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Photo Credit: NASA/Sean Smith

ON THE COVER

A mobility chassis prototype is demonstrated in 2008 as part of a series of tests of lunar surface concepts. This is one prototype of many that are field tested as part of NASAs ongoing Desert Research and Technology Studies, or Desert RATS. The Desert RATS tests offer a NASA-led team of engineers, astronauts, and scientists from across the country an opportunity to come together to conduct technology development research for future planetary exploration missions.

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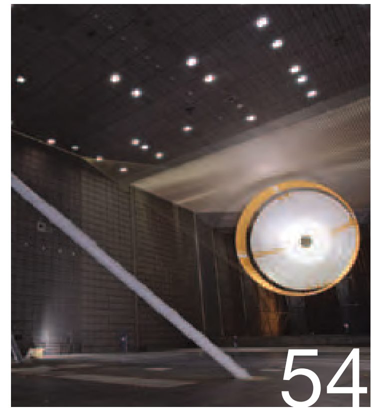

ask

Issue No. 42*

* The ultimate answer to the ultimate question of life, the universe, and everything.

ACADEMY OF PROGRAM / PROJECT & ENGINEERING LEADERSHIP
APPEL

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

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

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In This Issue

In his article on a technique devised to help pilots and others deal with emergencies ("Crew Resource Management Improves Decision Making"), Jerry Mulenburg sums up the core actions of crew resource management as "see it, say it, fix it." That's a good way for the members of any project team to approach problems. Identifying problems (through testing or merely keeping your eyes and your mind open), communicating them to other team members so your collective knowledge can be applied to solving them, and acting on that knowledge pretty much describes how teams should operate.

So it's not surprising that Scott Cameron's "Managing in an Unsettled Environment" makes roughly those same points. He recommends working to understand the changes on the horizon clearly and thoroughly, communicating their implications, and taking action to ensure that you have the capabilities needed to work successfully in a new environment.

Both Mulenburg and Cameron emphasize respect in communication and joint action. It's obvious why. Good communication is impossible without respect (for others' expertise and good will). And, in organizations like NASA, where people in effect volunteer their best efforts to projects (see Keith Woodman's "Volunteers Wanted"), respect is essential to commitment and good teamwork. In the interview, Rüdiger Süß describes learning how to win the cooperation of others at the German Aerospace Center by respecting their needs and fears. Respect also underlies the kind of shared meaning-making Laurence Prusak describes in the "Knowledge Notebook."

Erik Nilsen and Trisha Jansma's "Galileo's Rocky Road to Jupiter" is a vivid study of "see it, say it, fix it" and mutual respect in action. Galileo's recovery from a series of setbacks, including a potentially mission-ending problem, is a tribute to teamwork, ingenuity, and determination. Also interesting is the fact that the four-year journey to Jupiter gave the Galileo team the time they needed to respond to the challenges.

There are, of course, various ways to "see"—that is, to understand problems and situations clearly. "Solar Dynamics Observatory Lessons Affirmed" and "Mars Science Lab: The Challenge of Complexity" both insist on the need for rigorous testing to "see" potential problems in spacecraft under development. And field testing prototypes of new technologies ("Rapid Prototyping and Analog Testing for Human Space Exploration") lets engineers quickly see whether a proposed approach is likely to work. That is a form of seeing by doing, which is very much the subject of Don Heyer's "Reflecting on HOPE." Heyer was project manager of a project designed to give NASA early-career hires the hands-on experience of taking a mission from concept to completion, an experience that taught them things they could not have learned in other ways.

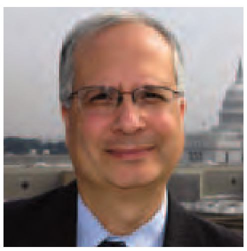
Configuration management, skillfully carried out, gives current and future project teams a way to see a project through documents that accurately chart its course. (See Debbie Dusterwald's "Configuration Management: A Record and a Resource.") The NASA EDGE vodcast team helps us see NASA work by asking the right questions. Finally, we can literally see the history of the space program by looking at the outstanding photographs of talented and thoughtful NASA photographers ("Permission to Stare").

Don Cohen
Managing Editor

From the Academy Director

2011 Trends in Project Management

BY ED HOFFMAN



Throughout the past year, I have seen organizations, leaders, and managers wrestle with challenges brought on by economic, political, technological, and organizational change. The complexity of the global economy continued to present surprises. Political powers shifted. E-books outsold paperbacks for the first time in history. Organizations like British Petroleum and Johnson & Johnson faced greater public scrutiny and accountability than ever before. All this leads me to believe that organizations with open and global mind-sets will gain the inside track in the project world. Three trends in particular are shaping the future of project management, requiring a more global mind-set from practitioners.

Transparency

Projects exist in a more transparent, networked environment than in the past. President Obama's open government directive initiated a shift toward government transparency. Thirty-nine government agencies, including NASA, have developed open government initiatives. World Wide Web pioneer Tim Berners-Lee highlighted the work of Data.gov, introducing the possibilities (and controversy) that open data and ideas can offer, from new uses of satellite data to provide relief to earthquake victims in Haiti to WikiLeaks. Managers and leaders are expected to be open about their work. Information and decisions are no longer easily hidden. The jig is up—the public knows where to find the wizard behind the curtain.

Frugal Innovation

The growing demand for breakthrough technologies in engineering and management has led to the emergence of innovation grounded by cost. Associated with products like the Nokia 1100 and the Tata Nano, this innovation paradigm is spreading to aerospace projects like the Lunar Crater Observation and Sensing Satellite, CubeSats, and Johnson Space Center's Project M to put a humanoid robot on the moon. The next big thing will come from incremental changes punctuated by revolutionary leaps. It is a continuous process. *Homo sapiens* didn't walk out of the primordial soup.

Smart Networks

Today's projects are about collaboration, alliances, and teaming—you're only as good as your network. In 1965, the world's first communications satellite introduced the "frightening prospect" of man being able to communicate anything anywhere in the world. Now wikis, Facebook, Twitter, and blog-like platforms are rapidly spreading and transforming the way we connect. Organizations need to harness the power of these platforms' multiple ways to transfer knowledge and information. Cultivating "smart networks" that provide broad streams of information, a global perspective, and a sophisticated ability to manage information overload is integral to success.

Tomorrow's project world will be driven by an integrated and nearly invisible game-like framework that will enhance virtual work, connect distributed teams, and encourage collaborative discovery. This framework will be a unifying medium for the next generation of young professionals, almost all of whom will work intensively with international partners.

We live in a society that expects to know about and believe in the work that we are doing—and we owe them nothing less. ●

GALILEO'S ROCKY ROAD TO JUPITER

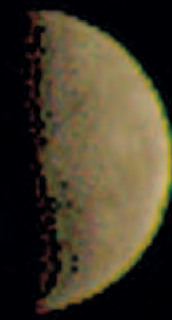
BY ERIK N. NILSEN AND P. A. "TRISHA" JANSMA

On October 18, 1989, the Galileo spacecraft lifted free from the shuttle cargo bay. This step was the culmination of a development effort spanning eleven years and six major mission redesigns, and the first step on a long, rocky road to Jupiter. Galileo's ultimate success is a tribute to the creativity, hard work, and determination of the many individuals and groups who wrestled with problems that easily could have doomed the mission.

During STS 34, the Galileo spacecraft atop the inertial upper stage is deployed from Atlantis *s payload bay.*

Photo Credit: NASA

THE EXTENDED JOURNEY REQUIRED DESIGN MODIFICATIONS, INCLUDING ADDING SEVERAL SUN SHIELDS TO PROTECT THE SPACECRAFT WHEN FLYING TO VENUS FOR ITS FIRST GRAVITY ASSIST.



Galileo was originally conceived in the late 1960s and received its first development funding in 1978. Planned for launch in 1982, its fate was inextricably intertwined with that of the Space Shuttle, then under development. Galileo was to be one of the first deep-space missions to launch on the shuttle; early slips in the availability and capability of that vehicle directly affected Galileo. They also influenced the design.

Early on, the decision was made to use new technologies previously used only in Earth-orbiting spacecraft. Dual-spin spacecraft design was new to interplanetary craft and new to the Jet Propulsion Laboratory (JPL). The dual-spin design has one section of the spacecraft fixed while the other part spins. Remote-sensing instruments (which desire a stable platform for imaging) could be mounted on the fixed section, and the fields and particles instruments (which desire a complete view of space in all directions) could be mounted on the rotating section. This was an innovative way to meet science requirements, but it presented many design hurdles.

The second decision was to use a deployable high-gain antenna (HGA). Constraints on the size of an antenna that could fit within the shuttle cargo bay and a desire to reduce mass—a constant Galileo design issue—led to this choice. But both decisions created difficulties on the way to Jupiter. By far the most serious was the failure of the HGA to deploy.

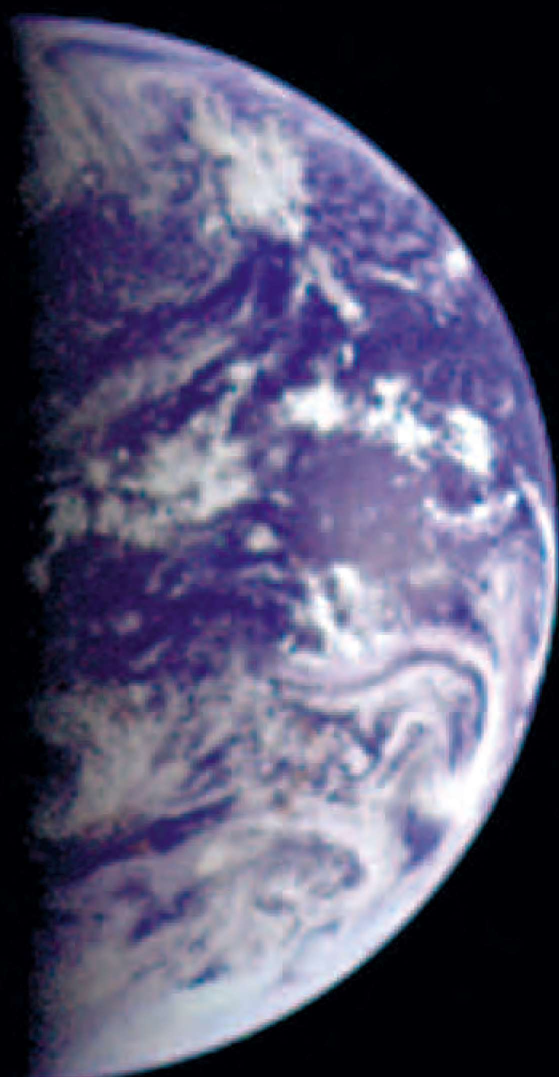
Political pressures dogged the initially underfunded project as costs began to rise. Slips in capability and delivery of the planned shuttle necessitated several major redesigns, including options to move Galileo to an expendable launch vehicle, and dual launch options, with the spacecraft and the Jupiter probe (an integral part of the mission concept) launched on separate vehicles. Launch slipped from 1982 to 1983, then 1985, and finally to 1986 before the shuttle was successfully completed and flown, and the Galileo design stabilized. The spacecraft and the launch team were at the cape when the *Challenger* accident occurred on January 28, 1986.

Galileo was shipped back to JPL for storage and continued testing. Ultimately, the spacecraft would make three transcontinental trips, which may have contributed to the antenna failure. While awaiting the shuttle's fate, the Galileo team investigated alternatives. As the *Challenger* investigation drew to a close and recommended changes were made to shuttle operations, it became clear that Galileo was at a crisis point. To get the energy for a direct trajectory to Jupiter, Galileo planned to use the Centaur liquid-propellant upper stage to boost it on its way after exiting the shuttle. After the *Challenger* accident, the decision was made to prohibit liquid-propellant upper stages, forcing Galileo to use the much-less-capable inertial upper stage, which used solid propellant. This booster was not capable of sending the spacecraft on a direct course to Jupiter, but by the clever use of gravity assists from Venus and from Earth, a viable mission could be flown, with a much longer flight time to Jupiter.

THE SCIENCE TEAM HAD TO WORK LONG AND HARD TO PRIORITIZE SCIENCE GOALS, DEVELOP NEW SCIENCE PLANS, AND, IN SOME CASES, PLAN UPDATES TO ONBOARD SOFTWARE IN THE INSTRUMENTS TO INCREASE DATA EFFICIENCY.

The extended journey required design modifications, including adding several sun shields to protect the spacecraft when flying to Venus for its first gravity assist. Operational changes were needed also to ensure the systems would survive. One was to delay the deployment of the HGA until the spacecraft was past the first Earth flyby.

The HGA was made of a metalized mesh attached to a set of ribs, and looked very much like an inverted umbrella. The ribs were held to a central tower by a series of pins and retaining



Eight days after its final encounter with Earth, the Galileo spacecraft looked back and captured this remarkable view of Earth and the moon.

Photo Credit: NASA

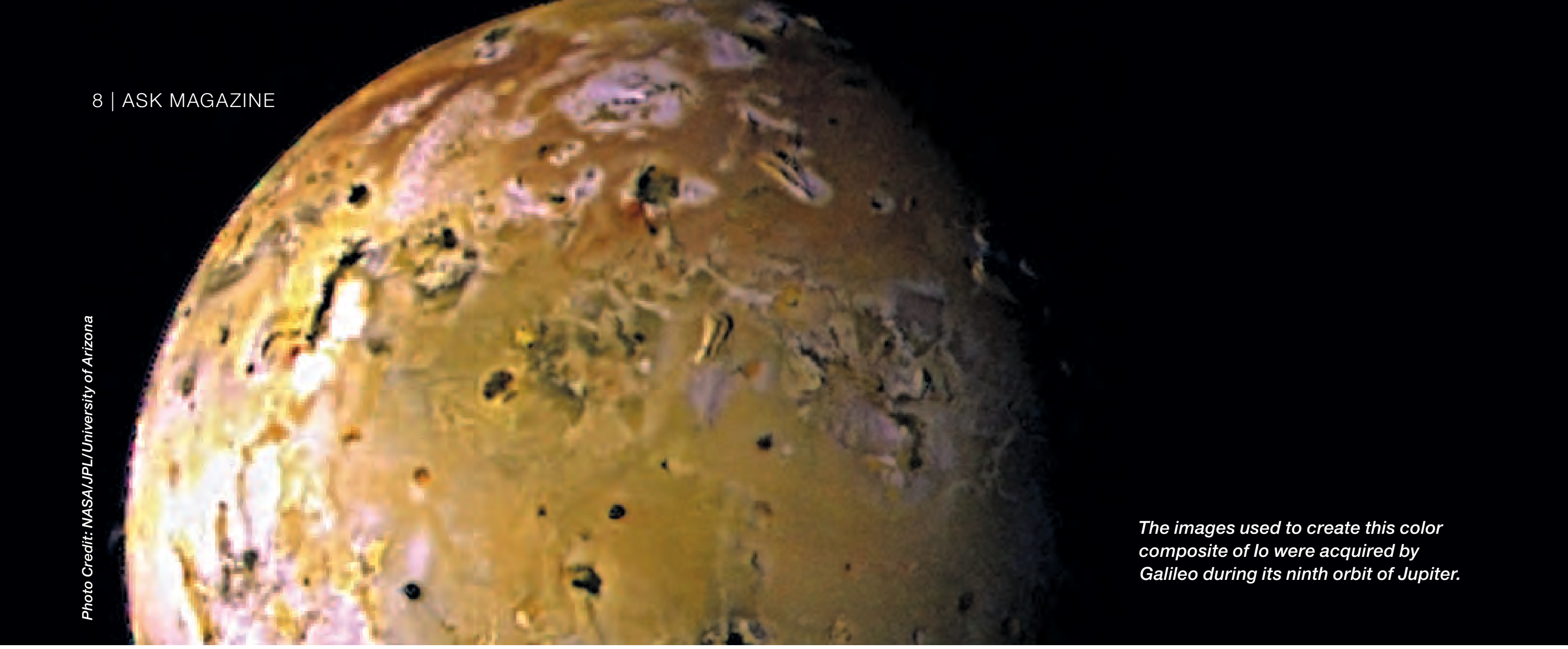


Photo Credit: NASA/JPL/University of Arizona

The images used to create this color composite of Io were acquired by Galileo during its ninth orbit of Jupiter.

rods. Shortly after launch, the retaining rods were released, but the antenna was held in a closed configuration, protected under the sun shield when the spacecraft was within 1.0 astronomical unit of the sun—the distance from Earth to the sun.

During the first two and a half years of the mission, the operations team communicated with the spacecraft via the first low-gain antenna (LGA), and a second LGA added specifically for communications during the Earth-to-Venus-to-Earth leg of the trajectory. On April 11, 1991, shortly after the first Earth flyby, the operations team at JPL commanded the HGA to open. After twenty minutes of anxiously waiting for the fully deployed signal, the project team realized that something terribly wrong had occurred, and the HGA mission was in jeopardy. An investigation team was quickly organized to determine the state of the antenna and find a way to rectify the problem.

Over the next two years, numerous attempts were made to further deploy the antenna. At the same time, the project commissioned a separate, multidisciplinary study team to investigate ways to continue the mission without the HGA. Radical alternatives such as launching a relay satellite were quickly discarded due to time and budget constraints, so the team concentrated on alternatives using the LGA to support Jovian orbital operations. The project's worst fears were realized. All efforts to fully deploy the antenna were unsuccessful. The HGA was virtually useless.

Emergency Redesign

To support operations using the LGA, we needed to radically redesign the telecommunications link architecture. Without any modifications, the LGA would only support 10 bits per second (bps) at Jupiter, less than one-ten-thousandth of the 134 kilobits per second (Kbps) planned. The task of the team was to recover as much functionality as possible, given the capabilities of the communications link. Major modifications to the spacecraft hardware to boost transmit power were not possible, so much of the effort was focused on increasing the receiving capability on Earth and developing a much more efficient data and telecommunications architecture.

Using advanced arraying at the Deep Space Network complexes, the receive aperture available (and thus the data rate) could be increased by a factor of 2.5, and additional changes to the receivers and the telecommunications link parameters increased capability significantly. These changes increased the data downlink rate from 10 bps to approximately 300 bps. More efficient downlink encoding and onboard data compression further increased the effective data rate. Together these efforts could increase the information downlink to approximately 4.5 Kbps, more than four hundred times the initial 10 bps.

THE MOST SIGNIFICANT RESOURCE THAT THE GALILEO TEAM HAD WAS TIME: APPROXIMATELY FOUR YEARS BETWEEN THE TIME THE HGA ANOMALY OCCURRED AND THE SPACECRAFT'S ARRIVAL AT JUPITER.

But even this improvement was a huge decrease in the expected data-return rate. The science team had to work long and hard to prioritize science goals, develop new science plans, and, in some cases, plan updates to onboard software in the instruments to increase data efficiency. Clear, frank, and frequent communication between the science team and the development team was required to balance science desires with the capabilities of the system.

The most significant resource the Galileo team had was time: approximately four years between the time the HGA anomaly occurred and the spacecraft's arrival at Jupiter. Having that span of time was critical to the redevelopment of the onboard software to

THE SUPPORT OF THE NASA MANAGEMENT THAT MADE FUNDING AND RESOURCES AVAILABLE TO THE PROJECT TO DEAL WITH THE ANOMALY WAS CRITICAL, AS WERE THE ENORMOUS CONTRIBUTIONS OF THE TECHNICAL COMMUNITY IN UNDERSTANDING THE SYSTEM CAPABILITIES AND DESIGN OPTIONS.

do the required data processing and data compression. This was also a time when some other preflight decisions became crucial.

As a backup to the real-time downlink, an onboard tape recorder (the Data Memory Subsystem, or DMS) had been designed to record data during certain high-activity periods. Since these periods were few, only a single DMS had been included in what was largely a dual, redundant avionics system. In addition, during the delay due to the *Challenger* accident, the project team investigated a potential solid-state memory failure and decided to double the onboard memory. Both of those resources became critical to the new orbital operations, to buffer high-rate data during the Jovian encounters, and trickle it to Earth over the remainder of the orbit.

Over the next four years, two updates to the onboard software were prepared and extensively tested. The first was a minor update to the software to support the critical probe relay and Jupiter orbit-insertion sequences. The project team wanted to make only those changes necessary to buffer the critical probe data to allow downlink over the LGA. The second update would completely replace the onboard software to implement the changes to the data system.

One More Glitch

The fates were not through with Galileo. On October 11, 1995, as the spacecraft was approaching Jupiter, the mission controllers commanded the Solid-State Imager to record an image of the planet and store it on the DMS. At the conclusion of this activity, the tape recorder was to be rewound and the data played back onto the downlink. When commanded, the DMS began to rewind, but failed to stop at the end of the tape. All indications were that the DMS was broken and would not be available for orbital operations.

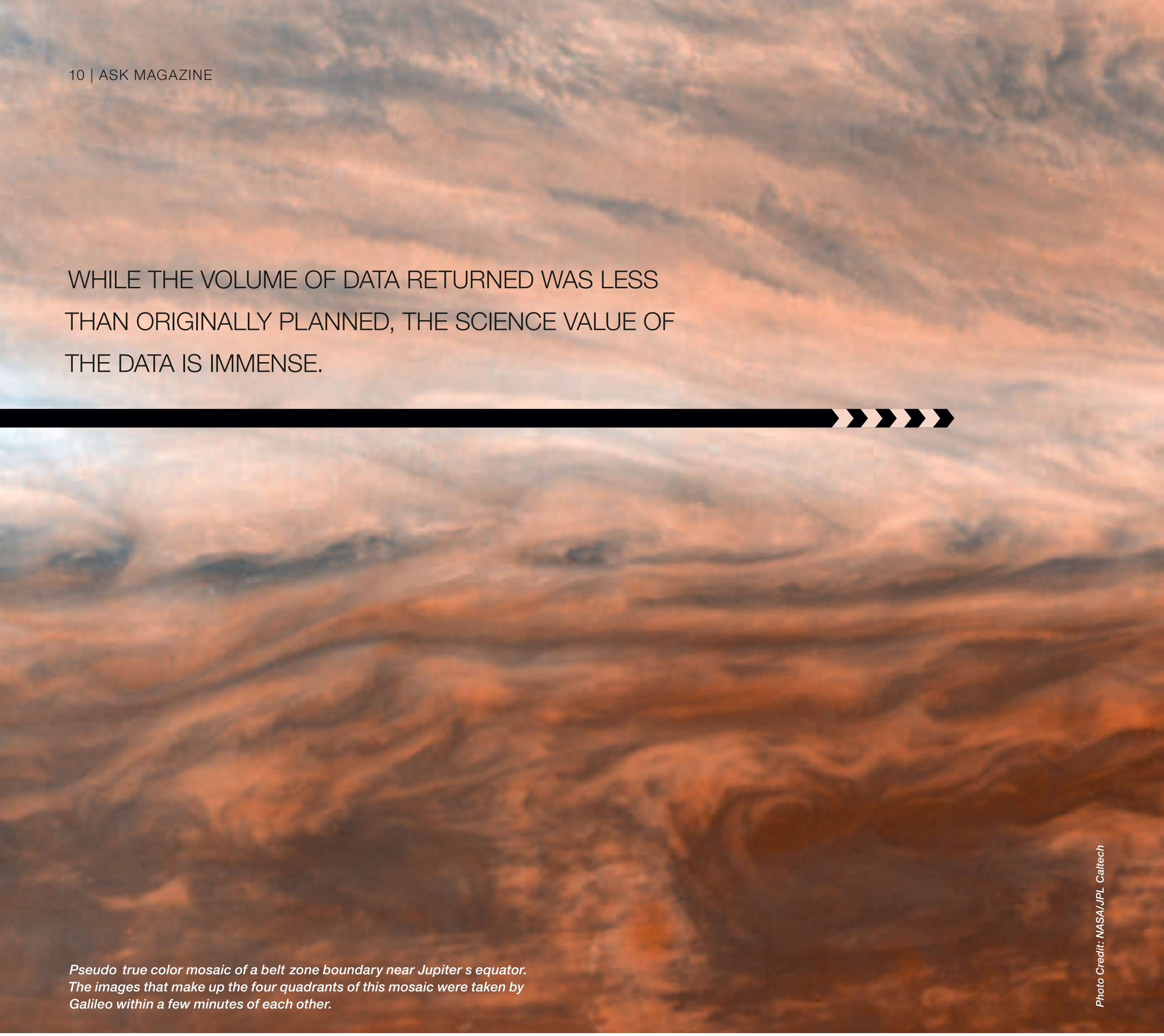
The project team immediately began an intensive effort to determine the actual state of the DMS, while initiating a concurrent activity to redesign the LGA orbital-operations software to work without this critical equipment. After two weeks of effort, the flight engineers were able to determine that the DMS was not broken, but that the tape itself had stuck to the erase head and did not rewind. The tape capstan was turning without tape movement, resulting in burnishing a spot on the tape. Subsequent efforts moved the tape forward, and the team decided it was prudent not to run the tape across the damaged area ever again. The burnished area was buried under several wraps of tape on the reel. The Phase 2 flight software was modified to use the tape recorder in a new way, using recorded markers to indicate the end of tape (rather than the tape markers), ensuring the damaged area would remain buried.

After Jupiter orbit insertion, and successful reception of the critical probe data, the flight team carried out the first complete reload of flight software ever performed on a deep-space mission. Loading the Phase 2 flight software was a major operational undertaking, requiring several weeks. After all the software was loaded, the flight team waited breathlessly as the command was transmitted to turn on the new capabilities. After a brief blackout while the ground system synchronized with the new telemetry stream, data started flowing, and the new system became operational. The team was tremendously relieved, and as the science data flowed, they all celebrated the accomplishment.

Science Success

The ability of the Galileo project to face and overcome a debilitating failure in flight was a testament to the creativity and determination of the NASA community. The support of the NASA management that made funding and resources available to the project to deal with the anomaly was critical, as were the enormous contributions of the technical community in understanding the system capabilities and design options. The contributions of the Deep Space Network and the telecommunications community in advancing the state of the art in antenna arraying, low-noise receiver technology, and advanced modulation schemes provided hope that a solution could be found. And the dedication of the Galileo flight team and the software development and test crew proved that the loss of the HGA could be overcome. The HGA anomaly workarounds were

WHILE THE VOLUME OF DATA RETURNED WAS LESS THAN ORIGINALLY PLANNED, THE SCIENCE VALUE OF THE DATA IS IMMENSE.



Pseudo true color mosaic of a belt zone boundary near Jupiter s equator. The images that make up the four quadrants of this mosaic were taken by Galileo within a few minutes of each other.

Photo Credit: NASA/JPL Caltech

truly a team effort involving a system approach that included science, flight, ground, hardware, and software.

In the end, the science return was the clearest testament to Galileo's success. While the volume of data returned was less than originally planned, the science value of the data is immense. The textbooks on Jupiter and its moons have been rewritten, and intriguing new questions have surfaced. One is whether Europa could harbor an immense ocean under its icy surface. It will be up to future missions to build upon the legacy of Galileo and find out. ●

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

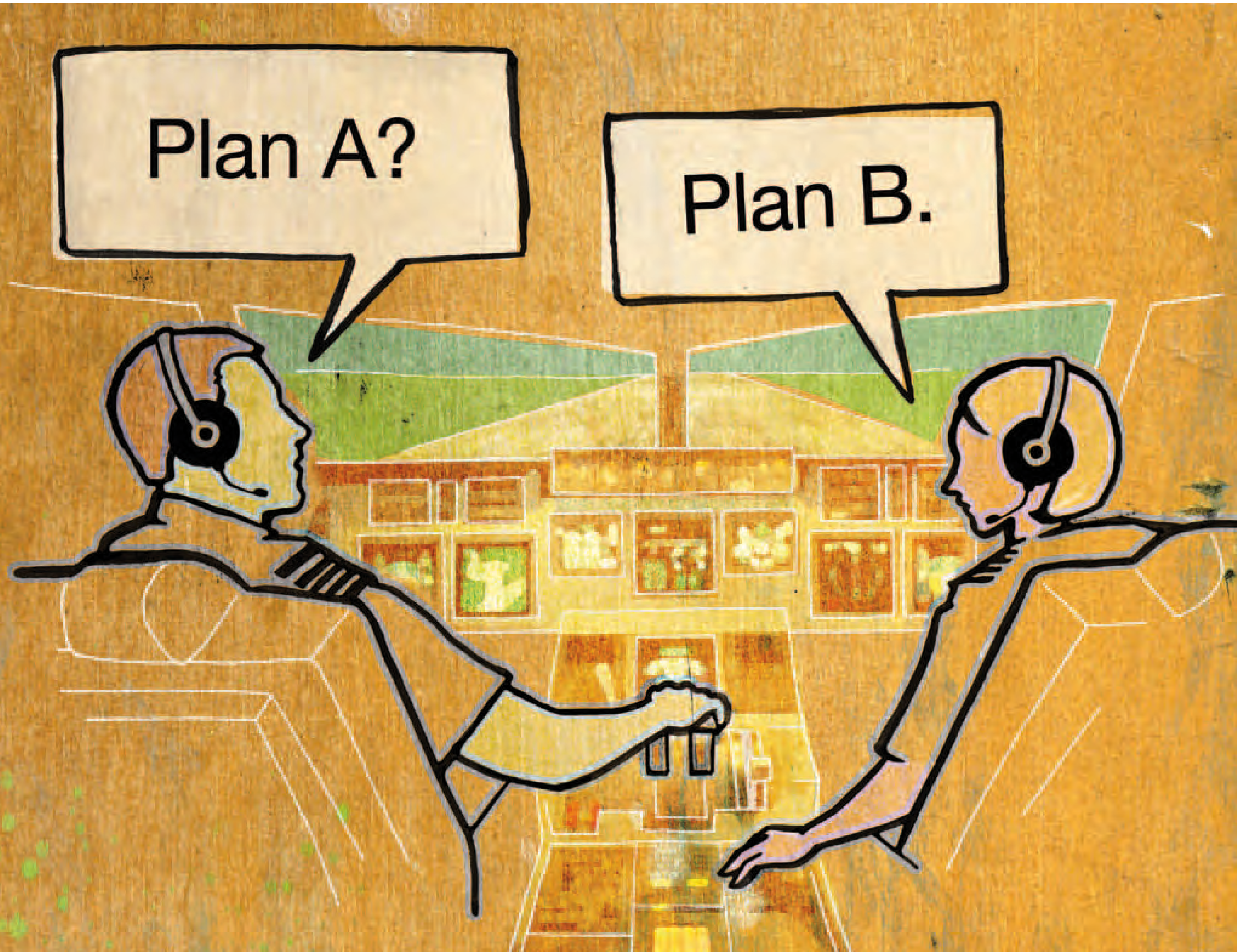
ERIK N. NILSEN joined the Galileo flight team shortly after launch and was integrally involved in the HGA anomaly investigation team and the LGA mission development team. He is currently the Mars Sample Return Advanced Concepts manager, working on the campaign to return surface samples from Mars to Earth for study. He is a registered professional engineer in the state of California and has more than twenty years of experience in space mission analysis and design.

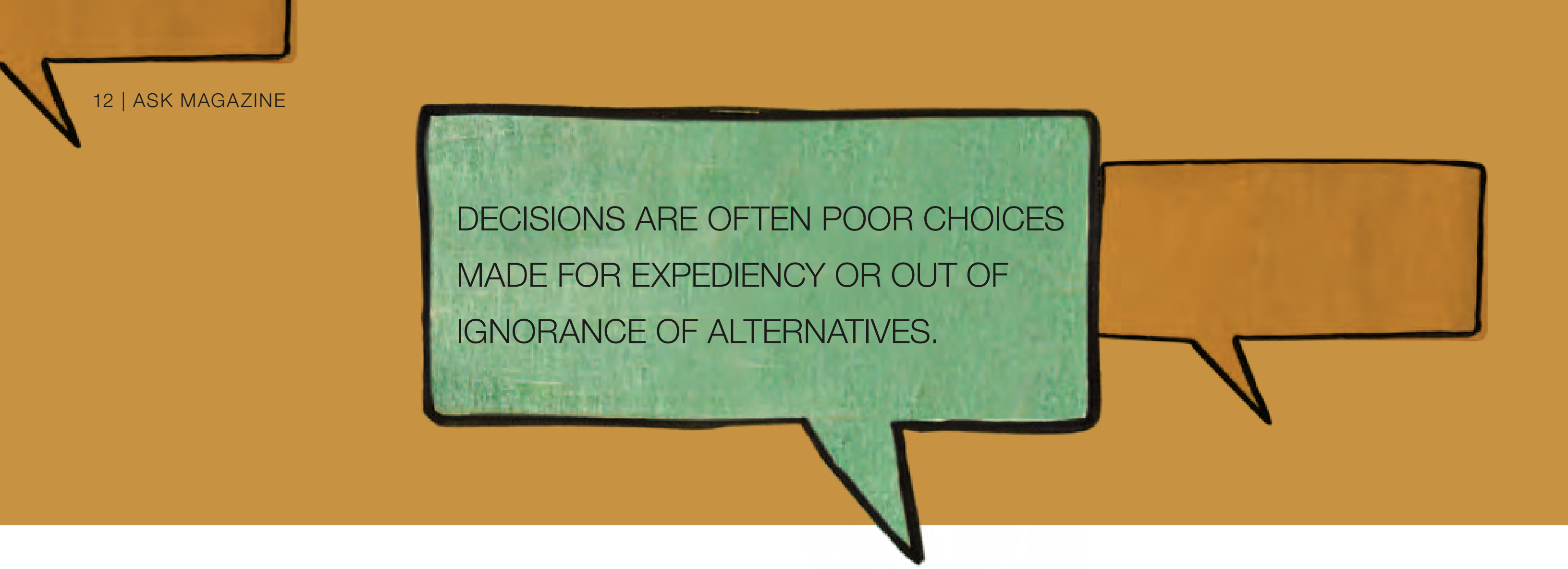
P. A. "TRISHA" JANSMA is the lead for the deployment subgroup for the NASA Systems Engineering Working Group for the Office of the Chief Engineer. She also supports training and deployment for the Systems Engineering Advancement Project. With more than thirty years at the Jet Propulsion Laboratory in both line and project management positions, she has a broad background in systems and software engineering in both engineering and scientific environments. She received a NASA Exceptional Service Medal for her work as the implementation manager for the Planetary Data System Version 1.

Crew Resource Management Improves Decision Making

BY JERRY MULENBURG

People make decisions, and people are fallible. So how can we make the best decisions in a particular situation given the information available? Crew resource management techniques designed for aircraft emergencies can help.





Some think of decision making as a logical, well-defined process and teach it that way in management courses and elsewhere. The evidence of practical experience shows, however, that decision making is seldom a precise, rational activity. In reality, it is often plagued with bias, misconception, and poor judgment. Decisions are often poor choices made for expediency or out of ignorance of alternatives. In my own experience, the person at the top in the hierarchy in most organizations is expected, or assumed, to be in the best position to make the important decisions. Having served in several different NASA Ames Research Center divisions, and as the head of two of them, I experienced firsthand the fallacy of this expectation.

As managers, we get in our own way sometimes because we don't think enough and sometimes because we think too much. Thinking hard about the decision is not enough; we need to think about it in the right way. Rather than make us better decision makers, a lot of experience in an area can sometimes blind us to alternatives because of our investment in what we've done before. In his book, *How We Decide*, Jonah Lehrer describes the need to embrace uncertainty and new ideas in decision making: "There is no secret recipe for decision making … only … commitment to avoiding those errors that can be avoided. There's not always time to engage in a lengthy cognitive debate. But whenever possible, it's essential to extend the decision-making process [to] entertain competing hypotheses [and] continually remind yourself of what you don't know."[1] Lehrer also warns that we are often most ignorant of what is closest to us. These ideas have special relevance to high-risk and other complex decision-making situations.

For instance, what if you were piloting an aircraft full of passengers and suddenly ran out of fuel? How would you go about making the decision about what to do first, next, and, if none of these efforts solved the problem you're facing, then what? This type of situation is so out of the ordinary, fortunately, that few people have experienced it, but such emergencies can and do happen. Thanks to a program called crew resource management, or CRM, decision makers can learn how to handle them.

Crew Resource Management

The best example of CRM in use may be the safe landing on January 15, 2009, of U.S. Airways flight 1549 by Captain Chesley (Sully) Sullenberger in New York's Hudson River. Hitting a flock of geese on takeoff from New York's LaGuardia Airport completely shut down both engines on his Airbus A320. With more than 19,000 hours of flight time, including flying gliders, Captain Sullenberger's experience and training helped prepare him for the once-in-a-lifetime decision he faced. In less than three minutes, this is what Captain Sullenberger did:

- Requested permission to return to LaGuardia—approved *(normal procedure)*
- Performed engine restart procedure—engines didn't restart *(multiple attempts would have resulted in the same outcome and time was short)*
- Asked for alternate airport-landing location in New Jersey—granted *(wanted to avoid densely populated area near LaGuardia)*
- Made final decision to land in the Hudson River—successful in saving all onboard *(copilot provided airspeed and altitude readings for pilot to glide aircraft in)*

As Sully put it: "I was sure I could do it. I think, in many ways, as it turned out, my entire life up to that moment had been a preparation to handle that particular moment."[2] During a talk about his experiences, Captain Sullenberger mentioned that he owed a lot to the CRM training he went through.

The CRM training Sully refers to is a program Ames developed in the 1970s in response to a number of flawed in-flight decisions that resulted in aircraft crashes. CRM is now widely used in military and civilian aviation throughout the world. So what is CRM, and how can its lessons about decision making apply to complex project situations?

The driving idea behind CRM is to train aircrews in communication skills to maximize coordination and minimize the chance for errors. According to AirlineSafety.com, CRM is "… one of the most valuable safety tools we have today. It has contributed significantly toward the prevention of 'pilot error' accidents; it has

DESPITE ALL THE SEASONED VETERANS WORKING ON A PROJECT (AND SOMETIMES BECAUSE THEY TRUST THEIR EXPERTISE TOO MUCH), MISTAKES ARE MADE, OMISSIONS OCCUR, AND CLEAR THINKING IS OFTEN DISPLACED BY A FALSE SENSE OF KNOWING WHAT IS GOING ON.

saved airplanes and lives."[3] The basic tenets of CRM are to avoid, trap, or mitigate the consequences of errors resulting from poor decisions. To do this, according to CRM, it is essential to

1. recognize that a problem exists,
2. define what the problem is,
3. identify probable solutions, and
4. take appropriate action to implement a solution.

CRM techniques have been applied to other high-risk situations, including the high-stress environment of the operating room. Poor decisions are not simply due to surgeon error but also to the processes and systems that allow errors to remain undetected. CRM in the operating room has shown positive results due to improved communication, teamwork, error reduction, and better training of the whole team, reducing avoidable mortality rates.

One CRM trainer describes the CRM process as "see it, say it, fix it." This is a good approach to problems on complex projects, including NASA projects.

Applying CRM at NASA

Flawed decision making was one of the root causes of the loss of the *Challenger* and *Columbia* Space Shuttles and their crews. It also contributed to the loss of the Mars Climate Orbiter, Mars Polar Lander, and problems on other projects. Despite all the seasoned veterans working on a project (and sometimes because they trust their expertise too much), mistakes are made, omissions occur, and clear thinking is often displaced by a false sense of knowing what is going on. For most complex projects, the decisions are not as monumental as for in-flight emergencies or surgery. But the mistakes matter and sometimes lead to the expensive and disappointing loss of mission or, tragically, loss of crew.

NASA would benefit greatly from applying CRM-like techniques to its complex projects. One of the things CRM does is integrate the knowledge and experience of all team members to arrive at a wise and robust decision. The acronym TRIM, which stands for team resource integration management, clearly describes the process. TRIM embraces the three CRM tenets of avoid, trap, or mitigate the consequences of decision-making errors, and helps ensure that the four CRM steps—recognizing that a problem exists, defining the problem, identifying probable solutions, and taking appropriate action—will be carried out effectively. "Integration" describes the need to integrate the whole team's knowledge and skill into a final solution. TRIM also stands for terms that emphasize communication:

- **T**alk with each other
- **R**espect each other
- **I**nitiate action
- **M**onitor results

CRM is already a mature discipline with clear benefits in high-risk situations that can translate to complex projects. Using its successful training methods, CRM seems ideal for application to project management decision making. I believe it is important that the project management community recognize the benefits gained by the application of the CRM/TRIM technique to reduce decision errors and the consequences of those errors. CRM is a systematic way of helping us use our collective cognitive skills to gain and maintain situational awareness and develop our interpersonal and behavioral skills to establish relationships and communicate with everyone involved, to achieve accurate and robust decisions. *ASK* readers responsible for managing complex projects can take the initiative to begin implementing the CRM/TRIM processes and provide feedback on their results. ●

JERRY MULENBURG retired from NASA in 2006 with more than twenty-five years of distinguished service. He held positions as assistant division chief for Life Sciences, and division chief of the Ames Aeronautics and Space Flight Hardware Development Division and of Wind Tunnel Operations. A former air force officer, he is a Project Management Institute Project Management Professional and a trained MBTI administrator, and he currently teaches project management at the university graduate and undergraduate levels. He also provides training in project management as an independent consultant.

1. Jonah Lehrer, *How We Decide* (New York: Houghton Mifflin, 2009).
2. Alan Levin, "Pilot: 'I was sure I could' land in river," *USA Today*, February 9, 2009.
3. Robert J. Boser, "CRM: The Missing Link," November 1997, www.airlinesafety.com/editorials/editorial3.htm.

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BY DOUGLAS CRAIG

Space Exploration Vehicle docking with Cabin A for a simulated rescue mission. This simulated mission was part of the 2009 Desert RATS held at Black Point Lava Flow in Arizona.

Humanity's dream of exploring the wonders of space—to look for life on other planets and to better understand our place in the universe—has not diminished over the years. But advances in human space exploration beyond low-Earth orbit have been slow to emerge.

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Photo Credit: NASA

Photo Credit: NASA/Bill Todd

NASA Aquanaut crew performing demonstration of incapacitated crewman recovery on the side hatch of the SEV during the NEEMO 14 mission.

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NASA's new human space-exploration enterprise requires a strategy that will enable us to explore new worlds, develop innovative technologies, and foster burgeoning industries, all while increasing our understanding of Earth and our solar system. It will allow us to work on objects in Earth's orbit such as the International Space Station (ISS) and satellites while also exploring objects such as near-Earth asteroids, the moon, Mars, and Mars's moons. But traveling to and living on these destinations will require us to develop cutting-edge technologies and new ways to work in space to help us survive and thrive in these forbidding, faraway places.

As a first step, NASA has implemented two separate but integrated activities: rapid prototyping and using analog test environments. Rapid prototyping creates innovative concepts for exploration by rapidly developing low-cost but functional space-system prototypes using small, dedicated teams drawn from NASA's ten centers. These prototypes are incorporated into terrestrial, analog mission tests that enable an inexpensive, integrated validation of mission concepts in a representative environment. These analog missions include going out into the Arizona desert to perform long-distance traverses over lunar- and Mars-like terrain, using the National Oceanic and Atmospheric Administration's (NOAA) underwater *Aquarius* habitat to conduct simulated extravehicular activities under differing levels of gravity, using the Nuytco Research Deepworker submersibles to study microbialites in a remote freshwater lake in Canada for traverse planning and science data collection, and using the volcanic environment of Mauna Kea in Hawaii to test systems that extract oxygen from volcanic rocks.

Rapid Prototyping

Using lessons learned from the Department of Defense and the sub-sea industry's rapid-prototyping activities, NASA created a management environment for the rapid development of several prototypes at very low costs. The philosophy was to establish a series of iterative design-build-test projects, built on the principle that NASA is at its best working with a clear, simple, and understandable vision and a limited amount of time to achieve that vision. The projects focus on producing functional prototypes of increasing fidelity so systems integration issues can be understood early through rigorous design, build, and human in-the-loop testing.

The project teams are multi-center, multidisciplinary groups of capable and motivated individuals working together virtually from their home NASA centers. Several systems were developed using this philosophy, including the Space Exploration Vehicle (previously the Lunar Electric Rover), a habitat demonstration unit, Robonaut 2, a portable communications tower, and an extravehicular activity suit port.

The Space Exploration Vehicle (SEV)

In the past, many people believed the best way to explore the lunar surface would be similar to the Apollo missions: astronauts in space suits using a rover with no enclosed cabin. Others believed a small rover with an enclosed, pressurized cabin that allowed astronauts to function without being in their space suits—but with the ability to quickly put on or take off a space suit—would be more effective. This debate continued for about a year with experts arguing over presentation charts until, at a workshop break, three people came up with a plan to develop a low-cost, low-fidelity version of the rovers needed to test the competing concepts.

Nine months later, the concept vehicle now known as SEV was sent out into the desert to pit its performance against an unpressurized rover—and prove that pressurized rovers were 67 percent more effective than unpressurized rovers while providing an environment better suited for long-duration surface exploration missions.

Key to SEV's success was a high-level set of architecture questions to be addressed and a clear vehicle concept. The project manager also had the flexibility to develop a project structure and choose team members. Because of the tight funding and schedule, this team was kept very small, with members having much more

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Photo Credit: NASA

An astronaut and a geologist don spacesuits to test an unpressurized version of a lunar rover concept that enables them to easily disembark and explore. The test was part of the 2008 Desert RATS held at Black Point Lava Flow in Arizona.

responsibility than on larger NASA hardware-development projects. This empowered the task leaders and required them to be creative in their areas of responsibility, instilling a feeling of greater accountability. They also had more agility since the process for making changes involved much less review and paperwork than typical NASA projects.

The SEV project was able to make important design decisions in a thoughtful but cost- and time-efficient manner, due mainly to the small team and the prototype vehicles not being flight vehicles. Quick decisions in the early stages of development—when mistakes are less expensive and less consequential—gave the project team an understanding of how those decisions interact and how they manifest in hardware.

For example, the initial design of the suit port on the SEV consisted of a manual latching mechanism, on the principle of keeping the design as simple as possible. The test at the Desert Research and Technology Studies (Desert RATS) demonstrated that the mechanism design did not perform well in the environment. These results formed the basis for changing the mechanism from the manual mechanical latch to an electrically powered latch. Learning this early on in the design phase allowed the change to be made with minor cost impact.

As missions to other destinations are studied, the SEV concept has been found to be very advantageous for in-space activities such as satellite servicing and exploration of asteroids. As a result, the SEV now has two variants: one for surface exploration and one for in-space exploration.

Analog Testing

Driving a rover around a center's rock yard isn't enough to reveal the true operations and limitations of a vehicle designed for long traverses. It is important to test the systems in an integrated, operational field mission to ensure relevant test results. These extreme environments greatly enhance our ability to analyze concepts in simulated conditions and enable experiments with long-range and long-duration expeditions. Additionally, members from the NASA mission and ground operations team as well as international space agencies, industry, academia, and other government agencies take part in these tests. Each test refines our understanding of the systems and human capabilities needed to successfully explore beyond Earth's orbit while developing the teamwork and methodologies to ensure that future space systems are efficiently built to accomplish their tasks.

NASA has developed a process for these tests of system and operational concepts on Earth and on ISS, known as analog missions. These missions are carried out in representative environments that have features similar to the missions' target destinations. These can include locations underwater, in the arctic, on terrestrial impact craters, in the desert, on volcanic lava flows, and on ISS. Two of the larger missions are the NASA Extreme Environment Mission Operations (NEEMO) and Desert RATS, or D-RATS.

NEEMO

NEEMO uses the only underwater research facility in the world: NOAA's *Aquarius* habitat. Working in partnership with NOAA, NASA uses the habitat because it provides some of the best conditions for practicing space operations in a harsh environment, giving astronauts a broad knowledge and awareness of risks, issues, and objectives associated with human space-exploration missions. There have also been numerous discoveries made during NEEMO missions on human health, engineering, telemedicine, space operations, education, and public outreach that directly relate to spaceflight needs and are being implemented with each mission.

The NEEMO mission tests are developed with the same rigorous timelines as current shuttle and ISS missions. Upon completion of the latest NEEMO mission, the NEEMO mission commander, Astronaut Chris Hadfield, who has flown on two Space Shuttle flights and was the first Canadian to walk in space, stated that this mission was the closest to a real spaceflight

QUICK DECISIONS IN THE EARLY STAGES OF DEVELOPMENT—WHEN MISTAKES ARE LESS EXPENSIVE AND LESS CONSEQUENTIAL—GAVE THE PROJECT TEAM AN UNDERSTANDING OF HOW THOSE DECISIONS INTERACT AND HOW THEY MANIFEST IN HARDWARE.

mission as you could get on Earth. This rigor allows us to make informed decisions about design changes before project development begins.

For example, the size of side hatches changed significantly between the first and second SEV designs based on testing configurations at the NEEMO and D-RATS analog field tests. The tests were designed to address the human factors group's belief that a larger hatch was needed for mission operations. Results showed that the astronauts had no issues using the smaller hatch size for standard or emergency operations in a low-gravity environment. This enabled the design to be changed to the smaller hatch size, thereby reducing the overall mass of the architecture vehicles that contain a hatch. This, in turn, reduces the cost of the architecture due to less propellant required throughout the architecture phases. The cost of these tests was minor compared with the cost impact if this information was learned during the flight vehicles' development.

D-RATS

D-RATS field tests have become large missions where multiple prototype systems are tested together to evaluate concepts about integrated operations. Using the Black Point Lava Flow and SP Mountain areas in Arizona—because their terrain, geologic features, size, and dusty environment are similar to what would be encountered on surfaces in space—allows NASA to test prototypes under realistic communications and operational scenarios.

The latest D-RATS field test focused on the simultaneous operation of two SEVs, including new ways of performing surface-science operations. Over a fourteen-day period, the astronaut and geologist crew teams performed a science- and exploration-driven course of more than 300 km under different communications and operations scenarios, only egressing to perform simulated extravehicular activities: to collect geological samples or to work in the habitat demonstration unit.

One of the major concerns about the SEV was that its size was relatively small. There were people who did not think it was large enough for a fourteen-day mission; they thought it would be too small for two astronauts to work in the confined space for that period of time due to psychological issues. The ability to perform a fourteen-day mission in an SEV would have a major impact on the mission architecture, reducing the number of heavy-lift launch vehicles needed for a lunar campaign. Upon completion of the test, the crew stated that not only was the size adequate for a fourteen-day mission, but they felt as though it would be suitable for a thirty-day mission. A mission spanning thirty days would allow much more exploration of the lunar surface at a greatly reduced cost.

Inexpensive and Informed Decision Making

Validating rapid prototypes of innovative concepts through analog field tests has greatly advanced NASA's understanding of more effective methods for human space exploration. In addition, the process has provided an example of how future human space-exploration systems can be developed at a greatly reduced cost. Rather than sitting through design reviews and trying to understand how systems would be used, these approaches provide realistic insight into system and operational requirements, guiding design changes early in the development phase and saving the time and cost associated with changing designs and contracts later on. ●

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NASA EDGE:

BY BLAIR ALLEN

PROVIDING AN INSIDE AND OUTSIDE LOOK AT NASA

NASA has many outlets for sharing details about what goes on behind its doors, but none so personable as NASA EDGE, a video podcast (or vodcast) that grew out of an idea to be "different … unscripted and unpredictable." After four years, sixty-two vodcasts, and more than seventeen million downloads, the description still applies.

The show originally came together after Chris Giersch and I, who had both worked in NASA education programs, connected right after I finished my work on the NASA SCI Files, a series of instructional programs comprising broadcast, print, and online elements. He called my manager to talk about a potential new show, so I put together a few ideas—none of which were great. It didn't matter, however, because Chris really was hoping to do a show for NASA that resembled ESPN's *Mike and Mike in the Morning.*

He pitched that idea to me and asked if I thought we could do it. I loved the idea and really liked the format of hosts/characters talking freely and openly about NASA. We had been doing that for years, it just wasn't a "show."

Chris went to NASA Headquarters and got enough money to shoot a pilot. It wasn't a lot of money. In fact, we hosted the show ourselves because we didn't have enough money to pay actors. As it turned out, Debbie Scrivner, former NASA Exploration Systems Mission Directorate communications lead, loved the pilot and funded it with the caveat that Chris, Franklin, and I remain on the show.

Being unscripted has proved vital to the show's success. When the NASA EDGE team interviews NASA engineers and scientists, we rely more on instincts than talking points to explore projects and missions. This helps keep the show conversational, and guests don't have to worry about memorizing scripted responses. We ask questions, get clarification, joke and laugh about things—all of which doesn't happen well with a script.

Photo Credit: NASA EGDE

Co Host Blair Allen at the Kennedy Space Center Space Life Sciences Lab to investigate dust mitigation.

That spirit of creative freedom has been an important part of the development of NASA EDGE. Our formula can be unpredictable and has its own inherent risks—like not coming across as well as you could with scripted material or saying something completely wrong or using the wrong name for something NASA has renamed—but the reward is a growing, loyal audience that seems eager to learn more about NASA in a nontraditional way.

"You have to take risks," Ron Beard, our set therapist, laughingly said. "These guys take risks, and the co-host fails, a lot. But the risks are how we all find out what really works and what doesn't."

Mission Madness was one such risk. We had developed the idea of putting NASA missions (past, present, and future) together in an online, head-to-head, single-elimination tournament based on popular vote. We generated a huge amount of exposure, discussion, and fan participation during the tournament, but we took a lot of valid criticism for allowing multiple voting. There were lots of ways to go with the voting, and we felt like we went with our best option, but in the process we learned so much. If Mission Madness returns, it will look different as a result.

One thing that has continued to work is our combining both an inside and outside look at NASA. To identify with a broad audience, you need to really talk to them—and speak in terms they understand. NASA can come across as too "sciency," which isn't necessarily bad—after all there are tons of engineers and scientists within and outside NASA who want to learn about what their peers are doing. But when non-scientists and non-engineers hear about goings-on at NASA, they come up with very different questions, which need different answers. If I, the goofy co-host, can ask crazy questions, then the audience feels their questions can be asked as well. We all ask scientific and wacky questions, but on the whole, the co-host asks a lot more of the wacky and a lot less of the scientific ones.

Staying in touch with fans is an important part of the show's character. "Facebook and Twitter are huge for us," said Chris, co-creator, project manager, and host of NASA EDGE. "We talk to our fans all the time. Sometimes we take questions, quotes, and status updates and use them on the show. We have even had a few Facebook fans come on the show and report the news."

And when NASA EDGE travels or attends an event, we can usually find a few of our fans willing to meet us for lunch or dinner. People love NASA. They'll even come and hang out with me to find out more about the agency. It is also a great way for us to find out more about them—exactly what our fans like and dislike about the show. We may not do focus groups, but we do listen to our fans.

Listening to the fans is critical, but it is also important to listen to the folks at NASA. We are NASA, after all. We're not out just to get a story. We're here because NASA does really cool stuff, and we want to be part of it.

This became really evident during our recent work with the Desert Research and Technology Studies (D-RATS). What started as a simple interview became a team effort to contribute to the amazing work of the D-RATS team.

"I remember talking to Barbara Romig about opportunities to shoot, and she mentioned that they weren't able to cover everything they wanted to with video," Chris recalled. "Well, we have three cameras. So after the interview, we just started shooting more and more video and gave it to them." This helped us realize that there were more opportunities to serve NASA in addition to giving them exposure through our vodcast; we could actually contribute to their work.

This is now a standard procedure for NASA EDGE, and we actively look for these kinds of opportunities. For example, in January 2011 we were shooting an interview about dust mitigation with Dr. Carlos Calle at Kennedy Space Center. We shot a nice demonstration of their test article, but we only got one angle. Dr. Calle and his team helped set up the demonstration in a different part of the lab to get an even better view and greater magnification. When they saw the footage, even they were blown away: they hadn't seen the view we were able to give them.

We shot several versions and provided them with high-definition video of their test the next day.

Covering the launch of Pad Abort 1—the test of the Orion launch abort system—was another great experience; it was the audience response that really made it. Three entirely different motors developed by three different teams were tested during that launch. As Orion left the pad, the crowd erupted with cheers. During the flight, each of the three motors fired at different times. Loud cheers erupted as each fired successfully. It was great to see, hear, and feel their excitement at the success of their work.

Because we are covering all kinds of missions and aspects of projects, we get to see the big picture that many of the folks working on the details don't. Whenever we shoot a segment, we ask the NASA scientists and engineers if they need anything, and we share our relevant footage with them. This is another way of adding value to the overall production.

Most of the scientists and engineers are happy to work with us because we help them in an area with which they are unfamiliar, and we always try to make it a team effort. It is important for us to have them buy into whatever we do because ultimately we are all working to get the word out.

If a mission has a social media presence, we'll try to incorporate that into what we do. If we can find multiple purposes for our footage or promote a mission via NASA EDGE commercials, we will. We like to shoot promos that aren't simply about NASA but rather include NASA projects, personnel, and context. For example, we shot a promo at Johnson Space Center that featured the Space Exploration Vehicle being pulled over for speeding. We shot a space food promo with the people who actually work in the food lab.

This team building has worked so well that it has branched out into different media. In 2010, NASA EDGE released its first NASA app for the iPhone. It is a Lunar Electric Rover Simulator that allows players to drive the rover around the lunar surface and learn about the requirements of a lunar outpost. As a bonus, NASA EDGE used Barbara Romig and Joe Kosmo (D-RATS test leads) as voice talent. The team is currently working on a NASA EDGE iPad app.

Having fun with what we do really helps keep our team well knit but also makes it easier for us to create new connections with our extended NASA family, something I feel really comes across in our vodcasts. Being unscripted, being open to the outside view, working closely with the scientists and engineers—all of it comes together, not always seamlessly, but in a way that gives NASA EDGE its unique style: casual but respectful, goofy but informed, fast-paced and fun. We have a great time interacting with each other, our NASA colleagues, and our fans, and it shows. It draws in our audience and often gives us—and our viewers—access to things they might never have learned about otherwise.

Engaging our varied audiences in new and exciting ways presents a continual challenge for us, but it's one we approach happily. We learn more about NASA right along with our fans, and we love sharing the great many things NASA does in a way our audiences can understand and enjoy. ●

The Space Exploration Vehicle is pulled over for speeding in a NASA EDGE promo.

Photo Credit: NASA EDGE

Ron Beard during the NASA EDGE live broadcast from Pad Abort 1, launched May 6, 2010, at White Sands Missile Range, N.M.

Photo Credit: NASA EDGE

BLAIR ALLEN once participated in a focus group to determine the public's knowledge of NASA. After demonstrating a profound lack of even the most basic NASA facts, he became the poster boy for NASA outreach. If NASA could inform Blair, the public would bubble over with information on the agency's programs. After six years of intense work, he was approached by NASA EDGE to see if they could successfully educate him. He's been learning ever since.

BY KERRY ELLIS

PERMISSION TO STARE —AND LEARN

Russian security officers walk along the railroad tracks as the Soyuz rocket is rolled out to the launchpad on Sept. 28, 2009, at the Baikonur Cosmodrome in Kazakhstan. “It s just so different, a train pushing a Soyuz out to the pad as opposed to the crawler with shuttle. There s lots of different ways to capture that creatively,” said Ingalls. “Now I ve done it so many times that it s become a real challenge to make a different and unique picture each time. And to make it seem fresh and new, what it s become more of now   and unfortunately it s a harder thing to do   is try to capture the people and the personalities behind all this.

Photo Credit: NASA/Bill Ingalls

Knowledge obtained from decades of exploration and discovery, in space and here on Earth, would remain unknown if no one learned about it. One of the most effective ways to share that knowledge is through photography. A single image can tell a story and capture history more vividly than reading, as the cliché goes, a thousand words. Photography gives us permission to stare—to absorb, study, and understand.

"I was raised not to stare at people," said NASA Headquarters photographer Bill Ingalls. "Well, photography gives you full permission to do that: to really stare at something and take it in and think about it. And if it's a portrait, to really stare at that person and observe."

When one-of-a-kind projects launch into orbit, there's often only a moment to capture them so current and future generations have a chance to study them in depth. For missions that stay closer to home, macro and telephoto lenses allow photographers to give a close look at things that might otherwise be invisible.

"There's a responsibility that you are the eyes for everyone who can't be there," explained Ingalls. "So there may be times I think an image could be made that's particularly artistic, but maybe does not help tell the story, so I might have to wave off on that to help tell the story. The goal, of course, is to help tell the story in a creative and interesting way, but not so off the wall that the story somehow gets lost."

The beauty of a photograph is that not everyone sees the same story in an image. Engineers may marvel at successful technology, students may think about the adventure of spaceflight, and scientists may glean previously unseen information about Earth and space.

Similarly, no two NASA photographers see things in quite the same way. "I was always amazed with how many times the Space Shuttle and its launches have been photographed, the way each photographer approaches that subject," said Langley Research Center photographer Sean Smith. "I'm amazed at how different and beautiful are the different visions of the shuttle—it's never really the same shot twice. That's just an example of how many ways can you shoot the same thing, but with just a little bit of your own vision, it's different every time."

A Collaborative Community

For each assignment, NASA photographers learn as much as they can about the topic before they go out to shoot it, often viewing photographs that have been made by previous generations and by current colleagues to gain additional understanding and see what's already been done. But some things can't be learned until they're actually on site.

"I was amazed my first time in Russia," recalled Ingalls. "The hardware itself, in the beginning, was unique to me and to a lot of the viewers of the imagery, I think. It's just so different—a train pushing a Soyuz out to the pad as opposed to the crawler with shuttle. And the environment is different. I remember once I was lying down next to the railroad tracks as the Soyuz was coming and thinking, 'Any minute someone is going to tell me to get out of the way,' but they didn't care. As long as I didn't stop that Soyuz, if I wanted to get crushed, that was my business. Now, of course, they would not let me stay there—safety comes first."

A mock up of the Orion space capsule heads to its temporary home in a hangar at Langley Research Center. "It was close to eight hours of them moving it from where it was, and I was hoping we d have enough light," said Smith. "This shot was forced luck. I just stuck with it. I had shot through my card, and I was deleting as I was running along with the capsule. The sun was going down, and I just had enough sun on the horizon that made it pop a little bit. Paired with the lights of them going into the hangar, it just made the shot.

Photo Credit: NASA/Sean Smith

Photo Credit: NASA/Bill Ingalls

NASA management watch the launch of Space Shuttle Discovery *on its thirty ninth and final flight from the firing room at Kennedy Space Center, Feb. 24, 2011. "Since Return to Flight, I ve been in the firing room, which is a real thrill for me because I hadn t been in there before that," Ingalls said. "But there again, I ve done that so many times that it s a real challenge to come up with something new. What I like about that is it s all about the faces there. It s all about the emotion. It s about trying to capture that emotion but tie something in to be sure it tells a story.*

Working closely with the people building, launching, and operating missions has become an important part of telling NASA's story through photography. "They're the content experts," explained Smith. "They know what's going on, and they can explain it to me, which helps me realize what I'm trying to capture. Sometimes you go in and feel a little intimidated, but when you start meeting these people and talking to them, they're gracious. They really try to help you get the best shot possible. And they're interested in what you're shooting, too."

In one case, Smith arrived on location for an assignment and decided to do a site survey to prepare for the next day. What he discovered was a field test in progress for a mobile chassis, part of the Desert Research and Technology Studies (Desert RATS), with a perfect backdrop of golden-hour light and puffy clouds.

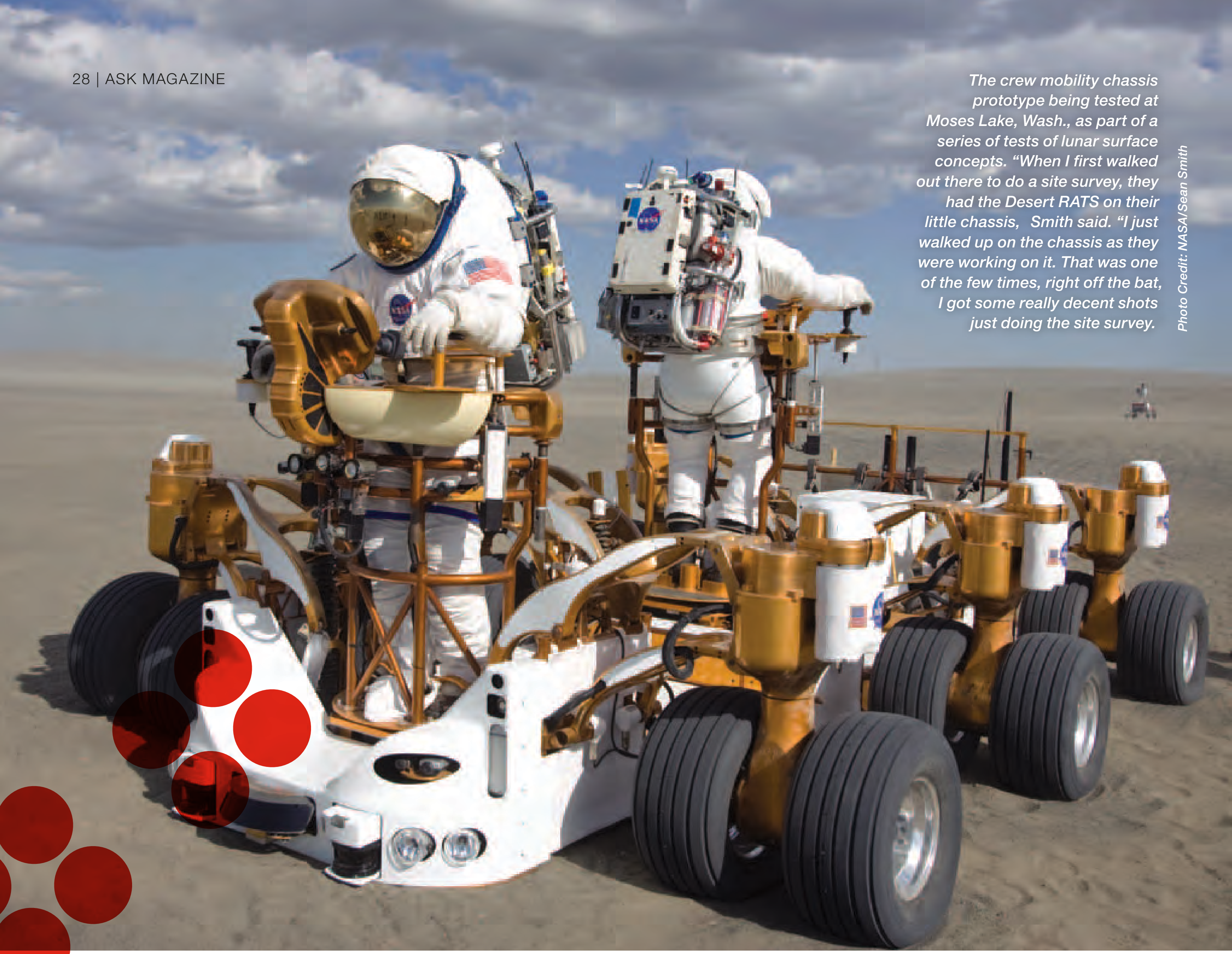
"I had just flown in, it had been a long day, and I just threw my bags in my hotel, and I walked up on the chassis. I just started shooting," recalled Smith. "Later I found out someone was not so happy with what I'd done because they had no idea who I was, and I talked to that person. Once we talked, he was like my best friend. He said, 'You just stick with me, and I'll show you where you can shoot, what you can shoot, and what you can't.' He even let me get on back of the buggy. I got some great stuff out of that trip."

Ingalls had a similar experience when he began to photograph launches from the firing room at Kennedy Space Center. "The first time I was in the firing room, I did get a lot of people looking at me like, why is he in here? But now I'm pretty well received." This has allowed him more freedom to capture the emotions of those involved in each launch and share that emotion with those outside NASA, giving the public a glimpse at the people behind the missions.

Documenting History

As important as it is to share NASA photography with people today, it's more so to document history in the making for future generations. "If you ask anyone what they think of when they think of Apollo, ask anyone what they think of the shuttle, most people will respond by describing an image," said Ingalls.

And future generations' ideas of NASA will be shaped by today's images of the space station and planetary exploration. "I have a son that's five and a half and I've got a daughter that's almost three, and I show my work sometimes to my son," said Smith. "I'll get a, 'Cool,' and then, 'What's for dinner?' And that's fine, but I know somewhere down the line, when he's older, he'll look back on some of these pictures. This is stuff that he'll be looking at hopefully years from now, and it's something for him to remember me by. I know I'm shooting for NASA, but at the same time, I'm leaving something for my kids as well, and for other kids that will grow and see NASA."



The crew mobility chassis prototype being tested at Moses Lake, Wash., as part of a series of tests of lunar surface concepts. "When I first walked out there to do a site survey, they had the Desert RATS on their little chassis,   Smith said. "I just walked up on the chassis as they were working on it. That was one of the few times, right off the bat, I got some really decent shots just doing the site survey.

Photo Credit: NASA/Sean Smith

For those who will learn about NASA in the future, it's as important to document the failures as it is to share the amazing successes, so those who follow do not make the same mistakes. Ingalls learned this most poignantly after the loss of *Columbia*.

He was at home when his phone rang to inform him of the loss and request his assistance at Headquarters. One of his responsibilities was to go to the room where people from NASA management and outside agencies had gathered to find out what had happened and photograph then–Deputy Administrator Frederick Gregory. Ingalls shadowed Gregory to another room, where the deputy administrator began making calls immediately to form an investigative commission.

"I made some images, and at one point I became a little uncomfortable with being there in front of Gregory," recalled Ingalls. "To his credit, he sensed that and said, 'I'm really glad you're here; I'm glad you're documenting all this. This is not pretty, but we need to remember what's happening today.' And I had two other people also approach me and say, 'We're glad you're here. We're glad you're documenting this terrible day.'

"While the circumstances were terrible, I'm glad that we were let in to document that for historic purposes."

Looking to the Future

Once a NASA photograph is released to the public, both Ingalls and Smith said they're already thinking about the next photo to be made. What's to come—and what they'll learn—is just as exciting as where they've been. And they use their past experiences to build upon future ones, striving to improve each time they go out on assignment.

As many stories as they've shared, they know there's another waiting to be told.

"Just look at the iconic shots of Mercury astronauts, the Apollo astronauts," said Smith. "It's a storyline, and it's a great story. It continues to be a great story, and it just needs to be documented—wherever we go next." ●

INTERVIEW WITH

Rüdiger Süß

BY DON COHEN

Rüdiger Süß is the project manager for corporate strategy and international relations for the German Aerospace Center (DLR). DLR is the national research center for aeronautics and space research and the German Space Administration. He and *ASK* Managing Editor Don Cohen talked in Long Beach, California, after NASA's 2011 Project Management (PM) Challenge.

COHEN: What is your current work at DLR?

SÜß: My main task is to coordinate the long-term orientation of DLR. Every five years, we update the work we have to do to improve things, the kinds of initiatives we need, and figure out where we want to be in fifteen or twenty years. My job is to get the bosses and researchers together to coordinate all this, to work from the vision to the mission, from goals to implementation.

COHEN: How long have you been in this job?

SÜß: This is my ninth year. I'm an aerospace engineer with a master in strategic management, so I understand both worlds. I can talk with engineers in more or less every aerospace field, but I also understand the administrative guys.

COHEN: What led you to take that master's degree?

SÜß : Even as a student, I recognized that I was most interested in how we cooperate. I got interested in how, for example, Airbus, a company located politically in four countries, can make one big thing—how the whole political system works. I did the master's degree in France and saw that they're more strategic thinkers than we are. We say, "Oh, we have a problem, we have to fix it." They first think about the strategies and the positions of what they're going to do. As an engineer, I want

FOR A STRATEGY GUY, IT'S ALWAYS talk, talk, talk, AND YOU SEE THE IMPACT two years later; SOMETIMES IT'S hard to see AT ALL.

to understand the problem and then solve it right away. With strategy, it's more about how we position ourselves, how to improve, how we work with partners.

COHEN: A very different kind of challenge from what an engineer does.

SÜß: When I hear people talk about participating in the Cassini mission or working as a thermal engineer for a satellite mission, I envy them. For a strategy guy, it's always talk, talk, talk, and you see the impact two years later; sometimes it's hard to see at all. The result is not a product but a behavior.

COHEN: And results like those are hard to measure, except anecdotally.

SÜß: You can't prove it. It's all "perhaps." Maybe you can talk about how many people came to DLR because this particular institute person was teaching. Or how much more money is made because of the certification of an institute. But these are secondary indicators. If an electronic device on a satellite goes wrong or the gyros are wrong, engineers can figure out why. For us, it's always, did I say something wrong, wasn't he well informed? Why didn't it work? Sometimes you can't figure it out, sometimes you can, but it's not like an engineer coming with a screwdriver. I can't screwdrive a strategy.

COHEN: What have you learned about how to do the work over the years?

SÜß: When I started this job, I went to people and said, "This is our new strategy; you have to help me implement it and figure out how to measure your work." A lot of times I came out with a bloody nose. They'd say, "I've been in this job thirty-five years and now a greenhorn is telling me what I should do?" Or they just smile and say, "Yes, we'll do everything you want," but nothing happens. I hadn't considered the personal impact. I began to understand about communicating with people. I understood I had to address their needs and fears—why they had this resistance. I had to ask, "How can we help you?" Then I could say, "This is what you want and this is the strategy; let's do something together that will give you what you want and the boss what he wants." I turned from focusing on technical strategy issues and KPIs [key performance indicators] to communications management.

COHEN: Can you give me a specific example?

SÜß: Working with someone on resource planning in space research, he and I made a lot of lists, but he saw that his boss was against what we decided. He saw the resistance from above, and nothing happened. So I addressed his boss via my boss to explain what kind of benefit he would get from the strategy. His boss got more and more informed and said, "OK, this is a good thing; I understand it." The next time we met, he said, "I got the go from my boss." He needed an official goal from his side.

In another case, I was working with two guys on developing strategies and their own KPIs. Then nothing happened. They said, "When we did all this, we hadn't talked to the CEO." I said, "I'm just here to serve you. I'll step back. You talk to the big boss. If he doesn't want it, he'll tell you. If he wants it, go for it." That's the kind of thing I've learned.

COHEN: When you're new at a job, you think you should do everything yourself, but you learn there are better approaches.

SÜß: Exactly.

COHEN: Are there ways in which your technical background has been important to this work?

SÜß: It's important to be accepted by the technical guys *as* a technical guy. They say, "Oh, you're an engineer," and they're more willing to listen. When we wanted to integrate a little research center into DLR, I needed my technical knowledge because it was about materials science. If I had no clue what they were doing, I couldn't have supported it. With a technical background, I could explain what part of the scientific chain from molecular research to application this technology competence is and why it's important.

COHEN: Part of your communications job must be to communicate within DLR what the strategy is and what it means in practical terms.

SÜß: There have been good changes in our communication policy. Now we put a lot of our strategy on the intranet, where everyone can read it and see what the KPIs are. There are also events for top performers and future leaders where we come in and say, "This is the strategy, let's talk about it." Mr. Wörner, our new CEO—he's been CEO for four years—has gone to every DLR location and said, "This is our strategy; this is what we're planning to do. What are your questions? Challenge me." I was with him the whole time. By being transparent and closer to the people, we get more acceptance. Also, now we say [to senior managers], "We want to go in this direction. You sit together and define the goals and how you think we'll achieve them." That makes it *their* strategy. That changes the commitment. It becomes their own idea.

COHEN: How would you describe your current strategic direction?

SÜß: On the corporate side, we want to be more visible externally, recognized as an excellent partner to industry and government. We are putting a lot of effort into innovation, which is a shift from years ago. The ministry of technology and economy has said, "Whatever you do, it has to serve industry." This means a mind shift. We want to consult more for the government. We are being asked to research, not only to develop interesting things—we want to deliver solutions for problems that the society has. We also want to increase scientific excellence.

COHEN: What are you doing to improve the science?

SÜß: We want to roll out quality improvement to our institutes, including a certification program that will mean people can say, "I know what my job is and I do it right."

COHEN: That sounds like another communication effort.

SÜß: It's partly communication. We have introduced a graduate program to train PhDs in communication and project management skills. We want to create alliances within DLR and with external partners so people can work better together and share information. We're hiring someone for knowledge and information management. All the heads of our institutes are professors at universities, but so far it's only the heads. We want more of our

I BEGAN TO UNDERSTAND ABOUT communicating with people. I UNDERSTOOD I HAD TO address their needs and fears—WHY THEY HAD THIS RESISTANCE. I HAD TO ASK, "How can we help you?"

staff teaching at universities so they get challenged and we attract the best people.

COHEN: What are your knowledge management plans at this point?

SÜß: One guy who is very into IT [information technology] has proposed using more and more social media applications within DLR—a wiki and Twitter and such things. We asked, "How do people know about these things?"

His answer: "We send them e-mail."

"Did you ever speak directly to them?"

"No."

He is not aware that most knowledge management happens when people are together talking face to face. We told him there are three things in knowledge management: technology, OK, but also organization and people. Especially people. If they want to use electronic devices they can do it, but first they have to meet. You start with the people and finish with the iPad, not the other way around.

COHEN: Have you learned anything at this PM Challenge that can help you in your work?

SÜß: I'm a project manager, so I can directly apply things like how to evaluate projects. I saw one session about using the balanced scorecard approach to evaluate projects, and think maybe I should introduce that, slightly changing the notions and figures. For us, before, it was just asking, "What do you think?" You make project evaluation much more systematic here—sometimes too systematic, but it's valuable. You ask the experts—the strategic management committee and the planning management committee—to judge a project rather than just judging it yourself. I will perhaps apply this method, evaluating to decide which of all the projects we want to do is the best.

COHEN: What do you see as a major difference in how NASA and DLR function?

SÜß: One difference is how you treat finance, scheduling, and money flow. You have to go to the Congress and get the money. We are associated to the Federal Ministry of Economy and Technology. Our government-funded research follows a five-year budget plan. Our scientific projects may take longer to approve, but when they're implemented, we can be sure to get funding for most of them for the next five years. We are therefore not as flexible as NASA is, but we may be more stable in the long term. ●

LEADING the Race to Space

BY PIERS BIZONY

During the space race of the 1960s, NASA Administrator James Webb and his Soviet counterpart, Sergei Korolev, shared the determination and skill needed to push a rocket program past countless political barriers, beyond the reach of jealous rivals, and toward success. Surprisingly, though, it was the American leader who exerted the kind of central control we typically associate with the Soviets.

NASA Administrator James E. Webb (center) cites the space achievements of the Project Mercury astronauts who received the 1963 Collier Trophy Award in a ceremony held at the White House on October 10, 1963. President John F. Kennedy (left) and Vice President Lyndon Johnson accompanied Webb at the ceremony.

Photo Credit: NASA


The Huntsville Times

Man Enters Space

'So Close, Yet So Far,' Sighs Cape

U.S. Had Hoped For Own Launch

Hobbs Admits 1944 Slaying

Soviet Officer Orbits Globe In 5-Ton Ship

Maximum Height Reached Reported As 188 Miles

To Keep Up, U.S.A. Must Run Like Hell'

Praise Is Heaped On Major Gagarin

'Worker' Stands By Story

First Man To Enter Space Is 27, Married, Father Of Two

Reds Deny Spacemen Have Died

Reds Win Running Lead In Race To Control Space

Image Credit: NASA

Huntsville Times *newspaper's front-page coverage of the Gagarin flight.*

In the proud Soviet announcements about Yuri Gagarin's historic ride into space, the man who sent him up there was not allowed to share any of the public glory. Born in 1907 in Ukraine to Russian parents, and educated in Kiev and Moscow, Sergei Pavlovich Korolev began his career as an aircraft designer. At first he saw rockets as a useful power source for aircraft, but by the late 1930s he knew they could be vehicles in their own right.

The Soviet military showed a keen interest in rockets. In 1933 Marshal Mikhail Tukhachevsky sponsored a research center, the Gas Dynamics Laboratory, hidden away behind the ramparts of the Petrapavlovskaya Fortress in St. Petersburg, known at that time as Leningrad. Another facility in Moscow, the Reaction Propulsion Laboratory, worked along similar lines. From the union of these two efforts, Valentin Glushko emerged as the most promising designer of combustion chambers and fuel pumps, while Korolev thought in broader terms about rockets.

Unfortunately, Joseph Stalin was terrified of intelligent soldiers, and in 1937 he began a purge of the officer class. All the rocket engineers that the military had sponsored came under suspicion, and by June the following year they were in custody and suffering various extremes of coercion and torture. Korolev was dragged away on June 27, 1938, and condemned to ten years in a Siberian gulag. Glushko seems to have escaped the camps by denouncing Korolev. The sequence of events is uncertain, but one thing is for sure: throughout their subsequent alliance on some of the greatest pioneering achievements in rocketry, the two men loathed each other.

Fortunately for Korolev, the aircraft designer Andrei Tupolev, also a political suspect, was head of a "sharashka" in Moscow, a research facility within the prison camp system where valued prisoners could work on engineering projects in relative comfort. At Tupolev's request, Korolev joined his team. A telling detail of Soviet leniency was the fact that Korolev was released from the Siberian camp and ordered to report to Moscow, but no transport was made available to him. His improvised return journey, on foot, by ship, and by hitching rides on trucks, took many weeks and nearly killed him.

According to Yuri Mazzhorin, one of Korolev's senior experts on guidance trajectories, "He was an extraordinary person. You'd think his time in prison would have broken his spirit, but to the contrary, when I first met him in Germany when we were investigating the V2 weapons, he was a strong-willed, purposeful person who knew exactly what he wanted. But he never insulted you. He would always listen to what you had to say. Everybody loved him."

Korolev's greatest creation was the R-7 missile, or Semyorka, "Little Seven" as it was affectionately known by the men who built it or flew on it. Fueled with liquid oxygen and kerosene, and incorporating four drop-away boosters parallel to a central core, this was the world's first intercontinental ballistic missile. Glushko's compact turbine fuel pumps and pipework serviced four combustion chambers simultaneously. The thrust of twenty separate nozzles was distributed among just five engine assemblies. The first launches of the R-7 failed, but on August 3, 1957, it flew a simulated nuclear strike mission (over Soviet territory), then began its career as a space launcher on October 4 that year, launching Sputnik, the world's first artificial satellite.

Dr. Andy Aldrin, director of business development and advanced programs for United Launch Alliance, and also a keen space historian, admires the speed with which Korolev could conjure up space triumphs. "He tried to go on vacation after Sputnik, and he got a call from Khruschev. 'Comrade, come to the Kremlin.' Of course he went, and Khruschev said, 'In a

STRANGELY ENOUGH, NASA'S APOLLO PROJECT WAS A SUCCESS BECAUSE ITS LEADERSHIP UNDER WEBB AND HIS CLOSE DEPUTIES, ROBERT SEAMANS AND GEORGE MUELLER, WAS SOMEWHAT SOVIETIST IN ITS NATURE …

month we have the fortieth anniversary of the glorious October Socialist Revolution. We want you to put up another satellite that will do something important.' He wanted a satellite that could broadcast the 'Communist Internationale' from space, but Korolev had another idea. He wanted to launch a living creature. And within a month, he and his people scratch-built a special capsule and did just that."

Sputnik II went up on November 3, 1957, carrying the dog Laika, a living, breathing mammalian creature. This was a clear indication where Korolev was heading. Dr. Aldrin takes up the story. "Korolev promised the military that he could build spy satellites, and then said, 'Of course we have to develop manned capsules first, so that trained pilots with good eyesight can report on what the cameras are likely to see.' Basically, he conned them. He really understood how to work the political system."

Unfortunately, command over Russian space affairs became increasingly less well defined throughout the 1960s. While Korolev won political backing for his R-7 programs by virtue of his successes, this didn't mean that he had much authority over his competitors, Vladimir Chelomei, mastermind of the Proton rocket; Glushko, the ever-resentful engine designer; and Mikhail Yangel, yet another missile tsar working out of Ukraine. The late-1960s Soviet effort to send a cosmonaut to the moon was not actually one effort but several, all viciously competing for funds and patronage. Korolev's death from cancer in 1966 allowed his rivals to wreak havoc unchecked. Russia's lunar ambitions decayed into a terrible mess, culminating in disastrous launch explosions and a costly lack of focus.

Strangely enough, NASA's Apollo project was a success because its leadership under Webb and his close deputies, Robert Seamans and George Mueller, was somewhat Sovietist in its nature: collective at ground level, but with tightly centralized and sometimes ruthless control from this small cadre within Washington Headquarters. One instance involved Harry Goett, the successful, hard-driving head of the Goddard field center in the early 1960s. Webb freely admitted that Goett had achieved an excellent record, but "he thought he was so good that he could get away with it—that, by God, nobody could really cause him any serious trouble. He said he wanted to draw an absolute line between the people that worked for him, and those that were in Headquarters." Goett was eased out of his post.

In 1963, an alarmed U.S. senator, William Proxmire, said that "NASA is probably the most centralized government-spending program in the United States. It concentrates in the hands of a single agency full authority over an important sector of the economy. This could be described as corporate socialism." NASA's Apollo-era chief, Webb, was feared by many prominent Americans precisely for those reasons, but his firm grasp on the reins was crucial to Apollo's success.

Portrait of Sergei Korolev.

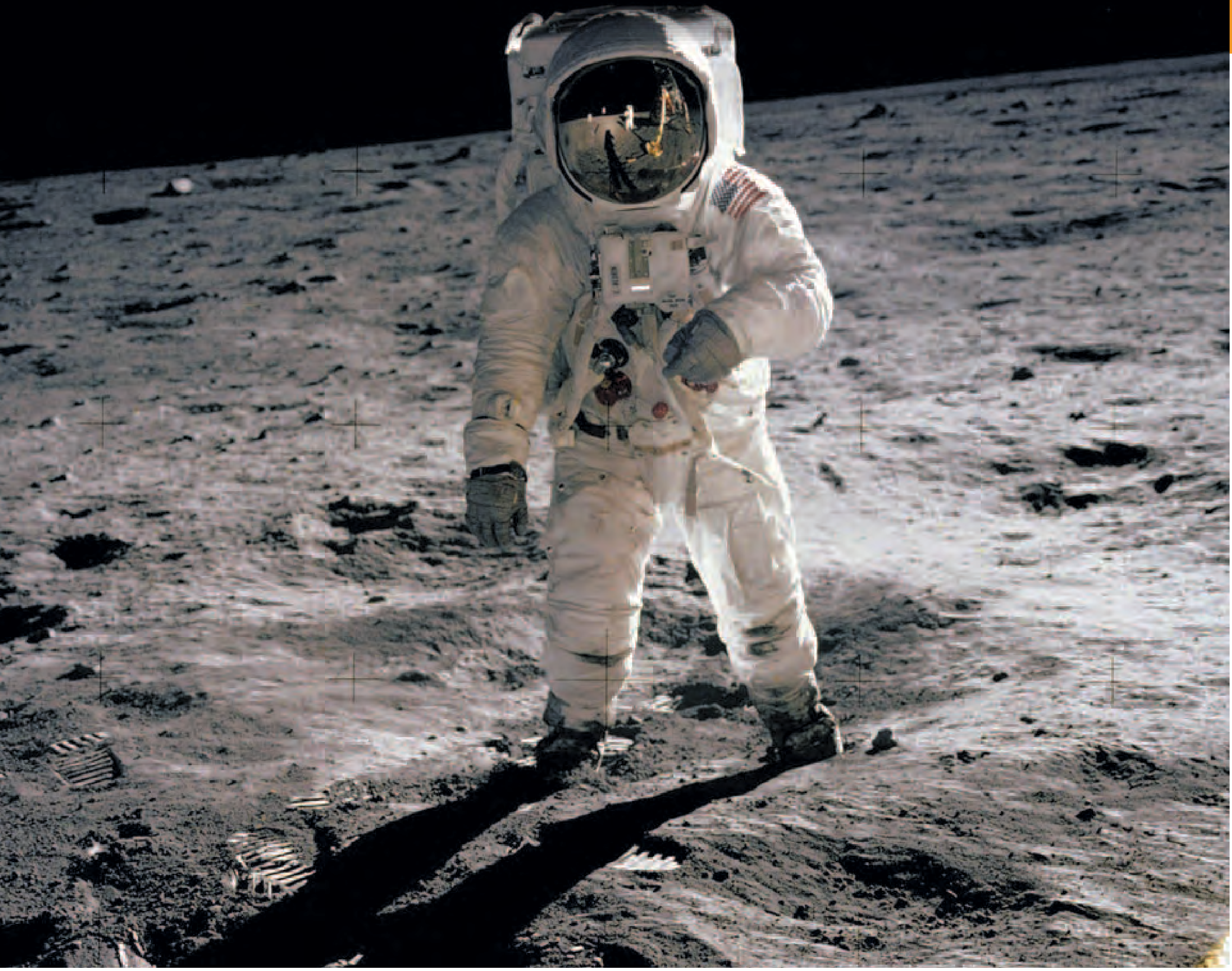


Photo Credit: NASA/Neil Armstrong

Astronaut Edwin "Buzz" Aldrin walks on the moon during the Apollo 11 mission.

It enabled the agency to achieve great success and prestige throughout the Mercury and Gemini programs, because of his insistence that all NASA field centers should be answerable to the needs of specific space programs, and not the other way around. Not everyone liked it, but Webb's imposed unity was valuable throughout most of the 1960s. The International Space Station is a great success today, but arguments among NASA centers before the first metal was cut lost time and cost the United States a great deal of money. Webb would never have stood for that lack of unity.

The Soviet lunar programs faltered because their power structures were not hierarchical and decisive but individualistic and quarrelsome. Korolev and his rivals were rather like nineteenth-century American railroad barons ruthlessly trying to shoulder each other out of the way, each determined to see their train, rather than the other fellow's, play the leading role. None of them seemed quite strong enough to take overall charge of Russia's space effort, while the Kremlin failed miserably to impose unity under one office.

The real test of Webb's strength of character came in the wake of the Apollo 1 fire of January 1967. He shouldered much of the blame during the subsequent Congressional inquisitions, protecting Apollo and its people as best he could from direct repercussions. His fury at some senior NASA colleagues was not because of the fire itself; they had failed to warn him about contractual problems with Apollo's manufacturers. Congress knew about these, and tried to use them to tarnish Webb's personal reputation.

People often think that "money was no object for Apollo." Nothing could be further from the truth. The political mood in 1967 was very different from in 1961, when the program had been initiated. Webb had to fight exceptionally hard to protect Apollo, especially given the fact that none of the new lunar vehicles had even left the ground at the time of the fire.

Webb may not have suffered such extreme physical cruelties as Korolev suffered, but by the standards of bureaucratic life in the United States, he also had to show extraordinary courage—in defense of NASA, its people, and its programs. Time and again he supported the judgment of colleagues within the agency against political interference. In his own words, he "couldn't let anybody dictate the decisions that were at the technical level, whether it was the president or the vice president or the scientists."

Today Webb is revered, but just as Korolev was accused of sabotage and disloyalty, and then had to spend more than a decade clearing his name, so the U.S. political establishment took just as many years to "exonerate" Webb from blame with regard to the Apollo 1 fire, and to remove once and for all the subtle accusations of dishonesty leveled against him during the Congressional inquiries and accompanying media assaults on his good name. Even a decade after the triumph of Apollo 11, the much-respected Republican Senator Margaret Chase Smith felt the need to lodge a formal letter with Congress, expressing her "disappointment at the lack of recognition for the man who put a man on the moon, James E. Webb. He had to take the heat and fire of partisan political attacks from headline-hungry politicians. I saw this at firsthand in my work on the Senate Space Committee. But as compared to the hero astronauts, what recognition or material gains did Jim Webb, and the thousands behind the scenes he typified, receive? Minimal, if any. They declined to commercially exploit their official positions. And today, they are forgotten men and women."

Korolev similarly gets too little of the glory for humankind's earliest space triumphs. Alexei Leonov, the first man to walk in space, described to this author a tragic last meeting shortly before Korolev's death on January 14, 1966, when a surgical procedure for stomach ulcers revealed serious cancers and internal bleeding. Throughout all his years working to give the Soviets a lead in space, Korolev seldom discussed his arrest, torture, beatings, and imprisonment under the old Stalinist regime. People thought of him as a burly man built like a bear, yet the truth was that his body was made rigid by countless ancient injuries. Leonov described a man who "couldn't turn his neck but had to swivel his upper torso to look people in the eye, and nor could he open his jaws wide enough to laugh out loud."

Two days before he was scheduled for surgery, Korolev was resting at his home in Moscow. Gagarin and Leonov came to visit him with several other friends, and at the end of the evening, just as most of the visitors were putting on their greatcoats to leave, Korolev said to his two favorite cosmonauts, "Don't go just yet. I want to talk." According to Leonov, "He told us how he was taken away and beaten. When he asked for a glass of water they smashed him in the face with the water jug. They demanded a list of so-called traitors in the rocket laboratories, and he could only reply that he had no such list. Then they sent him to the prison camp."

This great powerhouse of a man had never spoken before in such a fragile and personal way, and the two young cosmonauts were deeply affected by what they heard. Leonov told me, "This was the first time that he had ever talked about his imprisonment in the gulag, since these stories are usually kept secret. We began to realize there was something wrong with our country. On our way home, Yuri couldn't stop questioning. How could it be that such unique people like Korolev had been subjected to repression? It was so obvious that he was a national treasure." Webb was also a "national treasure," but the strange fact is most Americans have never heard of him. ●

PIERS BIZONY has written about science, aerospace, and cosmology for a wide variety of magazines in the United Kingdom and the United States. *2001: Filming the Future*, his award-winning book on the making of Stanley Kubrick's *2001: A Space Odyssey*, has become a standard reference work. It was also the basis for a C4 documentary film. In 1997, *The Rivers of Mars*, his critically acclaimed analysis of the life-on-Mars debate, was short-listed for the NASA/Eugene M. Emme Award for Astronautical Writing, while *Starman*, produced as an acclaimed book and a BBC film, told the story of Soviet cosmonaut Yuri Gagarin's life for the first time.

REFLECTING ON HOPE

BY DON HEYER

Photo Credit: White Sands Missile Range

Recent hires who work for the Jet Propulsion Laboratory successfully launched a sounding rocket carrying the TRaiNED project 75 miles above Earth s surface on Dec. 6, 2010, from the U.S. Army s White Sands Missile Range in New Mexico.

In the final days of 2008, the Science Mission Directorate and the Academy of Program/Project and Engineering Leadership released a new opportunity under a fledgling program: the Hands-on Project Experience, or HOPE. It was described as a "training opportunity" and solicited proposals for small-scale projects from in-house teams of young engineers and scientists. The philosophy behind HOPE was simple: the most effective way to learn how to do something is to actually do it. Only months earlier, management at the Jet Propulsion Laboratory (JPL) had teamed with a group of young employees to form the Phaeton Program around the idea that small-scale flight projects could be used as a tool to rapidly prepare personnel for larger-scale missions. These parallel ideas met in a shared undertaking in early 2009 when TRaiNED (Terrain-Relative Navigation and Employee Development) was selected to become the first HOPE project. I was selected to be the project manager for that project.

The TRaiNED Concept

The HOPE training opportunity requested proposals for a sounding-rocket project that would have a useful purpose for the Science Mission Directorate. Coincidentally, the JPL Phaeton Program had identified a sounding-rocket-based project to develop a technology called "terrain-relative navigation" (TRN) as one of its first projects.

TRN is a technology that could support precision navigation of future spacecraft. One can refine inertial-measurement-based position estimates using computer-vision technology to identify and track features in ground imagery. The objective of this TRN project was to advance the technology's development by collecting ground imagery, inertial measurement unit data, and GPS data during a sounding-rocket flight and to use that data set to validate TRN through post-flight data processing.

The TRN project presented significant appeal as a training experience. The project would be able to leverage a considerable portion of the technical design from a related sounding-rocket flight flown a few years earlier. The new project would essentially add to and incrementally improve the previous design, keeping the technical scope of the project manageable but challenging. What's more, most members of the project team from the earlier flight were available and many could act as mentors to the new team. Finally, the program would support the developing project team periodically with short classroom-training modules designed to follow the life cycle of the project.

The pieces fit together nicely, but there was one gaping hole: the program hadn't identified a way to get the TRN payload onto a sounding rocket. Project HOPE was the solution, and it quickly became clear that the two programs complemented each other nicely.

Implementing TRaiNED

The TRaiNED project was entirely staffed with early-career hires—employees less than three years out of school. These early-career hires were competitively selected at JPL from a large pool of applicants that wasn't limited to the engineering team: all the project positions were filled with early-career hires. Furthermore, the search for candidates for each position wasn't limited to those who worked in the related area of the institution. A wider search was conducted to give people who were hired out of school in one discipline an opportunity to gain experience in another.

While each member of the project team brought a different background to the table, there were several common learning experiences that we encountered and tackled as one. For example, nobody on the project team had experience writing requirements, yet each individual was responsible for developing the requirements on their own element of the project. There were many different opinions about how to best structure and define these requirements, and these inconsistencies showed through at the project's system requirements review. This review may not have gone as smoothly as many would have liked, but it served as strong motivation for the team to come together in the following weeks to rework project requirements as a group instead of individually. The result was not only a stronger set of requirements but a more integrated project team.

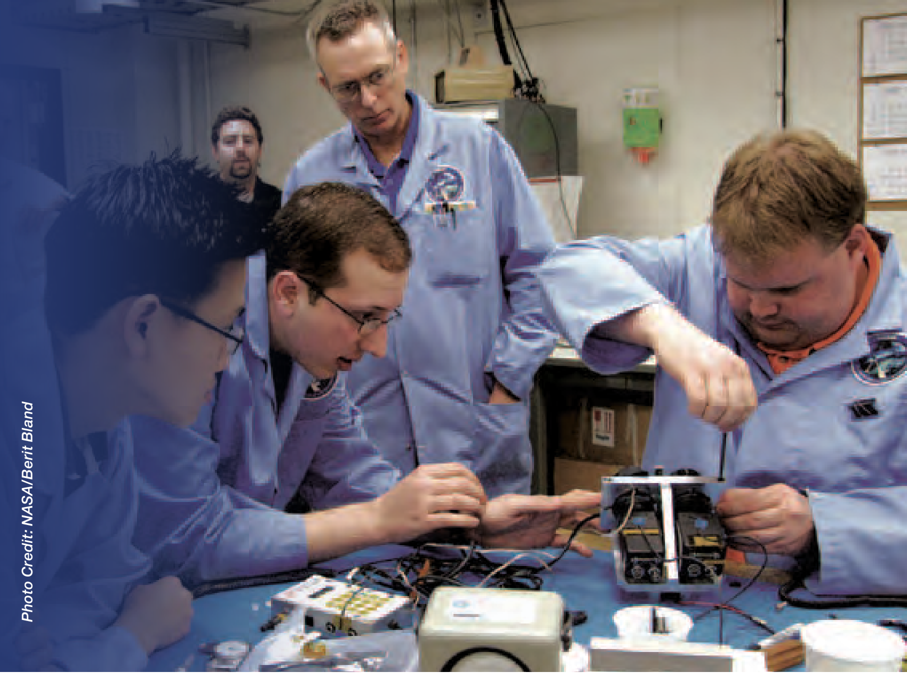
As TRaiNED was the first HOPE project, there wasn't any clear model to follow to effectively combine the training and technical goals of the project. Rather, the definition of both programs had to take place in step with definition of the project. At times this was a source of frustration: both programmatic training objectives and project technical objectives had to be accommodated, and these two objectives were sometimes in conflict. Working through these struggles became one of the cornerstone learning experiences for the project team, however, as we were forced to negotiate—as any other project would—the scope and expectations of our work with several stakeholders.

Most of the team quickly learned how many stakeholders they actually had as they started work on their work agreements (WAs)—agreements between the project and line management that describes the work that is to be done and the resources that will be available to complete it. We expected to be able to sail through the WA approval process with relative ease but discovered quite the opposite. In some cases, getting a WA approved became a lengthy process of give and take between the project and the line spanning several weeks. While completing the WAs wasn't automatic, the conversations they required helped to bring all the stakeholders together with the same understanding of the project's goals and approach.

In order for the project team to have an authentic hands-on experience, TRaiNED was treated like other flight projects. So, while only a fraction of the size of most flight projects, TRaiNED was planned and structured in the same fashion. Tailoring of the typical processes and requirements was conducted by the project team through normal channels. While there was significant tailoring to reflect TRaiNED's relatively small scale, the project team experienced firsthand all that goes into planning and executing a project from its conceptual stages through its launch.

Launch

Fast-forward to December 2010. The team that started the project nearly two years earlier is still almost completely intact. During the past two years, we have completed and passed the major project life-cycle reviews; have designed, built, and tested our payload; and worked with a team from Wallops Flight Facility (WFF) to integrate the payload into the sounding rocket that sits on the launcher ready to fly. The JPL, WFF, and White Sands Missile Range teams have gathered in the block house or at other posts around the range and are busying themselves with their prescribed prelaunch tasks. We've been here before:



Project HOPE team members work on the TRaiNED rocket during the assembly and debug processes.

Photo Credit: NASA/Berit Bland

once in June when the weather moved in at the last minute and forced the launch to be canceled, and again in September when the weather forecast didn't even hint at cooperating. After all the prelaunch tests check out, December's countdown is also placed into a hold because the skies have clouded over. As the launch window nears its end, most people are beginning to resign themselves to another weather cancellation when, with just a few minutes remaining, Dr. Martin Heyne (the TRaiNED principal investigator) announces that there's been just enough of a clearing in the weather to go for the launch.

If an argument ever had to be made in support of Project HOPE, it was exemplified by the following fifteen minutes. The calm, composed manner in which each member of the project team quickly transitioned from a weather-induced limbo to efficiently executing the final steps of the launch countdown was rewarding to watch and special to be a part of. The collective poise exhibited by the team as the rocket left the rail didn't exist in 2008. It was poise that could not have come from attending classroom lectures or from reading a stack of books. It came from experience.

Lessons Learned and Suggestions for Future Projects

Two more HOPE projects are currently under way, and with any luck their success will mean more to follow. Now that a few months have passed since the TRaiNED launch, I've had a chance to consider what helped make TRaiNED a success. While the following list is in no way comprehensive, I'd like to highlight four factors that I found to be of particular importance.

1. **Project Selection.** The selection of an achievable concept is critical. The project has to be challenging enough to be worthwhile, but manageable enough so that the project team can divide their attention between solving technical problems and learning about how a flight project is executed. Learning how to execute a flight project, let alone actually doing it, is time consuming and easy to underestimate.
2. **Institutional Support.** JPL provided us with a phenomenal level of support throughout the project. The institutional investment in a program to help direct and shepherd along this project and others like it was invaluable.
3. **Review Board Selection.** It is important to convene a standing review board that recognizes the developmental nature of the project, but will still give objective feedback where the project demonstrates weaknesses. The standing review board assembled by Project HOPE for TRaiNED was an asset throughout the project. The TRaiNED standing review board not only helped us identify weaknesses in the project and correct them, but helped coach us so that we were better prepared for the next review.
4. **Mentors.** Mentoring was critical to the success of the TRaiNED project. We were fortunate enough to have a team of engaged mentors who routinely took time out of their schedule to help us with whatever problem we happened to be facing that particular day. Most importantly, our mentors were invaluable in identifying upcoming problems that we weren't even aware existed. I lost count of how many times they asked me, "Have you thought about XYZ?" I invariably realized that I hadn't but needed to. ●

DON HEYER is an electrical engineer in the flight communications section at the Jet Propulsion Laboratory. He is currently working on the ExoMars Trace Gas Orbiter project, and he is the project manager for TRaiNED.

This illustration maps the magnetic field lines emanating from the sun and their interactions superimposed on an extreme ultraviolet image from SDO.

Photo Credit: NASA/SDO

SOLAR DYNAMICS OBSERVATORY LESSONS AFFIRMED

BY BRENT ROBERTSON AND MICHAEL BAY

It is always exciting watching something launch into space. It is even more thrilling when the launch is the culmination of many years of work. Having worked on a large space-science mission at Goddard Space Flight Center, we had the privilege of working with a team of people dedicated to developing a one-of-a-kind scientific satellite that would do things never done before. Watching the Atlas V blast off from the Cape with our satellite onboard was a moment of truth. Would the satellite perform as designed? Had we tested it sufficiently before launch? Did we leave a latent flaw? Had we used our resources wisely to achieve the greatest possible scientific benefit?

The Solar Dynamics Observatory (SDO) mission is changing our understanding of the dynamic structure of the sun and what drives solar processes and space weather, which affect our lives and society. Goddard led the team who built the spacecraft in house, managed and integrated the instruments, developed the ground system and mission operations, and performed observatory environmental testing. We had a compelling mission, adequate funding, a seasoned project management team, and a strong systems-engineering and quality-assurance staff. The instrument investigations were provided by highly competent and experienced organizations at Stanford University, the Lockheed Martin Solar and Astrophysical Laboratory, and the University of Colorado Laboratory of Atmospheric and Space Physics. It's what we considered a dream team for mission development.

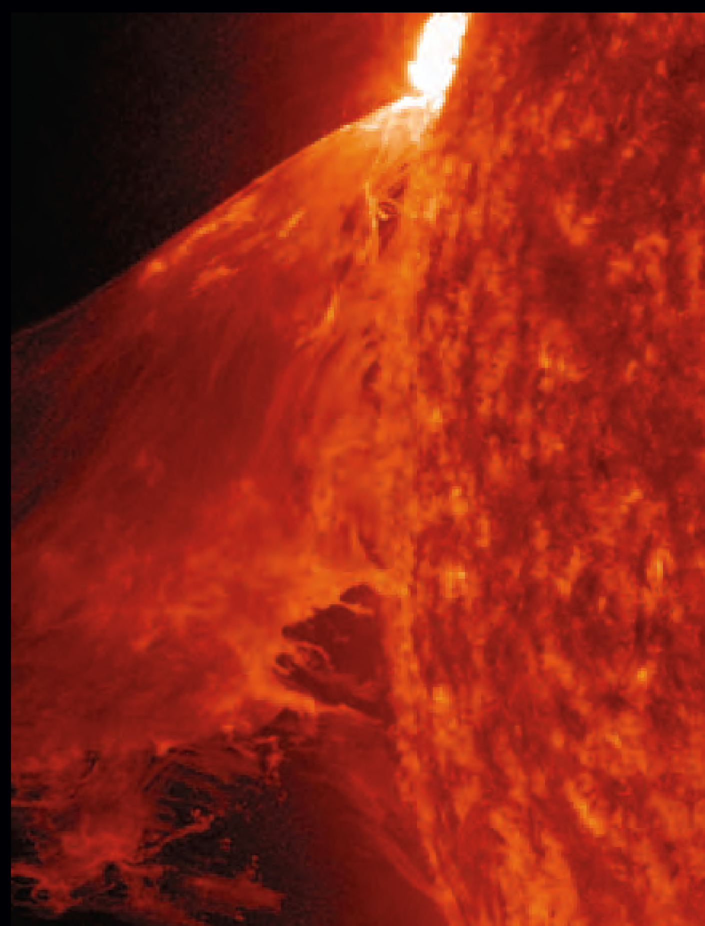
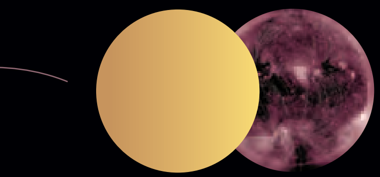


Photo Credit: NASA/SDO

A rather large M 3.6–class flare occurred near the edge of the sun on Feb. 24, 2011; it blew out a waving mass of erupting plasma that swirled and twisted for ninety minutes.

SDO was a technically challenging mission with stringent science requirements necessitating the application of new technology in a severe orbital environment. In order to mitigate potential threats and ensure success, the SDO project instituted a thorough "test like you fly" philosophy at the system level along with a rigorous risk management and problem-tracking approach. A risk identification and mitigation process was put in place for everyone to use early on. As we moved from the design to the build phase, we emphasized stringent problem investigation, tracking, and closeout across the entire project. This process proved to be an effective technique to aggressively identify and track threats to mission success. We found and resolved system-level anomalies that otherwise might have gone unreported or been left open. The result was reflected in the findings of the SDO prelaunch safety and mission success review, where it was noted that there were fewer residual risks than normal.

Like most projects, SDO encountered a number of programmatic and technical issues throughout its development. Looking back at these issues affirms a number of lessons that may be useful for other projects. A budget rescission just after critical design review removed 30 percent of the funding at a critical time during development. The project was forced to slow down instrument development and defer spacecraft procurements. At the time, we gave up some schedule reserve. The launch readiness date slipped by only four months, but we realized in hindsight it was not a wise decision. We later encountered delays in flight-hardware deliveries due to challenges in developing high-speed bus electronics needed for transferring large quantities of data for



NOT ALL TEST PROGRAMS ARE EQUAL; WHAT MATTERS IS HAVING THE RIGHT TEST PROGRAM AND, IN THIS CASE, FUNCTIONAL TESTING AS TEMPERATURES VARY OVER THEIR FULL RANGE.

transmission to Earth. The launch readiness date slipped another four months, which meant SDO lost its launch slot. Due to a backlog of Atlas V launches, a four-month slip ended up costing the project another fourteen months waiting for its turn to launch. We were very worried that we would lose critical people to other jobs during the wait, but in the end almost all the original team supported launch. ***Lesson affirmed: Giving up schedule reserve before starting a flight-build effort is a mistake.***

Looking back at the technical issues encountered by SDO, we can identify some as "high consequence." These were issues that required rework of flight hardware, issues whose resolution held up integration and test efforts, or issues that could not be fully mitigated and resulted in a residual risk at launch. Could these issues have been avoided? Maybe some of them. Unexpected events always happen, especially when building a one-of-a-kind spacecraft. That is why we test. More than half these issues were due to interactive complexity among components that was hard to predict analytically and could only be discovered after system integration. What is worth noting is how these issues were identified and how they manifested themselves.

Some issues were discovered with vendor components after they were delivered to the project. Although the vendor was required to subject components to an environmental test program, component testing did not always uncover all problems. For example, one component had a latent workmanship issue that was not discovered until thermal-vacuum testing. The device experienced anomalous behavior in a narrow temperature range. The problem was caused by an incorrect number of windings on an inductor that was selectable by an operator during the unit's building and testing. The device's functional performance had been verified by the vendor at the plateaus of component-level thermal testing but not during transitions. ***Lesson affirmed: Not all test programs are equal; what matters is having the right test program and, in this case, functional testing as temperatures vary over their full range.***

Another example involved the identification of a shorted diode on a component's redundant power input. Component-level testing verified the power-input functions one at a time but did not specifically test for power-feed isolation between redundant inputs. This short was not discovered until the component was powered by a fully redundant system on the observatory during a test designed to show power bus isolation. Such "negative testing," designed to verify protective functions, had uncovered a problem and was necessary to show the mission could continue in spite of failures. ***Lesson affirmed: Verifying functions may need negative testing at the system level, especially where protective or isolating features are intended.*** Both of these components were de-integrated from the observatory and returned to the vendor for repair, which delayed the completion of system integration and testing. But it was better to find these problems prelaunch instead of on orbit.

The SDO design used common products in multiple subsystems. This was not only cost efficient but also allowed for the discovery of potential issues through testing a larger number of common units, thereby enabling reliability growth. For instance, a common low-power switch card used in eight locations had a latent flaw that was found during the build of a flight spare unit. A short to ground that had not been uncovered during the testing of other similar cards due to a marginal tolerance was discovered. A possible on-orbit problem potentially induced by launch vibration or extensive thermal cycling was averted by having a design with a common product. Unfortunately, five electronics boxes were affected and all of them were already integrated on the observatory. We decided to de-integrate the boxes and fix the problem. It could have been worse; the observatory had not yet gone through its thermal-vacuum testing. But it was unnerving to find a problem like this so late in the test program. ***Lesson affirmed: The devil is in the details and the details can't be ignored, as Murphy's Law and Mother Nature will show you in flight, sometimes in dramatic fashion.***

One issue not due to complexity occurred during a bake-out. Most of SDO's hardware had been baked to remove contaminants; the satellite's high-gain antenna subsystem was one of the last pieces of hardware needing a bake-out. It was just

Moments after launch, SDO's Atlas V rocket flew past a sundog and, with a rippling flurry of shock waves, destroyed it.

Photo Credit: NASA/Goddard/Anne Koslosky

Photo Credit: NASA

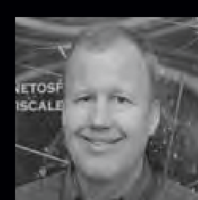
One of the four Atmospheric Imaging Assembly telescopes arrives at Goddard for integration and testing.

another bake-out; what could go wrong? It turned out that the facility control software for test heaters was left turned off and nobody noticed that the uncontrolled test heaters subjected the hardware to damaging hot temperatures until it was too late. The good news was we had spares on hand to rebuild the subsystem, but this was a problem that could have been avoided. ***Lesson affirmed: Apply product savers[1] to protect flight hardware from damaging conditions should test environments run awry, and continuously assess what can go wrong during testing of flight hardware, no matter how often similar tests have been performed.***

SDO used a rigorous "test like you fly" approach at the system level to find issues that might have escaped detection during design, review, and lower-level testing. In today's systems, where interactive complexity can conceal potentially serious issues and impede our ability to foresee failure, it is essential to understand mission-critical functions and work tirelessly to uncover the "unknown unknowns." It was especially critical to apply a "test like you fly" philosophy to increase the chance of finding the latent flaws that matter. Often, seemingly small problems and failures are the tip of an iceberg threatening something bigger. Many loss-of-mission failures are foreshadowed by prelaunch discrepancies. It was not good enough just to make things work. We needed to make sure we identified and understood why they didn't work and then properly obviate or mitigate that cause.

SDO was scheduled for launch on Feb. 11, 2010. But the SDO team was challenged one last time, when a winter "storm of the century" closed much of the Washington, D.C., area, where the Mission Operations Center was located. Undaunted, the entire team made it in to support the launch. It was a spectacular launch, with the rocket flying through a rainbow known as a sun dog, which the rocket's shock wave extinguished. The rocket did its job, placing SDO in a geosynchronous transfer orbit.

Since then, on-orbit science operations continue to exceed requirements and the spacecraft has performed flawlessly. The few residual risks accepted at the time of launch have not come to pass. The use of a rigorous process to uncover potential problems was a success. The technical issues, the wait for a launch, the snowstorm—all these challenges had been met. The years of hard work from many talented people paid off. ●



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MICHAEL BAY currently serves on the Goddard Space Flight Center's Global Precipitation Measurement mission systems engineering team and participates in NASA Engineering and Safety Center assessments for the avionics and systems engineering technical discipline teams. He served on the SDO systems engineering team and has thirty-three years' experience developing, testing, and operating space systems. He is chief engineer of Bay Engineering Innovations. E-mail: michael.bay@bayengineering.org

1. A product saver provides an independent shut-off of a potentially threatening environment (vibration, thermal) in case the prime environmental controller fails.

CONFIGURATION

A still from the animation, Global Precipitation Measurement (GPM) Mission: A fly up the Nile River in Egypt, then a pull out into space," showing Saudi Arabia, India, and the Caspian Sea.

Image Credit: NASA Goddard Space Flight Center/Scientific Visualization Studio; Blue Marble Next Generation data is courtesy of Reto Stockli (Goddard) and NASA s Earth Observatory.

MANAGEMENT: A RECORD [and a] RESOURCE

BY DEBBIE DUSTERWALD

At the 2009 NASA Project Management Challenge, I walked to the lectern wearing a white wig. I asked the audience to step back in time with me to the signing of the Declaration of Independence. I represented George Washington. When the audience stopped laughing, I said, "Imagine for a moment, if we had to have all the signatures on our documents that our forefathers had during the signing of the Declaration of Independence. It would take a long time, and we would not be very productive." The Declaration of Independence established requirements and standards for our nation. It was read, reviewed, and edited many times to be sure it was correct before it could go to England. The documents we process for our projects might not be as far reaching, but they are important to mission success. Reviews take time, but they ensure that our documentation complies with requirements and has lasting value.

Requirements and standards are the foundation of any NASA program and project. They define how a project accomplishes its objectives and moves forward to achieve its goals. It is the responsibility of configuration management to maintain the traceability of documents through the entire project life cycle. Configuration management is a formal process to document and control the coordination, evaluation, approval, and release of all changes; to maintain all project documents and drawings; and to ensure all requirements are complied with and all proposed changes have been implemented and resolved. Without configuration management, project activities would not have traceability. Configuration management ensures that technical errors are corrected and new requirements accommodated. It ensures that project objectives are being met and that the project team is performing effectively. Also, without successful configuration management, we would lack the wealth of accurate documentation that future projects can learn from and build on.

Learning by Doing

When I first started in configuration management, I worked for a company supporting Goddard Space Flight Center's Image Processing Division. I worked in the Technical Reference Library at the Inglewood facility in Landover, Maryland. One end of the facility housed the technical publications department; at the other end was the engineering department. The library was located in the middle. This was one of the times in my career that I happened to be at the right place at the right time. I found that it is important to be close to the project office for easy access.

It was my first opportunity to establish processes for configuration management of documents and drawings. I created a logbook for all the documents and drawings. It was a challenge to keep track of which documents and drawings were released and which were being changed because I had to do it all manually. I remember getting my first computer and using the dbase III Plus application for tracking documents and drawings. It was a whole new world for me and for the configuration management process. Throughout the years, computers and software have evolved and provided a much more effective and efficient traceability process. Over the years, I progressed from dbase III Plus, dbase IV, Microsoft Access, and the Next Generation Integrated Network (NGIN) to, now, the Management Information System (MIS) on my current project.

I have worked on four "in-house" and one "out-of-house" projects at Goddard. Each of these projects had different scientific objectives. The principles of configuration management—identification, control, status accounting, and verification—

do not change, but no two projects conduct configuration management in quite the same way. Configuration managers need to enforce the requirements, but still be flexible and work with the project to accomplish its unique objectives.

I learned quickly that I had to do configuration management a little differently when I worked on a project with significant cost and schedule constraints. It was a very fast-paced in-house project. Configuration management was done electronically. Before I started, the configuration management processes were viewed as a ball and chain that held back productivity. We had to accommodate the demands and limitations of the project. Because we did not do configuration management exactly as other projects may have done it, we heard criticism from the sidelines. But we met our objectives and the integrity of the documentation was not compromised. The spacecraft was launched, and the mission has been successful.

When I started working on the Extreme Ultra Violet Explorer payload module in 1989, a project manager recommended that I interact with the team I would be supporting. I realized that establishing a line of communication and a rapport with the managers and the engineers performing the actual work is very important. Configuration management personnel must get out from behind their desks, attend status meetings, and connect with the people creating the documentation. If they want to be successful, configuration management personnel have to be willing to earn their project team's cooperation.

Working on the Solar Terrestrial Relations Observatory project, I realized how important it is to have a sense of humor and enjoy doing your job. The configuration management office was responsible for project-level documents, instrument and observatory procurements, and deliverables. Sometimes some of the managers would be late to scheduled Configuration Control Board (CCB) meetings. With the clock ticking and no one coming to the meeting, I would go into the project office, toot my fake horn, and announce: "Doo-doo-doo-doo … Is everyone ready for the CCB meeting?!" The project manager would come out of his office and tell me, that's what he likes to see, people having a good time with their work. There are times when we are a little too serious about what we are doing, so to break the ice, you need to laugh and have a good time.

When I began working on the Lunar Reconnaissance Orbiter project in 2006, there were 250 open configuration change requests (CCRs). To close that many CCRs in a short amount of time, you need the support of the entire team. I worked with each individual subsystem lead and the project management office to get through the processing and release of the documents associated with these CCRs. I learned two

Animation still showing Lake Nasser, Egypt.

Image Credit: NASA Goddard Space Flight Center/Scientific Visualization Studio; Blue Marble Next Generation data is courtesy of Reto Stockli (Goddard) and NASA s Earth Observatory.

things from this experience: that teamwork is very important, and that everyone needs to share the same view of the objective.

The GPM Mission

I currently work as the configuration management lead for the Global Precipitation Measurement (GPM) mission. I lead a team of six configuration management professionals. The core observatory has evolved through many versions and architectures, each producing a surge of new documentation specific to the plan at the time. The mission was initiated as a Goddard in-house effort with design work starting in earnest in 2002. As the design approached preliminary design review in late 2004, the project transitioned to an out-of-house effort managed by Goddard. The following year, the project direction shifted to a collaborative effort between Goddard and commercial vendors, in which the flight electronics and software would be procured and used on a Goddard-designed spacecraft bus. Studies were performed with potential vendors and development of procurement documents were in progress when the project reverted to the original plan of in-house development in fall of 2007. Each of these shifts created an avalanche of new and modified documents and drawings. Only through the lessons I learned on previous projects and the support of a great configuration management team have I been able to manage the project's objectives.

The GPM core observatory successfully completed its preliminary design review in November 2008 and its critical design review in December 2009. Integration of hardware into the mechanical structure is currently under way, with integration activities scheduled for most of 2011 and environmental testing throughout 2012. Shipment to the launch site at Tanegashima Space Center in Japan is planned for early the following year for a summer 2013 launch.

Configuration management is responsible for managing all aspects of the GPM design cycle: requirements specifications, analyses and parts lists, schematic drawings, interface control documents, review materials, and test procedures and results. Many of the core observatory sensors and actuators, as well as the GPM microwave imager instrument, are procured from commercial vendors, which present a different configuration management challenge—to manage all the documentation associated with procurement activities and deliverable documents. The dual-frequency precipitation radar instrument and H-IIA launch vehicle are provided by the Japan Aerospace Exploration Agency, adding the challenge of international relations and compliance with international traffic in arms regulations.

I have two mantras that work for me. The first one defines the configuration management process: baseline, control, change, control, traceability, review, and release. I developed my second mantra a few years ago when I worked with an engineer who did not provide documentation to support the work he was doing and made changes without going through the process. He told me time and time again I was keeping him from doing the work he needed to do; the configuration management process was slowing him down and causing him to not be on schedule.

One day, I walked into the room and set down in front of him a 3-foot-long 2x4 board with his name on it. I held up the board and told him that if he did not do what needed to be done I was going to use it as it was meant to be used. Now, I am not a violent person and would never have carried out the threat: my second mantra is "do not hit the engineer." The threat was effective, though. Recently a systems engineer added his own twist to this story. The Project Management Office is the biggest force behind configuration management. They set policy and priorities, and they provide influence over the engineers to make sure they are compliant. In other words, he said, project management is the 3-foot-long 2x4.

Over the years, configuration management has grown into an important part of achieving project objectives. There are some key qualities that configuration management personnel need to accomplish their job. Good software tools to manage the information are important, but so are having good communication, people, and organizational skills—and a sense of humor. Configuration managers need to be part of the team and be grateful for the people who work to make the configuration management process successful.

Success is a team effort. It requires cooperation, flexibility … and maybe a 3-foot-long 2x4. ●

DEBBIE DUSTERWALD is currently the configuration management lead for the Global Precipitation Measurement mission at Goddard Space Flight Center. She works on the PAAC III contract and is employed by ASRC Research and Technology Solutions.

Managing in an Unsettled Environment

BY SCOTT J. CAMERON

Government service has historically been associated with a relatively stable work environment, at least when compared with private-sector organizations forced to continually adapt to shifting market forces in the pursuit of survival and profitability. The year 2011 is proving to be an unusually challenging one for NASA and other government agencies, however, replete with change and tumult. Fiscal year 2012 promises to be even more challenging.

The Unsettled Environment

The change and uncertainty are coming from a combination of three main factors: budgets, politics, and an aging workforce.

Budgets

More than half the fiscal year had elapsed before Congress and the president finally came to closure on annual funding on April 8, 2011. Unprecedented debate over how deep budget cuts needed to be this year represented a break in a pattern that goes back at least half a century, which saw presidents typically requesting less money than Congress eventually appropriated.

While the debate over the FY2012 funding level has barely gotten started, House leadership is talking about cuts on the order of $6.2 trillion over the next decade, while the president is also beginning to signal an interest in further reductions after FY2012. Even the Senate is talking about freezing some FY2012 spending at the FY2011 level. Given increased costs due to inflation, even a freeze constitutes a cut in real dollars.

At NASA, these fiscal challenges are compounded by programmatic changes. The Space Shuttle program is coming to an end. Constellation is slowly winding down, using precious financial resources in its last months that could be used productively elsewhere.

Political Environment

The year 2012 will see the return of a presidential election race and its focus on politics and political advantage. Preoccupation with politics will be heightened by the divided party control in Congress, with the Democratically controlled Senate and the Republican-controlled House each looking for ways to score political points. In such situations, sound, public policy-making can be impeded by political considerations, which often lead to stalemate and inaction.

Workforce

For years, federal human-capital management leaders have been warning of an impending retirement flood. The argument is that agencies will experience a massive wave of baby-boomer retirements any time now.

This flood has not yet materialized. The stock market decline in recent years has wreaked havoc with the Thrift Savings Plans balances of many federal employees; like many workers in the private sector, they have been reluctant to retire until their retirement funds regain their pre-financial-crisis strength. At the same time, a historically high unemployment rate has limited federal employee opportunities for post-retirement employment outside government.

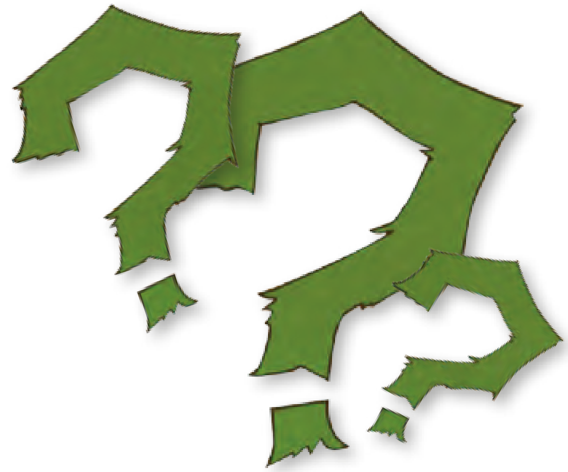
But the wave of retirements is coming. Prospective retirees are older now than they were two years ago and, for many people, the attractions of retirement pull all the more strongly as they age. Also, the president and Congress have decided that federal employees will not receive annual cost-of-living adjustments for two years. For many employees, that means their "high three" compensation years that affect the size of their annuity in retirement are not going to get any higher, so there is little financial incentive to continue in the federal workforce. Finally, potential turnover of political officials, even when an incumbent president is reelected, can create a period of frustration and drift that many senior employees may want to avoid.

Managing Through Uncertainty

Managers can and must do three things to navigate these uncertain times. They must plan for change, support the workforce, and ensure that the organization is capable of performing once most of the change has happened.

Plan for Change

The critical steps in planning are collecting potentially relevant material, with a bias in favor of official sources of information and against tapping into the office rumor mill; analyzing the information collected; and then deciding how to adapt to the anticipated change. In general, do not be swayed by press coverage; editorials; employee blogs; posturing by local, state, or federal elected officials; and interest-group efforts to thwart administration policy. Since purveyors of incorrect or trivial



STRIVE TO EXPLAIN WHAT THE ORGANIZATION WILL LOOK LIKE AFTER THE CHANGE, SO EMPLOYEES CAN VISUALIZE THE FUTURE AND THINK ABOUT THEIR PLACE IN IT. WITHOUT UNDERPLAYING DIFFICULTIES, IDENTIFY AND SHARE THE POSITIVE.

information are often among the loudest communicators, this can be a challenge.

Agency leadership testimony before Congress, official press releases, and approved communications to employees are among the best information sources. Those documents go through a thorough internal clearance process, and, therefore, are most likely to accurately represent the official viewpoint.

Analysis of the information collected needs to be done in the context of understanding how and when the change will likely happen, and who will be instrumental in accomplishing it. Change can be driven by a variety of processes, each with its own timelines and windows of opportunity for influence. It is critical to understand what's driving a particular change, so the interested manager may inject himself or herself into the process in the most effective way at the most opportune moment. Typical change drivers are budget, litigation, acquisition, regulation, executive orders, and congressional action to amend current or create new statutory authority. Agency managers should develop a mental model of what the organization will look like after the change, so appropriate strategies can be defined to get from the "as is" to the "to be."

The process driving the change will typically provide crucial information on when the change will actually begin and when it is expected to be completed. It is important to understand the motivation of those forcing change. Do they want to cut budgets, decrease staff, or simply shift the emphasis of an agency? Unless their motives are understood, there is a real risk that strategies chosen to manage change will be misguided and unsuccessful, since they may not address the "problem" to be solved. Indeed, there is even the possibility that an adaptation strategy chosen without regard to the driver behind the change may exacerbate the perceived problem, and cause the manager to lose credibility.

Support the Workforce

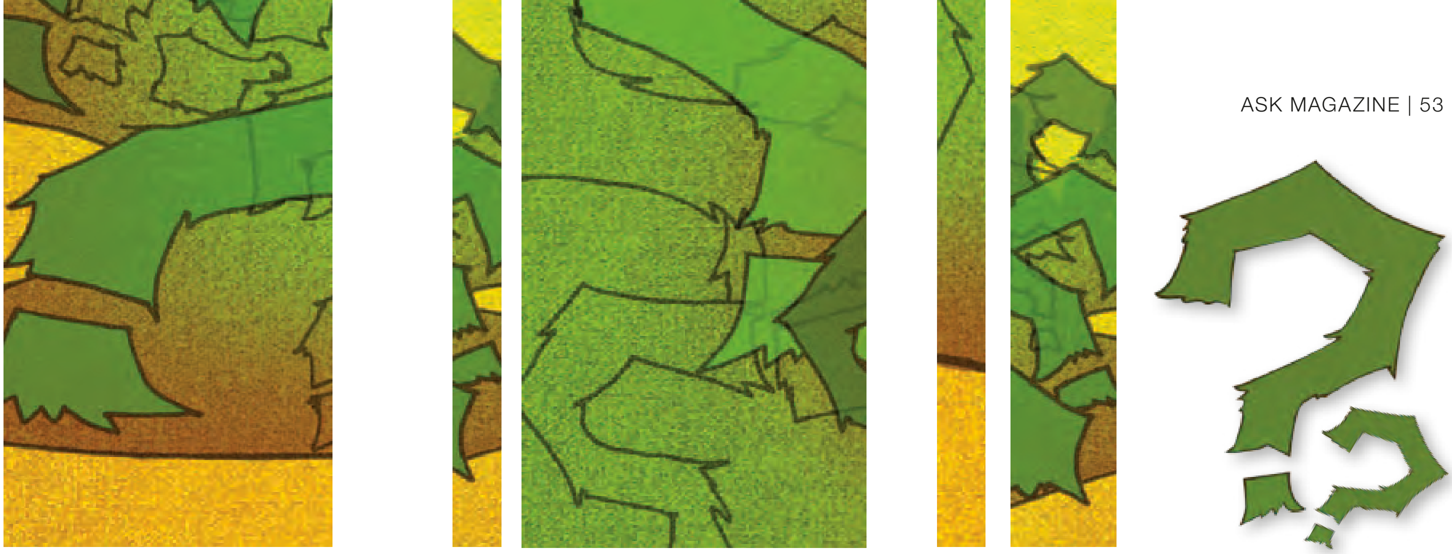
The single best way to support the workforce is through practicing good communication. Communication must be

- **Open.** Keep no secrets from employees unless you have been given information confidentially.
- **Frequent.** If employees don't hear from their manager enough, they will make up their own imaginative—but invariably wrong and often damaging—explanations of what is going on.
- **Honest.** Share what you know and what you don't know; don't try to fake it, because people will notice and you will lose credibility.
- **Respectful.** Recognize that employees will vary a great deal in terms of experience, sophistication, and anxiety, so don't give the impression that any questions are inappropriate.
- **Multimodal.** Don't rely on just one form of communication; people learn differently and not everyone may have ready access to a single mode of communication.
- **Consistent.** Leverage the chain of command to share and exchange information, but make sure that all communicators are "on message."
- **Current.** Stay on top of developments so you can share promptly when conditions change to retain confidence and reduce anxiety.
- **Prudent.** Avoid talking to the press without a handler from your public affairs office to avoid unnecessary pitfalls, since a reporter may be more interested in creating an exciting story than reporting the "truth" as you see it.

Strive to explain what the organization will look like after the change, so employees can visualize the future and think about their place in it. Without underplaying difficulties, identify and share the positive. Adhere to the party line, since nothing is gained by publicly disagreeing with policy decisions. Expect to repeat your message, since not everyone "gets it" the first time, and people will take comfort in constancy in an unsettled environment.

If it looks like your organization is going to have to absorb a significant budget cut, then you need to think strategically, tactically, and humanely.

From a strategic perspective, be active, not passive. Seek to drive change rather than be a victim of it. Discover if the change creates an opening to reshape the organization in ways you wanted to pursue in the past that may have been impractical in a



more staid institutional setting. Perform a multisector workforce analysis, taking the opportunity to reconsider the appropriate mix of federal employees, contractors, and other partners in light of the future mission. Envision the federal workforce that you will need to succeed after the change, and conduct all other activities with that end in mind.

Tactically, be willing to make difficult decisions intelligently rather than abdicating control to bureaucratic processes. Make sure you are aware of applicable labor-relations regulations and constraints. Use early-outs and buyouts selectively to reshape the workforce. Working closely with your acquisition office, consider modifying contracts to refocus effort on the highest-value work. Choose not to exercise option years or cancel unnecessary contracts to conserve cash. Manage vacancies thoughtfully, avoiding across-the-board hiring freezes. If all else fails and you find yourself presiding over a reduction in force, find and work closely with an expert in the human resources office who will show you how to use your discretionary powers to shape it. Creatively target the reduction functionally and geographically, to help shape the outcomes as much as possible. Finally, get it over with as soon as possible to control the damage to morale and reduce the flight of your best talent.

Be humane by being honest with people about their futures; don't try to protect them from the truth. If you have not been doing it all along, this is the time to separate senior people who are poor performers; the organization cannot afford to carry them anymore. Work closely with human resources, but get it done. Set up an outplacement process to help capable people who don't have a natural place in the changed organization to find a better niche in other parts of the agency. Pay special attention to your star performers; let them know that you want them around and plan to look after their interests as much as you can.

Preserve the Capability to Perform

Keeping in mind your vision for the "new" organization, be clear with yourself and your team, and human resources, on the competencies your people will need to succeed in the future. Then deliberately hire people who can catalyze the transition to the new organization. Do succession planning, and shape your training program so that it enhances the desired competencies and equips high-performing junior people to handle more-senior positions. Use the individual performance-management system to signal the new skills, knowledge, and competencies that you want in your new organization, and to focus the efforts of your staff on work that will advance the transformation. Work very hard to keep your high-performers engaged, so they will stick with the organization through the transition.

Don't forget to manage your relationships with contractors and other partners so they, too, begin to focus on creating the target organization. As applicable, revise contracts, grant agreements, and cooperative agreements so they are aligned with the new organization.

Resist the temptation to follow the typical but deplorable pattern of responding to budget cuts by eliminating travel, awards, training, and new hires. While this may be a tempting stop-gap strategy to solve a short-term budget problem, it is not a good long-term choice. You and your customers are better off with a relatively smaller organization that is well trained, well rewarded, gets to develop professionally through travel to important events or locations, and can hire new people when they are needed, than with a slightly larger organization that can do none of these things. This implies that initial staff reductions should be deeper than what is necessary to simply "squeak by." Squeaking by is no way to run an organization over the long term.

Finally, in managing an organization in an unsettled environment, do not forget to manage your own needs. Without allowing yourself to take the opportunity to periodically refresh yourself, your own morale and attitude will be less than what you want to project and less than what you need to successfully manage a difficult transition. ●

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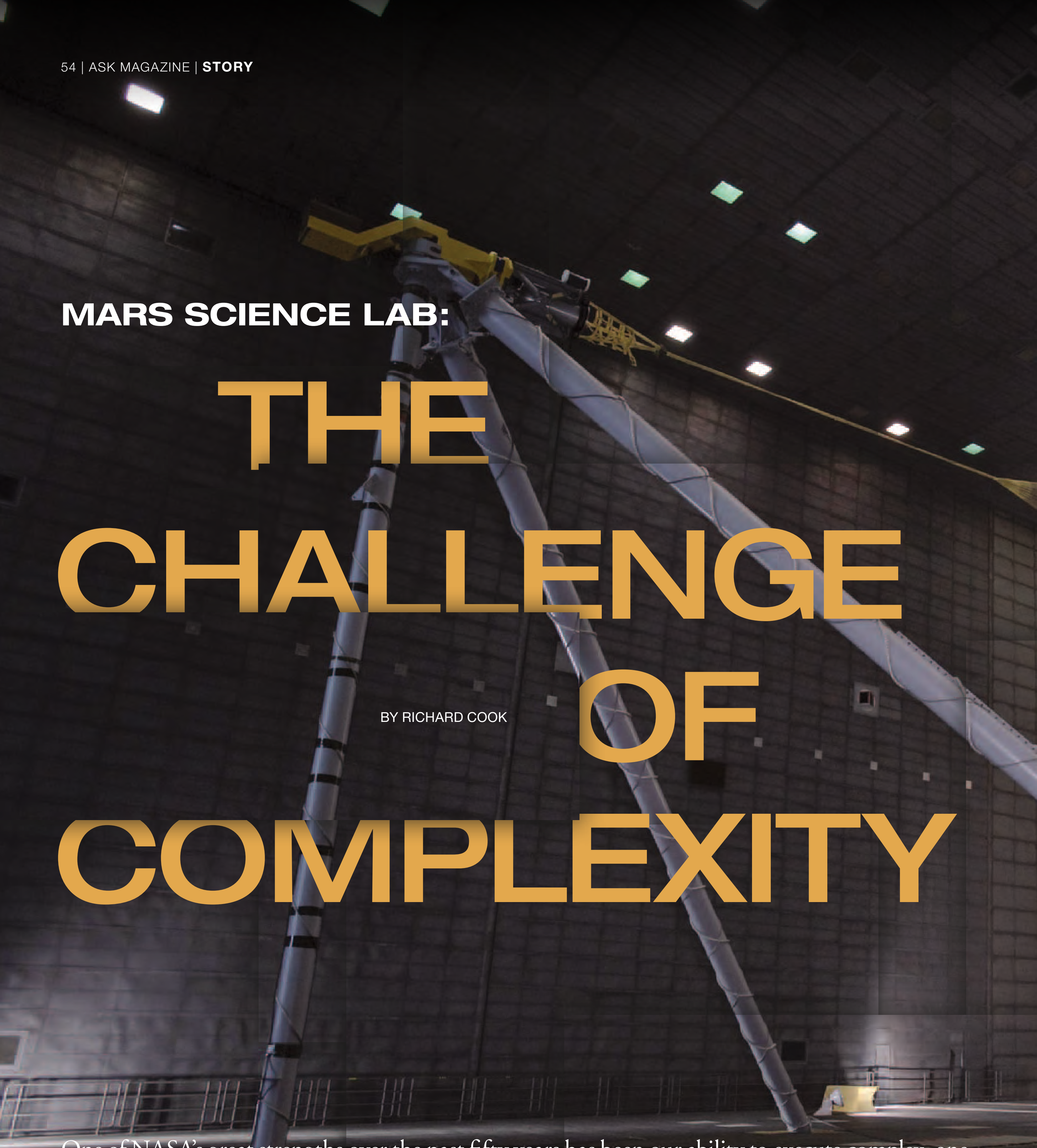


MARS SCIENCE LAB: THE CHALLENGE OF COMPLEXITY

BY RICHARD COOK

One of NASA's great strengths over the past fifty years has been our ability to execute complex, one-of-a-kind projects. In some cases, we have literally written the book on how to carry out programs with difficult technological, scientific, or programmatic objectives. It is somewhat surprising, therefore, that we've had significant problems in the past few years with some highly visible, complex projects. I work on one of those projects, the Mars Science Laboratory (MSL).

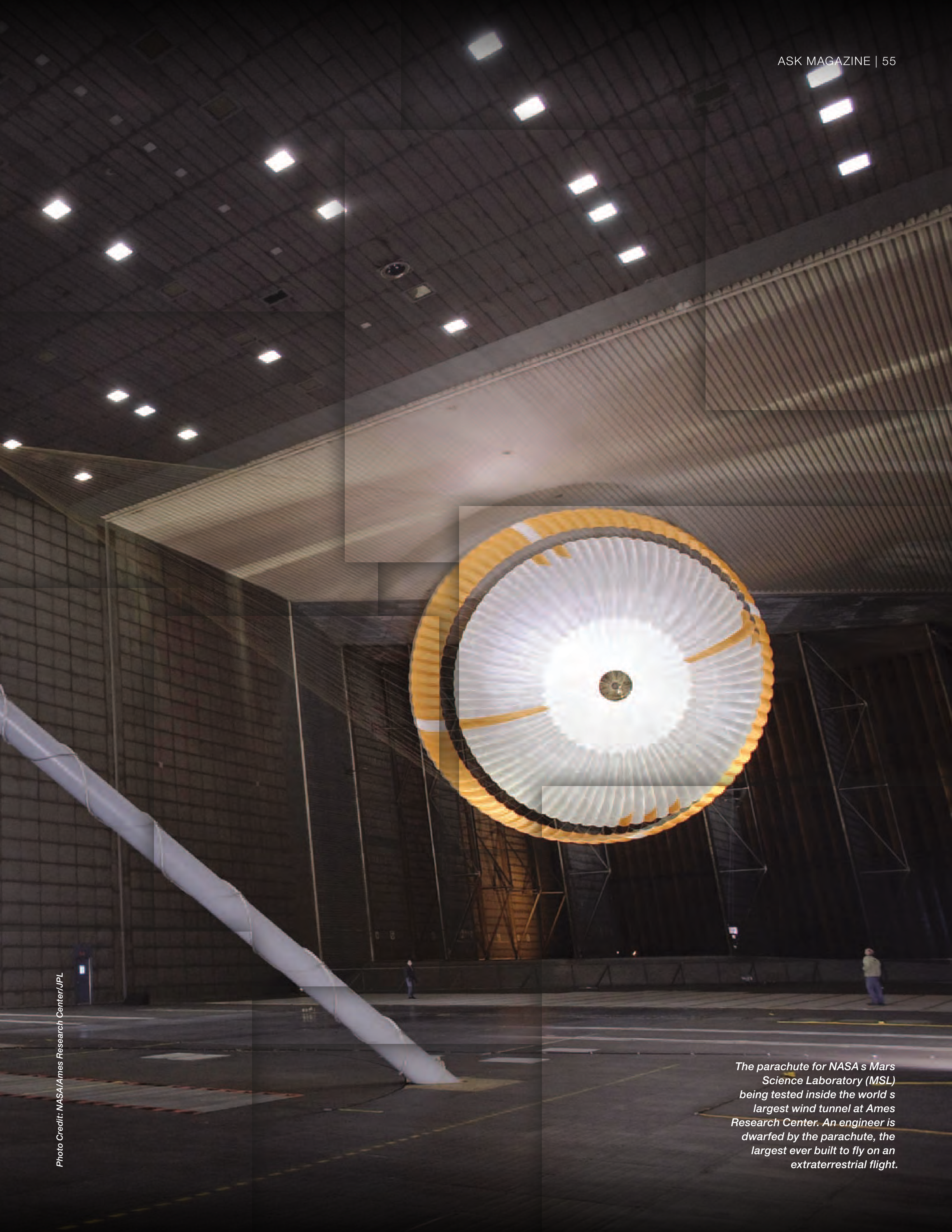


Photo Credit: NASA/Ames Research Center/JPL

The parachute for NASA s Mars Science Laboratory (MSL) being tested inside the world s largest wind tunnel at Ames Research Center. An engineer is dwarfed by the parachute, the largest ever built to fly on an extraterrestrial flight.

Image Credit: NASA/JPL Caltech

Artist s concept of the Mars Science Laboratory in Martian terrain.

MSL is the next major step forward in NASA's Mars Exploration Program and will address key questions about the past and current habitability of Mars. The project is also developing critical new technology for landing on Mars, acquiring and processing surface samples, and conducting long-duration surface operations. This is probably the most complex planetary mission that NASA has ever attempted. As a result, it has stressed our implementation processes, our technology, our engineering capabilities, and our people. Although the project hasn't launched yet, it has been extraordinarily useful in one regard: demonstrating the challenges of managing complexity on large-scale programs.

So, what is complexity? The word is frequently thrown around as a sort of synonym for "difficult." But it is more than that. Paraphrasing Webster, "Complexity is the quality of being intricately combined." The characteristic that separates complex projects from merely difficult ones is the number of interconnected elements that are tied either technically or programmatically. Flagship efforts are becoming increasingly difficult *and* complex. Increased complexity is a primary cause for the challenges we've experienced. The MSL development experience is rich with examples where our ability (or inability) to effectively manage complexity has provided valuable lessons.

At the recent Project Management (PM) Challenge in Long Beach, California, I gave a presentation on those lessons across domains including technology infusion, margin management, schedule planning and oversight, and the role of external reviews. Given space limitations here, I will focus on the connections between system architecture and complexity.

Defining the right system architecture—the top-level structural and behavioral relationships between parts of a system—is critical to managing complexity. So what makes the "right" system architecture? The easiest answer is, the one that is as simple as possible but no simpler; the one with the most "separation" between elements; the one with the simplest interfaces, the most functional independence, the least reliance on those one-size-fits-all solutions that drive custom-interface accommodation. Greater complexity and interaction mean increased potential for problems and increased difficulty in testing to discover them.

Unfortunately, a number of factors frequently undermine system architecture simplicity. Examples include technology limitations and complexity, mass/volume constraints, cost, and the use of heritage hardware. I could mention several examples of MSL handling systems complexity well, but I'll start with one where we didn't.

THE CHARACTERISTIC THAT SEPARATES COMPLEX PROJECTS FROM MERELY DIFFICULT ONES IS THE NUMBER OF INTERCONNECTED ELEMENTS THAT ARE TIED EITHER TECHNICALLY OR PROGRAMMATICALLY.

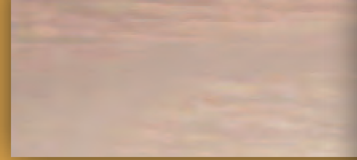
We inherited several key aspects of the MSL architecture from the Mars Exploration Rover program. One example was having the rover's avionics control the entire mission from launch through landing. This architecture was adopted for MSL despite the fundamentally different functions for launch; cruise; entry, descent, and landing (EDL); and rover operations. The intent was to take advantage of the core elements of the rover avionics (the processor, the power converters) to perform cruise and EDL functions. Adding additional boxes outside the rover required accepting the associated cost, schedule, and mass impacts. The problem with this architecture is that it significantly increased the complexity of the design by functionally integrating the rover and cruise/EDL systems. The cruise/EDL system could not be designed and tested independently from the rover because it was an integrated system.

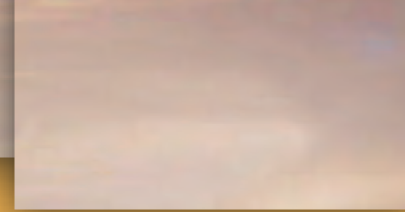
Spacecraft technicians at the Jet Propulsion Laboratory prepare a space simulation test of the Mars Science Laboratory cruise stage in a facility that simulates the cold, vacuum environment of space.

So why was this choice made? We did an early concept study of a "smart" descent stage. The idea was to put enough avionics on the descent stage to control the vehicle during cruise and EDL (the rover would be along for the ride). The primary reason we didn't choose that approach is that we have a tendency in the early phases of a project to base system-design choices on box-level factors. Because the cost, schedule, and design of boxes can be coarsely quantified, it is simpler to factor them into design choices. Less apparent factors like the amount of input/output a box requires, the interface complexity, fault-protection implications, and verification challenges—all byproducts of system complexity—are difficult to quantify and factor into system decisions. These items typically don't manifest themselves until later in the development cycle and are frequently the source of significant cost growth. By not adequately factoring this cost-growth risk into the system trade, we ended up with a design with the fewest number of boxes rather than the least complex architecture.

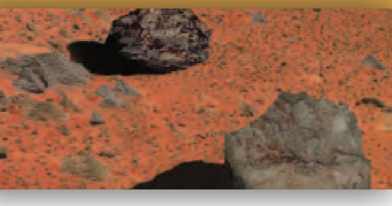
Another driver toward functional over-integration is the pervasive impact electronics technology is having on our core systems. Unlike the world of thirty years ago, virtually all electronics we use today come from a commercial sector with different and diverse technology drivers, not just space applications. The increased functionality possible with high-density field-programmable gate arrays (FPGAs), low-voltage parts, and high-speed bus architectures are dramatic and enabling, but they increase complexity enormously. The pressure to have "less" hardware and depend more on software results in highly integrated and highly complex designs.

One associated pitfall is that we don't approach the incorporation of these new devices into our systems with the same degree of rigor we treat other types of technology. That may partly be due to the perceived maturity of the commercial components. We frequently have trouble with parts that have a commercial track record but haven't been through a full flight-qualification program. A good success story on MSL was our efforts to "mature" high-density, radiation-tolerant FPGAs.





THE PRESSURE TO HAVE "LESS" HARDWARE AND DEPEND MORE ON SOFTWARE RESULTS IN HIGHLY INTEGRATED AND HIGHLY COMPLEX DESIGNS.



The Mars Reconnaissance Orbiter and other programs had experienced a series of problems with less dense parts, so MSL adopted an aggressive program to establish acceptable design guidelines, packaging/rework approaches, and thermal control/qualification strategies. The result was that the project did not experience significant FPGA technology issues during the build/test campaign.[1]

The FPGA challenges we did have were associated with the design complexity caused by functional over-integration. The large number of logic gates available in modern FPGAs allows many functions to be combined into a single component. This does complicate the design effort, although some parts of the FPGA "code" can be developed by parallel teams. The verification and validation effort, however, grows dramatically because so much functionality is combined. Our test methods don't really support ways of performing rapid, parallel testing of a single, highly integrated element. A long serial-test program is difficult to manage, is brittle to changes and problems, and can be inappropriately curtailed if schedule pressure mounts. A design based on a larger number of simpler elements would permit parallel component testing and (with appropriate interface definition) simpler system testing as well.

Fault tolerance is another system-architecture driver that can significantly affect complexity. Inappropriate evaluation of local-versus-system fault tolerance can dramatically increase complexity without necessarily improving overall reliability. An example from MSL was the incorporation of partial redundancy in the core rover avionics. The mass and volume of the avionics are major drivers on both the rover configuration and the required capabilities of the entry, descent, and landing system. Heavier or larger avionics increase EDL system risk by reducing control-system performance margins or increasing landing velocity and loads.

Intrinsically, however, avionics fault tolerance is provided by adding redundant boxes with some degree of cross-strapping. (Cross-strapping permits redundant boxes to work with other redundant elements in the system architecture.) On MSL, the project took an intermediate position of incorporating some partial avionics redundancy to mitigate box-level failures while not driving EDL risk adversely. Unfortunately, the resulting system is neither fish nor fowl from a complexity perspective. By having a combination of single-string and redundant elements, the resulting fault-containment architecture is more complex and more difficult to design, analyze, and verify than either a single-string or fully redundant design. The marginal increase in reliability associated with the partial redundancy may not have been worth the increased complexity.

These are just a few examples of the drivers that can push a system architecture toward increased complexity. Potential institutional mitigations could include additional training to increase our systems engineering expertise on both the sources and consequences of architectural choices. Additional efforts can also be made to rigorously review system architecture choices to understand the long-term implications. Upgrading our cost and schedule estimation processes to capture the impact of complexity on cost and schedule risk would also be very useful.

From the perspective of an individual project manager, establishing simplicity as a programmatic goal is both a symbolic and a real step toward managing development risk. This is particularly imperative for projects with profound technical and engineering challenges. Intrinsically difficult missions like MSL are made much more challenging if managing complexity gets inadequate attention. Policy direction advocating simplicity is a useful first step to keeping complexity contained. ●

RICHARD COOK is the deputy project manager of the Mars Science Laboratory at the Jet Propulsion Laboratory. He is a veteran of NASA's Mars Exploration Program, having held key roles on Mars Pathfinder, Mars rovers Spirit and Opportunity, and Mars Surveyor '98.

1. We did have FPGA problems associated with design complexity (we tried to put too much functionality into a given part), which led to very long delivery delays and test-program challenges. The fundamental part technology worked, however.

Volunteers Wanted: Best Practices from Volunteer Organizations

BY KEITH L. WOODMAN

I once had a NASA project manager who was notoriously hard to work with lament that people were leaving his project as fast as they could. Another project manager, who had no trouble retaining people, told me one of his secrets to success was to manage team members like volunteers. This insight intrigued me.

MANAGERS NEED TO MAKE CLEAR THE PROJECT'S GOALS, TIMELINES, ORGANIZATION, LINES OF AUTHORITY, AND ROLES—THEIR OWN AND THOSE OF OTHER KEY LEADERSHIP POSITIONS IN THE PROJECT.

NASA technologists definitely have some similarities to volunteers: they both dislike poor project management (the number-one reason volunteers quit), and they both have options when faced with an unpleasant work situation. While NASA technologists may not be able to just quit the way volunteers can, they certainly have more options than their counterparts in the private sector. Typically, NASA project managers do not directly supervise the employees supporting their projects. Instead, employees are matrixed from other organizations, which also support several other projects. So if a technologist is dissatisfied with a project manager, there is a chance she could move to another project. This chance greatly increases with the technologist's experience and competence, the demand for her particular skills, and the number of other projects the organization supports.

To help keep the best technologists onboard, NASA project managers can benefit from understanding how leaders of volunteer organizations attract, motivate, and keep talented people working for them. The United Press Service report, "A Guide to Investing in Volunteer Resources Management: Improve Your Philanthropic Portfolio," includes a comprehensive list of best practices for managing volunteer organizations, many of which could help NASA project managers retain the best employees.

Developing and Communicating a Compelling Vision

Project managers should establish and communicate a compelling vision for what they want their projects to accomplish. Compelling visions are common at NASA, thanks to the incredible work our agency does beyond the cutting edge of technology, accomplishing things that have never been done before. Unfortunately, I have seen great visions go to waste because the project manager never communicated them. Project managers must make communicating their visions a priority.

Setting the Example

Project managers must "walk the talk," demonstrating the commitment, values, and beliefs they want from their teams. In my experience, project managers who live up to the standards they profess inspire team members to meet or exceed those standards. On one project I worked on, members of our team were letting personal pride get in the way of working with other teams. The project manager called us in and talked about how our team needed to swallow its ego for the sake of the project. At the next project review, we saw him set the example when he ignored multiple insults from one of the project's sponsors, attacks I know I would have taken personally. Instead, he stayed focused on the project's technical problems and how to solve them. His demonstration of what he was telling us to do made us check our own egos at the door for subsequent project meetings. Had he not done so, it's doubtful the project would have pulled itself together. Project managers who fail to meet their own standards will be seen as hypocritical, which greatly diminishes their team's trust and will eventually lead to reduced support.

Orienting Personnel

Ensuring project personnel understand what they need to know to support the project from the very beginning is an important task for project managers. Managers need to make clear the project's goals, timelines, organization, lines of authority, and roles—their own and those of other key leadership positions in the project. Most importantly, the project manager must convey what is expected of the team: what they are required to do and how they are expected to perform. To the extent possible, job descriptions and project policies should be documented and accessible.

If possible, project managers should screen employees before they join the project teams to determine if they would be a good fit technically and otherwise, particularly on smaller projects. They should look for a genuine desire in each person to play an active role in the overall success of the project.

Providing Support

Volunteers want to feel supported by the organizations to which they donate their time; so do NASA personnel. Ensuring that employees have the resources they need to get the job done is one way project managers can provide that support. Another is to offer developmental support to help employees do their current jobs better or prepare them for future positions. NASA project managers have several opportunities to support employees' training, such as classes offered by the Academy of Program/ Project and Engineering Leadership or university classes through NASA's education system. Very often, projects reap immediate benefits as project personnel bring back new knowledge and apply it to make their projects successful. For instance, a project manager once sent me to the Massachusetts Institute of Technology for a short course on a new analysis technique. The moment I returned, he formed an analysis team whose product was based on the results provided by the new technique. Both the team and I benefited from the time our project manager took to aid my professional development.

On another of my projects, the project manager described his philosophy: he groomed engineers with a systems perspective for future work as systems engineers or instrument managers. This chance at advancement gave me incentive to develop a systems perspective.

Supervising and Communicating

Project managers should also be following the old management axiom that what gets measured gets done. As the project moves forward, monitoring the performance of project personnel is key. This allows the project manager to address problems sooner rather than later and provide feedback on how employee efforts are helping the project reach its goals. Employees want to know their efforts make a difference. But project managers should also actively seek feedback on their own performances. Some questions that would provide useful feedback might include the following:

- Do team members feel their efforts are having a positive impact on the project?
- Do they think the project is well managed?
- Is the project manager making them feel that they are a welcome and integral part of the team?
- In what ways is working on the project (or for the project manager) meeting or not meeting their expectations?
- And, perhaps most importantly, would project personnel work for the project manager on a future project? Why or why not?

Of course, employees may not be willing to share this kind of information openly, so developing a way to anonymously submit feedback may help. Hearing criticism is never easy, but there is always room for improvement. After receiving the results, project managers may want to work with a coach or mentor to improve in areas indicated by their former staff.

For more than a year, I have been working with a coach who is helping me to strengthen weaknesses indicated by my peers and through direct reports. Doing so has helped me increase my ability to listen, giving me more options to successfully conclude my projects. When personnel feel their ideas have value for you, they generally want to keep working with you.

Recognizing Performance

NASA project managers would also do well to remember another management axiom: what gets rewarded gets repeated. Appreciation tends to be listed as one of the primary motivators for employees and volunteers. Usually the simplest, and perhaps the most effective, way for project managers to motivate employees to keep working for them is to sincerely offer thanks for an effort well done. One NASA project manager I worked for (and would work for again) was rarely able to reward his employees monetarily, but he always made us feel appreciated by consistently recognizing and sincerely thanking us for our efforts. Combining rewarding with communicating can help reinforce behaviors project managers want from their employees.

A Voluntary Workforce

As any project manager in the private sector will tell you, retaining good people is critical to success. Investing the time and resources into training replacement personnel is costly on many levels. NASA technologists, like volunteers, have a lot of say over the projects they will and will not support. Therefore, it may be in NASA project managers' best interests to view the people supporting them as volunteers and provide the compelling vision, support, communication, and recognition required to retain their support. ●

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The Knowledge Notebook

The Meaning of Meaning

BY LAURENCE PRUSAK

A while ago I asked a number of colleagues, clients, and friends the following question: "If the word 'knowledge' were somehow banned from the English language, what existing word could take its place?" The answer I get most often, especially when I've asked students and others who are not in the business of thinking about organizational knowledge, is "information." It's a natural and reasonable enough choice, I suppose, but the answer I would give and the one I want to advocate is "meaning." When I explain why I prefer that word, I usually can get most practitioners of knowledge-related work to agree. After all, meaning is what gives information its value. The meaning-making process takes the codified symbols that we call information and makes sense of them in ways that help guide our thoughts and actions.

Meaning is subjective, of course. We develop our own mechanisms for giving meaning to things and words from the world around us and the world within us. Different people interpret the same information in different ways and sometimes discover in it (some might say, impose on it) very different meanings.

Yet we live in a world of collective activities. Teams, projects, organizations, schools—all have to develop collective meaning in order to do their collective work. This happens, of course. If it didn't, collaboration would be impossible. We assign common meanings not just to words but to all sorts of representations and symbols, and this collective sense-making allows organizations and cultures to flourish. Yet it happens in subtle and often unnoticed ways—pervasive yet invisible—and our failures to pay conscious attention to the process of shared meaning-making means that we often don't work together as effectively as we could.

The process, however, is often overlooked and even disdained by the latest incarnations of techno-utopians who continue to argue that information alone matters and that the more of the stuff we have, the better an outcome will be. I was told three times in the past month—by people in a federal agency, a prominent non-governmental organization, and a commercial firm—that more connectivity in any system (in other words, greater access to information) means that the proposed system will develop more knowledge. When I pointed out that this isn't at all a proven case, I quickly lost my audience. They wanted to move on to system configuration, not talk about whether the system would actually provide the promised value. I'm used to this kind of response, so I wasn't especially upset personally, but past experience suggests that their expectations are likely to be unmet.

Let's look briefly at a few of the things meaning can bring to information. I am inspired to do this by recently reading a wonderful new book on the history of information by James Gleick called *The Information: A History, a Theory, a Flood*, and by doing some teaching in Tokyo for Fuji and some of their clients on the subject of practical wisdom, which is closely related to what I am writing about here.

Context. Meaning puts information in context, showing where it belongs in the scheme of things, how it relates to other information, how it adds to or modifies existing knowledge.

Implications and Consequences. Meaning gets at the implications of information, its potential effects on individuals, organizations, and society.

Thinking in Time (also the title of a wonderful book). Meaning-making includes thinking about where information originated and where it seems to be going, and how its origins affect how we interpret it.

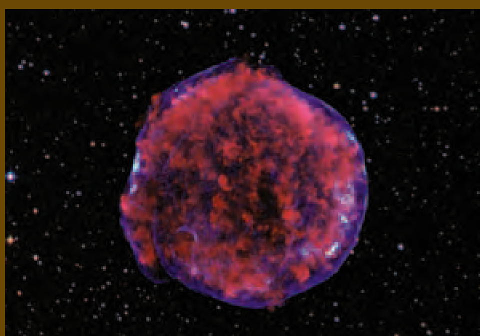
You get the picture, I hope.

Let me be just a bit more personal here. I was once a contestant on a national quiz show. I had a very good memory at the time and liked to read, so I was a natural for this type of thing. I did well and for a time thought I was much smarter than I actually was. I could recite facts that I didn't know the meaning of and confused this skill with having real knowledge, judgment, and discernment. This was a long time ago—I was a college student—so I won't be too hard on myself. Because of my quiz-show experience, I was quite interested in the reactions to Watson, the elegant IBM computer program that recently beat a couple of *Jeopardy* champions. But when pundits declare that the machine is "smarter" than people, I am reminded of my own experience of the silliness and shallowness of this type of thing.

Gleick ends his fine book by talking about how, among the seemingly infinite amount of information we now have at our fingertips, we still are always "looking for lines of meaning." Think about it. ●

… OUR FAILURES TO PAY CONSCIOUS ATTENTION TO THE PROCESS OF SHARED MEANING-MAKING MEANS THAT WE OFTEN DON'T WORK TOGETHER AS EFFECTIVELY AS WE COULD.

ASK interactive



NASA in the News

A pattern of X ray “stripes” in the remains of the Tycho supernova, discovered after long observation with NASA s Chandra X ray Observatory, may provide the first direct evidence that a cosmic event can accelerate particles to energies a hundred times higher than those achieved by the most powerful particle accelerator on Earth, the Large Hadron Collider. “We ve seen lots of intriguing structures in supernova remnants, but we ve never seen stripes before, said Kristoffer Eriksen of Rutgers University, who led the study. The results could explain how some of the extremely energetic particles bombarding Earth, called cosmic rays, are produced, and they provide support for a theory about how magnetic fields can be dramatically amplified in such blast waves. Read more about the discovery at www.nasa.gov/mission pages/chandra/news/tycho.html.

Building Curiosity

Curiosity Cam takes you inside the clean room at NASA’s Jet Propulsion Laboratory in Pasadena, Calif., to watch the next Mars rover being built. Technicians assembling and testing the Mars Science Laboratory, known as Curiosity, are covered head to toe in white smocks, booties, and facemasks to help protect against earthly contaminants hitching a ride to Mars. Watch Curiosity come together at www.nasa.gov/mission_pages/msl/building_curiosity.html.

NASA Image of the Day

Discover what’s going on inside NASA through beautiful photographs from across the agency. Images from current missions, new scientific discoveries, moments in history, and more are posted daily with extended descriptions to help you learn visually about NASA’s goings-on: www.nasa.gov/multimedia/imagegallery/iotd.html.

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