeply,” he says. Zell, deputy project manager for the Crew Exploration Vehicle Thermal Protection System, found that APEX meshed perfectly with his day job: “I didn’t have to go out and search for things to try and improve my skills on—I had it all sitting in front of me. The fact that I was on a large, multicenter project gave me plenty of opportunities to apply the skills to my work.”

Real-world applicability was precisely the intention of the program’s creators. “APEX is designed and driven to help people do what they’re supposed to be doing right now, and do it better. We consider their project work one big OJT [on-the-job-training] assignment,” says APEX Program Manager Claire Smith. Smith and Ron Johnson, chief of the Systems Management Office at Ames, were the driving forces behind APEX. “The process is designed so that development happens in a continuous loop,” Johnson explains. “Experiences and knowledge are generated via project work. Those experiences are discussed and reflected upon in the mentoring sessions, and then those new insights and sharpened awareness are taken back to the project work.”

In addition to on-the-job training, the program includes

mentoring, coursework, and coaching provided through the Academy of Program/Project and Engineering Leadership. The first task of each participant is to conduct a self-assessment and determine a skill level—developmental, functional, or proficient—in twenty-six core competencies for project management or systems engineering. APEX integrates each participant’s competency ratings with the needs that Ames center management has identified for competencies in its project managers. Participants then choose three or four competencies to concentrate on for the year and design an individual development plan (IDP) to attain the next level of capability in each.

“The thing I found manageable about the program was that it didn’t try to do everything. It didn’t try to improve you across the entire spectrum, which would’ve been overwhelming,” Zell says. He chose budget and full-cost accounting, requirements development, scheduling and work breakdown structure development, and risk management as the four areas in which he would like to improve his skills during the year. “I could pick something that I needed to do anyway. By doing that, it helped me focus within my project, which was valuable, and it gave me constant feedback.”

McCandless focused on NASA procedures, project planning and scheduling, and project control. “After [learning more about] NPR 7120.5D, I have a better understanding of the four key steps of a project’s development from the beginning all the way through to evaluation. I’ve been around long enough to see that some projects have failed because some of these pointers in 7120.5 haven’t been met or done. By seeing them in black and white in front of me, it drives that home so I remember it for the next project.”

A key component of APEX is mentoring. Each participant has four to six hours per month of one-on-one mentoring with a senior-level person in the field. Additionally, monthly team



mentoring sessions were held with their cohort of project managers or systems engineers and led by recognized experts who facilitated topical discussions. “The mentoring program had to be at least semi-structured,” Smith says. “People getting together to shoot the breeze is not mentoring.”

For McCandless, both forms of mentoring proved valuable. “What helped was a combination of talking to my own mentor and the sessions with the group mentor,” he says. “The group mentoring lined up really well with my IDP goals for project control and project scheduling. He [the group mentor] would make recommendations and give tips and relate them to his own experience.” McCandless’s personal mentor deepened his appreciation for project success at the center: “He had good pragmatic insight into what strategies were effective here at Ames, and which projects were succeeding and which were failing, and why.”

Zell found it easy to connect on a personal level with his mentor. “We hit it off in terms of our philosophies of project management,” he says. “We basically spent a lot of time talking about common experiences.”

The multidimensional design of the APEX program is the result of an extensive research and development effort dating back nearly a decade. “In the late 1990s and early 2000, we were pretty successful at getting new research and technology projects here at the center,” Johnson says, “and we had a lack of critical mass of project managers. We were taking people who were primarily researchers and putting them in the position of managing projects.” Smith and Johnson held a series of workshops across the center during 2000 and 2001 to gather feedback about how to address this issue.

When they briefed the center’s senior management on their findings, one of the top recommendations was to establish a project manager development program at Ames. At that point, they cast a wide net for ideas and information. “We did centerwide needs assessment, we did focus groups, we did surveys,” Smith says. “We came up with a proposal for what a program would look like, tying in what we knew about the Academy of Program/Project Leadership (now the Academy for Program/Project and Engineering Leadership, or APPEL), what we’ve seen at other

centers, what other centers have tried. We were always checking to make sure our program mapped to APPEL. We also looked at the PMI [Project Management Institute] model, INCOSE [International Council on Systems Engineering], CMMI [Capability Maturity Model Integration], you name it.”

“We had a lot of conversations with the Jet Propulsion Lab and Goddard,” Johnson adds. “We saw those centers as models for what Ames was aspiring to be in terms of a center for managing space flight missions.”

Their research confirmed what they already knew—that strong practitioner involvement would be critical to their program design process. “APEX is for the practitioner by the practitioner,” Smith says. “They have to be a part of designing it. Otherwise there’s no way we could design a program that meets their needs.”

At the same time that they worked at the grassroots level, they also solicited feedback from the center’s senior management. “We recognized that in order for anything to succeed here, we needed to have a champion at the center management level,” Johnson said. “You have to have champions, and you have to listen to what the senior managers are saying. They have their own ideas.”

In the case of APEX, one of those ideas fundamentally reshaped the program. “When we originally started, it was a project management development program,” Johnson says, “but in our meeting with our center director, he said, ‘Project management is important, but we also need to strengthen our systems engineering.’ So we basically added that component to the program based on what he wanted.”

Following the pilot year graduation, Johnson and Smith conducted a “lessons noted process,” and they are now applying these insights to the next iteration of APEX. “We call them ‘lessons noted’ because insights only become ‘lessons learned’ when we apply them and change the way we do things,” says Smith. As a second cohort progresses through the program, she believes that the Ames community as a whole has a better idea of what APEX can become as it matures: “I think the idea of [what constitutes] a development program is a lot more conscious, and there’s a lot more consensus around it.” ●



Photo Credit: Library of Congress

THE PROJECT MANAGER WHO
SAVED
HIS COUNTRY

BY JOHN BANISZEWSKI

George graduated with a degree from one of the finest engineering colleges in America and immediately went to work for the government. For several years, he worked staff jobs. His career took off when his organization put him to work on projects.

The projects George worked on were for state-of-the-art communication systems, which had to operate dependably in harsh environments. The primary payloads for these projects were expensive and complex optical systems that had to be integrated with support structures that provided for energy, command, and control. The success of these projects sometimes depended upon unproven manufacturing processes. When the manager of his first project unexpectedly died, George succeeded him and completed the project on time and within budget, meeting all technical requirements. George's bosses recognized his talents. During the next decade, he managed another nine similar projects, consistently meeting his technical, schedule, and budget goals.

There came a time when his organization faced a crisis. A series of projects had failed, and the organization's existence was in jeopardy. The biggest and most important project was a mess—the senior project team members were fighting among themselves, and the project manager was floundering. Senior management sacked the project manager at a critical stage of the project and put George in charge. Within days, he turned the project around and achieved one of the biggest successes in his organization's history.

The project manager's full name was George Meade. He graduated from West Point in 1835. In the 1850s, he managed the construction of lighthouses along the Atlantic coast. He was an officer in the Union army during the American Civil War. In June 1863, a Confederate army led by the legendary Robert E. Lee was marching through Pennsylvania, and Abraham Lincoln feared the end of the United States of America as a country. On June 28, 1863, Lincoln put Meade in charge of the North's largest army. Three days later, the Battle of Gettysburg began. On July 3, when the guns fell silent, George Meade and his army had won the most decisive battle in American history.

George Meade defeated Robert E. Lee, one of the greatest military leaders of all time. How did he do it? By using the skills he had learned as a project manager and outperforming Lee in all aspects of project management.

I work at NASA Goddard as a deputy project manager for resources. I am also a licensed battlefield guide at Gettysburg. A

few years ago, the Defense Acquisition University asked me to develop a training program that uses the Battle of Gettysburg as a case study in project management. I have taken dozens of project managers to Gettysburg in connection with this program.

Most project managers are familiar with the Project Management Institute's "Guide to the Project Management Body of Knowledge" (PMBOK), which identifies the skills and knowledge crucial to successful project management. An analysis of the Battle of Gettysburg shows that George Meade completely outperformed Robert E. Lee in seven of the areas identified in the PMBOK: project integration, scope management, time management, resource management, human resource management, communication, and risk management. Meade's superiority over Lee in these areas was critical to the North's success at the Battle of Gettysburg.

Project Integration

Project managers need to make sure that all the elements of a project work together. They must develop and execute plans and coordinate changes to those plans. Meade's predecessor had kept his subordinates in the dark. As soon as he was promoted, Meade found out everything he could about the condition and status of his army. He developed a well-coordinated plan for the movement of his scattered soldiers to simultaneously protect key northern cities, bring the southern army to battle, and allow his army to consolidate quickly where the fighting would break out. When the fight started three days later, he sent trusted subordinates to take charge of the fighting. He knew his job was redirecting the movements of his scattered army to make sure the efforts of his entire army were coordinated. Because of him, all 90,000 of his soldiers knew where to go and when to get there. They got there in record time. Each day of the battle, he gathered all his key subordinates together to ascertain the progress of the battle, to ensure everyone knew what was expected of them, and to revise plans for the subsequent day.

Robert E. Lee, in contrast, was completely surprised by the start of the battle and played no role in deciding when or where it would occur. He allowed his subordinates to talk him out of repositioning

MEADE HAD A CENTRALIZED ORGANIZATION, THE BUREAU OF MILITARY INFORMATION (BMI), TO COLLECT INFORMATION FROM HUNDREDS OF SOURCES AND TURN IT INTO KNOWLEDGE THAT COULD BE USED TO MAKE DECISIONS.

their soldiers, resulting in one-third of his army having little ability to affect the battle decisively. During the entire three days of fighting, Lee never had his three key subordinates in the same place, at the same time, to share information and ensure cooperation.

Scope Management

A project manager must define the scope of the work, break it into manageable pieces, verify and control what work is being done, and make sure that the work being done is essential to the project. One of the biggest causes of Lee's defeat was the southern cavalry soldiers' failure to do their most critical job: collect intelligence about the enemy. A week before the battle, Lee allowed his cavalry commander, General J.E.B. Stuart, to go on an ill-planned mission that crippled Lee's ability to gather information about the Union army. They wasted valuable time capturing supplies instead of focusing solely on their primary mission of scouting. As a result of this "scope creep," Lee's cavalry failed to play the role for which it was most needed. Lee went into battle knowing very little about the strength of his opponent and made key decisions with inadequate knowledge.

When Meade took command of his army on June 28 and ordered its advance, he had to separate it into several pieces to carry out all his requirements. Meade made sure that his subordinates did exactly what he wanted done by sending them frequent orders about the direction of march, number of miles to advance, and destinations at the end of each day. He monitored their progress closely. If his subordinates failed to reach their daily objectives, he chastised them mercilessly. He made sure their independent movements were completely in compliance with his master plan. He resisted pressure from Washington to send his cavalry chasing General Stuart, knowing that he needed his cavalry to focus on the crucial role he assigned it. Thanks to Meade's efforts, he was able to achieve an incredibly rapid concentration of his soldiers and fight the battle with an advantage of numbers.

Time Management

Every project manager knows the challenges of schedule and the value of schedule slack. The key to victory in the Civil War

was to get soldiers quickly to where they were needed—the battlefield. Meade had his men march an average of twenty miles a day for three days. Twelve miles a day was considered challenging. Supply wagons were ordered off the roads so they would not impede the combat soldiers' march.

In contrast, Lee did not seem overly concerned about the speed of his army's concentration once he knew a battle was likely. His official report said that "the weather being inclement, the march was conducted with a view to the comfort of the troops." At one point, 12,000 of his best combat soldiers were stopped dead for hours, blocked by supply wagons at a road intersection, greatly delaying their arrival at Gettysburg.

Resource Management

Project managers must get the resources they need and use them effectively. Meade's critical resource was combat soldiers on the battlefield. Meade knew the value of keeping a reserve. On day two of the battle, he kept 20 percent of his combat soldiers and 25 percent of his cannons as his reserve, to be used as needed. One of Meade's incompetent subordinates disobeyed his orders and moved his troop to a weak and vulnerable position, where they were hit with a devastating surprise attack by 15,000 Confederates. Meade immediately threw in his reserves, sending them where they were most needed, and shifted other resources from places where things were quiet. His prompt action prevented a disaster.

The Confederates never had additional troops where and when they were needed. When one of Lee's subordinates, James Longstreet, was on the verge of a breakthrough, he needed additional resources to ensure victory. None were there. He later complained, "We received no support at all, and there was no evidence of cooperation on any side."

Human Resource Management

Project managers get the people they need and use their talents to achieve mission success. George Meade knew the importance of using the right people for the right jobs. As a condition of accepting command, he demanded and got authority to



Photo courtesy John Baniszewski

promote, demote, and use his generals as he saw fit, based on their ability and competence. When Meade ordered his army to march northward, he informally reorganized it, putting almost half of it under the control of his most competent subordinate. When that man was killed in the fighting, Meade sent his most junior subordinate to take command, a general named Winfield Hancock, who had proven his skills on many past battlefields. Hancock performed superbly.

Lee's team had undergone major turnover. Stonewall Jackson, his best general, had been killed two months before Gettysburg. Lee promoted two men to take Jackson's place: Generals A.P. Hill and Richard Ewell. Lee had always used a "hands-off" management style that worked well with his previous team. It did not work with Hill and Ewell. Time and again, they failed to act when Lee expected action, or they took actions that Lee had not authorized. They were not ready for the independence Lee gave them. He did not give them the clear direction they needed.

Communication

Projects generate huge amounts of information. A key to project success is getting sufficient and accurate information to the people who need it when they need it. Meade had a centralized organization, the Bureau of Military Information (BMI), to collect information from hundreds of sources and turn it into knowledge that could be used to make decisions. This organization was located fifty yards from Meade's headquarters, and he continuously called upon it to apprise him of the status of both armies.

Lee had nothing comparable to Meade's BMI. He himself, assisted by a handful of aides, assumed responsibility for collecting and interpreting the information needed to prosecute the battle. Lee had little idea of the extent of the casualties his army suffered. On the last day of the battle, he ordered an attack in which he significantly overestimated the size of his attack force. That attack was a disaster. At Gettysburg, Meade had access to important information and used that information to make smart decisions. Lee's lack of comparable information led him to make crucial mistakes.

Risk Management

Project managers must identify and quantify the risks that jeopardize project success and make plans for dealing with them. Meade always considered what might happen if his plans went awry. On each day of the battle, he developed detailed contingency plans and was always prepared either to attack, hold his ground, or retreat. Meade never had to make use of these plans, but they were there if needed.

Lee seemed to operate under a constant expectation of success. In the case of the disastrous cavalry expedition made by J.E.B. Stuart, Lee had other cavalry soldiers that he could have used to fill Stuart's role. Instead, he sent those soldiers on other, less-critical missions. Lee made no plans to address failure in battle. At the end of day three, when he finally understood the horrible extent of his losses and realized that his army was in danger of destruction, he had no retreat plan to draw on. Had Meade been more aggressive on July 4, Lee's army could have suffered disaster due to Lee's lack of planning for a battlefield setback.

Learning from Meade

Studying Meade and Lee's performances at Gettysburg can help modern project managers appreciate, develop, and use the skills they need to be good project managers. The circumstances may be different, but the basic principles are the same. This dramatic event in American history shows how the skills of project management can be used in almost any situation. Former project manager George Meade used those skills to change the tide of the Civil War. ●

JOHN BANISZEWSKI has thirty years of experience as a contracting officer, procurement manager, finance manager, and deputy project manager on projects at Goddard Space Flight Center. He conducts training programs in which he applies the lessons learned at Gettysburg to present-day topics such as leadership development, teamwork, and project management. JDBano2001@yahoo.com



Choosing and Developing the Right Leadership Styles for Projects

BY DR. RALF MÜLLER

Analyzing extensive questionnaires completed by 400 project management professionals, Professor Rodney Turner of the Lille Graduate School of Management and I have identified competencies that contribute significantly to project management success. Our research helps define the managerial and emotional competencies needed to make projects work. We also found that different kinds of projects call for different combinations of competencies.

While some commentators focus on project tools and techniques, Aristotle knew thousands of years ago that effective leadership depends on the social competencies needed to form good relationships and evoke common values. The fact that fewer than 50 percent of projects succeed in achieving their aims on time and on budget suggests that even the best tools won't do the job in the wrong hands. Our research shows that Aristotle was right about the kinds of competencies successful leaders—including project leaders—must have.

Earlier research suggests that a manager's leadership style can be defined in terms of emotional (EQ), managerial (MQ), and intellectual (IQ) competencies. (See table on facing page.) We found that emotional competency correlates significantly with project success in high-performing projects of almost all types. The higher the EQ, the higher the level of project success.

However, different kinds of projects require different competencies. In engineering and construction projects, conscientiousness, interpersonal sensitivity, and engaging communication contribute most to project success. This is because of the need for discipline and due diligence in managing these complex projects and also because of the need to evoke and integrate various opinions and possible solutions to problems.

For IT projects, the important competencies for success once again include engaging communication, along with self-awareness and developing resources. Finding the right "tone" with others, together with good control over personal feelings and helping project team members take on challenging tasks, are the attributes of successful leadership in these projects. This combination helps IT leaders overcome the common problems of unclear goals and low budgets on the side of the

project team, and unrealistic expectations on the side of future users of the IT system.

Organizational change projects also require engaging communication in addition to motivation, an emotional competency. The project manager who rates high on motivation exhibits and encourages drive to achieve clear results. He or she actively creates the energy that major change requires. In combination with interpersonal competencies, this drive is essential for managing reorganizations or implementing new work processes.

We found that one competency correlates negatively with success in all high-performing projects: vision and imagination, an intellectual competency. Visionary and imaginative people are without doubt important to project success, but when the project manager is too imaginative he can compromise the task at hand. Conscientiousness is much more important to successful project management than vision. Vision and imagination are better supplied by people in other roles, such as the project sponsor, who sets and communicates a project's objectives.

These findings suggest that project managers should think consciously of the specific skills their particular projects call for, and leaders should pay careful attention to matching projects and project managers, developing project managers with the skills appropriate to the work they will be doing. It is commonly thought that IQ is somewhat fixed after the age of twelve. EQ and MQ, however, can be developed throughout life.* That makes it possible for people to learn the competencies that suit the needs of a particular project type.

But developing the intellectual, emotional, and managerial competencies that effective project managers need takes time

and focused effort. Reading a book on communication does not make a person an “engaging communicator,” and managers do not become experts in motivating others simply by realizing that motivation is important. Cultivating these and other competencies often requires open feedback from coworkers or mentors over an extended period of time to identify areas for improvement, followed by training and extensive practice to improve in the desired area.

The effort is worthwhile, though, because good project management is much more than tools and techniques. Matching project needs to emotional, managerial, and intellectual competencies is neither a panacea, nor the only way to improve project results. It supplements existing ways of selecting project managers for projects. Most importantly, it moves the discussion from *what to do* in projects to *how to behave* in projects. Isn't that something we learn from early childhood on? Finally, that approach is making its way into project management. ●

This article is based on joint research done with Professor Rodney Turner, Graduate School of Management, Lille, France. The researchers acknowledge the financial support from the Project Management Institute (PMI), the Graduate School of Management, Lille, and the School of Business at Umeå University. Without this support the study would not have been possible.

GROUP	COMPETENCY
INTELLECTUAL (IQ)	1. Critical analysis and judgment
	2. Vision and imagination
	3. Strategic perspective
MANAGERIAL (MQ)	4. Engaging communication
	5. Managing resources
	6. Empowering
	7. Developing
	8. Achieving
EMOTIONAL (EQ)	9. Self-awareness
	10. Emotional resilience
	11. Motivation
	12. Interpersonal sensitivity
	13. Influence
	14. Intuitiveness
	15. Conscientiousness

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* R. Boyatzis, D. Goleman, and A. McKee, *Primal Leadership: Learning to Lead with Emotional Intelligence* (Boston: Harvard Business School Press, 2002).

Knowledge in Brief

Learning by Listening

Successfully sharing knowledge is complicated. To acquire knowledge, you have to have some idea of what you need to know, find a good source for that knowledge, figure out how the people (or documents) offering that knowledge understand the concepts involved, and work out how the knowledge applies to your own activities. An effective knowledge provider needs to understand the needs and assumptions of the knowledge seeker. For both seekers and providers, an important but often overlooked element of the process is listening. Here are three stories about effective listening.

Red Auerbach and the Celtics

Red Auerbach coached the Boston Celtics to eight consecutive NBA championships. There's a bronze statue of him sitting on a bench in Boston's Faneuil Hall marketplace—balding, stocky, holding his famous “victory cigar”—an ordinary-looking guy, but a basketball genius. Part of that genius was an extraordinary ability to communicate with his players. It's true he had a loud voice, he was passionate, and he knew a lot about basketball. But the key to his effectiveness was his ability to listen.

Celtics star Bill Russell has said, “Red had the greatest of ears. After he talked to a player four times, he knew how to communicate with him.” Listening taught Auerbach how to talk to his players. He himself once said, “It's not what you say; it's what they hear,” putting his finger on an essential truth about communication: it only works when you understand the person you're talking with and shape your words and manner to how he hears—that is, to how he thinks, what he cares about, and what he needs. The only way to understand those things is to listen.

Doctors and Patients

In *How Doctors Think*, Jerome Groopman notes that, on average, doctors interrupt their patients' stories about their ailments within eighteen seconds. They interrupt not only because they are pressed for time but because they think they understand the problem; they have already made their diagnosis. Groopman

tells stories of doctor error that show how dangerous jumping to conclusions and cutting off patients can be.

Groopman talks about how important it is to respect patients and understand that they know things about their own conditions that the doctor, for all his training, cannot know. Respecting the person you're listening to—understanding that he or she has something to teach you—is important to all knowledge exchange. Equally important is being open to information that challenges your assumptions or hypotheses. Doctors who think they already know the answer often don't hear contradictory data even when they appear to be listening.

Listening to an Employee

A talented young woman had worked on organizational development for a high-tech firm for three years. Although she enjoyed the work and liked the people she worked with, she was beginning to think it was time to move on—maybe to go back to school to get an advanced degree.

She had not yet told her boss what she was thinking, but he seemed to sense that she was getting ready to make a change. He came to her office one morning and said, “If you were able to define the perfect job for yourself at this company, what would that job look like?”

She thought for a few moments, then described a job with more responsibility and flexibility than her current position, one that would allow her to knit together organizational development efforts at multiple sites, to visit other organizations to understand their related activities, and to develop new learning programs that she had not had the time or influence to make happen.

“OK,” said her boss, “that's your job.”

She stayed with the company for several years more, doing excellent work. ●

ASK Bookshelf

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

***The Black Swan: The Impact of the Highly Improbable*, by Nassim Nicholas Taleb (New York: Random House, 2007)**

One of the most interesting publishing phenomena in the past few years is the success of *The Black Swan*—a most improbable best seller. Written by a commodities trader with a PhD in statistics, it wrestles with a question usually reserved for professors of epistemology: how can we know things?

Why review this book in *ASK*? Here are some good reasons.

A “black swan” signifies a totally unanticipated event. At one time, everyone in the Western world thought all swans were white. Exploration of Australia turned up black swans, however, creatures that deductive reasoning—reasoning from a general principle—could not have predicted. Did deductive methods allow us to predict World War I, the Internet, the fall of communism? This book makes a strong argument for using induction—basing conclusions on observed cases—as well.

Nassim Taleb takes on the industry of people devoted to predicting the future in a scientific sort of way, who develop and sell sophisticated prediction models and structures. Using logic, observations from Wall Street and politics, his own philosophic musings, and arguments from radical empiricists such as David Hume and Karl Popper, Taleb shows why the entire industry is built on air. His views are well worth pondering by NASA project managers and engineers trying to gauge risk and anticipate mission challenges.

Taleb presents a valuable point of view, which we’d call “seeing life clear.” He believes that our minds have evolved to understand events as narratives—to see them as patterned. This fools us into attributing many events to causes that are difficult or impossible for us to know at the present time. Because our brains do not feel comfortable with causal ambiguity, we create explanatory narratives to make us happy. With suitable scientific dressing, these often baseless conclusions are sold to clients for huge sums.

This book is an unusually entertaining philosophical text. It is filled with stories, arguments, jokes, invective, and rhetorical excess. If you have even a slight taste for such things, *The Black Swan* is for you.

***In the Shadow of the Moon*, by Francis French and Colin Burgess (Lincoln, NE: University of Nebraska Press, 2007)**

The story is a familiar one: the trials and triumphs of the Apollo program, told mainly from the point of view of the astronauts. It is worth reading about again in this book, which dramatically details the skill, courage, and dedication that made the 1969 lunar landing possible. *In the Shadow of the Moon* also offers insights that are important to NASA today. We see how communication problems and schedule pressures hindered learning the lessons of the first spacewalks and contributed to the tragedy of the Apollo 1 fire, and how personalities and politics influence decisions even when everyone is dedicated to the same great goal. We also see vivid examples of the value of teamwork and training at NASA.

Above all, the book reminds us just how extraordinary the accomplishments of Apollo were. It was a triumph of technology and will and lived up to the stirring words of William Jennings Bryan, quoted in the epilogue: “Destiny is not a matter of chance. It is a matter of choice. It is not a thing to be waited for; it is a thing to be achieved.” ●

The Knowledge Notebook

The Costs of Knowledge

BY LAURENCE PRUSAK



One of the defining features of society and the economy at the beginning of the twenty-first century is the plummeting cost of working with information. The IT revolution, which started its public life slowly in the mid-1950s, picked up tremendous steam in the decades that followed. By the end of the century, the cost of accruing and distributing information had fallen to levels that would have been inconceivable a few dozen years earlier.

A computer scientist I know recently took his twelve-year-old son to a baseball game. The boy bought a box of candy that contained a little “prize”—a very small, cheaply made calculator. This boy, who lives with pretty sophisticated machinery, disdainfully tossed the toy into the nearest trash can. His father retrieved it and brought it home to look closely at it. He found that this trivial toy had more computing power than the largest machines built during the Second World War! All that change has happened in my own lifetime. The computing power of the mission control center that got Apollo to the moon in the sixties—a hugely expensive marvel at the time—is utterly insignificant today.

The effect of cheap and seemingly ubiquitous computing on the search for and retrieval of information is apparent to all. Less obvious is the fact that knowledge is *not* subject to these changes. In fact, one can make the case that knowledge costs have actually increased over the same period. Let’s look at why information and knowledge are so different in this regard.

Some recent research I conducted with some colleagues divided up the actual activities that working with knowledge entails into four discrete

activities: searching for knowledge, negotiating with knowledge sources, adapting and adopting new knowledge, and distributing knowledge. All these human activities take time and attention. While technology can play a role in mitigating their costs, knowledge still proves to be an expensive item in any organization’s budget.

Searching for knowledge is probably the most amenable to some sort of technological assist. Virtually everyone uses some sort of search engine, often Google, to try to figure out who knows something they need to learn about and how to contact them. While this isn’t a fail-safe process—the Web includes a lot of self-promotion and bogus information—it is a remarkably efficient way to get started.

But acquiring knowledge—genuinely learning something new—requires the consent and commitment of the person you’re trying to learn from. In contrast to information, which can usually be effectively transmitted in a document or diagram, knowledge comes from explaining, clarifying, questioning, and sometimes actually working together. Getting this kind of attention and commitment often involves some form of negotiation, since even the most generous person’s time and energy are limited. Few experts sit around waiting to share their knowledge with strangers or casual acquaintances.

In reasonably collaborative enterprises—I think NASA is one—this sort of negotiation isn’t too onerous. People want to help each other and share what they know, so the “cost” of acquiring knowledge is relatively low. In many organizations (and many communities and countries), however, there are considerable costs

associated with this activity, and many situations in which negotiations fail.

The greatest knowledge cost is in adapting and adopting knowledge to one's own use. Sometimes this means formally organizing what one learns in writing. Sometimes it means just taking time to reflect on someone else's thoughts and experiences—thinking about knowledge that is not exactly what you need but can lead you to develop ideas that will be useful. A long, discursive conversation, with all the back-and-forth that defines conversation, can be a mechanism of knowledge exchange. I have seen many participants at NASA APPEL Masters Forums talking, reflecting, and thinking—adapting what they are hearing to their own needs.

Knowledge transfer is not a simple proposition. An enormous amount of information flows through the world every day, but knowledge is local, contextual, and “sticky”—that is, it takes real effort to move it from one place to another. There is no way around this. To really learn a subject, you have to work at it, you have to pay your “knowledge dues.” So while, thanks to advances in technology, almost infinite amounts of information are instantly available, it still takes the same amount of time and work to learn French as it did in the year 1800—or to master physics or philosophy.

The computer on your desk is amazing. So is the Internet. They make a lot of things easier. (I wrote this little article on my computer and e-mailed it to *ASK*'s managing editor. Twenty-five years ago, I would have had to type it, put it in the mail, and wait for handwritten revisions, which would have required retyping and re-mailing the whole thing.) New technologies put a wealth of information at your fingertips. But don't mistake that information for knowledge. Information can fly through cyberspace, but knowledge resides in people, practices, and work routines. Information is fast and cheap. Knowledge costs time and effort. ●

IN CONTRAST TO INFORMATION,
WHICH CAN USUALLY BE EFFECTIVELY
TRANSMITTED IN A DOCUMENT OR
DIAGRAM, KNOWLEDGE COMES FROM
EXPLAINING, CLARIFYING, QUESTIONING,
AND SOMETIMES ACTUALLY WORKING
TOGETHER.

ASK interactive



NASA in the News

NASA recently launched a Web site that contains survey responses collected from 25,762 air carrier pilots and 4,777 general aviation pilots as part of the NASA National Aviation Operational Monitoring Service (NAOMS) project, which ran from April 2001 through December 2004. NASA funded NAOMS to investigate new methodologies that may be of use to the broader research community. The study

itself focused on aviation safety, reaching out to pilots for their responses, which would remain anonymous, instead of relying on them to proactively proffer information via other channels, such as the Federal Aviation Administration's Aviation Safety Action Program. NASA Administrator Michael Griffin commented, "Folks were looking to develop a methodology that would unearth precursor information, the kinds of data that, after an accident, one looks back and says, 'Oh, I could have seen this coming.' That is a goal in all fields of safety." The redacted data, as well as initial methodology analysis and insight into the process of disaggregating the data, can be found online at <http://www.nasa.gov/news/reports/NAOMS.html>.

Get Involved in Space Exploration

Looking for ways to get your children or students involved in space exploration? NASA offers several opportunities for students from kindergarten through college to gain hands-on experience in the space program, including several competitions—from lunar plant growth to the annual Great Moonbuggy Race. To find out more about the ongoing competitions, seminars, and special programs, visit <http://www.nasa.gov/audience/foreducators/index.html>. There are also opportunities for professional or amateur astronomers, as well as the general public, to have a hand in NASA mission activities, such as the Cassini-Huygens Saturn Observation Campaign: <http://soc.jpl.nasa.gov/index.cfm>.

Web of Knowledge

The transfer, application, and commercialization of NASA-funded technology occur in many ways: knowledge sharing, technical assistance, intellectual property licensing, cooperative research and technology projects, and other forms of partnership. The NASA Innovative Partnerships Program (IPP) directs programs and initiatives to foster technology partnerships, commercialization, and innovation in support of NASA's overall mission and national priorities. Their Web site includes links to other sites operated by NASA's national network of programs, organizations, and services sponsored by and affiliated with the IPP at NASA Headquarters. These sites explore NASA technology and give access to opportunities for technology transfer, development, and collaboration with NASA. Also learn how NASA technology has moved into the marketplace and contributed to NASA Mission Directorates and the nation's prosperity: <http://ipp.nasa.gov>.

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