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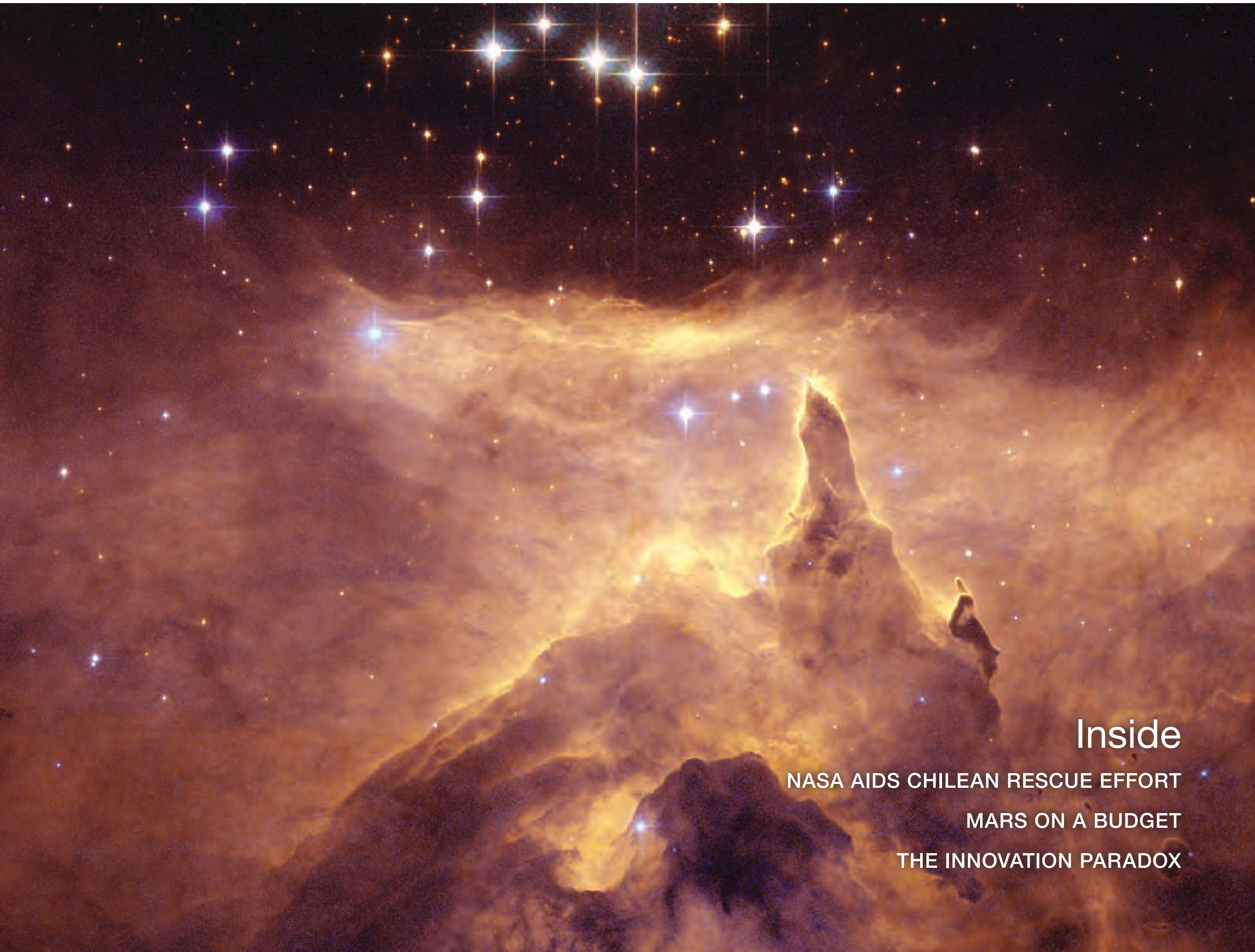

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THE INNOVATION PARADOX

Photo Credit: NASA, ESA, and J. Maíz Apellániz (Instituto de Astrofísica de Andalucía, Spain)

ON THE COVER

The small open star cluster Pismis 24 lies in the core of the NGC 6357 nebula in Scorpius, about 8,000 light-years away from Earth. The brightest object in the center of this image is designated Pismis 24-1; Hubble Space Telescope images of the star show that it is really two stars orbiting one another that are each estimated to be 100 solar masses, among the heaviest stars known.

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

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

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In This Issue

In the interview in this issue of *ASK*, Jill Prince estimates that 90 percent of the knowledge she needs as an aerospace engineer comes from work experience—her own and that of mentors and other colleagues. Most professionals would probably agree that experience is the best teacher. Several other articles here illustrate the importance of learning by doing.

For instance, Russel Rhodes's "Explosive Lessons in Hydrogen Safety" recounts how it took time and some dramatic accidents to show technicians just how treacherous liquid hydrogen can be and what they needed to do to handle it safely. Haley Stephenson describes knowledge about the effect of microgravity on the human body that could only be learned from experience; no amount of theorizing could have discovered it. And the Pathfinder team put a rover on the surface of Mars for a surprisingly small amount of money ("Mars on a Budget") by drawing on the experience of veterans of the Viking mission as well as private industry, other government agencies, and international partners. They knew they lacked the time and money to develop the needed technologies from scratch; the only way to succeed was to benefit from others' hard-earned knowledge. The Department of Defense's parachute know-how and Volvo's airbag expertise were essential to Pathfinder's successful entry, descent, and landing.

Pathfinder offers examples of experiential learning applied to new situations. "Applied Knowledge" does the same. The NASA team that aided Chile's mine rescue effort contributed knowledge about the psychology of confinement developed through decades of spaceflight experience and procedures for safely re-nourishing starving people derived from the tragic mis-feeding of prisoners of war and concentration camp internees.

The mine rescue article also shows expertise is most effectively communicated when those who have it go where it is needed and are in direct contact with the people who need it. In "Jamming with the Institute for Healthcare Improvement," Katrina Pugh and Jo Ann Endo describe a formal procedure for transferring experiential knowledge from one group to another based on similar principles.

Matthew Kohut's "Lessons from the National Ignition Facility" shows what can happen when a project is so large and complex that no one has sufficient relevant experience to understand its requirements. The Department of Energy team needed to get well into work on a new, uniquely powerful laser facility before they realized that the scope of the project demanded a new management structure and new work processes.

One of the lessons of experience is that it may be necessary to ignore some of what experience teaches—for instance, standard procedures and conventional wisdom—to come up with a technology or work process that is new and better. In his "From the Academy Director" column, Ed Hoffman acknowledges the value of veterans sharing their hard-won wisdom with younger colleagues while insisting on the importance of leaving them free to make their own mistakes on the way to innovations the older generation never thought of. On a related note, Hoffman's "The Innovation Paradox" says that experience shows that too much organizational attention—even attention meant to be supportive—can stifle new ideas. Organizations that value innovation need to find the right balance of *laissez-faire* distance and support, of respect for and dissatisfaction with the knowledge that experience has so far revealed.

Don Cohen
Managing Editor

From the Academy Director

And the Band Played On

BY ED HOFFMAN

Those who do not remember the past are condemned to repeat it.

The wisest mind has something yet to learn.

—George Santayana

During the last weeks of playing baritone horn in my high-school band, I started wondering how the band would be able to continue. I looked at Marco, who was the best trombonist; he was graduating. I looked at Frankie, the best trumpeter; he was graduating. The percussion section, graduating—to a career of crime no doubt. All the best talent was leaving. The incoming class seemed weak and inferior.

I asked the bandleader what he was going to do when we left, my concern about the future tinged with a sense of our superiority. He pounced: "You guys are all the same; you think because you are leaving that the band will stop. Well, I've been doing this for twenty years; every year guys go, and the next year the band continues to play."

Thirty years later, I was in a NASA task group. The person next to me would be retiring in a matter of weeks after a long and successful career. Someone asked, "What is NASA going to do to replace you?" Others agreed that replacement was impossible; we needed an exact replica. I smiled and thought: if only cloning were an option.

Then I realized I was thinking the band would not play next year because a talented player was leaving.

Giving the future the benefit of what we've learned is a good sentiment and often a good practice, yet it sometimes seems based on distrust of the next generation and new ways of being. Meetings and working groups develop competency models for the next generation; standards and policies are written to preserve our "wisdom." Veteran subject-matter experts promote career-development programs to train the next generation in proven, successful practices. Lessons learned, case studies, and shared-experience sessions abound, along with knowledge identification, capture, retention, and distribution activities. Much of this is good stuff. A society that has a successful future is one that educates, learns, shares, and openly exchanges knowledge. But some of it comes from thinking next year's band may not be able to play as well as we do.

Well, the future wants to make its own mistakes and discover how to use its own talents. It doesn't want to be tamed by the past. Innovation demands new thinking; new thinking means risky exploration of the unknown. Failure review boards and historians teach how mistakes could have been avoided "if only you listened to our lessons from ten years ago." But some mistakes are valuable, and sometimes "different" means "better."

So do we let the future shape itself, mistakes and all, or do we safeguard it, reducing mistakes and inventiveness?

Perhaps stories provide the balanced approach we need. Stories communicate what experience teaches without laying down rigid rules about what to do and how to do it. Stories are open to interpretation that fits their lessons to new contexts. Stories can be a foundation for future excellence, not a constraint that limits it. ●


Photo Credit: Hugo Infante/Government of Chile

The last of the trapped miners returns to the surface on October 13, 2010.

APPLIED KNOWLEDGE:
NASA AIDS THE CHILEAN RESCUE EFFORT

BY DON COHEN

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

Photo Credit: Hugo Infante/Government of Chile

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

Making the Connection

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

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

Being There

During the teleconference, Duncan offered to bring a NASA team to the mine site, a suggestion that was readily accepted. He made the offer, he said, because "experience tells you you get a better understanding out of being there." That proved to be true, but better insight into the situation was not the only benefit of the five days the team spent in Chile at the end of August and beginning of September.

Being there allowed team members to develop relationships with their counterparts that were the kinds of social connections through which expertise can be understood, trusted, and put to use. Shared professional experience cemented these bonds and helped overcome differences in language and culture. NASA Engineering and Safety Center (NESC) Engineer Clint Cragg discovered that, like him, his Chilean counterpart had been a submariner. In addition to creating common ground, that background gave them both firsthand knowledge of what it meant to share a confined space with a group of men. They also

NASA Engineering and Safety Center Principal Engineer Clint Cragg (right) consults with Rene Aguilar, deputy chief of rescue operations for the Chilean mine disaster.

Photo Credit: Cecilia Penafiel, U.S. Embassy in Chile

had engineering in common, just as the physician-to-physician and psychologist-to-psychologist connections created common ground. (NASA psychologist Holland's counterpart was named Alberto; sharing a name, though in most ways a trivial connection, also helped bring them together.) Physician Polk said, "We went down representing our government; we left as friends."

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

Applying NASA Expertise

Central to the medical expertise that NASA shared with the Chileans was an understanding of refeeding syndrome—the danger of overwhelming people who have been malnourished with the wrong kinds and quantity of food. After even a few days of starvation, a sudden influx of carbohydrates and calories can cause a rapid rise in insulin levels and associated metabolic effects that can lead to death. This lesson was learned the hard way after the world wars of the twentieth century, when well-meaning efforts to feed rescued prisoners of war and concentration camp internees caused many deaths. NASA has applied its understanding of the syndrome to contingency planning for the shuttle. The crew of a shuttle stranded at the Hubble telescope would have had to wait months for rescue, surviving on a diet of no more than 800 calories a day, so it was essential to plan for their safe renourishment.

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

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

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

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

The Rescue Capsule

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

BEING THERE ALLOWED TEAM MEMBERS TO DEVELOP RELATIONSHIPS WITH THEIR COUNTERPARTS THAT WERE THE KINDS OF SOCIAL CONNECTIONS THROUGH WHICH EXPERTISE CAN BE UNDERSTOOD, TRUSTED, AND PUT TO USE.

recommendations for the capsule as soon as they returned to the United States.

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

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

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

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

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

Again at a Distance

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

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

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

FACTORING IN HUMA

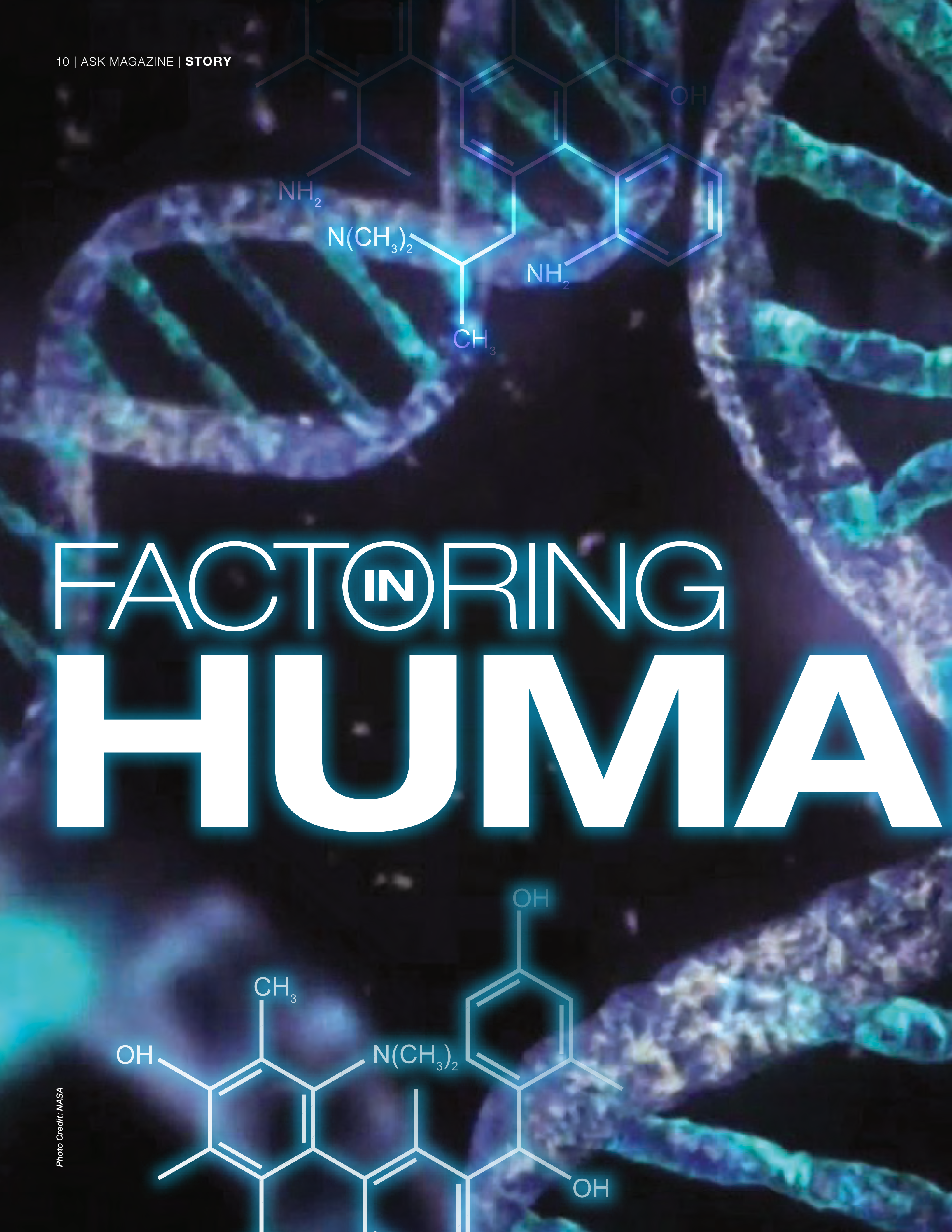


Photo Credit: NASA

Space radiation hitting cell DNA.

NS

BY HALEY STEPHENSON

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

— Mary Roach, *Packing for Mars*


Photo Credit: NASA

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

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

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

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

Gravity As Most of Us Know It

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

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

NASA ESTIMATES IT WILL TAKE TEN MONTHS FOR ASTRONAUTS TO REACH MARS FOR A YEARLONG MISSION, AND TEN MONTHS TO RETURN—A TOTAL OF NEARLY THREE YEARS.

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

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

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

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

Photo Credit: NASA Johnson Space Center

the head (and hopefully the body) are linearly accelerating.

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

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

A Hot Microphone

In the early 1970s, Reschke was teaching at a university when he got an offer to study neurosensory systems at NASA. Not one for university professing, he said, "I made a beeline for [NASA]."

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

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

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

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

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

Microgravity As Few of Us Know It

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

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

An overhead view from the Skylab 4 Command and Service Modules of the Skylab space station cluster in Earth orbit.

Photo Credit: NASA Johnson Space Center

the spine, head thrust forward, knees drawn up.

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

His crewmate was the first to reach for his emesis bag. Thornton's medical training kicked in. "I grabbed him and started doing a standard routine neurological exam," he said. There was no pre-indication it was going to happen, recalled Thornton. No nausea, disorientation, nothing. At this point his neurological exam "was totally normal." At least it was until Thornton had his crewmate close his eyes and proceeded to tilt him like the hands on a clock.

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

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

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

Reprogramming

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

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

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

The Future of Human Factors

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

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

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

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

The Path to Scientific Discoveries: DESIGNING THE CASSINI SOLSTICE MISSION TRAJECTORY

BY BRENT BUFFINGTON

Cassini-Huygens, a joint mission between NASA, the European Space Agency, and the Italian Space Agency, has roamed the Saturnian system for the better part of six and a half years. Data from the Cassini spacecraft have led to discoveries that include water ice and vapor geysers in the south polar region of the small moon Enceladus; an active hydrocarbon hydrological cycle (including liquid methane/ethane lakes, dendritic channels, dunes, clouds, and possible precipitation) on Titan; verification of the continued existence of a perplexing hexagon-shaped structure near Saturn's north pole, first observed by Voyager 1; and a number of new, highly complex, and dynamic structures in our solar system's most massive and diverse ring system. These and many other discoveries have been made possible by highly successful spacecraft operations and subsystem maintenance, sequencing, instrument monitoring, risk management, and navigation of the most complex gravity-assist tour in the history of unmanned spaceflight.

Photo Credit: NASA/JPL

Titan's golden, smog-like atmosphere and complex layered hazes appear to Cassini as a luminous ring around the planet-sized moon.

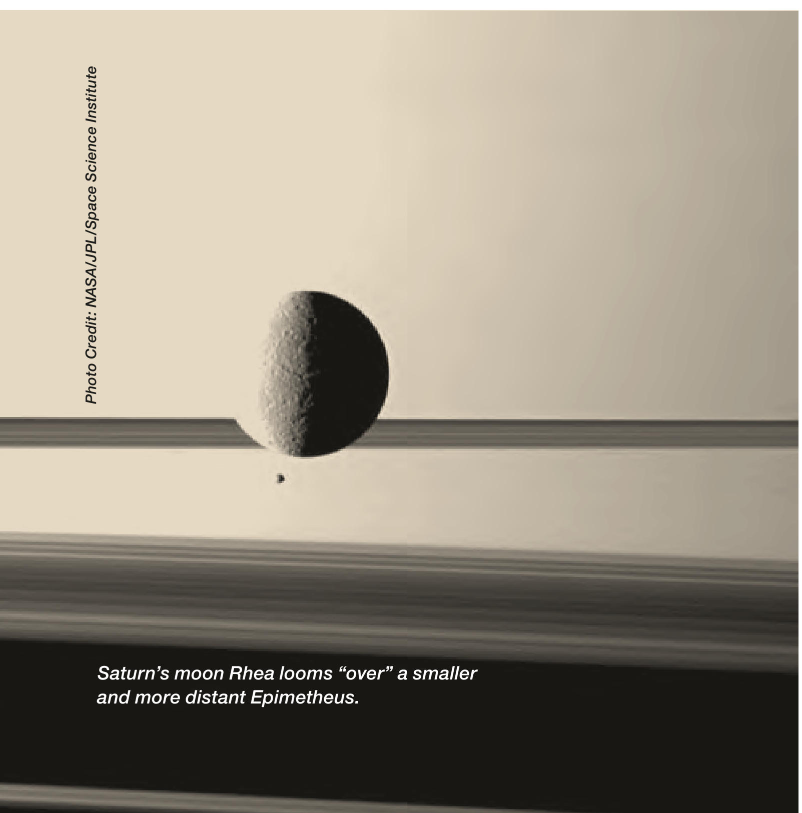
A Rich Scientific Harvest

Cassini's four-year prime mission, from July 2004 to July 2008, sustained a staggering pace of scientific discovery, generating more than one thousand independent publications in prominent science and engineering journals. During the prime mission—which included 45 encounters with Titan, 4 with Enceladus, and 6 with other icy satellite flybys; 75 Saturn orbits; 161 planned maneuvers (112 executed); and the many science sequence and flight software updates—Cassini averaged two key events per week. Through all these activities, spacecraft subsystems and instruments remained healthy, substantial consumables margins were maintained, and power levels from the radioisotope thermoelectric generators allowed for many more years of science operations.

The continuing quality of scientific return and the spacecraft's excellent state of health led NASA Headquarters to grant it two mission extensions. The first, the Equinox mission, was a 2.25-year extension from July 2008 to October 2010 that carried Cassini through Saturn's northern-hemispheric vernal equinox in August 2009. Even though this mission was technically an extension, it was similar in scope and funding to the prime mission, with science observations and the related navigation and spacecraft operations continuing at the same or greater pace. In all, the Equinox mission included 28 Titan flybys, 8 Enceladus and 3 other icy satellite flybys, 64 Saturn orbits, and 104 planned maneuvers (70 executed).

The second extension, the Solstice mission, required a radical change in design methodology. Its overriding scientific goal is to reach Saturn's northern summer solstice in May 2017, more than doubling the total mission duration, with only 20 percent of the propellant available at the beginning of the prime mission. Furthermore, an expected 40 percent reduction in staffing would limit the frequency of key events as well as the complexity of the observational sequences.

Photo Credit: NASA/JPL/Space Science Institute



Saturn's moon Rhea looms "over" a smaller and more distant Epimetheus.

Designing the Solstice Trajectory

The process of designing a trajectory is bound by the laws of physics and driven by scientific intrigue. The goal is to maximize the number of high-quality scientific observations and measurements while minimizing propellant expenditure and adhering to operational, spacecraft, and environmental constraints. Scientists from five discipline working groups (Saturn, rings, Titan, icy satellites, and magnetosphere and plasma) developed more than forty science objectives to guide the Solstice mission design and addressed two major themes: seasonal/temporal change and new questions that have arisen since the start of the mission.

The enabling mechanism for the complicated mission design of the Cassini trajectories is a concept understood for over a century and employed in a number of missions during the past forty years: the gravity assist. A gravity assist entails a spacecraft using a massive, intermediate, moving celestial body to significantly modify its trajectory. Depending on the flyby speed and distance, and how the spacecraft flies by the large gravitating body (above/below, behind/in front), the spacecraft's orbit size, period, energy, inclination, and distance relative to the central body can be altered in an incremental and predictable manner such that a wide range of geometries can be attained to meet myriad, often disparate, scientific goals.

Given the high velocities with which Cassini encounters the various moons of Saturn, Titan is the only Saturnian satellite massive enough to significantly alter the spacecraft's trajectory. To quantify the significance of Titan, consider this: the amount of propellant onboard a spacecraft is often expressed in terms of how much the propellant can change the velocity of the spacecraft in meters per second (m/s), or "delta v" (Δv). After entering into orbit around Saturn in July 2004 (which required a 627 m/s Saturn orbit insertion maneuver and a 393 m/s maneuver to raise periapsis, the lowest point of the orbit), Cassini possessed a total Δv capability of approximately 754 m/s. By contrast, a single Titan flyby can provide a change in the spacecraft's velocity in excess of 800 m/s. In the course of more than seventy Titan flybys to date, the large moon has imparted to Cassini a total Δv of more than 50,000 m/s.

For any given Titan flyby, several options exist for the post-flyby spacecraft orbit(s) depending on how we choose to fly by Titan. These choices increase geometrically as the number of Titan flybys increases, quickly overwhelming any attempts to design an optimal trajectory computationally. The immense number of possible tours creates both opportunities and difficulties.

To prune the multitude of options associated with a seven-year trajectory comprising more than fifty Titan flybys, John Smith and I (the tour designers) conducted parametric studies to determine how various science objectives fit with one another: which were complementary, mutually exclusive, and cheap or expensive both in propellant and time, and which made more sense to carry out at specific times in the tour. Guided by these studies, we built a handful of end-to-end tours, attempting to incorporate as many requested observations as possible for more than two hundred scientists (from the United States and seventeen European nations) to assess. The optimization of tours hinged on the communication between the tour designers and scientists, with the tour quality and complexity evolving as the interaction of scientific objectives became better understood and the geometric constraints defining them became refined. Based on the scientists' evaluations—what characteristics of each tour were good, bad, and ugly—we would adapt our strategies and develop a fresh crop of candidate trajectories to be released and evaluated three to four months later. Survival of the best trajectory traits and the development of new traits was Darwinism at its finest.

The core of designing trajectories resides in orbital mechanics—the fundamental understanding of how objects interact with one another in outer space—and the ability to model these interactions accurately and quickly enough to evaluate the efficiency and scientific quality of many different routes. But on many levels, trajectory design is as much an art as a science. We started with a set of initial conditions (the ending conditions of the Equinox mission) and a blank canvas of space and time in front of us. Much like a painter, we have a finite number of "colors" in our palette available to paint our masterpiece—in our case, resonant, non-resonant, and pi-transfers; equatorial and inclined orbits; and inbound and outbound Titan flybys. The way in which we combined these colors was motivated by high-priority scientific objectives, guided by experience-based intuition and flashes of inspiration, and governed by spacecraft capabilities (control authority, available propellant), environmental constraints (Saturn's rings, Titan's atmosphere, Enceladus' plume, solar conjunction), operational intensity constraints (time-of-flight between flybys, maneuver frequency), ground-system limitations, and a finite mission duration. Within those constraints, we had creative freedom, each brush stroke (that is, each Titan flyby) giving rise to certain geometric opportunities while precluding others, our choices an attempt to create the most aesthetically (scientifically) pleasing painting possible.

Achieving consensus among more than two hundred scientists from five different disciplines' working groups vying

THE CORE OF DESIGNING TRAJECTORIES RESIDES IN ORBITAL MECHANICS—THE FUNDAMENTAL UNDERSTANDING OF HOW OBJECTS INTERACT WITH ONE ANOTHER IN OUTER SPACE—AND THE ABILITY TO MODEL THESE INTERACTIONS ACCURATELY AND QUICKLY ENOUGH TO EVALUATE THE EFFICIENCY AND SCIENTIFIC QUALITY OF MANY DIFFERENT ROUTES.

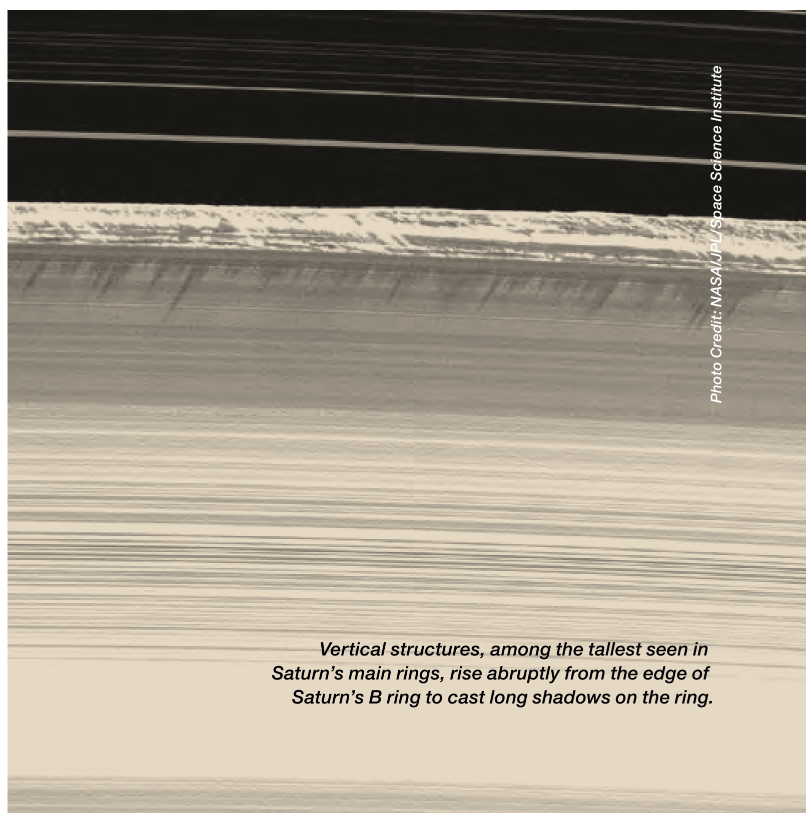
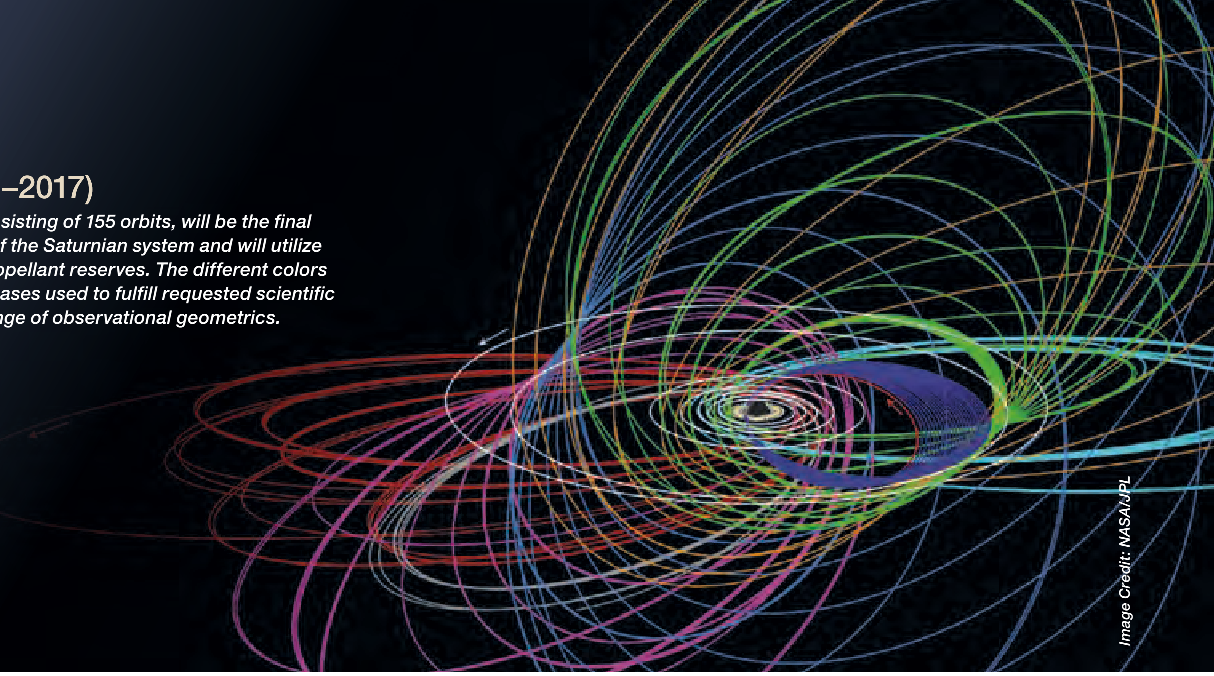


Photo Credit: NASA/JPL/Space Science Institute

Vertical structures, among the tallest seen in Saturn's main rings, rise abruptly from the edge of Saturn's B ring to cast long shadows on the ring.



Solstice Mission (2010–2017)

The seven-year Solstice Mission, consisting of 155 orbits, will be the final installment of Cassini's exploration of the Saturnian system and will utilize the remainder of the spacecraft's propellant reserves. The different colors represent the eight major mission phases used to fulfill requested scientific objectives, which required a wide range of observational geometrics.

The orbit of seven of Saturn's larger satellites are shown in white.

for observation time needed to carry out the scientific investigations to which they have dedicated their lives was not always a simple matter. With twelve instruments on Cassini, there were also numerous and competing interests within the discipline working groups. Some objectives required the spacecraft's orbit plane to be the same as Saturn's ring plane (which is also very close to the orbit plane of the larger inner satellites); other objectives required medium or highly inclined orbits. Additional examples of objective-driven geometry included being close to or far from Saturn, placing ground tracks over specific features or regions of satellites, flying during a solar phase, and orientating the line of apsides[1] with respect to the Saturn–Earth line. To further complicate matters, a single objective could require many different types of observational geometries, sometimes from multiple instruments, as well as repeated observations to determine temporal variation.

After two years of development and numerous iterations between the tour designers and the scientists (the number of iterations was limited by schedule deadlines), the project selected a single tour that best addressed the majority of the high-priority science objectives and fit within established operational and safety constraints. We then spent a few additional months implementing a number of small tweaks to further optimize science return. A final reference trajectory, the end product of the tour-design process, was delivered to the project in July 2009.

The Solstice mission, from October 2010 to September 2017, includes 54 Titan flybys, 11 Enceladus and 8 other icy satellite flybys, 155 Saturn orbits, and 206 planned maneuvers. It will extend Cassini's operational lifetime past Saturn's northern summer solstice to increase the observed temporal baseline beyond two Saturnian seasons. In addition, to satisfy the NASA Planetary Protection Office's requirement to minimize the probability of biological contamination of the Saturnian moons, Enceladus and Titan, from inadvertent spacecraft impact before control of the spacecraft is lost (that is, when the gas tanks are empty), a Saturn-impact, end-of-mission scenario[2] was incorporated into the Solstice mission. Before the spacecraft's fate is sealed, however, the mission will implement one last encore, aptly referred to as the "proximal orbits."

Prior to impact, a spectacular series of twenty-two orbits will be executed; during each one, Cassini will pass through a 1,850-mile gap (believed to be clear of any debris harmful to the spacecraft) interior to Saturn's innermost ring, just above the cloud tops of Saturn, at speeds in excess of 76,000 mph. Finally, on the twenty-third orbit, one last high-altitude Titan flyby will alter the spacecraft's trajectory such that Cassini will impact Saturn four days later, trading its temporary roaming residency in the Saturnian system for one of a more permanent stature via a fiery collision into Saturn. The elegance of this spacecraft-disposal option is that Saturn impact is guaranteed regardless of whether the spacecraft survives the first (or any) proximal orbit-ring plane crossing—no further propulsive maneuvers are necessary. And, en route, unique science opportunities beyond the initial scope of the Cassini project will be available. A spectacular ending to a spectacular mission. ●

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

BRENT BUFFINGTON is a member of the Outer Planets Mission Analysis Group at the Jet Propulsion Laboratory and was part of the trajectory design teams responsible for the Cassini Equinox and Solstice missions. Currently, he is an orbit determination analyst on the Cassini navigation team.

1. The line connecting the points of the orbit furthest from and closest to the planet.
2. This spacecraft-disposal option has been reviewed but not formally approved by NASA Headquarters.

INTERVIEW WITH Jill Prince

BY DON COHEN

Jill Prince has been an aerospace engineer at Langley Research Center since 1999. She was recently awarded a Women in Aerospace Achievement Award for her work on autonomous aerobraking. Don Cohen spoke to her at NASA Headquarters in Washington, D.C.

COHEN: Let's talk about your aerobraking work at Langley, maybe starting with a description of what it is.

PRINCE: Aerobraking is using atmospheric drag on a spacecraft to slowly reduce the apoapsis altitude of the spacecraft [the furthest distance from the planet] to something closer to what you want the final science orbit to be.

COHEN: What is the reason for using aerobraking?

PRINCE: There are two ways to get a spacecraft into a desired orbit. You can use a lot of fuel and immediately put it into a small orbit, or you can save much of that fuel by capturing into a large orbit and using aerobraking to reduce the orbit size. It may take extra time, though. Mars Odyssey spent seventy-seven days aerobraking. For Mars Reconnaissance Orbiter (MRO), it was 145 days. But it's worth the fuel, mass, and cost savings of launching a smaller mass to Mars.

COHEN: Are you making decisions and adjustments all during that time?

PRINCE: Yes. What's tricky about aerobraking at Mars is you have so much atmospheric uncertainty that you can't rely on past missions to understand your current one. The data helps in your atmosphere modeling, but you can't fully rely on it. You have to go into the atmosphere in real time and figure out what's going on, what perturbations you are seeing.

COHEN: The perturbations are winds …?

PRINCE: Winds, density variability, polar warming. There are a lot of atmospheric effects going on.

"YOU SHOULD REALLY DESIGN THE MISSION WITH entry, descent, and landing IN MIND, NOT DESIGN A MISSION AND FIGURE OUT THAT last seven minutes LATER."

COHEN: So how do you respond to those effects?

PRINCE: You can make a maneuver at apoapsis, the furthest distance from the planet, to affect your altitude at periapsis, the closest distance to the planet. You can therefore control your periapsis altitude but not much else. There are so many things to predict, model, and analyze: you don't know exactly how dense the atmosphere is going to be in the next orbit. You have uncertainties in aerodynamics. You have uncertainties in temperature modeling. Over the past few years, we've tried to develop the idea of autonomous aerobraking to put a lot of the work that has been performed on the ground onto the spacecraft itself.

COHEN: I've always been impressed by the amount of forethought that goes into planetary missions—having to imagine conditions that are going to arise millions of miles away and years later.

PRINCE: You have to preplan. I spent five years on Mars Phoenix entry, descent, and landing. That was a seven-minute descent. Five years for seven minutes. It's a long time planning to make sure that you know what's going to happen, within certain bounds. We don't just show up when the spacecraft gets there and say, "OK, where are we going to go next?"

COHEN: What has it been like working with project managers and engineers, contributing your knowledge to their plans and designs?

PRINCE: It's always been a good experience. The missions I've worked on have been at different centers across the country and in different industries. For the three missions that I was a part of mission operations, we were at Langley working with project managers at JPL [Jet Propulsion Laboratory]. We work very well across the country. On Mars Odyssey, we had a three-hour time difference. It was perfect. We'd get data in the morning and have a three-hour jump to get the rest of the team the data we all needed to make a decision early in the morning [in California].

COHEN: So there are sometimes advantages to working at a distance. Did you also spend time out there?

PRINCE: For Mars Odyssey and MRO, the Langley team all went for meetings every once in a while, but we did all of the Langley aerobraking work at Langley. We stayed in our separate locations. For Phoenix, I spent a month at JPL before the landing, trying to optimize the trajectory to target the planet exactly where we needed to go. For the two orbiters, aerobraking meant very long operations. Entry, descent, and landing was a one-shot deal. You don't get a couple of orbits to toe-dip in the atmosphere to see if it's to your liking. You have one shot and that's it. It was 145 days of excitement contained into one.

COHEN: Did you find—when you worked mainly from Langley—that you had to get to know the people you were going to work with at a distance?

PRINCE: Yes, you can't glean personality from a phone call or an e-mail. You have to talk with them one on one and spend time with them to know how they work and how they best receive data.

COHEN: How did you make that happen?

PRINCE: There were usually face-to-face meetings for years beforehand. The Langley engineers I work with and I are usually in the same building, and that is always a very easy working experience.

COHEN: Were you involved in projects from the beginning?

PRINCE: I joined the Odyssey team maybe a year prior to launch, if that, and I think Langley got involved at a relatively late date. For MRO, we started a lot earlier and were more involved in the aerobraking mission design.

COHEN: Did that earlier start mean differences in how the work went?

PRINCE: It did. There are fewer problems down the road when you can design the mission based on its atmospheric flight. If you don't take that into account until later in the mission life cycle, there can be some problems along the way that you might have to find a less-than-optimal solution for. In entry, descent, and landing, that's particularly important. You should really design the mission with entry, descent, and landing in mind, not design a mission and figure out that last seven minutes later.

COHEN: Can you give me a specific example of how the atmospheric flight analysis has influenced mission design?

PRINCE: On Mars Phoenix we discovered a year or so before launch that there was an issue with the reaction control system. There was the potential that the interaction with the atmosphere at upper altitudes would interfere adversely with the thrusters being fired so that when you thought you were firing thrusters to control the spacecraft in one direction it might have produced the opposite effect. You think you're going one way and the atmosphere is going to force you to go the other way. Because of that analysis, the team decided not to fire the thrusters at all. Instead of a controlled flight hypersonically, we left it uncontrolled. If we had tried to control that spacecraft in the upper atmosphere it really could have been problematic.

COHEN: How did you discover that problem?

PRINCE: There was a joint effort going on with Mars Science Laboratory, which will launch this year. Some of the analysis the aerothermodynamicists were doing at Langley discovered the potential. They ran some wind-tunnel tests, did computer modeling, and found this problem. We ran the aerodynamic uncertainties in a trajectory simulation and confirmed that it could be an issue. It was then shared with the Phoenix team so we could quickly mitigate this risk.

COHEN: I know landing a large spacecraft on Mars is a major challenge.

PRINCE: If we try to land anything of higher mass than Mars Science Lab (about 1 metric ton), we will have issues. We're working with Viking technology that's fifty years old. We need new technology to be able to land anything bigger than 1 metric ton on the surface on Mars. Otherwise we can't do it without a boatload of fuel.

COHEN: What direction might those new technologies take?

PRINCE: There are several studies looking at several different options: inflatable atmospheric decelerators, both hypersonic and supersonic; supersonic retro-propulsion. An entry, descent, and landing analysis wrapping up now has been investigating architectures to get a large mass to the surface of Mars.

COHEN: How did you get into aerobraking in the first place?

PRINCE: I jumped right into it. I went to George Washington University for my master's degree in engineering. Their program was physically located at Langley. I archived some Mars Global Surveyor data—the first Mars aerobraking mission. My thesis was on autonomous aerobraking. I've had the same phone number and I've been working with the same group of people ever since. It's been fabulous.

COHEN: How much of what you know came from school, how much from being on the job?

PRINCE: I would say 90 percent from job experience. You have to have the background to understand the physics behind the orbit, but you learn the operations from experience.

COHEN: How important was mentoring in the early part of your career?

PRINCE: I would say mentoring not only had an extremely positive effect on the early part of my career, but I still have mentors and often look to them for guidance. I don't think there is a point in any person's career where she or he should think they don't need somebody else's input.

COHEN: What kinds of things do people who have been around a long time know that newcomers don't?

PRINCE: People who have been around a while know more about how to handle situations, how to deal with other people. But they also give technical advice and have experience to back it up. For example, I wouldn't have known in my first aerobraking mission why certain atmospheric data didn't line up with what I would have expected. "Why is the density acting so strangely here and not over here?" Sometimes you have to ask somebody who has been there before. Maybe I would have figured it out for myself in ten years, but having someone with decades of experience is helpful.

COHEN: Now that you've been with NASA over ten years, what kind of advice would you give a new employee?

PRINCE: I'd throw them in the deep end. I'd tell them to dive right in and see where you can go. If you're given an opportunity, make the best of it. You can't let an opportunity go by.

COHEN: Which is what you did.

PRINCE: My advisor at George Washington helped to throw me in that deep end. He said, "I have a couple of students that I'd like to have help out Mars Odyssey." The engineers at Langley didn't know who I was, but they said OK. There was a lot of trust. When you're given the responsibility of working on a flight project you have to live up to that.

COHEN: Were you terrified? Excited?

PRINCE: I was too naïve to be terrified.

COHEN: I've heard similar stories from other people at NASA—that they were given responsibility for important work from the beginning.

PRINCE: If I hadn't been put on a project I had so much fun doing, I don't think I would have stayed. I was fortunate to really like what I got into, and in the past ten years I've been fortunate enough to work three different flight projects. I haven't left Langley other than for my current six-month detail at Headquarters.

COHEN: You're working with Bobby Braun on new technology?

PRINCE: Yes, I'm working in the Strategic Integration Office in the Office of the Chief Technologist with Bobby Braun and James Reuther. Along with others, I work on activities including the technology road mapping that NASA is doing to define the pathway of our technological future for the next twenty years or so. I'm here as part of a mid-level leader program that is in its pilot year.

COHEN: It's a leadership development program?

PRINCE: Yes. Part of that program is a three- to six-month detail.

COHEN: What is the biggest challenge of the assignment?

PRINCE: Understanding a much broader scope of technology development is a challenge. I have been focused on entry, descent, and landing for a while. It is exciting, yet still a challenge to open that

"IF I HADN'T BEEN put on a project I HAD so much fun DOING, I don't think I WOULD HAVE STAYED."

lens a bit and learn about technologies in other areas.

COHEN: So do you see yourself as a technician or a manager?

PRINCE: I've been an assistant branch head at Langley since 2007. Recently at Langley I've been doing a little more managing than technical work. I think I'm OK with that. Having an assistant branch head job is great because I have a supervisory role but I can keep playing with the technical toys.

COHEN: How has the work at Headquarters been going?

PRINCE: We're forging on, trying to push technology as far as we can with what we have available. We're wrapping up the technology road-map efforts right now in hopes of getting several road maps to the National Research Council that they can improve upon and help out with our technology pathways in the future. They are amazing products. It's inspiring to read what people have come up with and think about where NASA is going to be a couple of decades from now.

COHEN: Bobby Braun has talked about the importance of failure to innovation.

PRINCE: Sometimes experiencing failure is the best way to improve the current technology. When people talk about NASA, "failure is not an option" is one of the first catchphrases you hear. When you're dealing with technology (not human spaceflight, of course) that's not necessarily the attitude you want. In building successful technology programs, you push the boundaries and strive for innovation. Sometimes you run into the proverbial unknown unknowns. We want to learn and understand all we can in our technology efforts but we have to be willing to take risks and understand that failure is sometimes an outcome. But it's hard to change a culture mind-set. And several high-profile NASA failures remain fresh on many people's minds; in my area of work, those include the two failed Mars missions in 1999.

COHEN: Would you say those two Mars failures were total losses or were they learning opportunities?

PRINCE: We learned a lot, especially from Polar Lander. We learned many potential causes of failure and that contributed to the success of Phoenix, which was a sister spacecraft. Even though I didn't work on Polar Lander, I learned a lot from it.

COHEN: You recently got a Women in Aerospace Achievement Award.

PRINCE: I did. I was extremely honored by this award—what an amazing organization. It was specifically for my work in the development of autonomous aerobraking.

COHEN: Has being a woman engineer ever been a problem for you?

PRINCE: If anything, I think it has given me more opportunity. Because they are a minority in engineering, you typically remember the women you see in engineering. Sometimes that's positive.

COHEN: As a student, did you run into teachers who said, "You're a woman; you can't do math or science?"

PRINCE: Absolutely not. I get a lot of speaking requests to try to get young girls interested in math and science. I've probably talked to twenty different schools. I talk to Girl Scouts. I've talked to astronomy clubs. I recently gave a talk to a group of female physicians and attorneys in Syracuse, New York. Groups of women like to see another woman talking to them. I get a lot of students ask their teachers, "She's not an engineer, is

"WE WANT TO learn AND understand ALL WE CAN IN OUR technology efforts BUT WE HAVE TO BE willing to take risks AND UNDERSTAND THAT failure IS SOMETIMES AN OUTCOME."

she?" I think I'm asked to speak because I'm a woman, but I don't mind that anymore. I used to.

COHEN: Used to mind it because you thought of yourself as an engineer, not a female engineer?

PRINCE: There was a little of that. I think I've gotten over it. I realize that speaking to students is a great opportunity to motivate other young women into technical fields, and if I can do that, what better way is there to increase the diversity in those fields?

COHEN: How has the response to those talks been?

PRINCE: I keep doing it because of the great response I get. I don't just do it for kids; I do it for myself, too. It's very gratifying. It makes me remember what a wonderful job I have. It's amazing how smart kids are. They pick up stuff very quickly. They ask some really good questions. It's impressive and inspiring.

COHEN: What are your goals for the future at NASA?

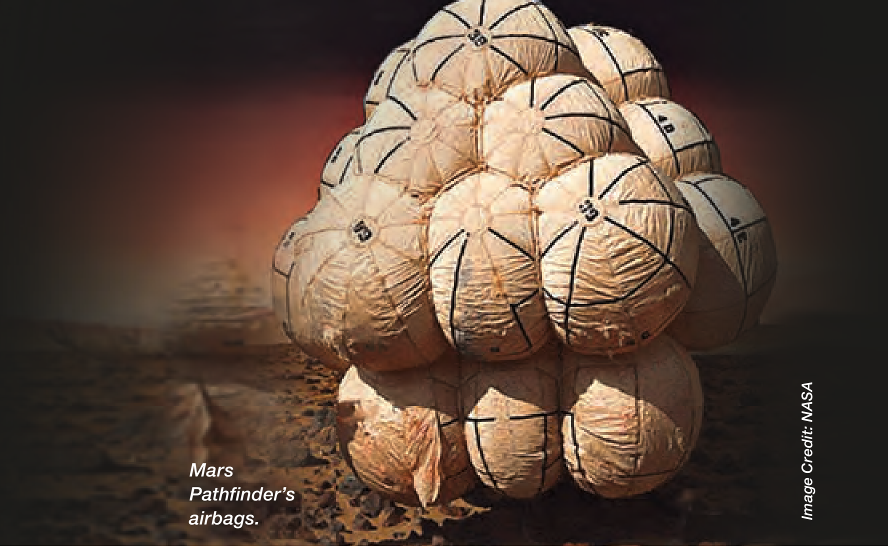
PRINCE: NASA is an amazing agency. We do things here that no other organization can. We pursue seemingly impossible challenges and improve our way of life along the way. I'm having so much fun right now, it's hard to think much about the future. When I stop having fun, I'll think about what's next. ●

MARS ON A BUDGET

BY RANDALL TAYLOR

Artist's concept of the Pathfinder lander and Sojourner rover on Mars.

Image Credit: NASA/JPL



Mars Pathfinder's airbags.

Image Credit: NASA

In December 1996, A Delta II rocket launched the Mars Pathfinder spacecraft. Seven months later, the Pathfinder lander, slowed by parachute and retrorockets and protected by a cluster of airbags, came to rest on the surface of Mars and released a 23-lb. rover that included cameras and a spectrometer for analyzing the Martian soil.

It was not the first time NASA had successfully landed a spacecraft on the planet. More than twenty years earlier, the Viking program had put two landers on Mars. But Pathfinder got there for a tiny fraction of Viking's cost. After a teleconference with Wes Huntress, during which NASA's Associate Administrator for Space Science approved Phase B mission planning, project manager Tony Spear said, "That was Wes. He asked me for a Mars lander for Discovery money. I told him yes. Now we have to figure out how to do it."

As the second mission in the agency's Discovery program of low-cost space science initiatives, Pathfinder was approved for Phases C and D (design and development) at a maximum of three years and $150 million to do the spacecraft development work. ($25 million was separately provided for the micro-rover development, and the launch vehicle was supplied by NASA, so the total project life-cycle cost was $250 million.) Going over budget was not an option; if Pathfinder couldn't be built for that amount of money—a congressional cost cap—it would be canceled.

We Are the World

Spear's plan was to keep a full 50 percent of the budget in reserve to deal with the inevitable surprises and adjustments the ambitious new technology program would bring with it. He was immediately forced to reduce that to 40 percent when news came that residual hardware from Mars Observer would not be available, due to that mission's failure and the reallocation of flight spares to the new Mars Global Surveyor project. Then there were the added requirements: two unfunded mandates. The budget would have to pay for a public-outreach program and a technology-transfer program. And—yes—let's not just land on Mars; please build a rover that can move on the surface, photographing and analyzing its surroundings. (The additional money provided for the rover did not fully account for accommodation costs on the spacecraft.) Finally, there was even a Level 1 requirement to create a "new way of doing business" for NASA, part of NASA Administrator Dan Goldin's Faster, Better, Cheaper directive, which we took very seriously.

Under those circumstances, figuring out how to do it meant adopting a dramatically anti-not-invented-here approach. Spear was ready to find partners anywhere and learn from anybody who could offer assistance. The Pathfinder team talked to the Department of Defense about parachutes and Volvo about airbags. We met with the Russians. We talked to Viking people. (Jim Martin, Viking's project manager, was on Pathfinder's review board.) We learned Apollo-era wisdom from Max Faget. We worked with two German institutes, the Danes, and other NASA programs in progress at the time.

Some of these working relationships demonstrated the generosity and flexibility of others and Spear's skillful management of the human dimensions of cooperative work. The Cassini program, which would launch a spacecraft to Saturn in 1997, bore the full cost of engineering and building the Deep Space Transponder; Pathfinder bought flight units at lower recurring-cost prices.

The Niels Bohr Institute of Denmark supplied the project's magnetics experiment. One of Germany's Max Planck Institutes helped build the alpha proton X-ray spectrometer, to be carried by the rover. The German hardware was in the trunk of a taxi that had an accident en route to their partner, the University of Chicago; fortunately, the flight unit survived intact. A second Max Planck Institute supplied detectors for the lander camera. Unfortunately, the camera builder destroyed the flight detectors. A second set was furnished at German expense (we couldn't pay for it due to NASA's no-exchange-of-funds policy); these, too, were ruined. Luckily, the third time was the charm. Our foreign partners performed with technical excellence and good grace.

Build a Little, Test a Little, Wreck a Little

People mattered, and process mattered. Tony Spear; Brian Muirhead, the spacecraft manager; and Donna Shirley, the rover manager, assembled a team that Tony described as a mix of "scarred veterans and bright, energetic youth." Old dogs were taught new tricks, and the next generation of robotic space developers learned from them. We did concurrent engineering (helped by advice from Lockheed's Skunk Works). We streamlined the procurement process. We partnered with Safety and Mission Assurance on a Class A test program and short-cycle documentation approvals.

To develop the supersonic parachute that would operate in the thin Martian atmosphere to slow Pathfinder during its descent, Pathfinder drew on the Department of Defense's experience of learning by doing. NASA projects typically go through preliminary design, final design, build, procure or fabricate, assemble, and test. In contrast, the Department of Defense's parachute programs involved building prototype parachutes, dropping them, and redesigning based on their performance. This proved an effective way of coming up with a design for Mars. What became known as "Desert Splat"—a notable parachute failure—helped point the way to eventual success.

Ingenious public relations helped defuse some potential problems. The contractor doing parachute work for Pathfinder discovered that a ballast rock lost during one drop in Connecticut had lodged in a farmer's pickup truck. They mollified the victim of the accident by not only paying for repairs to the truck but agreeing to do a flyover and festive balloon drop at the farmer's daughter's birthday party.

We had to invent how to crash-land on Mars, something never done before. The development process was guided by an

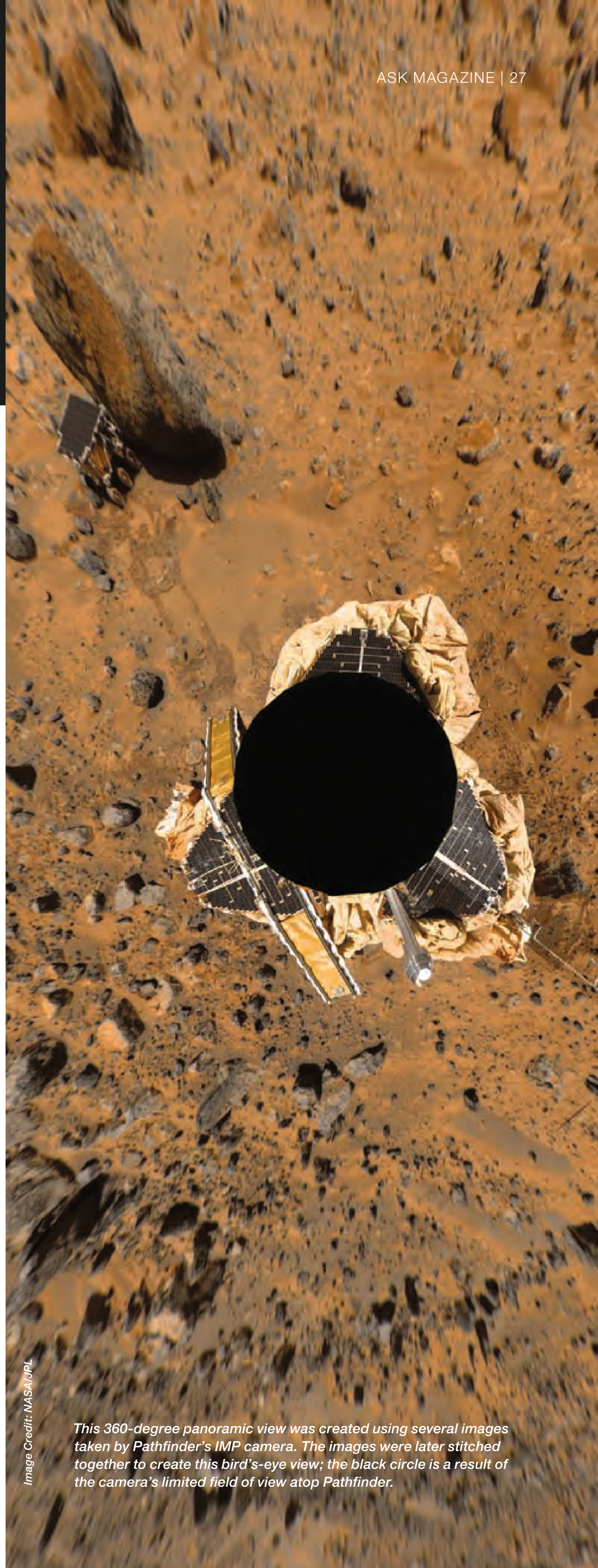
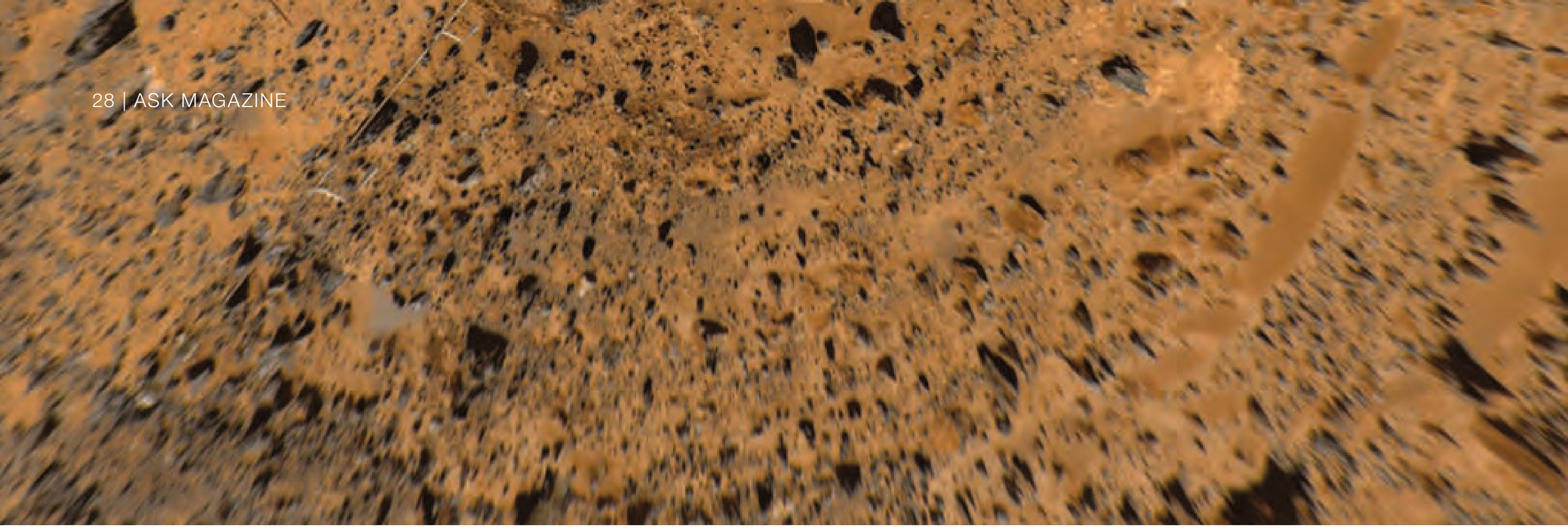


Image Credit: NASA/JPL

This 360-degree panoramic view was created using several images taken by Pathfinder's IMP camera. The images were later stitched together to create this bird's-eye view; the black circle is a result of the camera's limited field of view atop Pathfinder.



interdisciplinary entry, descent, and landing team that included all the major players (NASA centers, federal agencies, industry, small business, and consultants) and frequently evaluated progress.

Pathfinder had more than one hundred peer reviews. These involved spacecraft subsystems, the payload, and cross-cutting systems. The spacecraft manager chaired some of the rover peer reviews and the rover chief engineer chaired several of the spacecraft reviews. Reviews began early in the project. For example, one review compared a tethered rover design to an untethered one. These internal reviews provided a second set of eyes at key points in the project development. They were supplemented by six incremental delivery demonstrations, which forced the various project systems to play together early; the most famous occurred at the non-advocate review/preliminary design review, when the NASA Independent Review Board chair, Jim Martin, walked into the Jet Propulsion Laboratory (JPL) ground data-system area and had his picture snapped by the University of Arizona's engineering model lander camera. The pixels were sent through a Deep Space Network simulator, and his profile showed on the ground-system workstations before he exited the room.

Cost Control Is a State of Mind

Bringing the project in on budget meant that everyone working on Pathfinder—scientists and engineers as well as managers—had to be cost-conscious all the time. Because every element except the flight system was individually cost-capped by the project manager, groups working on project elements knew what they had to work with: there was no pot of general project money to draw on if they overspent; all reserves had to go toward the spacecraft.

One effect of this budget clarity was to eliminate competition among the groups—there was no extra money to compete for. That and the shared goal of a successful Mars mission fostered valuable cooperation.

One team whose subsystem had to locate the sun found that a sun sensor would be too expensive. Echoing Spear's anti-not-invented-here ethos, the team lead, David Lehman, said, "I can't solve this in my area, so we'll have to get help." The team approached the lander camera group about using that instrument to find the sun and transferred funds to them to pay for camera software routines that would meet the need.

Similarly, when the power team could not afford the caliber of solar cells they wanted, Allan Sacks, the ground data systems manager, told them, "I'll give you the $100K you need for better cells because that will make operations less complicated for my team."

Faster, Better, Cheaper

John Casani, the head of JPL's Pathfinder review board, made a bet with Spear that the avionics subsystem would not be delivered on time and on cost. It came in on budget and one day early, and Casani had to pay up, delivering two cases of wine to the project celebration at the subsystem manager's (Lehman's) home.

"Faster, better, cheaper," the mantra of that era, has been criticized for demanding too much for too little. We can point to cases where trying to accomplish ambitious goals with severely limited funds probably contributed to failure. Pathfinder is a faster, better, cheaper success story. Discipline, determination, teamwork, and openness to any and every source of expertise and assistance made the difference—a lesson for any project. ●

For more information, see 2007 IEEE paper, "Ten Years After: Enduring Lessons Learned from Mars Pathfinder," available from the author.

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

RANDALL TAYLOR was the procurement manager for the Mars Pathfinder project. He has worked at the Jet Propulsion Laboratory since 1979, with current assignments as project acquisition manager/review captain on the GRAIL project and project manager of the Acquisition Reengineering project.

The Potential of a New Workplace

BY NAOKI OGIWARA

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

KDI's Future Center.

Photo courtesy of Naoki Ogiwara


Photo courtesy of Naoki Ogiwara

The Sky Box at ABN AMRO'S Dialogues House.

Tax and Customs Administration Creativity

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

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

The Shipyard was built for internal use by the agency, and the more than one hundred topics discussed there in a year are all related to the agency's long-term vision. Over four thousand officers used the center last year, and inspector teams for substantial tax evasions are frequent users, as De Lange suggests. The Shipyard consists of more than a dozen different kinds of rooms for different types of discussions and activities. In addition to The Brain and The Silence, spaces include "The Workshop" for prototyping ideas, "The Harvest" for refining rough ideas, and "The Theater" for developing participants' perspectives and mind-sets. They are all well designed to meet their specific objectives.

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

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

The World's First Future Center

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

The Spread of Future Centers

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

Ceiling of The Silence at the Dutch Tax and Customs Administration's Shipyard.

Photo courtesy of Naoki Ogiwara


CHOOSING THE RIGHT TOPIC AND DESIGNING APPROPRIATE PROCESSES ARE KEYS FOR SUCCESS.

Photo courtesy of Naoki Ogiwara

Entering the Pressure Cooker at Dialogues House.

brainstorming and intensive discussions; and "Forum," for large-scale events with studio features. The bank's purpose in building Dialogues House is to drive innovation by incubating ideas related to entrepreneurship, innovation, sustainability, and collaboration. It is also open to outsider social entrepreneurs and nonprofit organizations. Many business ideas have been turned into actual businesses, including, for instance, using the bank's credit management abilities in new areas such as the art trade.

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

Key Elements of a Future Center

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

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

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

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

ABOUT THE ACADEMY

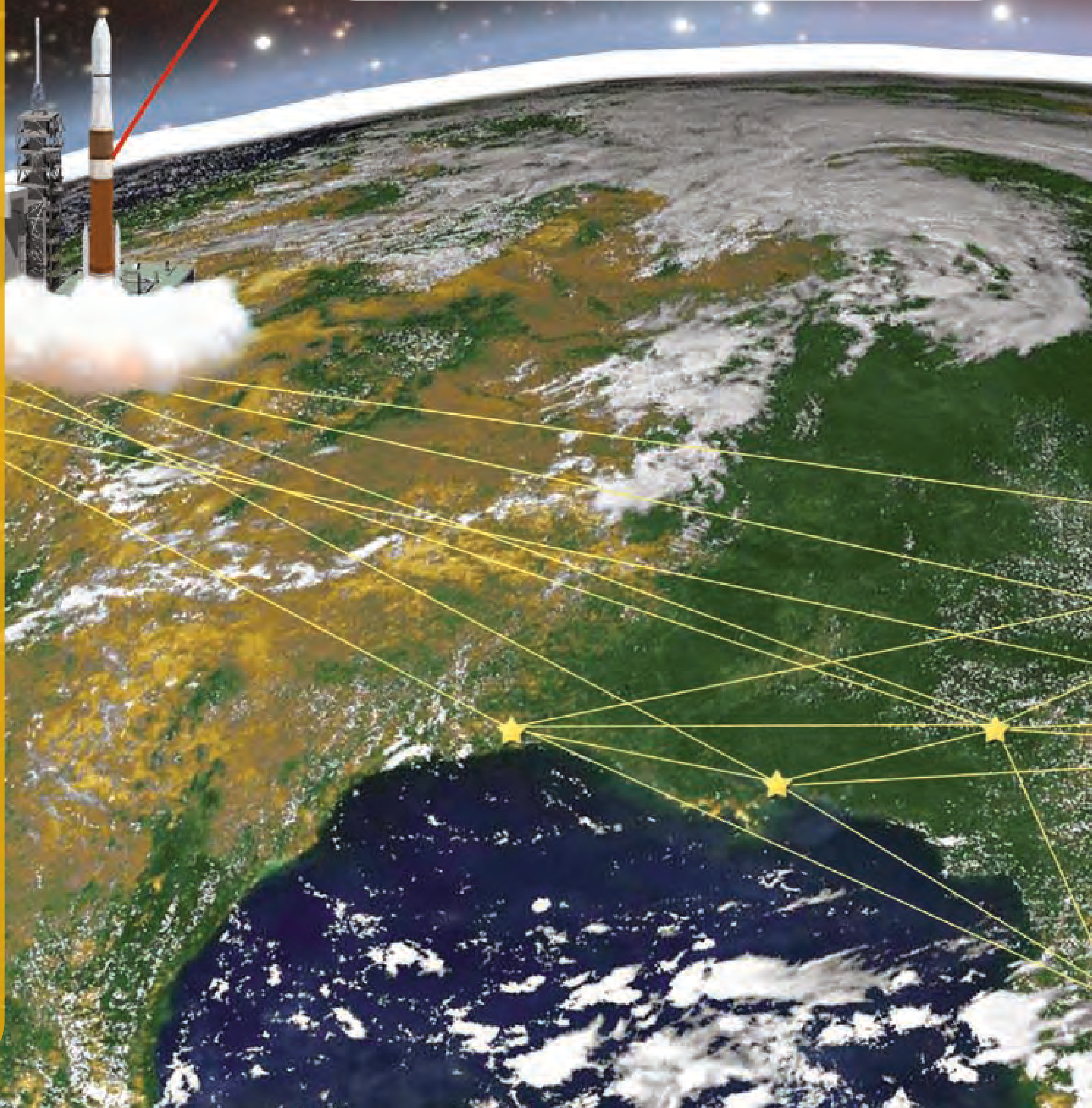
The Academy of Program/Project and Engineering Leadership is NASA's agencywide resource for professional development of its project managers and engineers.

NASA's missions demand a technical workforce with the ability to design, develop, and execute one-of-a-kind projects in aeronautics research, space exploration, and scientific discovery. These challenges are unique—and the solutions are often "firsts" or "onlies" that require innovation, knowledge, and learning. Projects have to meet the highest standards of safety and technical excellence while facing increasingly tight constraints in terms of cost, schedule, and sustainability. The majority of NASA's missions today include international partners, making project leadership a more dynamic challenge than ever before.

The Academy's activities promote learning on three levels: individual practitioners, project and engineering teams, and across the organization. It enables individual learning through its integrated curriculum and formal development programs, team learning through performance enhancement services, and organizational learning through knowledge-sharing activities. Discover more about the Academy at appel.nasa.gov.

CURRICULUM

The Academy's training curriculum enables NASA's technical workforce to develop NASA-specific expertise and capabilities in project management, systems engineering, and engineering. It is intended to supplement an individual's academic and professional work experience. The curriculum draws extensively on best practices and the knowledge of NASA subject-matter experts to ensure it addresses the needs of the agency's practitioners. All courses are developed following established instructional design processes, and include rigorous annual audits, revisions, and incorporation of participant feedback. Courses are highly interactive, featuring case studies, group discussions, and individual exercises.



PERFORMANCE ENHANCEMENT

Since most learning at NASA takes place within project teams, the best opportunity for facilitating project success is at the team level. The Academy offers team support in areas including team building, technical training, process development, planning and scheduling, program control and analysis, systems management, risk management, and software management. Through mentoring, coaching, consultations with expert practitioners, focused workshops, and large group sessions, these activities facilitate immediate improvements as well as enhance long-term team capabilities.

KNOWLEDGE SHARING

The Academy's knowledge-sharing activities promote excellence in project management and engineering by using the power of stories to build a community of practitioners who are reflective and geared toward sharing. By facilitating agencywide knowledge sharing through forums, conferences, award-winning publications, case studies, and multimedia offerings, the Academy helps ensure that critical lessons and knowledge remain accessible. The Academy's knowledge network extends beyond NASA to include expert practitioners from industry, academia, other government agencies, research and professional organizations, and international space agencies.

FORMAL DEVELOPMENT PROGRAMS

Since NASA practitioners report that 90 percent of learning takes place on the job, the Academy facilitates on-the-job experiences and developmental assignments through its Systems Engineering Leadership Development Program (SELDP) and Hands-On Professional Experience (Project HOPE). These formal development programs provide early- and mid-career professionals with hands-on opportunities for learning that accelerate their professional development and readiness to lead.

ACADEMY SHARING KNOWLEDGE

NASA's *ASK Magazine* gives program and project managers, engineers, and scientists a way to share expertise and lessons learned with fellow practitioners. This is only one way *ASK* helps share knowledge as part of NASA's Academy of Program/Project and Engineering Leadership.

Stories recounting the real-life experiences of practitioners communicate important practical wisdom and best practices that readers can apply to their own projects and environments. By telling their stories, 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 professionals just like you, primarily from NASA, but also from other government agencies, academia, industry, and international partners.

Many of these stories are heard firsthand at Academy events, such as Masters Forums, Knowledge Forums, and Masters with Masters. This pullout includes more information about the Academy and its offerings, and how you can become more involved in sharing knowledge with us at *ASK*.

Connect with *ASK* and the Academy

Looking for a way to share your own stories and experiences with us? You can always reach us online at askmagazine.nasa.gov. We also look for stories at these Academy events.

MASTERS FORUMS

The Masters Forum program was designed to enable NASA and the program's participants to share project management best practices and lessons learned, cultivate a community of reflective practitioners, build cross-center relationships, and develop the leadership expertise of the agency's veteran and emerging project managers and engineers. Thought-provoking presentations and dynamic group discussions allow attendees to network with influential leaders from government agencies, universities, private industry, and international partners. Many stories from these events are shared with a broader audience through *ASK Magazine*, the *ASK the Academy* e-newsletter, and videos published online on the Academy's web site and YouTube channel.

KNOWLEDGE FORUMS

Knowledge Forums are small, engaging, one-day events that address different aspects of knowledge acquisition, capture, and transfer. The forums feature leading experts and practitioners from government, industry, and academia who deal directly with knowledge-related challenges. Participants interact with panelists to share stories and experiences in open discussions related to the evolving field of knowledge management. Emphasis is placed on informal discussions and networking in order to cultivate a strong and innovative knowledge community. Summaries from each forum, as well as resources on good storytelling and lessons in leadership, are published on the Academy's web site.

MASTERS WITH MASTERS

Masters with Masters is a series of web-based learning videos that bring together two master practitioners to reflect on their experiences, lessons learned, and thoughts about upcoming challenges. The goal of this series is to engage master practitioners in conversations that bring insights to the surface and promote reflection and open sharing as a regular practice at NASA. All Masters with Masters events are recorded before a live audience and include time for questions and answers. The videos are archived on the Academy web site, and select clips are posted to the Academy's YouTube channel.

NASA'S PROJECT MANAGEMENT CHALLENGE

The Project Management Challenge is an annual seminar designed to examine current program/project management trends and provide a forum for sharing knowledge and exchanging lessons learned. By attracting stakeholders from all experience levels, we help establish an important link between NASA's world-class experts and the emerging leaders of tomorrow.

Have something good to share, but you aren't sure where to start? The following articles were published in *ASK* after face-to-face conversations at these Academy events. We hope they will provide you with some inspiration.

- "The Freedom to Learn," by Jack Boyd: www.nasa.gov/offices/oce/appel/ask/issues/40/40s_freedom.html
- "Peer Assist: Learning Before Doing," by Kent A. Greenes: www.nasa.gov/offices/oce/appel/ask/issues/40/40i_peer_assist.html
- "Islands and Labyrinths: Overcoming Barriers to Effective Knowledge Transfer," by T.J. Elliott: www.nasa.gov/offices/oce/appel/ask/issues/39/39i_islands.html
- "Space Exploration in the 21st Century: Global Opportunities and Challenges," by Jean-Jacques Dordain: www.nasa.gov/offices/oce/appel/ask/issues/38/38i_space.html
- "Petrobras and the Power of Stories," by Alexandre Korowajczuk and Andrea Coelho Farias Almeida: www.nasa.gov/offices/oce/appel/ask/issues/38/38s_petrobras.html
- "Big Facilities, Hard Lessons," by Michael Ospring: askmagazine.nasa.gov/issues/37/37s_big_facilities_hard_lessons.html
- "Management by Wandering Around: A Potent Arrow in the Manager's Quiver," by Noel W. Hinners: askmagazine.nasa.gov/issues/35/35s_management_by_wandering.html
- "Answering the Call: Communicating with Soyuz," by Ed Campion: askmagazine.nasa.gov/issues/35/35s_answering_the_call.html
- "Is Software Broken?" by Steve Jolly: askmagazine.nasa.gov/issues/34/34i_software_broken.html
- "International Cooperation: When 1 + 1 = 3," by Toshifumi Mukai: askmagazine.nasa.gov/issues/31/31s_international_cooperation.html

Learn more about the Academy at appel.nasa.gov.

Spaceflight Hardware on a

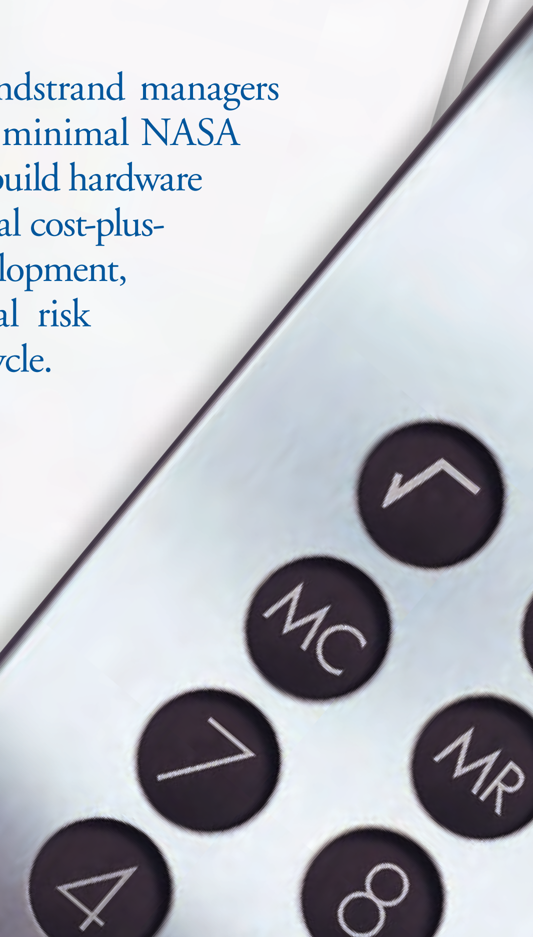
Service Contract

BY JASON CRUSAN, MARYBETH EDEEN, KEVIN GROHS, AND DARREN SAMPLATSKY

What began as conversations between NASA and Hamilton Sundstrand managers grew into an idea to develop a piece of spaceflight hardware with minimal NASA oversight. We expected this approach would allow the contractor to build hardware faster and cheaper while providing higher profit than the conventional cost-plus-fee contracting approach. In exchange for this free rein during development, the contractor would take on significant financial and technical risk throughout design, testing, and the hardware's operational life cycle. The idea came to fruition with the Sabatier system.

Signature *Hamilton Sundstrand*

Signature *NASA*



After departing the International Space Station, the STS-130 crew onboard Space Shuttle Endeavour captured this view of the space station high above Earth.

The system catalyzes the reaction between carbon dioxide and hydrogen—byproducts of current life-support systems onboard the International Space Station (ISS)—to produce water and methane. In exchange for Hamilton Sundstrand conducting and financing the design, development, testing, and evaluation of the Sabatier system, NASA would pay for its capability to produce water on orbit. If the system failed due to Sabatier-related hardware or software issues, then NASA would not be responsible for any payments to the contractor. In effect, NASA would pay for the availability of water production while the contractor would be responsible for maintaining system operability during the contract period. Holding Hamilton Sundstrand accountable for success significantly reduced NASA's technical, cost, and schedule risks.

The water produced by Sabatier will be useful when we reach the end of the Space Shuttle program and the "free" water the shuttle has been providing as a byproduct of its fuel cells. But the Sabatier hardware will not be a critical ISS system, since future plans include water delivery by other resupply vehicles.

While it seems odd to build a system for manned spaceflight that does not have to work, this was the key to developing and executing our idea for the service-contract model: it allowed failure to be an option. At the same time, the risk of failure was relatively low since the existing technology needed for development was mature.

NASA and Hamilton Sundstrand had been researching Sabatier systems for more than twenty years. The contractor also had significant hardware-development experience and had developed the oxygen-generation system that interacts directly with the Sabatier system to provide hydrogen. In addition, the interfacing systems for the Sabatier were already in place and operational onboard the ISS. Since the Sabatier was always planned as part of the regenerative environmental control and life-support system on the station, the interfacing systems were ready for it.

Communication and Teamwork

To increase our chance of success, we had open and honest communication between the organizations that allowed us to understand each other's goals and challenges clearly. Frank communication began during initial contract negotiations, when it became apparent that without both parties being completely up front about their expectations, it would be impossible to close the deal. This meant each side had to explain its ultimate negotiating objectives and constraints in order for discussions to reach a mutually acceptable middle ground. Otherwise, significant differences that needed to be reconciled would have made it impossible to come to any agreement.

With an understanding of what was driving NASA and Hamilton Sundstrand requirements, we were able to define an approach to provide milestone payments before activation that were subject to a 100-percent refund to NASA if the hardware did not work upon on-orbit activation. This met NASA's need to keep Hamilton Sundstrand's "skin in the game" until activation and met Hamilton Sundstrand's need for income during the development phase; it was referred to as a 100-percent look-

WHILE BEING OPEN AND HONEST ABOUT THE REAL DRIVERS BEHIND OUR NEGOTIATION STRATEGIES WENT AGAINST OUR BARGAINING INSTINCTS, IT ENABLED US TO WORK TOGETHER MORE EFFICIENTLY TOWARD A COMMON GOAL: A MUTUALLY ACCEPTABLE AGREEMENT THAT ULTIMATELY MET ALL PARTIES' OBJECTIVES.

back clause. While being open and honest about the real drivers behind our negotiation strategies went against our bargaining instincts, it enabled us to work together more efficiently toward a common goal: a mutually acceptable agreement that ultimately met all parties' objectives.

We also had unwavering team commitment within both organizations, which allowed us to work through unexpected difficulties that arose as new contracting approaches were generated and implemented. Some of these issues were simple on the surface, and some were very complex. In one case, Hamilton Sundstrand provided a data product that met contract requirements, but because NASA did not sufficiently define the requirement for its format, the data could not be added to the relevant NASA database. To correct this, both NASA and Hamilton Sundstrand evaluated options for reformatting the data and shared those solutions with each other. In the end, NASA reformatted the data product because it was the easiest solution for everyone concerned.

Team commitment was critical to integrated safety analyses. Hamilton Sundstrand had successfully completed safety reviews for the Sabatier system as a stand-alone piece of hardware, and thus met their contractual requirements. But when the ISS program began to perform integrated safety analyses six months prior to flight, a number of issues arose concerning a vent line the Sabatier would share with the oxygen-generation system. Hamilton Sundstrand provided critical expertise not only on the design and operation of their system, but on the approaches they had identified for mitigating risks discovered in the integrated analysis. If the contractor had not helped resolve these issues, they would have met their contract requirements, but NASA would never have been able to install and activate the system. In more traditional contracting relationships, problems such as these could have led to cost increases and delays.

Developing the Approach and Requirements

Part of the challenge to successfully implementing this contracting approach was communicating what the benefits and risks were to both NASA and the contractor organizations. We also needed to create custom contract clauses that defined termination liability for every day of the contract and the 100-percent look-back penalty. The contractor had to ensure the return on investment was sufficient to account for the fact that funds would be spent in 2008–2009 but payments would not be made by NASA until 2010–2014, so the "cost of money" had to be included in profit calculations. The decision to make early milestone payments had the additional impact of reducing life-cycle costs to the government by providing some funding up front. This reduced the cost of money to Hamilton Sundstrand, and the contractor has the potential to realize financial returns commensurate with its risk, provided the system works as promised.

Technical and schedule issues presented their own challenges. The overall schedule was under two years, a significant challenge for developing any piece of spaceflight hardware that contains what is essentially a furnace, a multistage compressor, and a condenser/phase-separation system. Developing the compressor was a key technical concern. All previous work on the part had been done by NASA, so Hamilton Sundstrand would need to get up to speed on that technology quickly.

To help mitigate risk, NASA limited its requirements to technical interfaces and safety. Requirements related to the launch environment and system reliability were removed because NASA would not pay for any service if the hardware did not survive the launch or was otherwise unusable. Items such as the failure modes and effects analysis and the hazard analysis were retained along with the requirements of normal safety review panels. This allowed more than 70 percent of NASA's standard requirements to be removed. Verification of the remaining requirements was left as flexible as possible, and specific verification criteria were defined only where absolutely required. In many cases, certificates of compliance from Hamilton Sundstrand were accepted as verification compliance.

One of the other unique aspects of the contract is that NASA did not require commitment to a specific launch date or launch vehicle for the hardware. Instead, the agency gave itself and the contractor a six-month window from final delivery of the hardware to launch and on-orbit checkout.

Photo Credit: NASA

In the Tranquility node aboard the International Space Station, NASA Astronaut Doug Wheelock, Expedition 25 commander, works to install the new Sabatier.

Since NASA's contracting goal was for Hamilton Sundstrand to take on the majority of the risk, and we knew from experience that initial activation of a system on orbit is always challenging, there was a grace period in the contract to allow the contractor to work through any start-up issues before the look-back penalty took effect.

The performance-based criteria didn't end after activation; they apply to the entire on-orbit life cycle. To simplify the on-orbit criteria, we created a system to calculate the number of days the Sabatier is available for water production. The performance payment for any given year is a simple calculation that subtracts down days from a maximum payment based on full-time functioning. We also defined protocols covering contingency scenarios to address whether system inoperability related to NASA interfaces or the Hamilton Sundstrand system.

What We Learned

The Sabatier hardware was activated on orbit in October 2010 and successfully passed its checkout period. This meant we did not need to exercise the look-back clause for initial milestone payments. Future payments depend on the hardware continuing to be available to produce water onboard the ISS.

A number of things helped make this service-contract approach work well:

- Fully defining safety and interface requirements, as well as minimal verification requirements, at the beginning of the project
- Defining roles and responsibilities for both NASA and the contractor, from the working troops all the way through the highest-level management
- Having an experienced spaceflight-hardware contractor
- Having sufficiently mature technology to keep hardware development risk low
- Making NASA's expertise openly available to the contractor
- Fostering open and honest communication regarding business goals and limitations, legal options, issues, and drivers for both parties

Additionally, the roles of NASA and the contractor during certification for flight readiness must be defined so NASA teams understand the limits of their role and don't inadvertently add requirements that are typical of "normal" contracts. Coordination with other contractors who will interact with the new hardware is also important. For example, our unique contract approach and the fact that NASA is not taking ownership of the hardware had numerous effects at Kennedy Space Center, where Boeing and Lockheed Martin are responsible for performing some operations on flight hardware to prepare it for launch to the ISS. Since NASA was not taking ownership, the data required for the property and accounting systems used by Boeing to track hardware they were performing work on could not be provided. It was impossible to assign a value to the hardware for the accounting system since NASA did not know what Hamilton Sundstrand had really spent on the hardware, and the value was ultimately dependent on how the hardware performed on orbit. As a result, the hardware sat for days in shipping and receiving until workarounds could be developed and implemented.

This contract approach delivered process efficiency and innovation but drove out innovation in hardware and software design, given the contractor's need to minimize the risk of hardware failure in order to maximize profit. Even though failure was an option for NASA, since our risk was minimal, the incentive for the contractor to succeed was much greater. This suggests that the service-contract approach can work well for some technology initiatives, but not all. For instance, it would not be feasible for high-risk, innovative development. And it might be difficult to give contractors so much independence when they are building critical systems that *must* work. But there are many situations where this approach can benefit both NASA and its contractors. We should think about when and how it is appropriate. Successful flight-hardware development does not mean always defaulting to a cost-plus-fee contract. ●

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Jamming with the Institute for Healthcare Improvement

BY KATRINA PUGH AND JO ANN ENDO

What do you do when you have valuable knowledge spread among multiple people in multiple organizations, and they don't consider themselves experts? Here's an example of just that: a number of quality-improvement teams working for health-care providers around the country with some remarkable successes and some failures, but few seeing what we call the "wider view"—the cause and effect of their teams' success.

The Institute for Healthcare Improvement (IHI), a not-for-profit organization dedicated to fostering improvements in health-care delivery throughout the world, saw the imperative of knowing what made health-care quality-improvement teams successful. Spreading the knowledge could mean the difference between life and death for patients.

One of IHI's most far-reaching efforts is their IMPACT Communities. Made up of hospital teams from around the United States, these distributed communities use IHI's tools and methods to introduce quality-improvement initiatives. IMPACT Communities have dealt with important issues, including health-care-associated infections and improving care in emergency departments and clinical office practices, resulting in improvements that have saved millions of dollars annually. In 2009, the multi-hospital "Perinatal" IMPACT Community of about one hundred doctors, nurses, technicians, administrators, and project managers had been working with IHI for two years to reduce medical errors, using IHI's process-improvement methods in maternity wards. IHI knew that they would be launching future improvement communities in other care areas and believed that those communities could learn a great deal from this group.

Hidden Know-How

During planning discussions, IHI leadership felt there were some remarkable cases of hospital teams quickly coming together to do effective work while other teams took longer to form, agree on goals, establish effective communication, and become productive—if they ever did. They wanted answers to these questions:

- How do hospitals become ready to consistently adapt IHI's practices?
- How do diverse hospital quality-improvement team members "gel" into a team that is a force of change within their organizations?

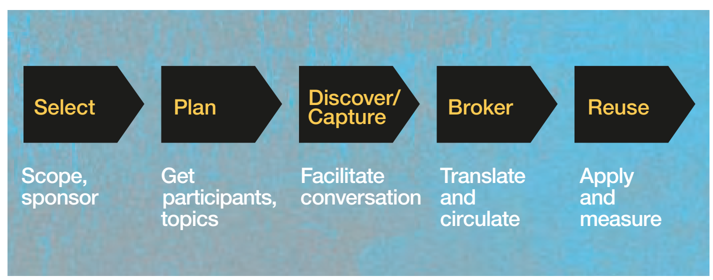
IHI needed a process that could capture what people knew intuitively (and collaboratively) but wasn't written down. And IHI needed to incorporate their knowledge into new processes rapidly. If there were efficiencies to be had and lives to be saved, there wasn't a moment to spare.

Enter Knowledge Jam. Knowledge Jam is a process for bringing out the tacit knowledge of teams and experts through a formal process of targeting specific knowledge, facilitating a knowledge conversation between experts or veteran teams (knowledge originators) and knowledge seekers (or their representatives, the "brokers"), and then ensuring the knowledge is put into practice. Knowledge Jam's steps are select, plan, discover/capture, broker, and reuse. The Knowledge Jam cycle extends from targeting what (and whose) know-how is needed to eliciting it, translating it, reusing it, and measuring its impact.

Consultants Katrina Pugh, Align Consulting, and Nancy Dixon, Common Knowledge Associates, facilitated a Knowledge Jam with IHI in the spring of 2009. Knowledge originators were seven health-care practitioners (nurses, doctors, administrators, and project managers) from six hospitals. Brokers from IHI included IHI staff Jo Ann Endo, Sarah Jackson, Jonathan Small, and Kiette Tucker and IHI faculty Marie Schall and Ginna Crowe, who also occasionally doubled as originators.

Efficiency is a critical part of a Knowledge Jam. The actual discover/capture event, which involves originators and brokers, generally lasts only 90 minutes. Rigorous planning and ongoing, purposeful interactions between brokers and originators, brokers and brokers, and originators and originators save meeting time for everyone. The event is more about "channeling insight to a target" than the "harvesting in bulk" and dumping into an all-too-often stagnant repository that characterize some knowledge management efforts.

Another key to Knowledge Jam efficiency is the three disciplines of facilitation, conversation, and translation. These are threaded into the Knowledge Jam's five-step cycle:



Facilitation

A facilitator helps select, plan, and coordinate the Knowledge Jam process, organizing the early structuring of concepts, providing quality control, aligning Jams to business objectives, and, most importantly, setting a tone of curiosity and respect for the Jam that fuels conversation that yields unique and reusable insight. Facilitators model and reward respectful, open inquiry and discourage defensive, criticizing, or protective attitudes. During the four planning months, we identified topics and participants, held a planning meeting, and prepared for the discover/capture event. We also conducted approximately ten interviews with brokers and originators. Participants in the planning included nurses, doctors, quality-program managers, IHI faculty and staff, and program designers. (Note that none of this was full time; Knowledge Jams have a surprisingly light time footprint.)

Conversation

Knowledge Jams invite the curiosity of those who will use (or transmit) the knowledge. An open conversation between the brokers and originators surfaces the conditions around the facts (How did you decide to do *that*?). The Jam can also reveal connections between events, outcomes, and people that we hadn't considered. Drawing out context in this manner makes captured know-how reusable in other contexts.

Three dimensions of effective conversation are the "posture of openness," "pursuit of diversity," and "practices of dialogue."

The diversity dimension deserves some emphasis, as it played a key role in drawing out valuable context during the discover/capture step in the IHI Knowledge Jam. The group was critiquing a draft definition of what it means for multidisciplinary hospital quality teams to "gel" as they come together to implement improvement practices.

IHI Knowledge Jam Excerpt Showing Cognitive Diversity

KNOWLEDGE JAM COMMENTS	SUMMARY/IMPLICATIONS
	Add to "gel" definition:
Facilitator: *What would you add to or take away from this description of what team "gelling" is?*	
Originator 1 (Nurse, New Hampshire Hospital): Open communication is a big piece of it. There needs to be a process to work through disagreement. By "open communication" I mean safety in the group to say what you think.	• Communicating openly
Originator 2 (Nurse, Connecticut Hospital): Taking the appropriate steps (intervention) to get the results. Having agreement about what those interventions will be.	• Working for multidisciplinary agreement on interventions
Broker 1 (IHI staff, Statistician): A team may gel before it actually has results.	
Originator 1: A willingness to hold each other accountable for each piece of the project. That includes committing to having that hard discussion about desired results, and ensuring that you are getting those results out of the process.	• Holding each other accountable
Broker 2 (IHI faculty, Psychologist): For me, what we are describing is a "functional team." There needs to be a relationship factor, beyond just our functional needs.	• Having relationships at human, not just task, level
Facilitator: *Please, can you elaborate?*	
Broker 2: You need to know people as humans, and not just be task-oriented. That means developing a relationship that has to do with our personal space—for example, what we are working on. It means acknowledging that life gets in the way. To me, that makes it a more sustainable team.	
Originator 3 (Nurse, Louisiana Hospital): A mutual respect within your team.	• Respecting each individual's role in the program
Facilitator: *How is this different from the personal getting-to-know-you?*	
Originator 3: If I am working in a multidimensional team, there is more than just "respect." What I mean is, "knowing what each other is doing." For example, [implementing a change] means step A–J for nurses, and for physicians that means Y. So when we meet collaboratively we are taking the time to see what the implications are for each area.	• Knowing more about each others' tasks and what it takes to get the job done
Originator 2 (commenting at the end of the discover/capture event): We all have the same goals, but it is interesting that the way we meet them may differ. It has to do with culture, structure, and management styles of the organization. Maybe it's the styles of people who have quality-improvement roles, who bring their uniqueness to the table.	

The nurses, doctors, and IHI staff contributed a spectrum of ideas to the definition of "gelling," including communicating, having mutual respect, recognizing each team member's work and life burdens, building relationships, and accomplishing measurable quality-improvement goals together. They also made clear that a team can gel before it has results. The participants' expanded definition helped make their subsequent recommendations far more useful, decisive, and prescriptive.

Translation

Involvement by brokers throughout the Jam gives them a sense of ownership. They remix the ideas into their context (their division, country, project, or product) and integrate those ideas for action. The translation of the knowledge into a project template, a design spec, or a marketing protocol suits the knowledge seekers who are embarking on a decision, innovation, process revision, or outreach program. Brokers often use change management strategies and collaboration or social media technology like team sites, wikis, and microblogs to ensure jammed knowledge gets communicated, amplified, and used.

The three disciplines make jamming more efficient, but they also extend to more strategic forms of knowledge transfer. For example, the culture of facilitation (intention), conversation (openness), and translation (stewardship) is just as applicable to communicating, socializing, and adopting a new business model as it is for remixing an expert's or team's know-how for a tactical program.

A Big Insight

Effective perinatal community teams revealed that it is critical to gel intentionally (say, by adopting new methods and metrics) but that informal interactions, such as holding check-ins and telling stories, help them stick together. The group came to agree on the following dimensions of gelling:

1. Conduct goal setting as team building.
2. During the relationship-building process, meet with peer organizations with experience in similar health-care improvement methods.
3. Infuse shared decision-making with a diversity of experience and values.
4. Build cohesiveness through both performance data and storytelling.
5. Integrate new members intentionally.
6. Formally sustain the organization's commitment to the new health-care improvement culture through project management and work structures.

As a consequence of the Knowledge Jam, IHI added these gelling components to an organization-wide design model called the "Results Driver Diagram." The diagram is a critical part of the development of all IHI's collaborative programming, affecting hundreds of health-care organizations around the United States.

Starting Your Own Knowledge Jams

Taking Knowledge Jams into your organization requires thinking ahead to where the tacit knowledge of experts and teams could potentially improve processes, accelerate innovation, or expand margins. Next is prioritizing topics with potential originators and brokers. Then let the jamming begin! Good facilitators can set the tone, encourage broker–originator conversations, and manage the whole process through epiphanies and low points alike.

Because the application of the knowledge (and the corresponding choice of knowledge to jam) are targeted and collaborative, Knowledge Jams' outcomes can be substantially more cost- and effort-efficient than traditional means of knowledge transfer. IHI was able to capitalize on newfound gelling insights just at the moment they were preparing to launch new IMPACT Communities. So, too, might you find that a Knowledge Jam could inform your critical program with the hidden know-how of those brilliant, but time-starved, experts and veteran teams. ●

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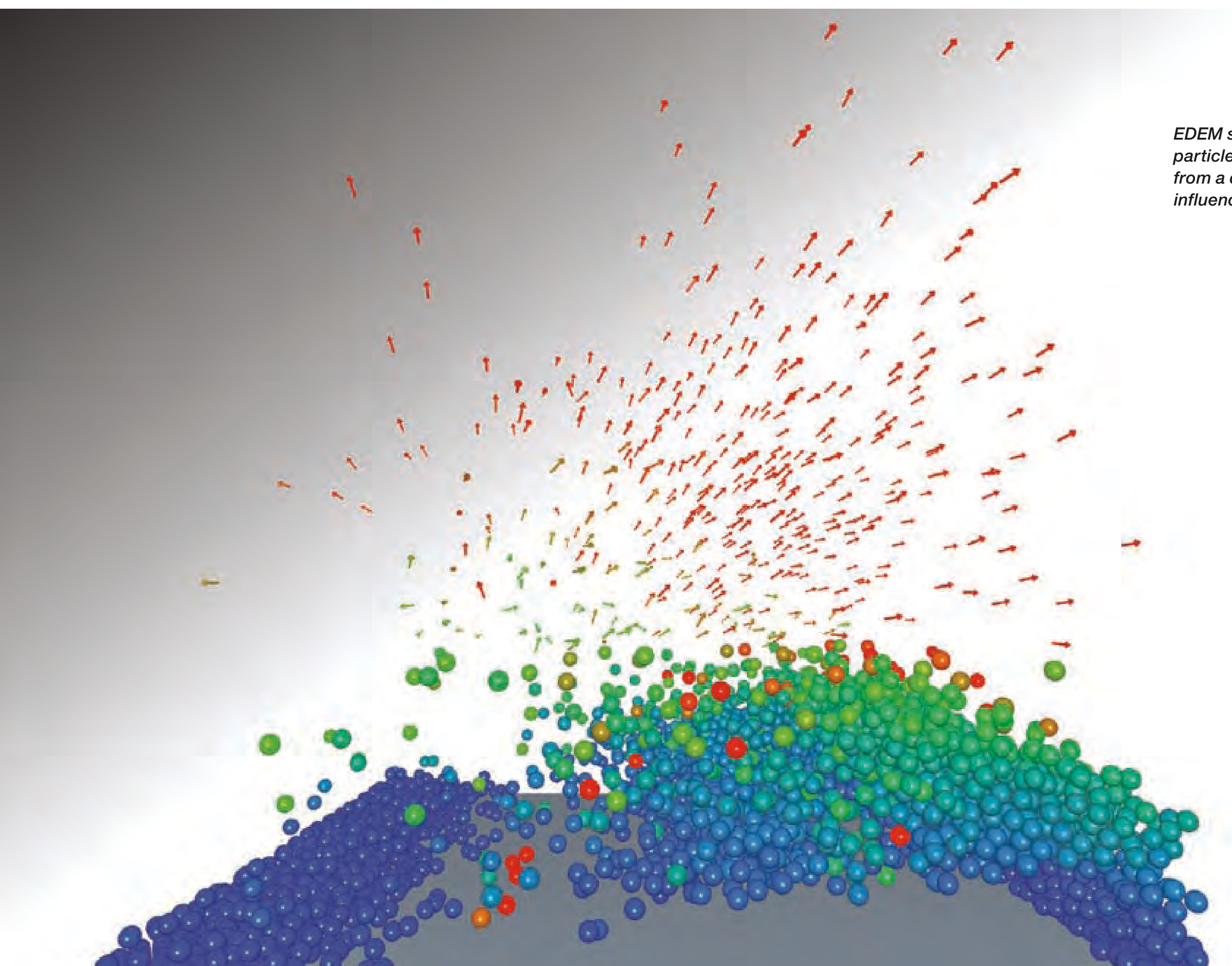
JO ANN ENDO is the Institute for Healthcare Improvement's (www.ihi.org) communications specialist and administrator of the Mentor Hospital Network. She has worked at IHI since 2005, focusing first on the 100,000 Lives and 5 Million Lives campaigns and now on the IHI Improvement Map.

Innovative Partnership Finds Answers to Modeling Lunar Dust

BY CAROL ANNE DUNN, CARLOS CALLE, AND RICHARD LaROCHE

A major problem facing manned or unmanned missions to the moon is lunar dust. Dr. Carlos Calle, founder and director of the Electrostatics and Surface Physics Laboratory at Kennedy Space Center, is familiar with the problem. He has carefully reviewed Apollo mission reports and debriefings to familiarize himself with problems encountered during those missions. The Apollo astronauts had limited visibility during descent due to dust effects, and NASA was uncertain how the astronauts' health would be affected as they inhaled and ingested the dust. During the Apollo 15 mission, a camera failed because highly abrasive dust entered the drive mechanism.



EDEM simulation of dust particles being removed from a dust screen under the influence of an electric field.

Image Credit: DEM Solutions

Lunar dust is thought to be electrostatically charged, which would make it difficult to remove from solar panels, viewports, camera lenses, and astronaut suits, gloves, and visors. Similar problems would be encountered on the dusty surface of Mars. With possible missions to the moon to try out enabling technologies for Mars exploration, scientists like Calle are concerned for a number of reasons. We would be staying longer on the surface than the Apollo astronauts; future missions may include dust-raising activities, such as excavation and handling of soil and rock; and we would be sending robotic instruments to do much of the work for us.

Understanding more about the chemical and physical properties of lunar dust, how dust particles interact with each other and with equipment surfaces, and the role of static electricity build-up on dust particles in the lunar environment is imperative to developing technologies that can remove and prevent dust accumulation as well as successfully handle regolith, also known as lunar soil. Calle is currently working on the problems of the electrostatic phenomena and is involved in developing instrumentation for future planetary missions.

The Electrostatics and Surface Physics Laboratory performs research and development on technologies that can assist operations at Kennedy and at other NASA centers to detect, mitigate, and prevent electrostatic-charge generation and discharge on spaceflight hardware, ground-support equipment, International Space Station modules, and payloads.

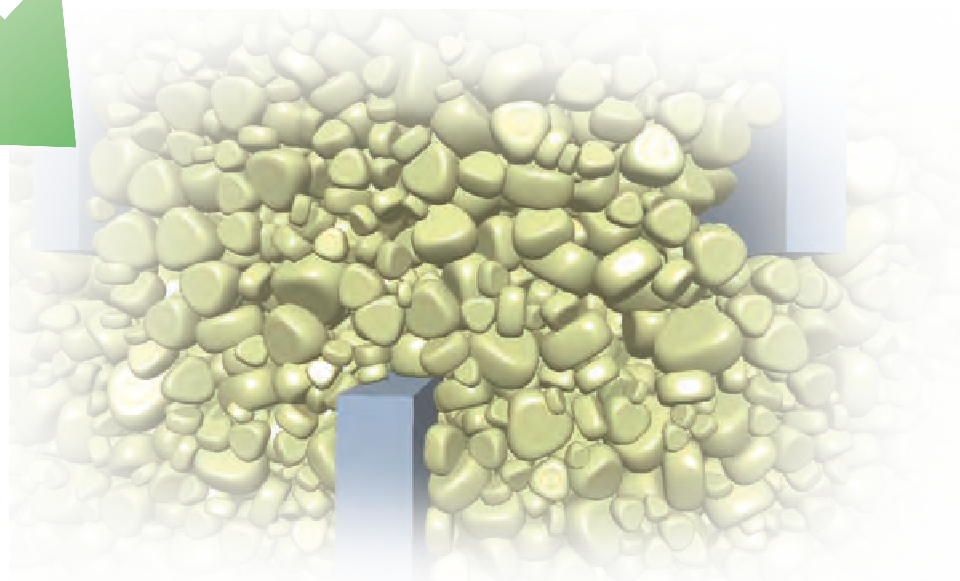
"We are particularly excited about our work on the Electrodynamic Dust Shield," said Calle. "We first worked with the University of Arkansas at Little Rock to mitigate and prevent the accumulation of dust on solar panels for Mars missions." Every fifteen months to three years, Mars is engulfed in a dust storm that can last for months, and every day there are dust devils, tornado-like columns of spinning dust. The project is now part of the NASA-wide Dust Management Project. Even though NASA is not planning on manned moon missions, the lab expects there to be unmanned lunar missions where this technology for preventing and removing surface dust will be important.

To further this research, Kennedy's Innovative Partnerships Program (IPP) Office partnered with DEM Solutions, Inc., a global leader in particle-dynamics simulation software, after NASA personnel made a seed fund proposal to IPP. Customers in pharmaceutical, chemical, mineral, and materials processing industries as well as oil and gas production, agriculture, construction, and geo-technical engineering use DEM's EDEM software to improve the design and operation of equipment that comes into contact with particulate material.

EDEM can simulate and analyze particle handling and manufacturing operations, which allows users to create a model of any granular-solids system. Computer-aided design models of real particles can be imported to obtain an accurate representation of their shape. In addition to particle size and shape, the models can account for physical properties of particles along with interaction between particles and with equipment surfaces and surrounding media. The flexibility and extensibility of the software enables simulation of granular materials from powders to gravel. In order for the software to simulate regolith, however, additional modeling and validation of electrostatic and surface-energy adhesion forces, dynamic friction, and particle shape were required.

DEM Solutions was able to use previous experience working closely with NASA scientists to develop custom solutions for modeling the effects of electrostatic forces on particles. The NASA scientists provided a theoretical framework for introducing the electrostatic force component to the software, and DEM engineers developed the computer code that implemented it.

The new proposal enhanced the existing EDEM software to provide more accurate modeling of lunar dust and regolith—with the potential to improve design quality and provide significant savings, especially in respect to field testing. "We wanted to build on off-the-shelf software, and the user-friendliness and range of capabilities in EDEM made



Simulation of lunar soil particles.

Image Credit: DEM Solutions

it attractive. The experience of the staff at DEM Solutions in modeling complex particulate systems such as [those] encountered in space applications gave us the confidence that they would be a strong partner," said Calle.

Once the work was under way, NASA provided a simulation that had been developed earlier for the study of electrodynamic dust-shield technology. DEM Solutions incorporated that simulation into EDEM and developed a more complete simulation of the dust shield in action. This early implementation not only served to show that the theoretical framework and the computer code were correct, but also provided NASA with a tool that could be used immediately.

Most of the technical work was performed by David Curry, a senior consulting engineer at DEM Solutions in Edinburgh, and Michael Hogue, of Kennedy's Electrostatics and Surface Physics Laboratory. To ensure that work remained focused and moving in the right direction, regular web-based conferences were used to share results and discuss ideas for extending the modeling capabilities. In addition, Curry visited Kennedy near the end of the project to work directly with Hogue to provide training and transfer knowledge about the technology developed in EDEM.

"The NASA IPP project enabled us to extend the capabilities of our EDEM particle-modeling software for NASA's applications," noted Richard LaRoche, vice president of engineering and U.S. general manager of DEM Solutions. "But this project also spawned innovations resulting in advanced features that our current customers now use for modeling cohesive materials and particle-fluid systems."

The DEM Solutions partnership provided NASA with expertise in particle-dynamics simulation and a custom computer-aided engineering tool that supported initiatives in the Exploration Science Mission Directorate's Exploration Technology Development Program, particularly in dust mitigation and in situ resource utilization, modeling the behavior of the dust as it came into contact with an electrodynamic dust shield. Other simulations now augment the development of other NASA dust-mitigation technologies, such as those designed for dust removal and cleaning optical and thermal radiator surfaces, connectors, and seals.

To help create accurate simulations, Kennedy's Electrostatics and Surface Physics Laboratory and Glenn Research Center's In Situ Resource Utilization Lunar Regolith Characterization Laboratory identified the correct physics to add to the EDEM code. Glenn researchers Allen Wilkinson, Enrique Rame, and Al DeGennaro shared abstracts of relevant research papers from their on-site NASA Exploration Soils Bibliographic Database Resource. Using this information, DEM Solutions engineers proposed several approaches for the lunar-soil particles that could be integrated into existing EDEM software without significantly slowing down the simulation or unnecessarily increasing user inputs.

One challenge was calibrating the new EDEM model to obtain the right lunar-soil parameters. The teams decided to run a laboratory experiment—the Schulze shear test—with lunar-soil simulant and then simulate the same experiment in EDEM. Enrique Rame from the National Center for Space Exploration Research in Fluids and Combustion at Glenn ran the lab test and provided DEM with the operational parameters and results. Philip T. Metzger from the Granular Mechanics and Surface Systems Laboratory at Kennedy provided additional information on lunar-soil particle-size distribution. This information was used to create an initial model for lunar soil and then to run simulations with different EDEM parameters to identify the best input parameters.

These new EDEM capabilities can be applied in many industries unrelated to space exploration, and they have been adopted by several U.S. companies, including John Deere, Pfizer, and Procter & Gamble.

Carol Plouffe, an engineering manager working for John Deere, said, "The goals of the project are of great interest to John Deere since we have similar objectives as NASA in terms of

EVEN THOUGH NASA IS NOT PLANNING ON MANNED MOON MISSIONS, THE LAB EXPECTS THERE TO BE UNMANNED LUNAR MISSIONS WHERE THIS TECHNOLOGY FOR PREVENTING AND REMOVING SURFACE DUST WILL BE IMPORTANT.

being able to build reliable models of bulk particulate behavior and are users of EDEM software. Most of the agricultural and construction machinery developed by Deere involves the movement of bulk material. By developing the capability to model regolith, which is a fine material with angular particles and cohesive properties, the project is likely to solve some of the modeling challenges we face on Earth with cohesive or sandy soils."

This project benefited all involved and shows that NASA's IPP Seed Fund can help both the space program and other U.S. industries. Working together with external partners contributes to NASA's ability to help stimulate the economy and provide solid answers to difficult problems. ●

Special thanks to DEM Solutions for their help in writing this article. For more information, visit www.dem-solutions.com. For questions regarding NASA's Innovative Partnerships Program Seed Fund, contact Alexis Hongamen at alexis.hongamen-1@nasa.gov.

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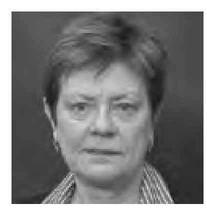

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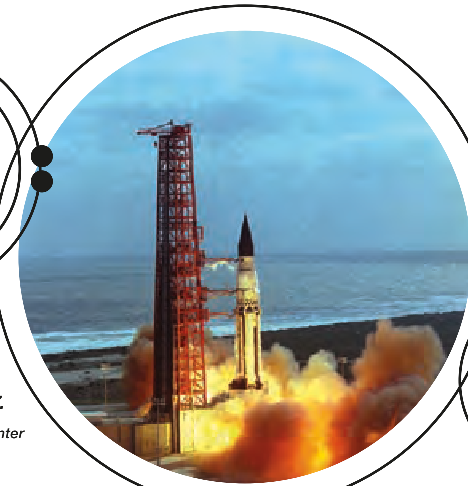
EXPLOSIVE LESSONS IN HYDROGEN SAFETY

BY RUSSEL RHODES

The Centaur program, which developed a high-energy second-stage rocket in the early sixties, marked NASA's first effort to use large quantities of liquid hydrogen. Following in parallel, and using a second stage fueled with liquid hydrogen, was the Saturn I block II vehicle. I was selected to be the engineer responsible for the design and operation of the new liquid storage and transfer systems these rockets needed. Even small amounts of liquid hydrogen can be explosive when combined with air, and only a small amount of energy is required to ignite it. Both its explosiveness and the extremely low temperatures involved make handling it safely a challenge. It has taken a lot of experience, including the experience of dramatic failures, to teach us just how dangerous it is and how carefully we need to treat it.

Smoke and flames belch from the huge S-1C test stand as the first stage booster of the Apollo/Saturn V space vehicle is static fired at the NASA Mississippi Test Facility, now Stennis Space Center.

Photo Credit: NASA



Launch of the Saturn I SA-5 on January 29, 1964. This was the first flight of a live S-IV (second or upper) stage with the cluster of six liquid-hydrogen-fueled RL-10 engines and the first use of Launch Complex 37.

Photo Credit: NASA Marshall Space Flight Center

EXPLOSIVE LESSONS

August 30, 1963. We were ready to fuel the Saturn I block II vehicle, our first configuration with a liquid-hydrogen-and-oxygen-powered second stage. The stage had six RL-10 engines, and the launch complex to support it contained a 125,000-gallon dewar for storing liquid hydrogen about 600 ft. from the launchpad. For additional safety, we had two ponds where hydrogen that was vented during preparation could be safely burned off.

We began filling the transfer line and chilling the stage tank while venting hydrogen down to its burn pond. Everything seemed to be working fine when Al Zeiler, who was watching the process through a periscope (we had very little closed-circuit television in those days), told us we'd had an explosion at the pad. Inside the blockhouse, we hadn't heard a thing, but Al reported seeing steel trench covers, which weighed about 300 lbs. each, flying several hundred feet in the air.

We immediately closed the vehicle tank vent valve and activated a helium purge to eliminate any hydrogen gas in the line and put out the fire. The system operator did not understand the severity of the situation, however. He closed the helium purge and vented the vehicle tank, which restarted the flow of hydrogen and reignited the fire. I instructed the operator to shut the vent valve and again turn on the helium purge.

There was considerable damage to the vent system, and about 200 ft. of trench covers were blown off. We ended up using the Labor Day weekend to remove the damaged system and clean up the area. Some of the damaged hardware was placed on the floor of the operational butler building, including aluminum bellows sections—which allowed the vent line to expand and contract—that had been cut out of the line. The following Tuesday morning, I gave one of the bellows a kick and water spilled out. That was the first clue to what had happened.

With the vehicle venting helium, closing the vehicle tank vent valve creates a partial vacuum in the ground system vent line. This triggers a siphoning effect that starts filling the vent line with water from the burn pond. This may have been the source of the water in the bellows. The other possible cause may have been from another crew's prior attempt to clean the vent system.

The bellows were fully expanded during our first test; flowing in liquid hydrogen made the line cold, causing it to shrink about 30 in. This allowed water to freeze and fill the bellows with ice. As the pipe expanded during warm-up after the flow test, the bellows tried to collapse to their minimum dimension before the ice melted, resulting in a rupture and a large leak path into the trench. So water from either the cleaning or siphoning incidents created conditions that resulted in the failure.

The solution involved replacing the original design with a solid line with no bellows sections. Instead, a bellows flex hose was installed at the end of the line where it connected to the base of the tower, which gave 30 in. of freedom to accommodate expansion and contraction.

Hydrogen has a very broad flammability range—a 4 percent to 74 percent concentration in air and 4 percent to 94 percent in oxygen; therefore, keeping air or oxygen from mixing with hydrogen inside confined spaces is very important. Also, it requires only 0.02 millijoules of energy to ignite the hydrogen–air mixture, which is less than 7 percent of the energy needed to ignite natural gas. That is why a burn pond using a 1-in. water seal was considered safer than a flare stack. Experience over the next several years showed us that keeping air out of the vent system was difficult and required strict procedural control and maintenance.

EXPLOSION AT THE MISSISSIPPI TEST FACILITY

More often than not, fears about the potential for explosions were justified. Designers at Kennedy Space Center were concerned about using a hydrogen flare stack to manage waste hydrogen because they believed air could enter it and lead to an explosion. During the developmental testing of the SII stage of the Saturn V moon rocket at the Mississippi Test Facility (now Stennis Space Center), their concern was validated.

Marshall Space Flight Center workers fill fuel tanks with liquid hydrogen used for test firing at the S-IVB (Dynamic) Test Stand.

Photo Credit: NASA Marshall Space Flight Center

Test operations had removed a problematic vent valve and installed a blanking plate to seal the opening. When the vent valve was removed, low-density helium flowed out of the high-elevation opening on the test stand, causing air to be drawn into the system through the flare-stack opening. One morning, a high-pressure relief valve vented hydrogen gas into the system.

A helium purge pushed gases from the system to the flare stack. When the gaseous hydrogen reached the top of the stack, it burned; however, because there was air in the system, the flame flashed back into the system to burn any flammable gases. Operational personnel having lunch in the nearby control room heard the flame flash back with a screeching sound. This flashback occurred several times until it found a hydrogen–air mixture that was detonable. The resulting explosion destroyed several hundred feet of the vent system.

HYDROGEN FIRES

From our experience at the hydrogen production facility in West Palm Beach, Florida, and our first Saturn storage facilities at Launch Complex 37, we learned that unflared vent stacks used for disposing low volumes of gas could be ignited by a static charge in the air. The first time the vent caught fire from a static charge, the techs tried to use a fire hose to extinguish it. Of course, this didn't work, and the valve was closed while purging the system with nitrogen gas to remove any fuel present.

To prevent static charge, a lightning rod was mounted directly to the vertical vent system with its tip above the flammable hydrogen–air mixture. But when the lightning rod grounding connection became slightly corroded and lost its continuity, the vent system outlet caught fire again, melting the metal rod. We replaced it with a fiberglass rod, and operators learned they must maintain a good ground connection to avoid fires.

FINDING LEAKS

During the design and activation of the LC-39 Pad A liquid-hydrogen facility, concern about hydrogen leaking from the seal on a supply-line shutoff valve drove the need for a fault-tolerant solution. Since the tanker-replenishment operation was performed with personnel in the area, our concern was great because the valve was the last opportunity to isolate the tank's hydrogen from personnel.

The valve used an extended bonnet (or valve cover) that had two sets of seals separated by a ring that had a port to allow for hydrogen purging if the valve needed maintenance. The fault-tolerant solution was a high-pressure helium purge ported into this bonnet and controlled by a panel located about 100 ft. from the valve. This purge was supplied at a pressure slightly higher than the intended operating pressure of the liquid-hydrogen line. Some operations personnel didn't believe this capability was needed, though, so they did not set up the pressure accordingly while replenishing liquid hydrogen.

During a transfer, a leak developed at the valve bonnet seals and prevented anyone from getting close enough to the valve to close it. This provided us an opportunity to not only verify our fault-tolerant solution, but also educate the technicians on the need for safety backup systems and the importance in following procedures to use them as directed.

We instructed the technicians to go to the helium-purge control panel located safely away from the storage tank and activate the system that would supply ambient helium gas to the valve bonnet and warm the shaft seals, making them expand and seal. The system stopped the leak in less than a minute.

CRYOGENIC PROPELLANT LEAKS

We have made progress on safely and surely detecting hydrogen leaks. In the early days of launching ballistic liquid rockets, vehicle propulsion systems were visually checked for leaks by launch personnel at ambient temperatures before propellant was loaded, after a small quantity of cryogenic propellants were chilled and loaded, and after we completed cryogenic loading.

My responsibility as the launch operations fuels section chief was to safely load the fuel propellants on the Saturn vehicles. Because of requirements for cryogenic propellants, I was looking for an automatic process to verify that exposed systems were purged dry of moisture and liquid-hydrogen systems were purged of air or incompatible gases.

I approached my division chief for permission to purchase a small mass spectrometer to provide this capability. He was more concerned about developing a leakage-verification capability of the vehicle's closed compartments and asked if I thought this mass spectrometer technique could perform leakage verification instead. I told him I was sure it had great possibilities. He passed on the idea of using this technique to the design organization in Huntsville, Alabama.

Before the mass-spectrometer system was ready, a visual leak check was performed by launch-site personnel wearing Scott air-packs and an external light source. This practice was discontinued as soon as the hazardous-gas detection system (HGDS) was ready for use. This system is still used on all launch vehicles using liquid hydrogen for fuel.

CONTINUING CHALLENGES

Although we have learned a great deal about safely handling liquid hydrogen, the challenges continue. The RS-68 engine being considered for use in a new cargo launch vehicle has a 2-second hydrogen flow for start-up, compared with the Space Shuttle main engine 100-millisecond lead. A launchpad shutdown of a vehicle with five such engines could generate enough unburned hydrogen in the exhaust to create a very large fireball rising around the entire vehicle and the mobile launch tower—obviously not a safe operating environment.

DURING A TRANSFER, A LEAK DEVELOPED [AND] … PROVIDED US AN OPPORTUNITY TO … EDUCATE THE TECHNICIANS ON THE NEED FOR SAFETY BACKUP SYSTEMS AND THE IMPORTANCE IN FOLLOWING PROCEDURES TO USE THEM AS DIRECTED.

To help make safety for future launches more affordable, research was initiated for hydrogen and helium visualization techniques. A study led by Glenn Sellar, University of Central Florida, and supported by Sandra Clements, a summer facility professor from Florida Tech, identified two very promising techniques: "Rayleigh Scattering" and "RAMAN/LIDAR." The idea is to replace the many-point sensors covering the ground hydrogen systems with a visual scanning system that can better detect, visually locate, and quantify the hydrogen present. If the system can operate as a helium detector as well, it can also be used to verify leak-free fluid systems.

This single system would replace not only the hydrogen sensors, but also the many methods of performing leak checks on the fluid systems. The HGDS currently used for monitoring a vehicle's confined spaces will not indicate where the leak or leaks are located within the compartment. The visual technique would provide this vital information to allow for quick assessment and corrective action. This same technique would also be used to perform the fluid systems functional verification for leak tightness prior to its operation. This would take us one step closer to a fully automated safe approach to managing the perils of liquid hydrogen. ●

RUSSEL RHODES has been employed for more than fifty years at Kennedy Space Center. During this time, he has been engaged in the design, development, testing, and operation of ballistic missiles and space transportation systems, and has specialized experience in space vehicle propellant loading, cryogenic, hydraulics, high-pressure gases, and other propulsion systems.

The Innovation Paradox

BY ED HOFFMAN

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

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

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

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

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

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

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

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

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

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

PLENTY OF GOOD IDEAS HAVE BEEN DISCARDED AS "FAILURES" BECAUSE THEY DIDN'T PAY OFF AS SOON OR AS SPECTACULARLY AS MANAGEMENT THOUGHT THEY SHOULD.

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

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

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

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

LESSONS FROM THE NATIONAL IGNITION FACILITY

BY MATTHEW KOHUT

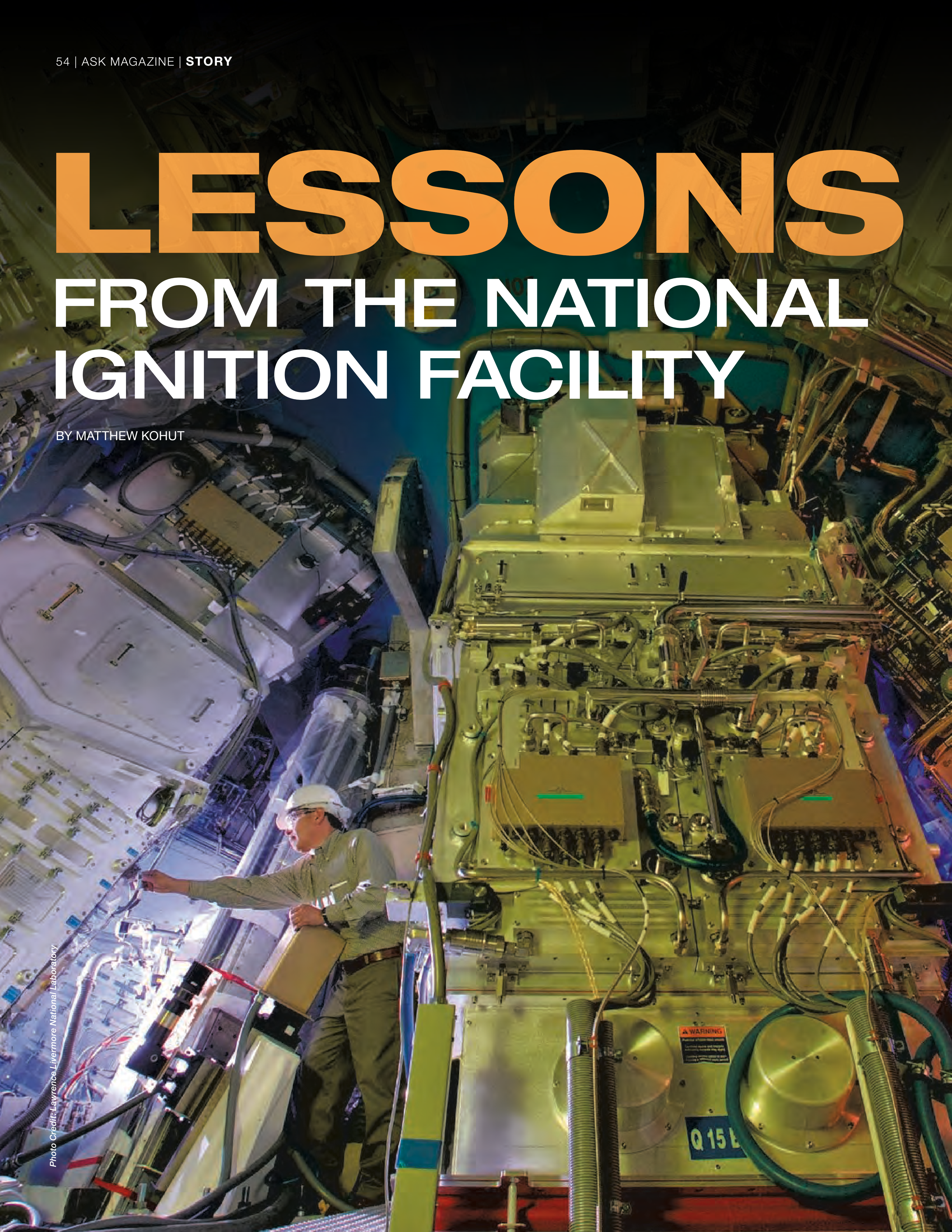
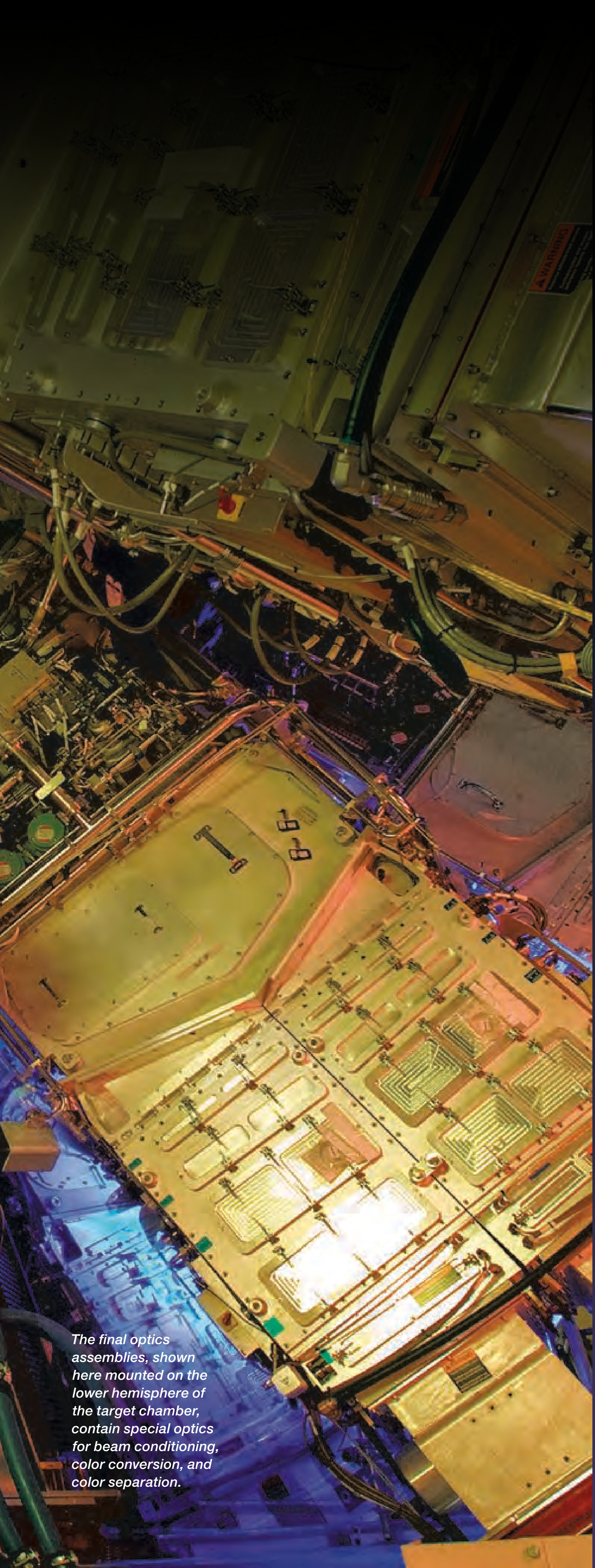


Photo Credit: Lawrence Livermore National Laboratory



The final optics assemblies, shown here mounted on the lower hemisphere of the target chamber, contain special optics for beam conditioning, color conversion, and color separation.

The National Ignition Facility (NIF) is home of the world's largest laser. With 192 laser beams that can deliver more than sixty times the energy of any previous laser system, NIF represents a significant step in enabling the study of high-energy density science. The design and construction of this unique, highly complex facility posed management challenges that the project team overseeing its development could not foresee.

A One-of-a-Kind Facility

The Department of Energy (DOE) formally broke ground on NIF at Lawrence Livermore National Laboratories (LLNL) in May 1997. The federal government used a lean management structure for NIF, relying on a small core team of civil servants to oversee a contractor organization of hundreds. DOE chose to implement this project through one of its existing Management and Operating (M&O) contracts—broad agreements that provide the government with access to the capabilities of its national laboratories.

NIF, a ten-story building the length of three football fields, actually consists of three connected buildings: the Optics Assembly Building, the Laser and Target Area Building, and the Diagnostics Building. In the Optics Assembly Building, assembly of precision-engineered laser components takes place under Class 100 clean-room conditions. The Laser and Target Area Building houses the 192 laser beams in two identical bays. Large mirrors direct the laser beams into a target bay, where they are focused to the center of a 10-meter-diameter target chamber. The cleanliness inside the beam enclosures typically exceeds that of a semiconductor or pharmaceutical manufacturing plant.

LLNL had built several complex laser systems prior to NIF, but nothing approaching its size and scope. "When you do work planning and estimating for something where there isn't a direct comparison that provides you the basis for a parametric estimate, you go with what you understand," said Scott Samuelson, who began working on the project in the mid-1990s. "All the prior laser systems at the lab were put together one beamline at a time by trained technicians who worked for the lab. Our initial thinking assumed we'd use the in-house [workforce], and they'd put it together just like the previous systems."

The challenge proved greater than expected. "As we got closer to having to start the assembly of the beam-path infrastructure—as the building was getting finished on the inside and you could start to get a physical feel for the scale of the laser system and the components we would be assembling,


Photo Credit: Lawrence Livermore National Laboratory

Deformable mirrors, located at the ends of the NIF main amplifiers, use an array of thirty-nine actuators to create a movable surface that corrects aberrations in a beam due to minute distortions in the optics.

and the challenge of doing that work in a clean environment—I thought, 'You know, I don't think we can do it the way the previous systems were built; I don't see how those techniques and people can successfully put this thing together.'" Samuelson, then acting as field director for the project, agreed with LLNL management that a new look at the original plan for building the laser system should be conducted.

Resetting the Baseline

In 1999, one of the largest cranes in the world lifted NIF's 10-meter-diameter target chamber into the target bay in a dramatic event attended by Secretary of Energy Bill Richardson. Shortly after the event, the project team came forward with an estimate to complete, which identified deficiencies in the existing project planning and projected schedule delays and several hundred million dollars of cost overruns. When this came to light, Secretary Richardson issued a forceful press release setting out a six-step approach for addressing NIF's cost and schedule problems. "These are project management issues, and we will get ahead of these problems and turn them around with aggressive and tighter management action from this department," Richardson wrote. This action plan led to management changes at LLNL, increased and more-focused oversight from DOE, and reviews by a Secretarial NIF Task Force as well as the General Accounting Office.

The reviews resulted in significant revisions to the project's baseline cost and schedule. "Basically what happened is the project just didn't understand how hard the job of building that ship in the bottle and keeping it as clean as it needed to be inside while we were doing it would be," Samuelson said. "The work scope was there, but the effort associated with that work scope was underestimated."

Samuelson attributed the cost-estimation errors to the lack of a model that could offer a meaningful basis for comparison: "The lab did their best estimate. We had external reviewers come in, we had independent cost estimators come in, but in the end, they could only look at what they understood; they had to take our word for the things they simply had no experience with. As a result, the estimates for the 'conventional' parts of the facility were pretty much right on, but our existing management systems never gave us a good independent estimate of the 'first-of-a-kind' portion of the project. That's where you end up when you're doing something that nobody's ever done before. The real lesson to me is that we proved one more time that the old RAND study on mega projects was right: on these highly complex, one-of-a-kind projects, you make your best estimate of what it's going to cost and then double it. Don't plan on spending the extra, just sit on it until you find out what you didn't know and understand what you really need it for. "

After the Shakeup

The multiple reviews led to changes in the management approach. "It changed a lot of things," said Samuelson. "It redefined a lot of management relations. It certainly redefined the teams that were working on the project, and the way we were using the suite of project management tools and techniques that we had available to us."

Managers tightened the scope of the project. "We took the opportunity to review our project-completion criteria and scrubbed them very carefully," explained Samuelson. "We made some small changes based on input from the scientific community and incorporated them through the change-control process. The final product was included in the project execution plan so there wouldn't be any doubt what we were signed up for; it never changed after that."

The management chain on the federal side shortened. "Back when this started, you had a program manager in Washington, and you had a project manager in Washington who was part of another organization, and they had no real contractual authority to direct the people at the M&O contractor doing the work. All that came down a separate line through what was then the operations office manager to one of his assistant managers, and

The target chamber under construction. Holes in the target chamber provide access for the laser beams and viewing ports for NIF diagnostic equipment.

Photo Credit: Lawrence Livermore National Laboratory

then eventually to the guy out in the field, which was the job I held back then. It made for a pretty difficult situation when you needed to reach the person where all those lines came together," said Samuelson.

The reviews led to the creation of the Office of the NIF Project, whose director reported to the assistant secretary for defense programs. "Anytime you do anything that's this big and this hard, I think that's what you ought to do," said Samuelson. "You need to focus on the project. You can't have other priorities. You can't have distractions from other places. The person you're reporting to must be able to make decisions and allocate resources consistent with the Department's commitment to the success of the project."

For the next two or three years, the project continued with an office director in Washington, D.C., and a deputy who served as the field director on-site at NIF. There was more formality than in the past in the use of external review groups as well as more rigor in reporting. The changes in the project management approach and tools made a difference.

"In the earlier time period, we were using an earned value management–like system, not a real earned value management system [EVMS], because a full EVMS wasn't required in those days. We probably had a little less insight into future performance based on what we had observed under that old system than we did later in the project, but we thought it was adequate at the time," Samuelson said.

He also noted the forecasting limitations of project management tools: "Earned value management is a great tool, but for better or for worse, it measures past performance against your plan. You can use that information to project what may happen in the future against that plan, but what we identified that led to the revised estimate to complete (prior to the 1999–2000 re-baseline) wouldn't have been identified until later through an EVMS. We were performing against the plan; the problem was that the plan was underscoped going forward, but what we'd done so far was not an indication of that. It was just a matter of looking at the work ahead and saying, 'It's not going to happen that way.'"

The project also made greater use of external reviews than it had in the past. "We really ran the reviews using the model the Office of Science uses. Dan Lehman has run reviews on their projects for years, and he has a pretty specific formula for how you conduct them. We would have a group of very experienced people who'd come in and turn us inside out, and tell us what they thought, ask us what we thought, and then they would leave us with their opinions," Samuelson said. "I'd say 99 percent of the time, we took care of what they told us. It was almost completely embraced, and it paid a lot of dividends over the years."

The Role of the Federal Project Director

After the director of the Office of the NIF Project retired, Samuelson and others rotated responsibilities for a time. In 2004, DOE established the federal project director (FPD) designation and began the process of certifying Samuelson to fill the new position for NIF.

One of the biggest differences having an FPD made was focusing contact between the government and its contractor. "The project organization got even tighter, and there was increased emphasis on the importance of providing direction via the contract. It made it a lot easier to keep straight what the government was officially saying to the contractor with regard to the project. The contractor knew that while program managers and other senior managers in HQ made decisions and communicated directly with them, project direction implementing those decisions came out of my [FPD] office through the contract," said Samuelson. "That really helped on both sides. It's hard to overplay how important that was."

Samuelson described the FPD's role as one that shapes the reaction the system will have to events that occur. "Project management is about solving the hundred problems that come up every day. If every time something happens, you just say, 'They're normal, and we're taking care of them, and I know it's happening—thanks for keeping me informed, and let me know if any problem is getting bigger,' then people tell you about them," he said. "If you make a big deal and stir up the whole system every time you hear that something didn't happen when it was supposed to, you're going to have a hard time finding out about it, and you're going to be too busy with things that the contractor should just be handling to pay attention to the stuff you need to be paying attention to. That's especially true with something the size of NIF."

NIF's federal employees focused on creating a strong team with the M&O office. "For all intents and purposes, everything that was going on there was transparent," said Samuelson. "We had access to all their information and management systems, and we defined very carefully what the thresholds and boundaries were on responsibilities." He emphasized the importance of developing a certain level of trust with the contractor workforce: "I don't know any way to do that other than to be here [in the field] in the middle of what's going on, being able to have the trust of the people so they feel comfortable talking to you about what's really happening and they understand that you're going to be focused on helping find a solution and moving things forward."

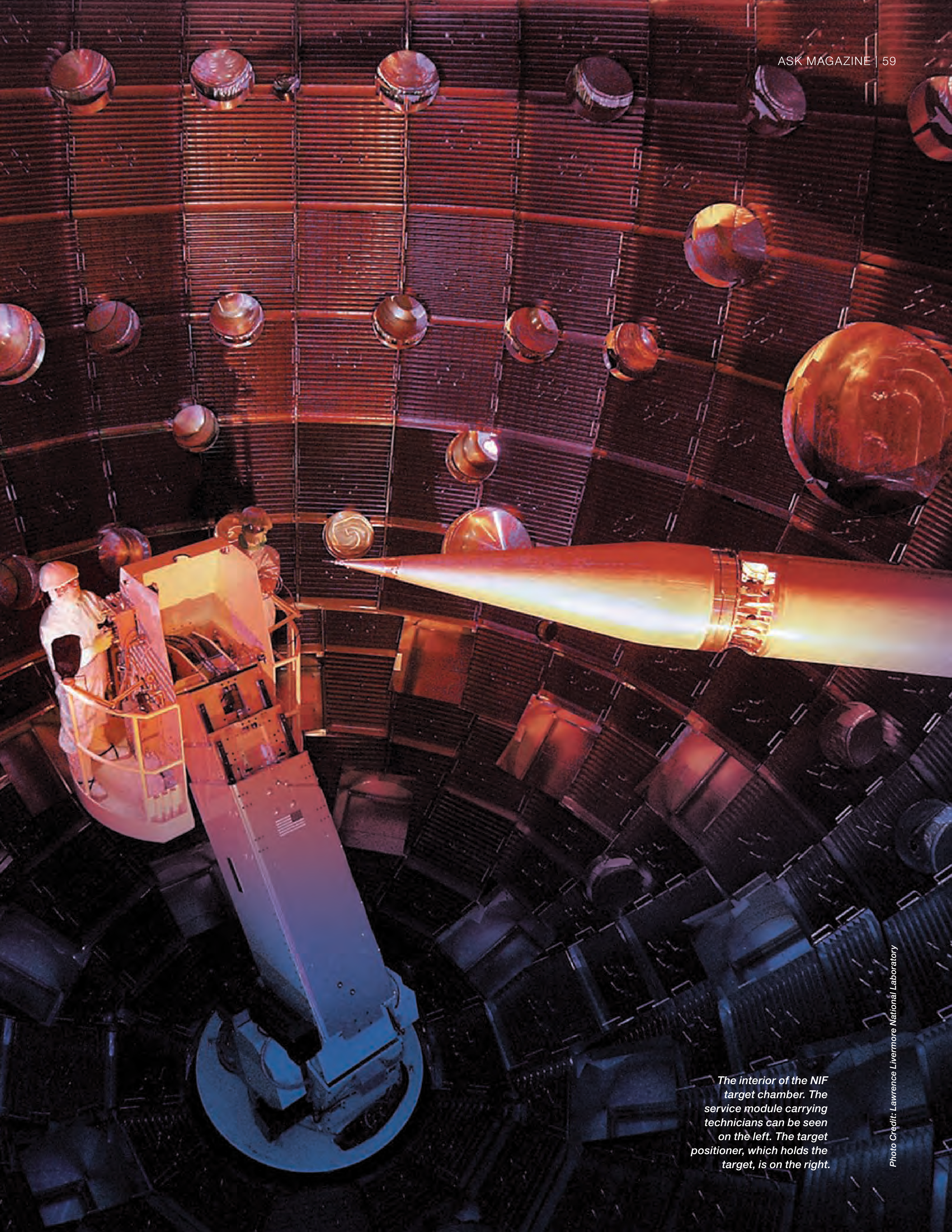
From Samuelson's perspective, the oversight role revolves around access to information and the ability to evaluate it. "I got lots of numbers and pieces of paper and statements of whether milestones were being met. That's all good. But it's developing the ability to determine whether or not what you're seeing matches what's really going on. Is the system giving you data you should believe?" he asked rhetorically. "Then when you look at that data and it matches your other observations, and you do see something going on, do you understand why that's happening?"

Most importantly, Samuelson and his team focused on eliminating roadblocks and keeping the project moving toward completion. "I think that one of the things that all of us as a group did well for the last nine years was just handle stuff: resolve the issues and make sure people were aware and informed," he said.

Crossing the Finish Line

On March 31, 2009, DOE announced that the National Nuclear Security Administration had certified the completion of the National Ignition Facility. Eighteen months later, the Project Management Institute named it the 2010 Project of the Year. ●

This story has been provided by the Department of Energy's Office of Engineering and Construction Management.



The interior of the NIF target chamber. The service module carrying technicians can be seen on the left. The target positioner, which holds the target, is on the right.

Photo Credit: Lawrence Livermore National Laboratory

The Knowledge Notebook

The Limits of Knowledge

BY LAURENCE PRUSAK

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

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

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

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

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

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

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

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

- **Look to all sources of potential help.** Knowledge comes in many flavors and varieties. Make sure your sample size is adequate to your needs.
- **Think in terms of past and future time.** Nothing happens without background or potential consequences. Encourage others to do the same.
- **Pay attention to context.** No project or situation exists in isolation, and understanding the context of your work can lead to a wiser choice than a narrow focus on a problem to be solved.
- **Consult your values as well as your knowledge** when making decisions. ●

NO PROJECT OR SITUATION EXISTS IN ISOLATION, AND UNDERSTANDING THE CONTEXT OF YOUR WORK CAN LEAD TO A WISER CHOICE THAN A NARROW FOCUS ON A PROBLEM TO BE SOLVED.

ASK interactive

NASA in the News

NASA's Fermi Gamma-ray Space Telescope has unveiled a previously unseen structure centered in the Milky Way. Two gamma-ray-emitting bubbles that extend 25,000 light-years north and south of the galactic center were discovered after processing publicly available data from Fermi's large area telescope. The bubble emissions are more energetic than the gamma-ray fog seen elsewhere in our galaxy, and these emissions, as well as the structure's shape, suggest it was formed as a result of a large and rapid energy release—the source of which remains a mystery. Scientists are conducting more analyses to better understand how the never-before-seen structure was formed. Read more about Fermi and this discovery at www.nasa.gov/mission_pages/GLAST/main/index.html.

NASA Tweetups

Get a behind-the-scenes look at NASA with Tweetups. A Tweetup is an informal meeting of people who use the social messaging medium Twitter. NASA Tweetups provide @NASA followers with the opportunity to visit NASA facilities and speak with scientists, engineers, astronauts, and managers. The events range from two hours to two days in length and include a "meet and greet" session to allow participants to mingle with fellow tweeps and the people behind NASA's Twitter feeds. Registration for upcoming NASA Tweetups is announced at www.nasa.gov/connect/tweetup/index.html, @NASA, and @NASATweetup.

Web of Knowledge

In 2010 NASA set a new course for human spaceflight, helped rewrite science textbooks, redefined our understanding of Earth's nearest celestial neighbor, put the finishing touches on one of the world's greatest engineering marvels, made major contributions to life on Earth, and turned its sights toward the next era of exploration. Read more about these accomplishments at NASA's Year in Review: www.nasa.gov/externalflash/YIR10/index.html.

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