National Aeronautics and Space Administration

Academy Sharing Knowledge

ask

The NASA Source for Project Management and Engineering Excellence | APPEL

WINTER | 2009

Image courtesy the NASA Art Program

ON THE COVER

“Power 1963,” by Paul Calle

In this oil on panel piece, Calle depicts the Atlas launch vehicle, producing 360,000 lbs. of thrust, as it lifts the last Mercury astronaut, Gordon Cooper, into Earth orbit for a thirty-four-hour flight on May 15, 1963—at the time, an American long-duration record.

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

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

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

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In This Issue

When Megan was fourteen years old, she started to have trouble swallowing and keeping food down. The family general practitioner examined her and ordered some tests. Finding nothing obviously wrong, he assured Megan and her parents that the problem would take care of itself. But Megan's digestive problems got worse. She went to one specialist who prescribed an antibiotic that had no effect. Other doctors were baffled. Then her parents took her to the Hospital for Sick Children in Toronto. Soon after she was admitted, three specialists entered Megan's room together: an internist, an allergist, and a gastroenterologist. They had all studied her records. They asked a few questions and examined her. Then they shared their ideas.

The allergist said he was sure the problem was not a food allergy.

"I think it's an infection," the gastroenterologist said.

The internist agreed and thought he knew why the earlier course of antibiotic treatment had not worked. Within five minutes, the three physicians agreed on a diagnosis and a treatment—a particular antibiotic effective against the unusual infection she had contracted. Her rapid recovery proved them right.

This true story illustrates the value of a multidisciplinary approach to difficult problems, the theme of several articles in this issue of *ASK*. The knowledge of people from different fields working together can combine to generate ideas that individuals or groups with a shared specialty are unlikely to come up with. So, for instance, the varied members of the Human System Risk Forum (Judith Robinson's "Human System Risk Management") arrive at a solution that members of a cardiovascular research lab couldn't see from their necessarily limited perspective. Similarly, the different viewpoints Barry Goldstein describes bringing together in "Working with a Team of Zealots and Skeptics" ensured that Phoenix's entry, descent, and landing processes got a more knowledgeable and rigorous examination than either group alone would have provided. Matthew Kohut's article about the IDEAS course and Svetlana Shkolyar's "Conquering Space by Capturing Imaginations" both show how important a role diversity of ideas plays in innovation.

There is more to reaping the benefits of diversity than throwing dissimilar people together. Ed Hoffman's "From the Director" column discusses the skills needed to turn a diverse group of people into a successful team. The manager of a multidisciplinary project team must understand enough about the varied technical specialties of members to earn their trust and make informed decisions about the value of their contributions (as well as foster trust and communication *among* team members). The project leader also helps keep the group focused on the team's goals and the practical realities of schedule and cost—the project basics Steve Goo talks about in "Staying Focused on Fundamentals."

The interview with scientist Charles Kennel looks at similar issues of coordination and communication in a different context: the development of a system of Earth-observing satellites and the challenge of making the information they provide accessible and useful to both scientists and politicians.

Finally, Piers Bizony makes a case for a multidisciplinary approach broad enough to include artists. His "Viewpoint: The Bigger Pictures" suggests that we need artists, writers, and musicians to capture the emotional complexity of space flight, to show the public why we do it and win their support for future exploration.

Don Cohen
Managing Editor

From the APPEL Director

Multidisciplinary Project Leadership

BY ED HOFFMAN

If you were building a house, what set of skills would you need? It might be best to be a carpenter, capable of working on the rough framing, the exterior, and the trim details. There's also a good argument for being a mason: a house is only as strong as its foundation, and a good brick or stone exterior will last a lifetime. Then, of course, there are electrical systems, plumbing, heating, ventilation and air conditioning, and other specialized trades.

It's possible that specializing in one construction trade over another has advantages, but the skills I'd want would be those of a project manager. In home construction, that person is called the general contractor, but the responsibilities are those of a project manager: managing cost and schedule, communicating to promote coordination and integration of team members from different disciplines, knowing enough about the technical details to ask the right questions, and ensuring that the finished product meets all requirements and performs as expected.

Project managers have been playing this role on engineering projects since the time of the pyramids. We know this has been the case in research-driven industries since early in the last century. In his book *The Scientific Life*, Harvard Professor Steven Shapin writes that "corporate research centered not on the competencies and career interests of any one worker, or on any one group of specialized workers, but on the *project* [his emphasis], which typically called on the skills of research workers from a variety of scientific disciplines … placed in organizational structures where communication … was facilitated and encouraged." He goes on to note that Eastman Kodak, which opened its first industrial research laboratory in 1912, was organizing cross-disciplinary groups of scientists to work on photographic emulsion nearly 100 years ago. Since then, technical organizations have increasingly organized around projects because they have found it to be the best way to synthesize the efforts of talented individuals with diverse areas of expertise and knowledge.

A modern project brings together people of multiple talents over a finite period of time to accomplish a specific objective. There is a strong focus on understanding the customer—getting the requirements right is critical. The project takes place in a dynamic environment that demands adaptability. Teams typically cross all kinds of boundaries: geographic, cultural, organizational, and professional. Outsourcing for expertise is the norm. Team members can be employees, partners, consultants, or even vendors, which means the project manager has limited authority. So professional management skills like persuasion, negotiation, and collaboration are as essential as traditional project controls like cost and schedule management.

Leading a diverse team of highly talented individuals requires earning respect and trust. The key word is "earning." Credentials matter, of course—experts won't tolerate being led by an amateur—but they are only the price of admission. Team members ultimately care about actions. Respect and trust are reciprocal. When leaders practice them, the team will follow, and vice versa.

A project leader is like an orchestra conductor. An orchestra brings together strings, woodwinds, brass, and percussion, all of which require highly specialized skills. The conductor has to guide the entire ensemble through a composition—a project—that takes place in a finite period of time. Of course, an orchestra rehearses. There is no rehearsal for project leadership; it is a continuous on-the-job learning experience. ●

A New Design Approach: MODULAR SPACECRAFT

AS TOLD TO MATTHEW KOHUT BY BUTLER HINE AND MARK TURNER

Engineers prepare the Hover Test Vehicle for ground tests.

Photo Credit: NASA

When Pete Worden took over as the center director at Ames Research Center, one of the charters he came in with was to inject low-cost ways of doing spacecraft development into NASA as an agency. He kicked off a handful of projects to achieve this, including the Modular Common Bus. At the outset, he told us to design for a broad range of target locations: lunar orbit, lunar surface, libration points, and asteroid rendezvous. He also said we had to make the spacecraft compatible with a range of low-cost launch vehicles, from the Falcon 1 at the low end to the Minotaur 5 at the high end.

Capabilities-Driven Design: Fly It and They Will Come

The Common Bus basically flipped the standard NASA spacecraft development pyramid, where you start with your requirements and instruments and flow a spacecraft design from that. We call the Common Bus approach capabilities-driven rather than a requirements-driven development. The idea is to maximize the use of off-the-shelf or readily available components and look for a sweet spot in the design that will enable you to create a small spacecraft for common use independent of the payload you're going to carry.

If you build a standard size and form factor, the science community will create payloads to fly on it. Once you standardize anything that's going into space, the science community is creative about making packages work in that form factor. And while we didn't design the spacecraft for any particular payload, we did look at the list of possible payloads: some of the robotic precursor concepts for the lunar lander, dust experiments and other science for lunar orbit, communication relay packages for lunar orbit, and typical packages for asteroid rendezvous. We picked the most challenging payloads in each of those areas and used them to shape our design. So even though we didn't design for one payload, we did work with a lot of examples.

An Atypical Team

One thing Director Worden did early on was bring in Al Weston and Pete Klupar, two people from outside NASA who had extensive experience at the Air Force Research Laboratory (AFRL). Al was halfway a team member and halfway our primary customer. He was involved every step of the way. Formerly director of the National Hover Test Facility at Edwards Air Force Base, he had a lot of experience. Pete, who came from AFRL to Ames, has flown something like forty-five to fifty small spacecraft. During a typical NASA career, you get a half-dozen missions under your belt, if you're lucky. The AFRL model is one we looked at in trying to enable small spacecraft design, and Pete was the one who brought that experience to the table. So we had a lot of resources around us with tremendous experience, but it wasn't the traditional NASA experience.

We were set up like a skunk works, and we were allowed to handpick the best people on the team. A lot of them had some flight experience in International Space Station and Space Shuttle payloads or sounding rockets, but the team as a whole did not have a lot of experience with free-flyer spacecraft. One of the things we learned when recruiting people for this kind of team was to look at their hobbies, because that tells you a lot about how they'll approach their work. Most people on this team had hands-on hobbies: woodworking, machining, racecar fabrication.

Our team has an extremely strong foundation in engineering design and materials. Most of our folks have fifteen to twenty years of hardcore engineering design experience. Their greatest strength is that they have multidisciplinary skills. Many of our engineers are capable of performing tasks typically done by a variety of engineering disciplines. For example, some have run

Photos courtesy Mark Turner and Butler Hine

smaller projects in which they have had to design, analyze launch loads, develop requirements, manage configurations, write their own test plans, and do their own verification and validation.

For the Common Bus effort, our designers assembled the prototype hardware they designed to the greatest extent possible. This was done to contain costs and also to allow them to experience firsthand what worked and what did not. Having a smaller cross-disciplinary team creates efficiencies by requiring less time to communicate and transfer information and instructions. For projects of this size, this approach has been very effective. They also had incredible intellectual curiosity. As soon as we gave them a problem, they ran out and researched everything that had been done.

A Modular Approach

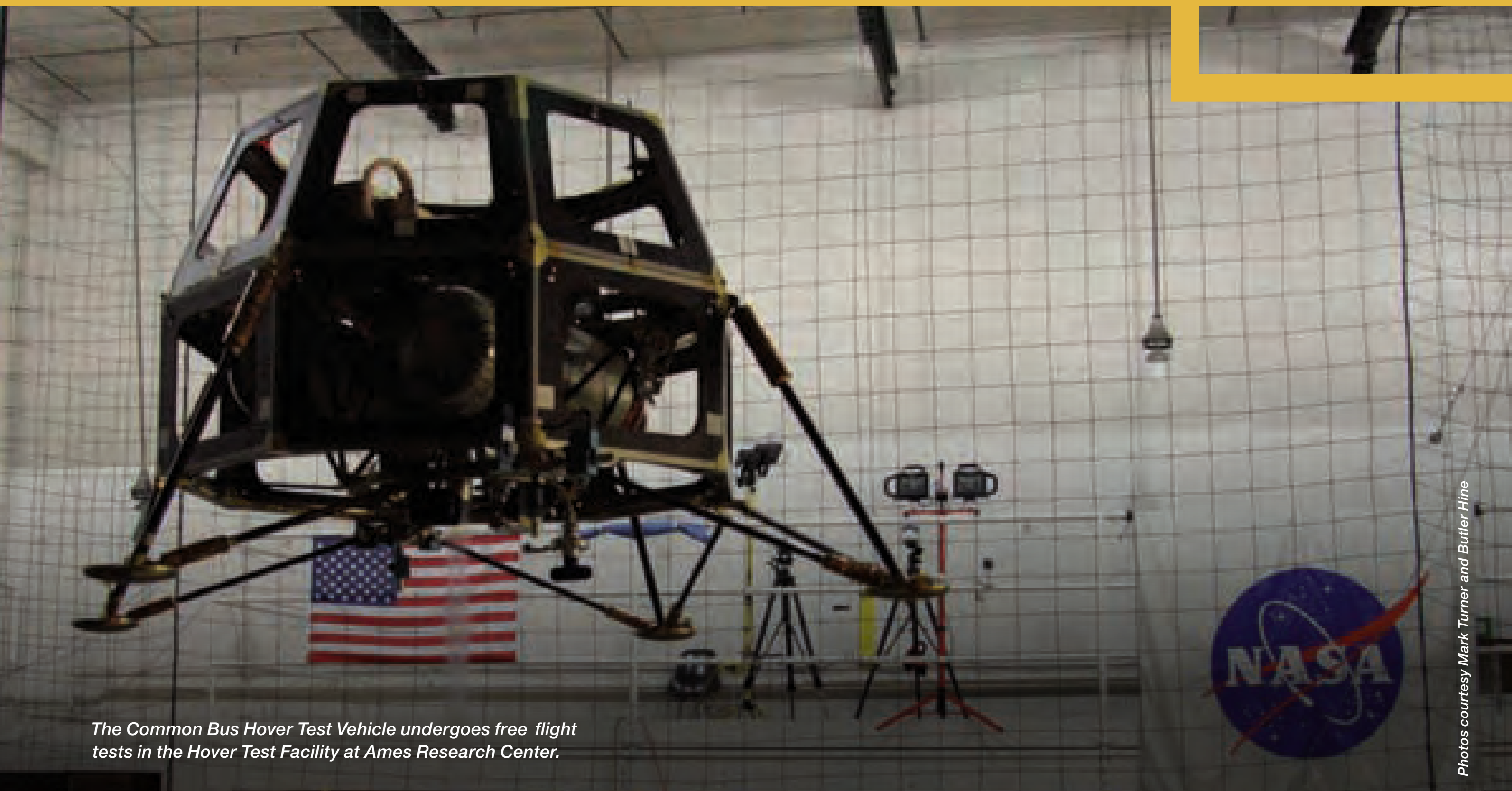
Given the range of targets, we figured we'd have to design an orbiter and then separately design a lander, because we assumed that one spacecraft couldn't meet such radically different requirements. So we started out designing landers and orbiters in parallel. As the designs evolved, the design team started breaking the systems up into modules. There were a lot of reasons to do that.

The thing that stretches out the cost and schedule of a typical spacecraft build is the integration flow—downstream integration that depends on upstream integration being completed first. We pushed for modularity so we could have parallel integration of the spacecraft development. According to some of the schedule rough cuts we analyzed, parallel integration could save us up to a year.

There was a "Eureka!" moment when the team suddenly realized that we could use some of the same modules for both orbiters and landers. Suddenly the team coalesced around these module designs that become an orbiter configuration when you combine them one way and a lander configuration when you combine them another way. And if you standardize the modules, then theoretically you can reuse that design for each mission and recombine the modules to meet specific mission requirements.

When you look at design drivers, especially your launch loads, a cylindrical structure is close to ideal. Early spacecraft like Pioneer have very efficient shapes; they're usually cylinders with body-mount solar panels. Then you realize that, if you start using advanced composites, which they didn't have in the sixties, you could have the beauty of flat surfaces for mounting your electronics, payloads, brackets, and harnesses very easily, yet maintain close to the same structural advantages of a cylindrical shape.

Through the use of composites, what worked for a lunar lander was also ideal for an orbiter. These common segments enabled us to maximize payload capacity, which was critical for these very small, mass-sensitive launch vehicles.



The Common Bus Hover Test Vehicle undergoes free flight tests in the Hover Test Facility at Ames Research Center.

Photos courtesy Mark Turner and Butler Hine

A Design Trade: Body-Mount Solar Panels

Historically, Ames has done body-fixed solar panels for a lot of designs. Other NASA centers standardized around deployable solar panel wings. Our preference for fixed solar panels was kind of a running joke because we wound up there for reasons having nothing to do with past Ames designs.

Body-fixed solar panels made us independent of attitude in space. That gave us structural advantages as well, and it also gave us a lot of flexibility to handle the thermal environment operationally rather than in the design. It meant we could be a three-axis stabilized spacecraft, or a spinner, or a combo. We could have a pointed instrument that needed to be three-axis stabilized, and then for thermal reasons we could do a slow rotation to avoid having one side constantly hot and the other constantly cold. One of the main reasons reusable spacecraft designs haven't really worked in the past is because of issues like thermal design. Typically your thermal design has to be customized for the payload and the location where you're sending the spacecraft. That's what makes each spacecraft unique: the mission, the launch loads, and the thermal environment.

As we got deeper into the solar panel work, we also realized that, from an orbital mechanics standpoint, we could go on longer, slower-duration missions by being body-mount fixed instead of deployable. Vehicles sometimes take many days or weeks to get to their final destinations. If you're going to the moon, you'd have to do a descent—a braking burn as you approach the moon—and the g-loads would be so great that you wouldn't be able to use deployable solar arrays until you got to the moon. But if it takes days or weeks to get there, your only real option is to keep everything body-mount fixed. That bought us a lot of flexibility for many of these small science missions. It's perhaps not optimal from a power standpoint, but it provided tremendous flexibility from a mission operations standpoint.

When you go body-fixed, you have less surface area for solar panels. Our design was able to produce 200-plus watts, which gave us plenty of power for the baseline spacecraft use and 60 watts or so available for the instruments. For the whole range of instruments we looked at, 60 watts was plenty. Instruments with higher power requirements may call for deployed wings that articulate to track the sun, which can give you a kilowatt, but that starts to limit the types of missions you can do. That was one of our direct trades: power availability versus thermal and attitude generality.

Deployed arrays also went counter to our philosophy of keeping costs low with short turnaround time. Deployables require one of the more elaborate, lengthy, and expensive test

sequences. The gimbals, for example, are typically one of the longer lead items on spacecraft development. So we saw body-fixed panels as a real risk-reduction enhancement without compromising the particular science suite we were trying to address in this particular portfolio. But it was a trade-off. We did give up power in order to get this flexibility.

A Knowledge Network

Because Ames is a research and development center, the systems engineering group here has the ability to work on a diverse array of engineering projects. Since most of our engineers work on smaller, shorter-run projects, they typically have to be jacks-of-all-trades. To survive in this environment, you have to be able to synthesize a state-of-the-art problem quickly and figure out how to extract the knowledge you need from the resources available. Nowadays the Internet has made that much easier, but most of the guys on our team were practicing this in the days before the Internet. The ability to extract that type of knowledge—tracking down the necessary information, setting up a network of colleagues around the country to get the answers you need—is really a black art.

ONE OF THE KEYS TO SUCCESS IS KNOWING HOW TO ESTABLISH A HUMAN NETWORK. EVERY ENGINEER ON OUR TEAM RELIES ON A HUMAN NETWORK TO GET AT STUFF THAT WOULD BE OTHERWISE QUITE DIFFICULT.

Since our team as a whole was relatively new to spacecraft design, we looked at what everybody else had done. None of our engineers like to reinvent the wheel. So we started by absorbing everything that had already been done historically and making sure we had an appreciation for that.

The two of us had the advantage of working for the Robotic Lunar Explorer Program (RLEP), so we had substantially researched prior lunar robotic missions such as Surveyor, Ranger, and even Lunakhod, a Russian lunar rover. We actually extracted Russian books and had parts of them translated so we could learn as much as possible. We also looked at robotic lander missions flown to Mars. So we didn't start from scratch. We had extensive research already at hand on robotic missions—lunar and Mars, Apollo data from the past, ranges of instruments that could do robotic precursor activities for the Vision for Space Exploration. We found gold mines in the early Apollo precursor missions. A lot of smart people had gathered a lot of data, and a lot of deep thinking had been done.

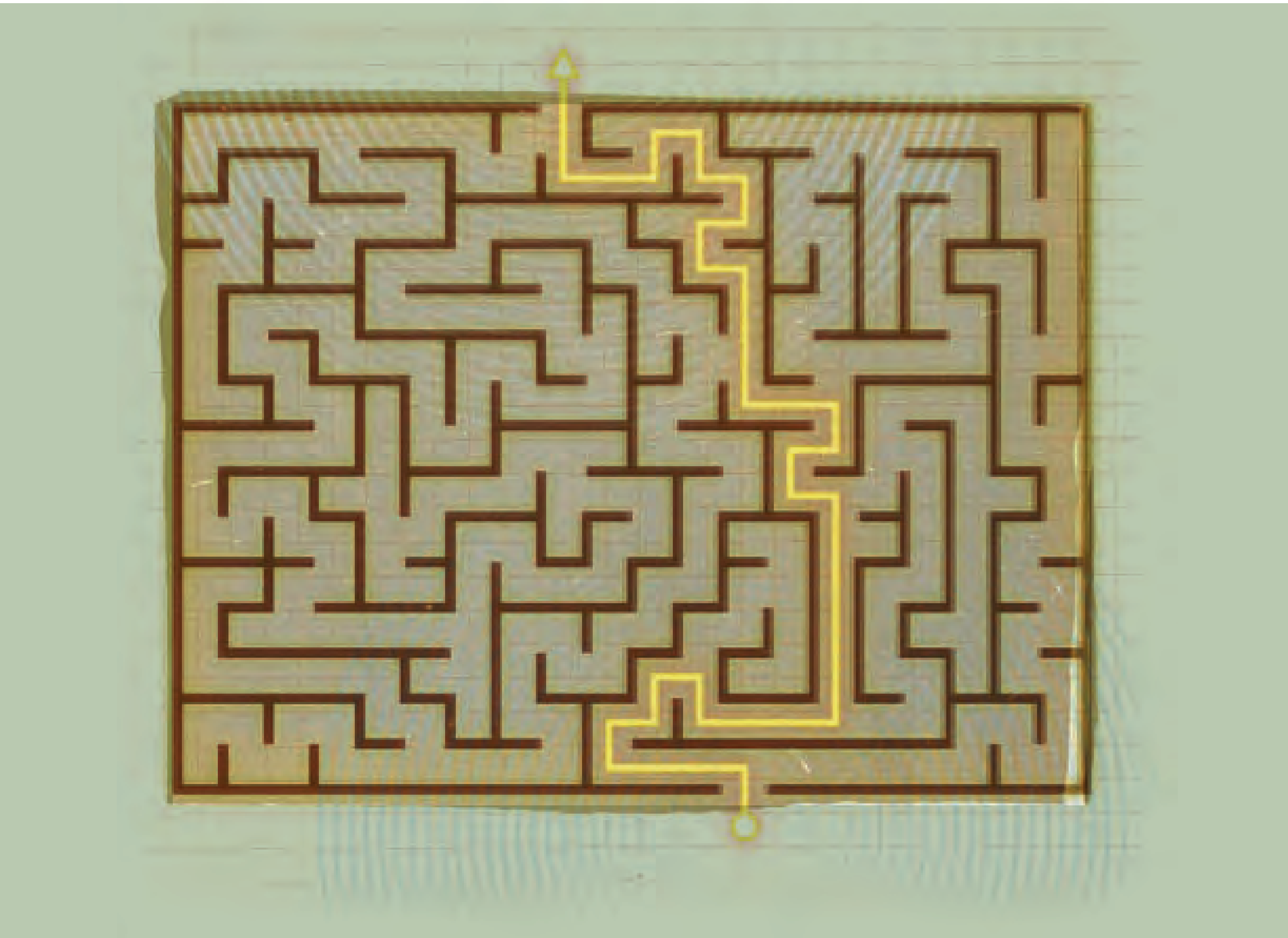
During our time in the RLEP program office, we were able to tap into a few of the remaining lunar scientists who participated in Apollo and pre-Apollo programs. We managed to find one of the early Ranger project managers, who was extremely helpful in giving us some of the rationale for decisions made in those early days. Gary Olaf, who was heavily involved in lunar dust studies, was a treasure trove of information from these early experiments. He knew where to find the information, and he gave us a lot of pathways to find information that would typically be very, very hard to get. Again, it's part of building a network.

One of the keys to success is knowing how to establish a human network. Every engineer on our team relies on a human network to get at stuff that would be otherwise quite difficult. Sometimes those contacts provide unexpected benefits. One of our Surveyor mission reports came from a consultant who happened to know a project manager from Surveyor, who gave him one of the few remaining hard copies of a document. Looking at the thousands upon thousands of people who worked on Surveyor and the millions of man-hours put in perspective how daunting it was for us to do our work with a dozen people. If we did not leverage the work thousands had done four decades prior, our job would have been impossible. ●

Staying Focused on Fundamentals

BY STEVE GOO

My first teacher in rocketry had a saying: "Pointy end up and fire out the bottom." His description of a perfect takeoff didn't mean that the execution was simple. It requires a lot of difficult engineering to get a rocket into space and keep it on course. But it also requires that many talented people stay focused on the fundamentals.



THE BIG 8: BOEING PROGRAM MANAGEMENT BEST PRACTICES

- **Create and Review Business Plan:** Set strategic objectives and measure progress throughout the life of the program.
- **Business Offer:** Understand customer, regulatory, and other requirements. Prepare executable and profitable proposals and contract changes.
- **Organization:** Develop a product-based organizational structure with clearly documented team responsibilities.
- **Supplier Integration:** Establish and maintain a collaborative working environment with suppliers from the earliest stage through program end.
- **Program Execution and Control:** Use a formal concept of operations to manage technical, quality, schedule, cost, and other activities.
- **Risk, Issue, and Opportunity Management:** Use an integrated method to grasp opportunities and mitigate or correct risks and issues.
- **Help Needed and Independent Reviews:** Promote a culture of open communication and continuous improvement.
- **Program Communication:** Develop and maintain strong relationships with internal and external stakeholders.

Most days, program management seems a lot like rocket science. At Boeing, we execute very well on many complex programs, but not without problems. The typical troubles found in our programs—and in other companies inside and outside the aerospace industry—occur because we lose our discipline and forget to focus on the basics.

Ten years ago, Boeing chartered a team to investigate why some of our programs did well and others struggled. It discovered the high performers used management strategies the other programs didn't. This finding led to the creation of the Boeing Program Management Best Practices, a management system for successfully leading a program through the twists and turns that invariably occur during its life span.

The eight best practices the team identified represent the fundamentals of program management. They serve as a road map for creating a focused, disciplined, and integrated approach to leading a program team.

Boeing has made use of these practices a top priority and put in place policies, processes, tools, and metrics to help our program managers employ them successfully. We built our best practices into an implementation model that is like CMMI (Capability Maturity Model Integration). It has 134 attributes, each with five maturity levels. Every year programs assess their implementation of the best practices, and every year we raise the bar a little, improving the model by incorporating new approaches and lessons learned. Refining and sharing the best practices allow us to replicate our successes and take maximum advantage of what we have learned as a company.

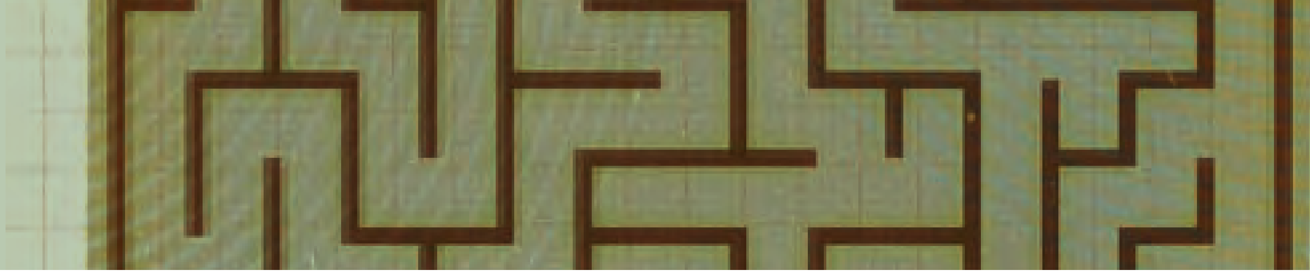
Of course, our best practices offer no guarantees. But over the past decade, they have demonstrated their value time and again. They have helped healthy programs see better results and reduced problems in programs that were overcommitted or at high risk because of technical, schedule, or budget challenges.

The first best practice, *Create and Review Business Plan,* starts with the program's strategy. It gets at the heart of what the customer is trying to accomplish: what customer needs you are trying to fulfill with your program. Program managers must understand both requirements and strategy. That way, when changes occur, they can better manage their impact on cost, schedule, and other aspects of the program. We make this the number-one best practice because it focuses on the customer.

The second best practice is the *Business Offer* or proposal: what you are going to commit to. This is important because it is much easier to successfully execute a program that is actually doable. This sounds fundamental, doesn't it? But how many times have we seen programs that cannot get there from here? The business offer makes sure you take a scientific, rigorous approach and are grounded in reality by experts in scheduling and cost accounting. The goal is to make commitments you can keep.

Organization comes next. How are you going to organize the program? Many program managers have trouble with this one. There should be a tight linkage between the work breakdown structure and the organization charts. What you have to build must be aligned with who is responsible for building it. A product-based organization helps the program manager because he or she can point to who is working on every one of those things you have committed to deliver to your customer.

Suppliers are the people who know the most about those things they are building for you. Program managers must integrate



IN AEROSPACE, WE DELIVER PRODUCTS THAT ARE HARD TO BUILD, SO IT IS UNREASONABLE TO EXPECT THAT ALL YOUR TEAMS ARE GOING TO BE ABLE TO SOLVE EVERY PROBLEM THEY ENCOUNTER ON THEIR OWN.

them into the overall team so absolute transparency exists up and down the contracting chain. Good **Supplier Integration** keeps you from getting surprised because it tells you what's going on. Failing to manage and communicate requirements with suppliers usually leads to cost overruns, missed deadlines, and rework. When we understand and properly manage our supply chain, we can seize opportunities or take corrective action quickly.

Program Execution and Control is where a program manager "lives" most of the time. This best practice helps you to consistently manage the seven baselines—requirements, organization, cost, schedule, configuration, information technology, and technical performance measures—as an integrated set. It is about having a plan and looking at metrics with real data every week. To manage effectively, you must have a plan that tells you where you should be and information about current status that tells you where you really are.

Risk, Issue, and Opportunity Management gives program managers the ability to look around corners, anticipate what might become a problem, and prepare to deal with it. A risk is something that could go wrong but hasn't yet, while an issue is something that is going wrong. At Boeing, we manage risks and issues as integrated sets because so many issues were risks that we were unable to mitigate successfully. Opportunities are the opposite of risks; they are the things that allow you to perform better than planned. Your team will likely say you don't have any opportunities. That just means they haven't been identified yet. When a team has problems, it creates opportunities to get out of trouble. This best practice is about seizing opportunities before there are problems. You also need opportunities to offset the risks and issues you were unable to predict so you can end up on plan.

Help Needed and Independent Reviews promote a team approach to problem solving and finding better ways to get the job done. In aerospace, we deliver products that are hard to build, so it is unreasonable to expect that all your teams are going to be able to solve every problem they encounter on their own. "Help needed" is about openly communicating, finding out what teams need, and getting them help to make sure they can succeed. At Boeing we require the last chart of any briefing to be titled "Help Needed" and to describe what outside help, if any, you need. We then use a "Help Provided" system for tracking and reporting the actions we take in response to the request.

The **Program Communication** best practice requires program managers to keep everyone inside and outside the program aligned with its vision, strategy, and status. Program managers don't actually build hardware, release drawings, or analyze performance. We lead the people who do. You've got to communicate with your employees and contractors to keep them motivated. When I was on the space station program, we would get the team together and talk about our vision and how someday we would be able to go out into our backyards, look at the sky, and show our grandchildren what we built. That helped when the going got tough and we had to work some incredibly long hours. You also have to communicate with your external constituents—your senior management, your contractor's senior management, and Congress—who need to know your plan and how are you doing so they will keep funding the program.

Boeing's eight Program Management Best Practices are not rocket science. They are the basics, as fundamental to a program manager as blocking and tackling are to a football team. Without these basics, your program is at risk. With them, a capable leader has a good shot of being successful.

In aerospace, we expect our products to be perfect. We don't seem to have that same expectation about the way we *manage* our programs, but perfection is certainly within our grasp. As we continue to take on inherently risky development programs, program managers must not lose sight of the fundamentals. We must require them to be disciplined in the basics of program management so the performance of our programs is as predictable and as good as the performance of the products we build. ●

STEVE GOO is vice president of international operations for Boeing Integrated Defense Systems.

PATHFINDER'S MARS LANDING:

TO REBOOT OR NOT REBOOT

BY ROB MANNING

Photo Credit: NASA Jet Propulsion Laboratory

This picture from Mars Pathfinder was taken after the spacecraft landed on July 4, 1997, and shows the Sojourner rover perched on one of three solar panels.

On July 4, 1997, half an hour before Pathfinder was scheduled to enter the Martian atmosphere, we had just finished the transition from Earth control to fully autonomous control: the spacecraft was now responsible for its own actions. Monitoring Pathfinder's telemetry, we looked for the expected sequence of actions that would prepare for Mars entry, descent, and landing. One step was closing valves in the propulsion system, but the spacecraft told us the valves were staying open. The valves being open or closed was not critical in itself, but we needed to know why we had gotten that unexpected message and whether it signaled a larger problem that would threaten the mission.

Our best guess was that the spacecraft might be running an old version of software, the version it launched with. During the seven-month journey to Mars, we designed, tested, and uploaded new software that made the entry, descent, and landing (EDL) system much more tolerant of noise and possible radar outages. This unexpected message looked a lot like how the old software used to behave. Had we booted up the old version by mistake? It was possible; both versions were still on board.

We did have time—but barely ten minutes—to send a command to reboot into the right version before the EDL sequence started. It would take eleven minutes for any signal we sent to reach the spacecraft. But rebooting the computer minutes before entering the Martian atmosphere was not something we wanted to do unless we were absolutely sure that Pathfinder was running the wrong version of the software. How could we find out? The spacecraft was not configured to send down the current version number and there was no time to ask it.

Glenn Reeves, the flight software lead, turned to Richard Cook and, virtually at the same time, they yelled, "Jordan Kaplan!" Cook, our mission manager, then raced into Jesse Wright's office in search of the answer in the few minutes we had to make a decision.

Jordan had been a member of the Pathfinder team who, sadly, had died in April when his private plane crashed. To honor his memory, the software team had added his name to the software "fill packets"—text available to insert in communication from the spaceship to Earth when the actual data being sent did not fill the standard-size "frames" the data transmission system used. His name appeared only in the new version of the software.

Richard ran to Jesse's computer, where Jesse quickly decoded the fill packet. Moments later, they came back yelling, "Jordan Kaplan! Don't reboot!" They had found his name; Pathfinder was running the right version of the software.

Pathfinder landed successfully. The tension of that last-minute crisis is memorable, but so is the quick thinking of the Pathfinder team and the thoroughness of their knowledge of the system—down to the software fill code. The experience also shows the potential value of frivolity (and human feeling, in this case). The supposedly meaningless content of the fill packets turned into a valuable analytical tool. In planetary exploration, you can't predict all the problems you'll face or all the resources you'll have to solve them. ●

ROB MANNING was chief engineer for the 1997 Mars Pathfinder project and is currently chief engineer for the Mars Exploration Program at the Jet Propulsion Laboratory.

MARS EXPRESS: Global Collaboration

BY KERRY ELLIS

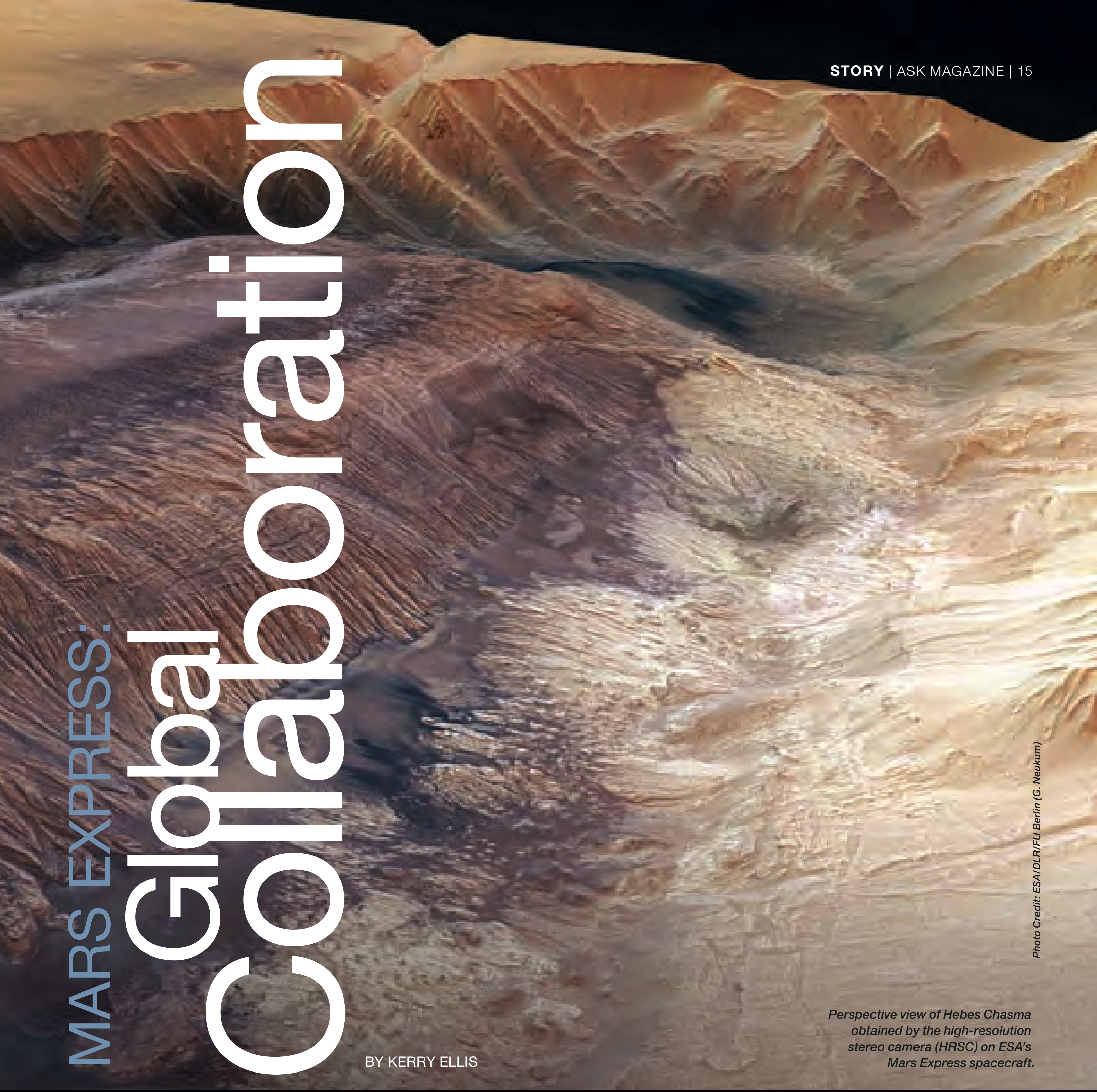


Photo Credit: ESA/DLR/FU Berlin (G. Neukum)

Perspective view of Hebes Chasma obtained by the high-resolution stereo camera (HRSC) on ESA's Mars Express spacecraft.

The pursuit of space science does more than reveal new facts and spawn new theories about the universe and our place in it. It also provides common ground for international collaboration. Scientists all over the world share their passion for investigating and learning about other planets, and Mars in particular draws attention. But why are we so eager to keep exploring our neighbor in the solar system? And how do scientists scattered across the world collaborate on one mission to a destination millions of miles away?

Many of the missions flying in space today begin with a scientist somewhere asking a question. Agencies like NASA and the European Space Agency (ESA) provide the means to answer those questions, and those scientists frequently join the resulting projects as principal investigators. When several scientists ask different questions about the same place, missions offer a way for a variety of experiments to catch the same ride into space.

The ESA's Mars Express orbiter, Europe's groundbreaking first planetary mission, involved principal investigators from Germany, Sweden, Italy, and France and contributions from Japan, the United States, and Russia. It gave a ride to seven exploratory instruments, and while each instrument measures something different about the red planet, they are all seeking to answer the same questions: What happened on Mars? And could it happen on Earth?

Seeking Answers Together

To obtain cohesive answers, principal investigators collaborate with each other and communicate continuously among themselves and with ESA. Each principal investigator works with a team of scientists and engineers on his or her instrument and coordinates with many scientific groups in different countries. The high-resolution stereo camera (HRSC) team, for example, includes nine co-investigators from across the United States, at Arizona State University, Brown University, the Jet Propulsion Laboratory, and the U.S. Geological Survey.

Before launching Mars Express, the principal investigators also had to coordinate with the ESA engineers building the orbiter and lander. Since the mission is currently in operation around Mars, they keep in close contact with each other through weekly teleconferences and many meetings coordinated by the ESA Mars Express project scientist. To plan their observations, they are also in constant contact with the ESA science operations center.

The scientists work closely with their fellow principal investigators, coordinating when each instrument will make its observations or discussing how data obtained from one instrument could benefit a sister experiment. Most of the principal investigators had worked together on the failed '96 Russian mission to Mars, so they came prepared to meet with old colleagues and improve their instruments for the ESA mission. Sometimes their conversations helped evolve the design of an instrument as it was being built to ensure better coordination with the other experiments on the mission.

Apollinaris Patera is an ancient shield volcano measuring approximately 180 km by 280 km at its base and rising to a maximum of 5 km above the surrounding terrain. The image also shows the terrain partly covered by thin, diffuse clouds indicated by bluish tinted areas.

"The concept of our experiment evolved substantially from these discussions," said Vittorio Formisano, principal investigator for the planetary Fourier spectrometer (PFS). "We attempted different solutions to different aspects in the beginning, and when we passed from the Russian mission to the ESA proposal, there was a strong mass reduction requirement. We decreased the experiment mass by 12 kg, reorganizing the international collaborations and contributions."

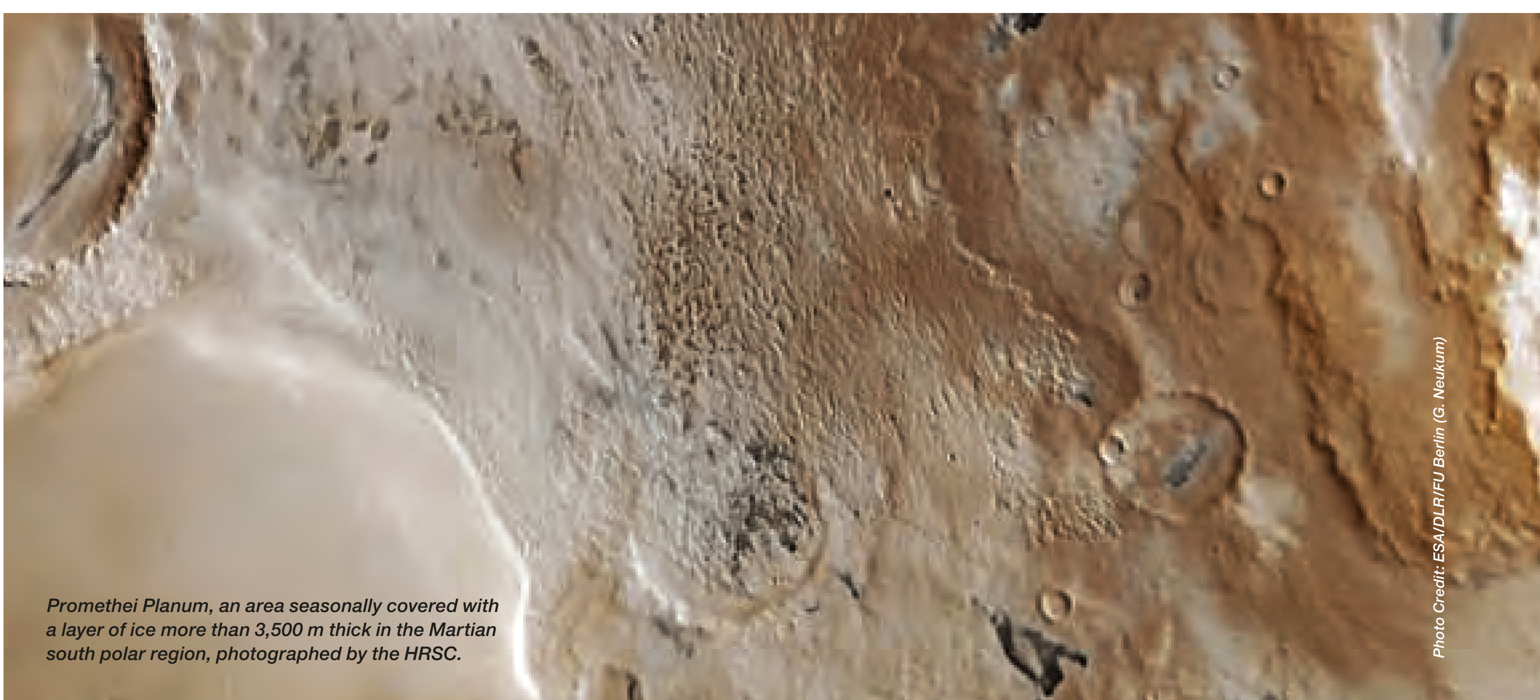
Even after Mars Express launched, scientists continue to adapt their observations as they receive new information from their experiments. These discoveries have changed the course of the mission as it is operating.

"Most discoveries were made along the course of the mission, without being predicted, concerning the composition of both the surface and the atmosphere—clouds in particular," said Jean-Pierre Bibring, principal investigator for the visible and infrared mineralogical mapping spectrometer (OMEGA). "Consequently, we modified our observational strategy accordingly, trying to coordinate with the other principal investigators as much as we could."

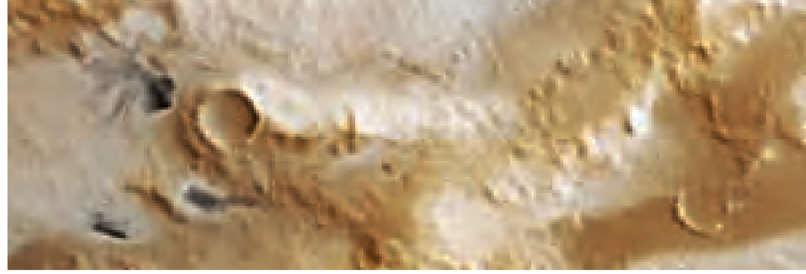
These discoveries go beyond informing the mission during its journey; they also help shape future missions to Mars. "Earlier on, most of our understanding of Mars surface structures and evolution came from the interpretation of optical images and altimetry data," said Bibring. "The study of the surface minerals with new tools like OMEGA is providing us with a new fundamental set of information to reveal, for instance, the history of liquid water on the red planet. We have discovered the presence of hydrated minerals—called phyllosilicates—which show that water must have flowed abundantly in the early history of Mars. This opens the possibility that conditions for life to grow may have existed, as on Earth. Sites featuring such minerals could be favored targets for future missions, as they would be among the most likely to contain microfossils if ever life once emerged on Mars."

To obtain these findings, Bibring worked in tandem with the other principal investigators at all levels, from programmatic to scientific. "We had to coordinate observation scheduling and data sharing, and we even exchanged co-investigators and students," he said.

Working closely with the OMEGA instrument is the PFS instrument, which studies the atmosphere by measuring its composition and temperature and the way it varies with altitude. PFS obtains these measurements by studying the sunlight absorbed by molecules and the infrared radiation they emit. "OMEGA has a lower spectral capability but can produce images, unlike PFS," said Formisano. "PFS has a very high spectral resolution, and it identified traces of methane in the



Promethei Planum, an area seasonally covered with a layer of ice more than 3,500 m thick in the Martian south polar region, photographed by the HRSC.



atmosphere from orbit for the first time. Methane is another important element to track when looking for traces of life." OMEGA, PFS, HRSC, the ultraviolet and infrared atmospheric spectrometer (SPICAM), the energetic neutral atoms analyzer (ASPERA), and the other instruments are providing a complete picture of what makes up Mars's atmosphere and surface, and if water could have existed there for a prolonged period of time.

Mars Express's collaborative successes have extended beyond its primary mission. The spacecraft helped NASA's Mars Phoenix mission by capturing and relaying data during the lander's entry, descent, and landing.

Learning About Mars—and Earth

"We think of Mars as a sister of Earth," said Martin Pätzold, principal investigator for the radio science experiment (MaRS). "It could well have harbored life in its early years. It is therefore very interesting to look closely at the similarities and differences between our two planets, from a geophysical point of view, analyzing its upper atmosphere and the effect of the solar wind on it, the roughness of the planet's surface, and even its interior by measuring the effects of Mars's gravity field on the spacecraft velocity." Among other things, the MaRS experiment also allowed the most precise measurement ever of the mass of the Martian moon Phobos.

Jean-Loup Bertaux, principal investigator for SPICAM, is testing the theory that more water vapor in the atmosphere means less ozone. "This could have vital consequences for Earth because we have both ozone and very little water vapor in our stratosphere," he said. "With changes in our climate, our water vapor levels could increase drastically in the stratosphere, and this may be developing a new threat for ozone. On Mars, we can check our theory on the chemistry of water vapor and ozone, and since chemical reactions are the same on both planets, we would thereby learn more about our planet's possible future."

The greatest ambition of MARSIS, led by Giovanni Picardi and Jeffrey Plaut, is to find liquid water still existing on Mars, "because this is the basis of life, both in scientific thought and also according to the Greek philosopher Eraclito's ancient principle of 'panta rei'—everything flows!" Picardi said. MARSIS is looking deep below Mars's surface and has already identified, for the first time ever, ice-water deposits underground.

Future Exploration

Mars Express launched successfully in June 2003 and was originally planned to run for one Martian year (687 days). The mission has already been extended twice, and it is now funded for operation until May 2009. Its success, despite the loss of its Beagle 2 lander, represents Europe's first foray into planetary exploration and paved the way for ESA's Venus Express, which launched in 2005. The collaborative discoveries of the Mars Express principal investigators, combined with those of space scientists across the world, help create a cohesive picture of the solar system's—and Earth's—evolution and the unique circumstances required to support life. Their discoveries are also informing future exploration of Mars.

Stas Barabash, principal investigator for the ASPERA instrument that is studying how particles in the atmosphere interact with solar wind, is building on the data returned by Mars Express. By studying ionized gases at the boundary between Martian atmosphere and space, Barabash says, "We are studying just how quickly water vapor and other gases are being lost from Mars. Ultimately, these measurements could help us decide whether Mars supported conditions suitable for life in the past."

Gerhard Neukum, principal investigator for the HRSC, is also confident his 3–D measurements, mapping of Mars's surface, and study of volcanic and glacial activity could help us understand the planet's evolution as well as aid future exploration efforts. "In a way, we are investing in the future generations of scientists to come," he said. "We are uncovering a whole new world in 3–D, showing exactly what Mars looks like as though the images were taken from a low-flying airplane. And, who knows, we may be preparing the ground for somebody to go to Mars one day." ●

Viewpoint: The Bigger Pictures

BY PIERS BIZONY

First Steps 1963," by Mitchell Jamieson
In this silver colored spacesuit, Astronaut Gordon Cooper steps away from his Mercury spacecraft and into the bright sunlight on the deck of the recovery ship after twenty two orbits of Earth. Jamieson spent two weeks in mid Pacific Ocean awaiting Cooper s return. He documented the recovery and medical examination and accompanied the astronaut and recovery team back to Cape Canaveral.

Image courtesy the NASA Art Program

I am endlessly curious about the logic of NASA's hardware designs and mission architectures, but I am a writer by trade and an engineer only in the armchair sense. My "mission" is to keep people interested in the possibilities of space exploration and persuade them that the collective global investment—in tax dollars, euros, rubles, yuan, and yen—is justified. Mine is an engineering challenge of sorts: manipulating the responses of as many individuals as I possibly can so as to keep them on my side. Every vote counts. Writing as one who believes that human expansion into space is virtuous, and for whom NASA represents a wonder of the civilized world, I am now going to play devil's advocate. Let us not deny that quite a lot of folk don't think the way I do. Some of them doubt that the federal government should continue to have a central role in sustaining human space flight. Those are the people that we NASA advocates have to reach.

Half a century ago, at the very dawn of the space age, government advisors prided themselves on their supposed ability to identify potentially useful areas for large-scale national research, such as aviation, computing, rocketry, and nuclear energy. Today it's all anyone can do to just keep in touch with the bewildering pace of developments in medicine, genetics, electronic consumer goods, personal computing, and global communication. Policymakers are hard-pressed merely to cope with these myriad advances, let alone urge their invention. Even the bombs and missiles that were once our darkest pride have lost their edge in an era of "asymmetrical warfare." A few fanatics with dime store craft knives can change the world in a day, while the intercontinental ballistic missiles and their costly megatons stay sealed in their silos, impotent in a world that barely even worries about them anymore.

As for space exploration, that ambiguous child of the Cold War, let's face the uncomfortable truth that most launch vehicles are based, essentially, on antique technology. They have advanced less in the fifty years since their invention than just about any other vehicle except for the automobile. The public senses this and turns its attention to newer, sexier technological stimulations, such as iPods and the Internet. There is a problem in the language of space if young people no longer find quite as much excitement in the adventure as their parents and grandparents did fifty years ago, when they, in their turn, were young. To be sure, many thousands of people are still fascinated by space exploration, and millions more take at least a passing interest, but those multitudes may no longer be sufficient to ensure a long-term continuation of human space flight at a major national level.

NASA's plans for the future are therefore a cultural matter as well as an engineering issue. That's what I want to talk about here. I suggest that if NASA is to preserve and promote its status in society as a whole, it needs to speak to the nontechnical public in a more engaging way that satisfies the emotions as well as the intellect.

"Apollo 8 Coming Home," by Robert McCall
For the first time, human eyes directly observed the far side of the moon on Christmas Eve 1968. The Apollo 8 rocket engine was fired to bring the spacecraft out of its lunar orbit and home to Earth. McCall created this oil on canvas piece in 1969.

NASA's Web sites are beautifully designed and filled with fabulous images, texts, and download options. I have to assume that these vast electronic resources reflect the Agency's overall public posture. The "how" of getting into space is always perfectly expressed, but the "why" sometimes absents itself. This is because the "why" is not a question that can easily or fully be answered in terms of immediate economic benefits, scientific rewards, or educational spin-offs. The "why" of space exploration is a matter of emotions and instincts.

As a government entity funded by taxpayers, NASA has to be extraordinarily careful how it describes its motivations. The safety of a collective mission statement protects NASA from potentially damaging criticism but at the same time eliminates much of the emotional drama of the Agency's work, because its public communications have to be checked against the possibility of annoying Main Street or Capitol Hill. Of course there is nothing that NASA can do about this. It is part and parcel of being a federal organization with an obligation to reach out to a wide constituency without alienating any part of that constituency.

It is difficult for NASA to talk, for instance, about the spiritual or emotional aspects of space, because there are more opinions about such matters than you can shake a stick at. Apollo 11's Michael Collins once said, "I think a future flight should include a poet, a priest, and a philosopher. Then we might get a much better idea of what we saw." We can only imagine the chaos that would ensue if one kind of priest was selected over another. As for the prospect of philosophers arguing semantics aboard a spacecraft—well, the mind boggles. It is easy to understand why NASA sticks to selling space in terms of scientific and societal benefits: themes that can be expressed in terms that taxpayers and politicians can argue about rationally.

Rationality is the only tool that can help us decide how a space mission can be done, and how it should be funded. However, when it comes to winning support for that funding, I think that NASA may be missing a trick or two. I propose that it should make greater use of what the intelligence agencies might describe as "deniable assets." I mean the people who can best express the poetry, the drama, the emotion, the glory, and, yes—although it is essentially a taboo subject—the thrilling dangers of flying into space, while at the same time not being official spokespeople for NASA.

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Artists, I believe, should have more of a role in NASA's public relations strategy. I adore the wonderful computer graphics of hardware concepts, from John Frassanito's company and many others employed by NASA. I'm a total junkie for that stuff—my downloading habit verges on the alarming—but in this article I am talking about expressive artists, writers, and performers, not realistic illustrators or technical journalists.

A little history. In 1962 Hereward Cooke of the National Gallery of Art in Washington, D.C., wrote a letter of invitation to a number of prominent artists, inviting them to tour NASA and create works based on their impressions. He was eloquent about the need for both art and science in any space endeavor: "When a major rocket launch takes place, more than two hundred cameras record every split second of the activity," he wrote. "Every nut, bolt, and miniaturized electronic device is photographed from every angle. But the camera sees everything and understands nothing. It is the emotional impact, the interpretation and hidden significance of these events, that lie within the scope of the artist's vision." Cooke assured the selected artists that they would be given access to NASA facilities and would be subjected to no editorial pressures whatsoever.

Paul Calle, famous for his scenes of life in the Old West, took up the challenge, producing superb pencil drawings of astronauts and their capsules. Robert Rauschenberg's semiabstract silk-screen prints seem both celebratory and mildly sarcastic at the same time; Bob McCall, a well-known aerospace illustrator, delivers romantic yet technically accurate pictures to satisfy space hardware buffs; and Lamarr Dodd captures an impressionistic morass of wires, switches, cables, and dials, with silver-clad humans embedded in the machinery of their ships.

Jamie Wyeth's delicate watercolors show the forlorn scrublands surrounding the launchpads. Rockets, with their barely constrained capacity for disaster (admit it, revel in it), have to keep their distance from the everyday human realm of towns and streets and family backyards. This is a dark yet thrilling truth that artists can explore more freely, perhaps, than NASA press officers. The drab safety-zone territories around Wyeth's launchpads are a sort of endless "nowhere," inhabited neither by man nor machine: a wasteland for explosions to vent their fury without causing more harm than necessary.

A more inward landscape is explored by Mitchell Jamieson, who understands the psychological drama behind the Space Age's political and technological rhetoric. It needs only the lightest sweep of an artist's brush to expose the religious and mystical desires implicit in cosmic exploration. Jamieson's painting of a geometrically fragmented astronaut in his spacesuit brings to mind the saintly figures in a cathedral's stained-glass window.

The art collection that emerged from the efforts of Cooke and his collaborators grew into a major body of work, which is now under the guardianship of the Smithsonian Institution's Air and Space Museum. However, I am sad to observe that times have changed.

Last year, in London, I was fortunate to hear the singer and performance artist Laurie Anderson talk about space: "I was the first NASA artist in residence. And I was the last artist in residence." Five years ago, she accepted a yearlong commission to haunt the corridors of various NASA field centers and respond, in her inimical way, to what she saw and heard. With her penchant for dreamlike electronic experimentation and restless curiosity about modern technological culture, she was the perfect artist to take a quirky, sideways look at the space business and to bring those observations to thousands of her fans, people not necessarily familiar with NASA's work.

Sadly, Congress had by then forgotten the importance of art. In June 2005, Anderson's modest honorarium of $20,000 was the subject of a Congressional debate, which art lost. A critic of the residency argued that "NASA should not be spending taxpayer dollars on a performance artist." Congress voted accordingly and prohibited using federal funds for artists in residence at NASA in the future. That kind of thinking could cost NASA its second shot at the moon. The majority of American citizens are not engineers or scientists. It takes a variety of languages, including those of art, music, and literature, to reach them.

At the same time, the subjectivity of our individual responses to space is not something that NASA itself can afford to tangle with. Therefore, I reiterate that the Agency should be allowed

Hot Shot,” by Robert Rauschenberg
Rauschenberg attended the first launch of the Space Shuttle Columbia *in April 1981. This lithograph captures elements of the shuttle, Kennedy Space Center, and the space culture of the Cocoa Beach area around Cape Canaveral.*

Image courtesy the NASA Art Program

to communicate through independent artists and writers and musicians in order to reach as wide a spectrum of society as possible. Then, when some artist or other says something "controversial," NASA can properly distance itself from that artist's views. The point is not for artists to "toe the company line." The point is for them to put space flight into the culture so that it becomes something more than a niche activity for aerospace professionals.

Scientific discoveries in space are only half the story. It's what we make of those discoveries that counts; and, inevitably, what we make of them is subjective and open to debate. As always, human progress can only come from inside ourselves. We can't find it "out there," no matter how far we travel, or how complex our spaceships become. According to the British author J. G. Ballard, "The biggest developments of the immediate future will take place not on the moon or Mars, but on Earth, and it is inner space, not outer, that needs to be explored. Even in space, the most alien creatures we'll confront are ourselves." And that subject—in the end, the only subject that matters to any of us—is beyond the ability of NASA's scientists and engineers alone to convey to the public. They also need artists. ●

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.

RESPONSIBILITY, Not Blame

BY ANGELO "GUS" GUASTAFERRO

Why take responsibility for a major foul-up on a project outside your area of expertise that started before you were on the scene? Here's one story that may answer that question.

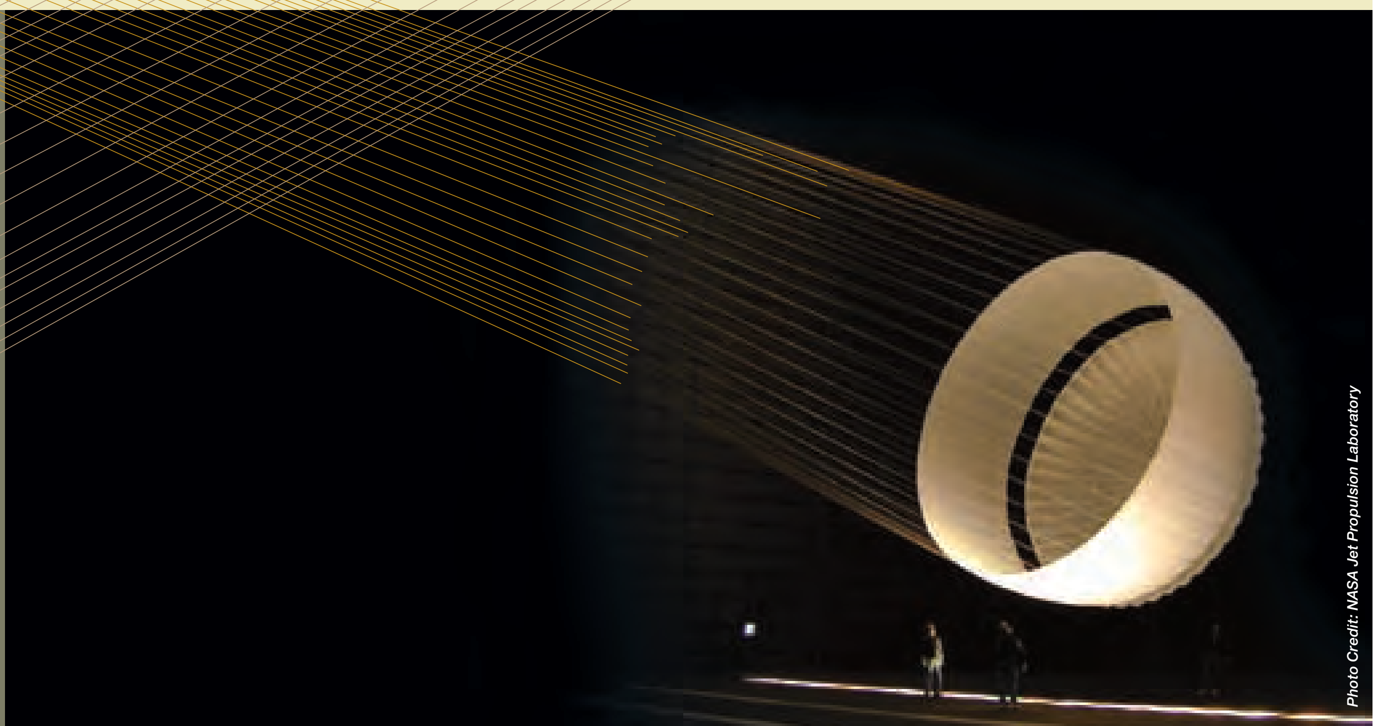


Photo Credit: NASA Jet Propulsion Laboratory

The Mars Exploration Rover parachute underwent deployment testing in the world s largest wind tunnel at Ames Research Center.

I became deputy director of Ames Research Center in April 1981. Having previously worked on the Viking mission and for the planetary exploration program at Headquarters, I was new to this level of management. I also didn't have a lot of experience in most of the work being done at Ames. But in 1982, I found myself acting director because the director, Clarence Syvertson, had coronary bypass surgery and was out for four months.

At that time, a group of Ames engineers were working to increase the capacity of an existing 40' x 80' subsonic wind tunnel used for full-scale testing of aircraft. They were adding an 80' x 120' test section and installing more powerful drive motors to increase the wind speed from 200 to 300 knots. One of the elements of the new design was a set of plywood vanes that would direct the airflow to one or the other test sections. On December 9, disaster struck.

TAKING PROMPT CONTROL OF AN ACCIDENT OR INCIDENT INVESTIGATION SHOWS, FIRST OF ALL, THAT YOU ARE COMMITTED TO FINDING OUT WHAT WENT WRONG AND RECTIFYING THE ERRORS.

During testing that day, the 130-foot-long turning vane set failed. Debris crashed into the wind tunnel's six fifteen-blade wooden propellers (each as high as a four-story building), damaging or destroying most of them. As I said at the time, "We generated a lot of toothpicks."

The accident investigation board eventually found multiple causes for the failure, including potential problems with the original design, late design changes that were not properly reviewed, construction quality that did not meet requirements, and inadequate instrumentation for measuring loads on the vane set. But this story is not about why the failure happened; it is about how leaders should respond when a problem like this one occurs.

It could have been tempting to find someone else to blame. After all, I was new to Ames. I hadn't been involved in the design decisions for the project. It wasn't my area of expertise. Approaching it this way was tempting, but not productive. The fact was I was acting director, and the failure happened on my watch. By telling myself, "Gus, you're responsible," I was able to get past the question of blame and concentrate instead on moving quickly to understand and solve the problem.

I thought it was important to do what needed to be done before being told by NASA Headquarters. Within hours, we had a recovery plan in place, and I received Headquarters approval from the chair of the investigation board, Bob Swain. Taking prompt control of an accident or incident investigation shows, first of all, that you are committed to finding out what went wrong and rectifying the errors. It also puts you in a position to shape the outside review team.

Bob and I took three days to complete the team and outline the investigation. With most of my career spent at Langley Research Center, I was determined to get the systems engineer at Langley and the U.S. Air Force Tullahoma wind tunnel facility involved in the investigation. Taking responsibility doesn't mean you have all the answers. I certainly didn't. We put together a team that I knew would do an outstanding job of analyzing the fatal flaw and coming up with the recommendations we needed to get the tunnel up and running. Their two months of dedicated work fully lived up to my expectations.

Then I went to the United Kingdom with the Ames Engineering Directorate to get new propellers made. Constructed of layers of hand-shaped, laminated spruce, they called for skilled precision work. It took at least six months to get new blades made to specification.

The wind tunnel was out of commission for a year—a pretty good recovery time, I think, given the extent of the failure. Since then it has been used successfully for full-scale testing of helicopters and Mars rover parachute designs, among many other applications. It is still operating today, more than twenty-five years after that December day when we found ourselves facing a tunnel full of toothpicks.

Handling that crisis was a formative experience for me. Looking back, I'd say it taught me several valuable lessons. The importance of taking responsibility is the biggest one, but a couple of others come to mind:

- It's important to stretch yourself. Don't always do what's in your comfort zone.
- If you admit you need help and give people credit for their contribution, they will help you.

ANGELO "GUS" GUASTAFERRO held the first of three leadership management positions in the Viking Mars mission that successfully landed two spacecraft on the planet in 1976. He has been director of Planetary Programs at NASA, deputy director of Ames Research Center, and vice president of Lockheed Martin in charge of Civil Space. Since 1998, he has been a lecturer and a consultant for NASA and other organizations.

Owning the Product + the Process

BY STEPHEN A. COOK

Organizations are like people—sometimes it takes a major shock or a disaster to change their behavior. For NASA, the shock occurred on February 1, 2003, when Space Shuttle *Columbia* broke up on re-entry. Even as we mourned the loss of the crew, many at NASA began some serious soul-searching. The *Columbia* Accident Investigation Board (CAIB) was formed within two hours of the accident. In addition to the technical reasons for the disaster, the CAIB report cited management and cultural problems inside and outside NASA. They faulted political leaders for not giving NASA a clear mission and faulted NASA for weakening its in-house engineering and safety organizations. In response, policymakers developed the U.S. Space Exploration Policy to provide the Agency with a long-term vision. And NASA changed internal structures and practices to strengthen engineering and safety.

NASA's New Approach

The CAIB report advised us to establish a strong engineering technical authority and focus on safety as a core engineering discipline, rather than relying on industrial safety policies. Establishing the Safety and Mission Assurance and Engineering Directorates as separately managed and separately funded entities means that NASA engineers in those organizations can be more forthcoming about raising safety issues without fear of retribution.

Engineering and safety are closely linked in a discipline as demanding as space flight. Every engineering decision has flight safety consequences, so our engineering and safety teams must be staffed with competent engineers and space systems managers to ensure we are applying an effective risk-based approach to the design. Routine, open, and honest communication among project management, engineering, and safety is a must. Cost, schedule, and political constraints exist in any project; all the parties have to understand them clearly and find creative ways to work within them. For Ares, we are cultivating a "Yes, if …" rather than "No, because …" culture by giving NASA civil servants a product ownership role.

NASA Administrator Mike Griffin gave us one clear directive for managing the Constellation program: NASA must own the intellectual property rather than use a proprietary design developed and owned by a contractor. The Agency used this development model to build the Apollo crew capsule and the Saturn launch vehicles in the sixties, but it is a new way of working for the current NASA team. For thirty years, NASA deferred to private industry for launch vehicle development and operations. We needed to get our hands dirty by delving into the details of development.

Ares Projects—Owning the Product

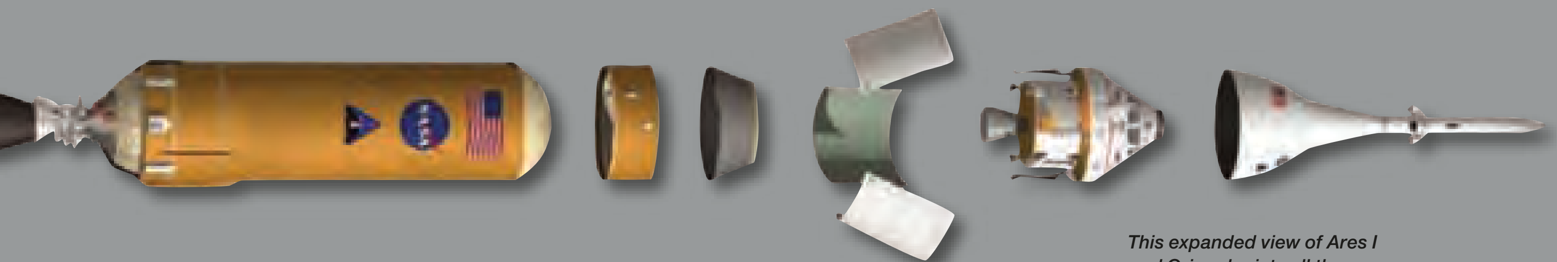
The Ares projects at Marshall Space Flight Center are charged with developing the launch vehicles to get the Orion crew exploration vehicle and Altair lunar lander into space. The Ares I crew launch vehicle will lift off from Launch Complex 39B at Kennedy Space Center using a five-segment solid rocket motor based on the ATK Launch Systems four-segment motor used on the Space Shuttle. The upper stage, powered by a liquid hydrogen/liquid oxygen J-2X engine—a modern version of the Apollo/Saturn J-2—will push Orion to low-Earth orbit.

To accomplish this enormous task, we have revived Wernher von Braun's practice of building and maintaining in-house engineering and safety expertise, but we have incorporated modern management practices, such as Lean Six Sigma and Kaizen, establishment of team norms, and an all-digital model and manufacturing process. Rather than reviving the top-down management of the 1960s, we are empowering engineers at all levels to identify improvements in their daily processes.

NASA Marshall and our partner centers are responsible for overall vehicle or "stack" integration and developing the upper stage in house, with an innovative partnership with Boeing for production. In addition, we are using Boeing's propulsion expertise to work very closely with first-stage contractor ATK Launch Systems and upper-stage engine contractor Pratt & Whitney Rocketdyne to develop these two key elements.

Photo Credit: NASA

This robotic weld tool at Marshall Space Flight Center is configured to assemble the domes at the ends of each of the Ares I Upper Stage propellant tanks.



This expanded view of Ares I and Orion depicts all the primary vehicle elements.

Image Credit: NASA

In-House Development in Action—The Ares I Upper Stage

One of the managers most affected by these changes is Danny Davis, the Ares I upper-stage manager. When asked to sum up his job, he said, "The NASA design team is responsible for all design, development, and testing of the upper-stage system. We are reducing development risk and cost by incorporating state-of-the-art technologies and minimizing the need for new technology development. We also have to reduce the overall cost of ownership of the upper stage by considering early in the design process the input of the Boeing team that will fabricate the stage and the operations team that will handle and operate the stage."

According to Davis, the upper-stage production system is being designed along with the upper stage itself, with the upper-stage production contractor (Boeing) providing "producibility" input to the NASA design team: "The NASA design team has exceptional capacity and passion to implement the upper-stage development and operations. For example, during one 'lean' event that included both NASA and Boeing personnel, the upper-stage team cut 100 days off the time it takes to manufacture a stage." One major savings came from Boeing's suggestion to tack weld the upper-stage barrel segments in a vertical orientation rather than build the stage horizontally, an insight gained from building Delta IV launch vehicles. The NASA/Boeing Kaizen team took that process one step further and decided to completely weld the barrel segments together vertically, resulting in substantial assembly time savings.

Tim Vaughn, chief of the Metals Engineering Branch of Marshall's Engineering Directorate, works with Davis on the upper stage. He has been on the leading edge of Ares development, and his team is working on the stage from the production angle: "We do weld development, materials and failure analysis, metallurgical engineering, and sub- and full-scale manufacturing and assembly. We are key players in the manufacturing and assembly area. We are developing all the components, manufacturing processes, the tools, and fixtures, and we're demonstrating all that with full-scale hardware."

Vaughn's team has started nearly from scratch. It has been forty years since NASA built rocket stages on this scale, and the technology has progressed quite a bit since the days of Apollo. As Vaughn explains, "There was nothing 'heritage' that we could draw upon except industry infrastructure and the initial development experience from the External Tank Program. Today we are using the strongest and lightest aluminum alloy currently available, Aluminum-Lithium 2195. It's difficult to weld and form. We are also using the friction stir weld process for all major structural welds. Our goal is to take advantage of all state-of-the-art technology development that we have available."

Developing the Team

Of course it's not just a matter of building the hardware. On top of the fundamental tasks of developing qualified components, manufacturing processes, and tooling fixtures, Vaughn notes, "We also need to develop people. All the components are new, and all the people are new. Everything we do on a day-to-day basis is new. Most civil servants and contractor partners have limited full-scale production experience, but they're all bright people and we're all learning. Everybody is enjoying learning how to go about doing this." He adds, "Engineers love to build things. I've got engineers who had been pushing paper for years now responsible for developing hardware components, and they're having the time of their lives. I've got welding engineers who are absolutely having a blast trying to figure out the best and most efficient way of assembling tank structures. There is no problem whatsoever motivating people. Everybody understands that what they are doing will be used as a basis for the next twenty to thirty years. Future generations, not just NASA engineers, will be using what we developed. This is engineering Shangri-La!"

Changing the Culture

Why is Ares's shift from an oversight to a development culture so important? As Vaughn puts it, "When you do development, you're starting from ground zero, and you get to design and develop the type of vehicle that you think needs to be developed. The design

DAVIS SAYS, "WE LEARN EVERY DAY WHAT IT MEANS TO 'OWN' THE DEVELOPMENT. OUR TEAM IS MAKING BINDING DECISIONS AND WORKING THROUGH PROBLEMS, BEING INNOVATIVE, AND LISTENING TO THE 'WISE OWLS' WHO PROVIDE ADVICE."

is being done in house, and we actually get to have input on how the design is being built, how we're going to manufacture the vehicle, and to me that's the beauty of engineering."

Asked if there were disadvantages to this culture change, Vaughn replied, "There are people who do not like the responsibility and the accountability that this new direction gives you. It's easy to sit back and criticize something that someone else has done, but to stick your neck out and say, 'This is the way it's supposed to be done,' is the key difference. The things that we're doing now, ten to fifteen years from now, someone's going to be critiquing or, if we are successful, using our program as a model to follow. We have to make decisions that influence the direction of the space agency, at least in terms of manufacturing, and that is an uncomfortable position for some people."

When it comes to the cultural changes within the upper stage, Davis says, "We learn every day what it means to 'own' the development. Our team is making binding decisions and working through problems, being innovative, and listening to the 'wise owls' who provide advice. We also listen carefully to our production contractor to make sure our design is carefully thought out for all aspects of our mission.

"The NASA design team is fortunate to have several of the men and woman who participated in the development of the Saturn and Space Shuttle launch system available for consultation and advice. Many of our advisors were in top management roles and understand the complexity and details of the job ahead of our team. They know the exhilaration of successfully accomplishing the mission. Each of them has relayed that our job is not easy—you must be tough and persistent and never give up—but in the end the space program and our nation will benefit from the sacrifice made by our team. Encouragement from someone that has been there is priceless."

When asked how his team approaches the Ares project, Davis added, "Our team is committed to forging a minimum-cost development and operational design by a close partnership with our production contractor and the operators who will inherit our hardware. Each team member owns the cost and operational efficiency of their respective components and subsystems. We ensure this by insisting on strict accountability for development and recurring costs, and modeling of the stage operations. Each team member owns the life cycle of their respective design."

Vaughn adds, "One of the culture changes we've had to make is moving to a 'badgeless' organization. What you want to do is set up an organization working a series of major tasks to have the latitude to assign lead roles to the best people. The best people aren't always civil servants. I've assigned lead roles for component development, weld tools, and various other technical tasks to Boeing, our Ares I production contractor, and Jacobs Engineering, our engineering support contractor. I've got contractor personnel and government personnel working together as teams; contractor reporting to contractor, contractor to government, and government to contractor. There has been resistance, but when you have the best people leading major tasks, it pretty well takes care of itself."

Preparing for the Future

Rebuilding an "oversight" culture into a "doing" culture may be more difficult than building a new rocket. Vaughn notes, "There's management theory that says it takes from three to seven years to change the culture of an organization," and emphasizes the patience and persistence needed to take a group in a new direction. Bringing critical work in house ensures a knowledgeable civil service workforce that understands the work to be done, owns the products and processes, and uses resources wisely. Owning the product and process is giving NASA's workforce the knowledge and skills needed to ensure the future development of the Ares V cargo launch vehicle and Altair lunar lander and, ultimately, to fulfill the challenges of the new U.S. Space Exploration Policy. ●

STEPHEN A. COOK is the Ares project manager at Marshall Space Flight Center.

INTERVIEW WITH Charles Kennel

BY DON COHEN

Dr. Charles Kennel was associate administrator for the Office of the Mission to Planet Earth from 1994 to 1996, when he helped restructure NASA's Earth Observing System. For many years he was a professor of physics at UCLA, carrying out research in space plasma physics and astrophysics. He is formerly the director of and now professor at the Scripps Institution of Oceanography, and he was the founding director of the Environment and Sustainability Initiative at the University of California, San Diego. Don Cohen spoke to him at the Jet Propulsion Laboratory in Pasadena, California.

COHEN: How did you come to work on the Earth Observing System?

KENNEL: I had spent my career since coming to UCLA working in astrophysics and space science. I'd been on a lot of NASA committees and NRC [National Research Council] committees and was deeply interested in NASA as an institution but had no idea of taking a management role. I recall I had been on one NASA panel that advocated a program of small spacecraft with very targeted missions in space science. I felt that small spacecraft were a good way to go for that subject; they offered a lot of flexibility. This idea turned out to be important for my subsequent life at NASA.

One day I was sitting in my office at UCLA and got a phone call from Dan Goldin [then-NASA Administrator]. He said, "Charlie, I'd like you to come to Washington."

I said, "You mean to work in astrophysics and space science?"

He said, "No, no, no: Earth science."

> “WE BENEFITED FROM **three years of dialogue** BETWEEN SCIENTISTS AND ENGINEERS ABOUT THE **initial concepts and designs.**”

When I asked him why, he said, “It’s a long story, but I’d like you to come and talk to me about it.”

So I duly flew to Washington. We had an eight-hour discussion. The gist of it was that the Earth Observing System needed to be restructured. We couldn’t sustain large spacecraft financially and needed to go to a system of small spacecraft. Goldin thought a lot of people in Congress and the political sphere believed that NASA, NASA scientists, and the universities working on such things as the ozone hole, deforestation, and climate change were being unduly alarmist in order to feather their own research nests. He said, “You’re a reputable scientist from another field. You’re going to have to make tough decisions, but I’m going to give you a completely free hand. I want you to make them strictly on the basis of science. Congress will perceive you as an independent voice.” He helped me very much by giving me two wonderful deputies, Bill Townsend and Mike Mann. They were able to run the institutional and the engineering side of Mission to Planet Earth, and did so very well.

COHEN: What were some of the challenges of restructuring the system?

KENNEL: We needed to go from two large spacecraft to many small ones. The challenge was to integrate the operations and data from a complex system of satellites to get the multidisciplinary knowledge that was needed. For that, we had to work with the scientific community. The essential point was that NASA engineers and the scientific community worked together to restructure the program using system concepts to build an Earth-observing *system*.

The original idea had been to observe all the variables pertinent to the earth system simultaneously. That’s how we first ended up with more than twenty instruments on each of two giant spacecraft. The integration of twenty instruments with demanding and conflicting requirements is difficult and expensive. We needed a little bit of give on both sides—the scientists had to figure out how to interrelate data taken at different times and places, and the engineers had to figure out how to make the measurements NASA had promised on a collection of smaller spacecraft. Clearly, absolutely simultaneous measurements were best. The system of satellites ultimately was able to observe all parts of the earth system during the same time period, but not simultaneously. By making these compromises, scientists and engineers working together figured out how to get scientifically meaningful results at one-third the original cost.

NASA then went to Congress and said, in effect, "Look, we're really in the business of making twenty-four measurements, not necessarily building a giant spacecraft." Congress gave us the leeway to put the instruments on new spacecraft without requiring a separate Congressional discussion of each one, so long as we brought the system in on a budget that enabled some cost savings.

COHEN: So you had quite a bit of freedom to decide how to build the system.

KENNEL: There were other kinds of freedom. We knew we were going to need measurements of ocean color. When you measure ocean color from space, you basically measure the amount of chlorophyll, which measures the richness of the ecosystems in the upper 100 meters of the ocean. These marine ecosystems are responsible for retiring about half the carbon dioxide in the earth system, so you need ocean color measurements. There had been an experiment in 1977 called the Coastal Zone Color Scanner, which did the first measurements. Then there was a long hiatus. When the Earth Observing System [EOS] came along in the mid-nineties, we consulted with our international colleagues in the committee on Earth-observing satellites and found that three or four nations were planning color missions. We, NASA, decided that we could cancel our small ocean color mission, EOS Color, which would have cost between $100 million and $200 million. But we didn't leave the U.S. ocean color community completely bereft. We created a program called SIMBIOS [Sensor Intercomparison and Merger for Biological and Interdisciplinary Ocean Studies], in which NASA actually paid for oceanographic ships to do validation experiments for the other international satellites. As a result, we got their color data and they got their data validated. So long as somebody was making the measurements, what was needed was intercalibration, so the different spacecraft data could actually talk to one another. That idea came from looking at satellites as a part of an observing system that could include other platforms.

COHEN: Did you have a complete concept of the system at the beginning or did it develop as you went along?

KENNEL: We had the general idea of a system of satellites. Each smaller spacecraft could be adapted to the instruments it was carrying with fewer requirements conflicts. The system would be more robust, because if you lost a small spacecraft, you would still have the rest of the observing system, whereas if one of those big shuttle experiments failed, you lost twenty measurements and five years. Because it was a system, an iterative process of incremental redesigns came out of the dialogue between the science community and the NASA engineers.

COHEN: What was that process like?

KENNEL: Nobody likes to lose funding, but we did have to make cuts. When you look at the different parts of a complex system, it's tempting for a manager to say, "We can save money on this subsystem. I need the money someplace else." That kind of struggle goes on all the time. The questions in my mind always were, "When are we going too far, how will I know we're going too far? Will the loyal engineers who are trying to make this whole system go tell you if things are getting out of hand and you've gone too far?"

There's always a trade-off. You have to sense where the sweet spot is. If you're running a big organization, you don't know. The engineers know their jobs very well, but how do I know when they are taking on needless risk because I asked them to?

COHEN: Did they tell you?

KENNEL: I hope they did eventually.

COHEN: What did you do to get them to talk to you candidly?

KENNEL: Remember, I had an absolutely wonderful deputy, Bill Townsend. He had the job of telling me, and everyone else, engineering truth. Bill would very often go out to Goddard Space Flight

Center to tell them, "I've got one more redesign study for you." They would groan, not always inwardly. But I think by going and asking them regularly, "Can we look at this option, can we look at that option?" Bill began to find out where the really tender spots were in the system, where help was needed. Goddard and Headquarters had an ongoing dialogue for all my three years.

COHEN: He talked face to face with them?

KENNEL: He was out there twice or three times a week. They began to trust him. His continuous pestering for new trade studies, new re-thinks, in its way led to defining what NASA really wanted. We weren't yet building the spacecraft, so what we were doing was getting the initial design right. We benefited from three years of dialogue between scientists and engineers about the initial concepts and designs. Other parts of the Agency had trouble with the faster, better, cheaper concept, but we were trying to implement it because it was right for Earth science—at least to go to smaller spacecraft. I think we were going for better and cheaper, but not faster. We built up a relationship of trust with Goldin, so there were not the bad feelings in that program that there were in some of the others.

When I left NASA in '96, the concept and the budget level were basically set. Once that was done, NASA could concentrate on executing. It fell to my successor, Ghassem Asrar, to make sure that the individual projects got managed rigorously. NASA managed all of those launches without a failure.

COHEN: Several NASA project managers have talked to me about the value of a longer-than-usual planning and design phase.

KENNEL: I think the benefits are huge. The biggest mistakes are made early on. One of the things we're doing in the [National Academy of Sciences] Space Studies Board is trying to get more realism into the initial mission conception. Our decadal surveys of astrophysics, planetary science, and heliospheric systems all will have study teams of scientists *and* engineers *and* project managers and will all do independent cost analysis. So in the future, when the Academy makes a recommendation, our panels will have thought through some of the major trade-offs.

COHEN: So what, briefly, is the chief benefit of having this system of satellites?

KENNEL: The key thing about spacecraft is that they observe the earth evenhandedly. The same instrument with the same calibration observes all parts of the earth in the same way. The purpose of the next round of Earth observing is not to diagnose whether climate change is happening or even really to improve the forecast of global climate change, though it will do both. Then, what is new? Every region will soon be deploying its own ground system to measure the things they care about. They'll correlate their own data with satellite data that will provide the global framework for their regional measurements. Suppose you live in Southeast Asia and read of problems in Africa; because of the impact of climate change, species are moving northward or moving up the mountains seeking colder weather. That's all very interesting, but it doesn't tell you what's happening in your region, or how it interacts it with other things you care about. The real issue is how will climate change affect my region, my economy, and the things I care about.

COHEN: Is part of addressing those concerns finding the right language to describe what's happening?

KENNEL: One of the great things the Intergovernmental Panel on Climate Change [IPCC] did was teach us in the scientific community how to speak more effectively to decision makers. Their last report reviewed the state of scientific knowledge on all the important climate questions they could think of and came up with an objective review. When they express these results in scientific terms, scientists in every country can check them out. The other part of the IPCC report recognizes that most decision makers don't understand the science and have a different set of questions. So the panel included a second layer, which they call the summary for policymakers. The leaders of the teams that did the scientific assessment sat down with the policymakers, listened to their questions, and tried to answer them in terms that the policymakers can understand. The IPCC invented a carefully thought-out language to convey the degree of their certainty about how the science bears on the main policy issues.

COHEN: Giving a kind of scientific precision to non-scientific language?

THE LEADERS OF THE teams THAT DID THE scientific assessment SAT DOWN WITH THE policymakers, LISTENED TO THEIR questions, AND TRIED TO ANSWER THEM IN TERMS THAT THE policymakers can understand.

KENNEL: Politicians meet all sorts of people, including people from either extreme of the spread of scientific opinion and understanding. They need a way to calibrate whether the person they're talking to is a crackpot or speaking from the center of the scientific community. Having an assessment that's been worked on by literally hundreds of scientists and revised many times in collaboration with policymakers gives the policymaker a way of calibrating the statements of the individual with whom he or she is speaking. The precision of that language is very important. This language also helps tremendously in public communication of the IPCC.

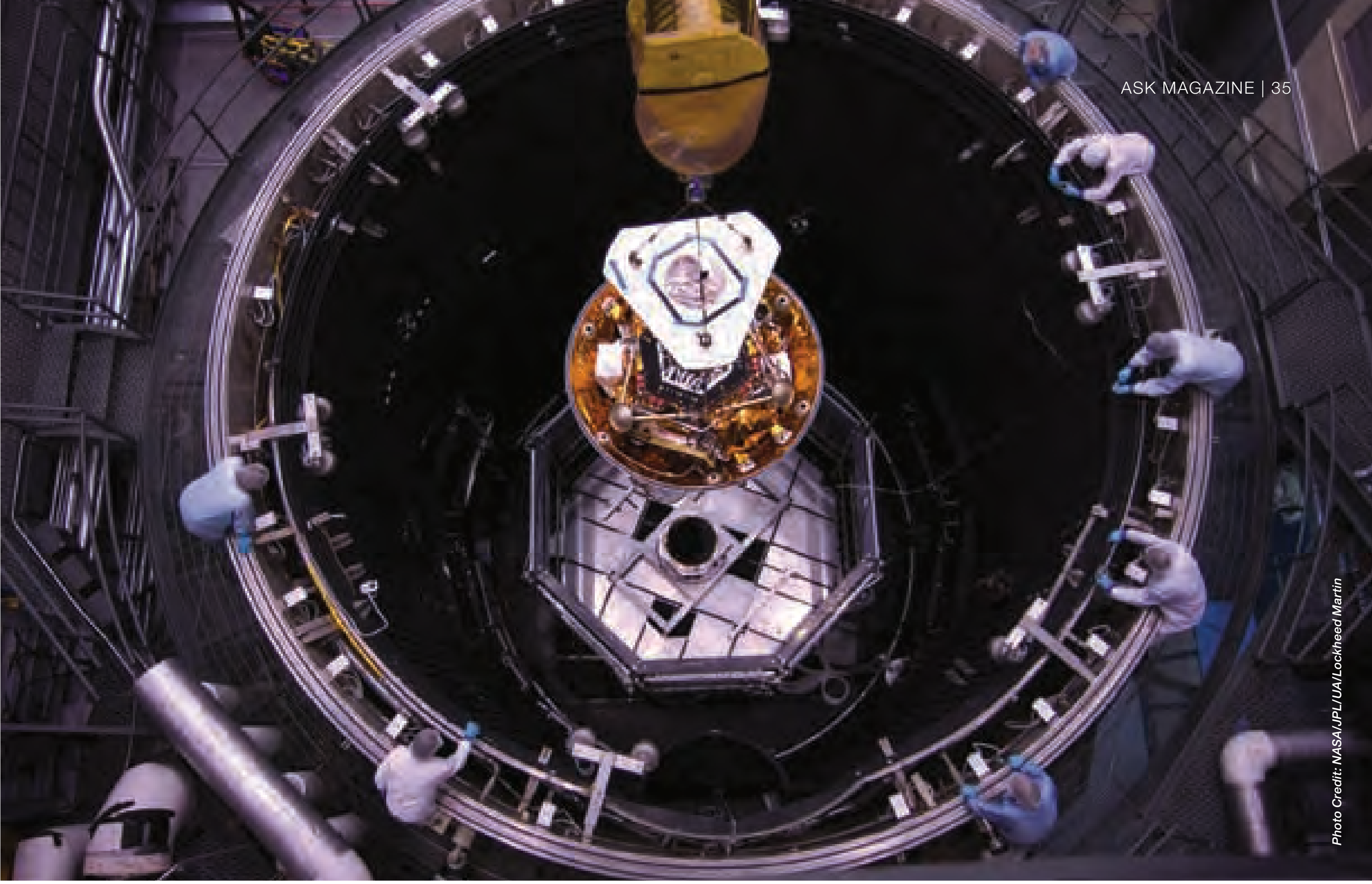
COHEN: **In the past, certainly, there's been a lot of controversy about climate change.**

KENNEL: One of the greatest difficulties that we've had in the climate debate came from a clash of fundamental values between the scientific community and the media. The media live in a world in which everything is politicized. When 52 percent of the people are on one side of an issue and 48 percent on the other, that's a big majority. So it is good journalistic practice to have statements from both sides of an issue.

But with climate change, hundreds of scientists are represented by the IPCC, which crafts collective statements. The IPCC is careful to characterize the degree of uncertainty of each statement it makes, but uncertainty is always a part of any scientific conclusion. The media, following their most basic ethical principles, seek out advocates of opposing views precisely because their view is opposed. The opposing views are given equal weight in the public presentation, whereas they do not have anything like equal weight in the community that's doing the research. The net result is the general public thinks significant uncertainty exists where it doesn't. Because of the checks and balances of the scientific method, because scientists meet frequently and check each other out, and because they have things like the intergovernmental panel, there does tend to be a broad consensus about at least the main aspects of the field. ●

WORKING WITH A TEAM OF ZEALOTS & SKEPTICS

BY BARRY GOLDSTEIN



The Phoenix Mars Lander is lowered into a thermal vacuum chamber at Lockheed Martin Space Systems, Denver, in December 2006.

The Phoenix Mars mission was born of failure. Like the mythical Phoenix bird that rose from the ashes of the previous generation's Phoenix, the mission was born out of the "remains" of earlier attempts. It used much of the hardware from the Mars Surveyor Lander and carried instruments either identical to or based on those of the Mars Polar Lander. The success of Phoenix is a testament to our ability to learn from our mistakes. The 1998 Mars Polar Lander (MPL) fell silent when it reached Mars in December 1999, a few months after the loss of the Mars Climate Orbiter. The former fell victim to problems during entry, descent, and landing (EDL)—by far the most challenging part of any Mars landing mission. After those failures, the 2001 Mars Surveyor Lander was canceled before launch.

Photo Credit: NASA/JPL/UA/Lockheed Martin

THE ZEALOTS HAD ESSENTIAL, INTIMATE KNOWLEDGE OF THE EDL ARCHITECTURE; THE SKEPTICS QUESTIONED EVERY ASSUMPTION AND HELPED DRIVE US TO DISCOVER, ANALYZE, AND DEAL WITH THE POTENTIAL PROBLEMS.

Spacecraft specialists work on the lander after its fan-like circular solar arrays have been spread open for testing.

Zealots and Skeptics

As Phoenix project manager, I had no doubts about the importance of getting EDL right. As a competed mission, Phoenix participated in a site visit at Lockheed Martin in Denver in the summer of 2003. When asked by the review team what the three highest priorities were for the development phase of the project, my reply was EDL and EDL followed closely by EDL.

The Phoenix project was selected in August 2003. We held the first EDL team meeting less than two months later. The project as a whole and specifically the EDL team was purposely populated with both zealots for and skeptics of the architectural design. The zealots were the fathers and grandfathers of the 1998 EDL architecture who believed that the failures resulted from limitations imposed by the faster, better, cheaper approach to missions but that the architecture itself was sound. The skeptics were not advocates for that architecture and would take a hard look at every conceivable source of failure.

At that first meeting, I told the team, "MER [Mars Exploration Rover] is on its way to Mars. If it lands successfully, we'll be lucky." I said it partly for shock effect—we had tested the MER vehicles and architecture as well as any previous spacecraft—but I knew how complicated those systems were. The moment you have confidence is the moment you stop looking for potential problems. That is precisely when overconfidence can lead to disaster. As a team, we would need to stay nervous right up to the point when we knew we had been successful. That is exactly what we did.

The MPL Failure Review Board and the Mars Surveyor Lander Return to Flight Review Board had collectively generated a set of forty-two actions to address presumed weaknesses that could have accounted for the failure of MPL. These actions were to be closed out by our team. At this initial meeting I informed the team, "If all we do is close out these forty-two, I'm going to recommend not to launch, because there's more out there." Again, this was partly for shock effect, but it was my sincere belief that if we did our job we would find important issues that were not on that list.

Some New Items

In fact, we found plenty. While testing the separation connectors used to conduct power and signals between the cruise stage and the entry vehicle, we discovered that less than an adequate safety margin existed at the temperatures expected at the time of separation. To increase the margin, we increased mechanical clearance at the core of the connectors and added heaters to make sure that thermal contraction would not further degrade margins.

Detailed assessment of the breakup analysis of our cruise stage, conducted for planetary protection reasons, revealed that some of the components on the cruise stage would not break up on entry; they could actually fly behind the entry vehicle and, given their ballistic characteristics, have the potential to catch up with it. To eliminate this risk, we modified the EDL architecture, altering our sequence so the entry vehicle would turn from sun point to Mars entry attitude after its separation from the cruise stage. This change provided additional lateral separation from between the entry vehicle and the phalanx of shrapnel that could have caught it from behind.

Several other changes were made in the structure and system software to correct for underpredicted loads and functional discrepancies with the landing radar, which was modified for space use. In short, there were over a dozen additional issues with the landing system that the extended Phoenix test and analysis program uncovered and rectified. In some of those cases, the skeptics played the valuable role of making sure our analyses were vigorous and thorough.

Team Dynamics

The composition of the EDL team and the ability of its members to work well together made this work possible. The zealots had essential, intimate knowledge of the EDL architecture; the skeptics questioned every assumption and helped drive us to discover, analyze, and deal with the potential problems. EDL as a technical discipline cannot be separated from the overall spacecraft development, and the Lockheed Martin team that designed, built, and tested the spacecraft welcomed the Jet Propulsion Laboratory team members as part of the development team who contributed to productivity, not just provided oversight. The relationships worked because of mutual respect among members, despite the differences of opinion. They were all professionals, all experienced, all highly skilled, and equally dedicated to the success of the project. Whatever conflict we had was creative conflict, because people took one another seriously and worked together to arrive at answers. This respect increased as we went along. By the time we got to the operational phase of the mission, we truly had a unified team whose individual organizational affiliations were no longer apparent.

Success

Our focus paid off. At launch day in August 2007, we were confident that our continued paranoia was doing its job. On May 25, 2008, we knew that our paranoia could end: Phoenix landed successfully. Phoenix scooped up and analyzed soil from near Mars's north pole. Along with other data about the planet's soil and atmosphere, it confirmed the presence of water-ice just below the surface and found evidence of the existence of liquid water in the past.

As expected, the decrease in daylight hours near the pole reduced the solar-electric power available for the lander. Five months after we landed, long after the anticipated three-month life of its mission, Phoenix stopped communicating with Earth. Dedication, belief, skepticism, and teamwork had been rewarded. ●

Photo Credit: NASA/JPL/UA/Lockheed Martin

Spacecraft technician Billy Jones inspects the Phoenix Lander's robotic arm, which was used to dig into the planet's icy soil to study the history of water and search for complex organic molecules.

BARRY GOLDSTEIN started his career at the Jet Propulsion Laboratory in 1982. Recent assignments have included deputy flight system manager for the Mars Exploration Rovers and, most recently, project manager for the Phoenix Lander. He holds an undergraduate degree in mathematics with a physics minor from the University of Colorado and an Executive MBA from the Peter Drucker school of management at the Claremont Graduate School.

Human System Risk Management

BY JUDITH L. ROBINSON

The human system is one of the most complex elements of space exploration missions. Our current long-duration space flight knowledge comes primarily from missions of up to six months' duration. Based on that experience, we know that lunar, Mars, and other long-duration missions will pose significant physiological, performance, and psychological challenges.

The mission of Space Life Sciences at the Johnson Space Center, as articulated in the May 2007 "NASA Space Life Sciences, Strategy for Human Space Exploration," is to "optimize human health and performance to enable space flight mission success." Under the leadership of director Dr. Jeffrey R. Davis, we have developed a comprehensive, integrated human system risk management process to foster the evidence-based, multidiscipline communication and discussion that are the foundation of successful human health and performance research, technology development, countermeasure development, and provision of appropriate ground-based and in-flight medical capabilities to meet space exploration objectives.

To integrate all elements of the human system into one comprehensive set of activities, employ a common approach to managing human system risks, and educate the larger community about human health and performance technical capabilities and ongoing work, the Johnson Space Life Sciences Directorate has established a human system risk forum and board, developed and baselined our initial human system risk master list, and developed a Risk Management Analysis Tool (RMAT) that is central to our continuous risk management process.

Understanding Human System Risks

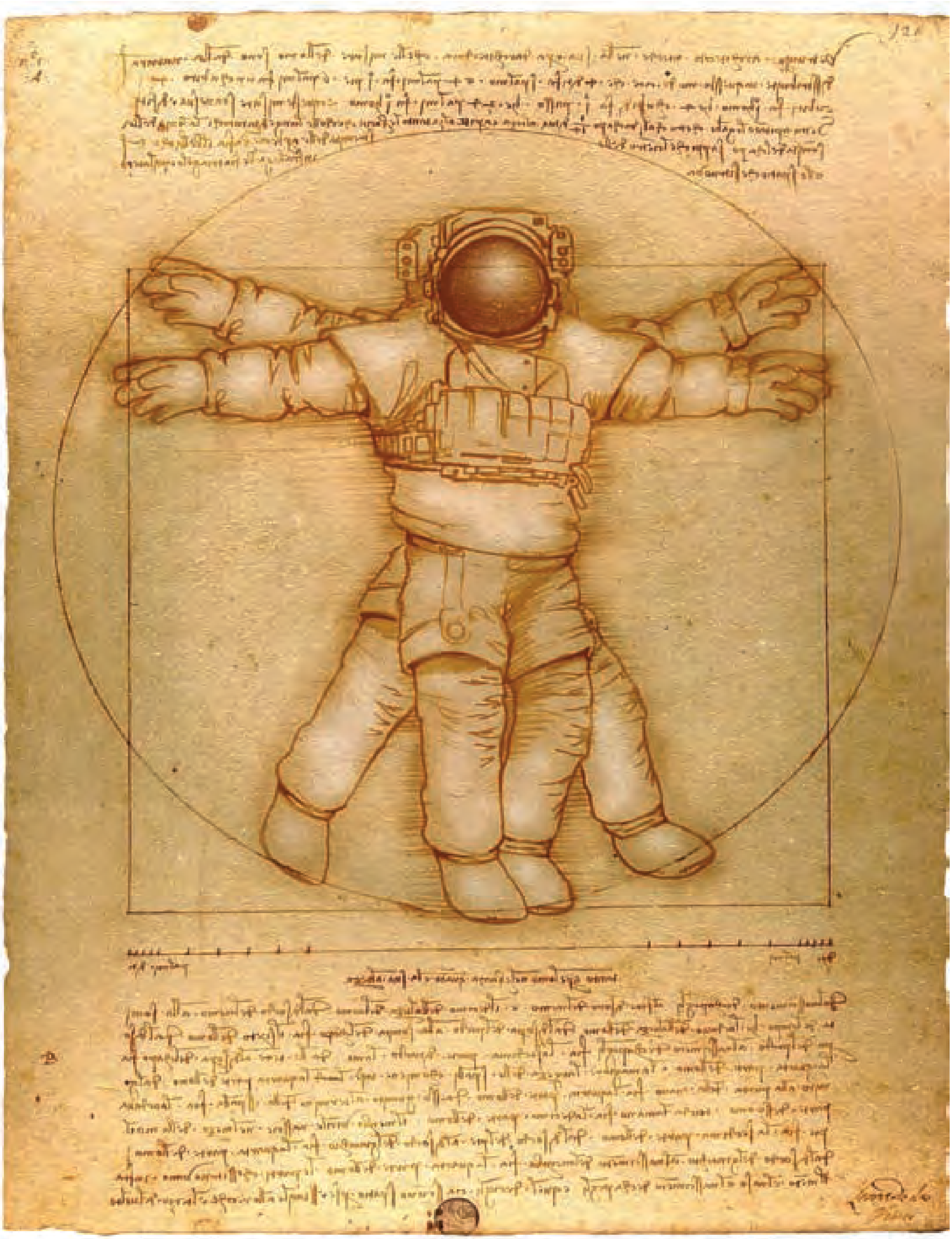
Early human space flight programs focused on ensuring that crews remained healthy and physically fit to allow them to meet mission demands. During Project Mercury, space life sciences investigated the astronaut's ability to function in space. The Gemini program gave us additional information on the physiological effects of weightlessness. Apollo provided even more information on the effects of weightlessness, while we developed and ensured human capability to work in the lunar environment for periods of up to twelve days. Beginning with Skylab and continuing with the Space Shuttle, NASA–Mir, and International Space Station programs, our focus broadened to encompass activities including human health and performance research and countermeasures development; medical operations based upon standards; and habitability, human factors, and environmental factors.

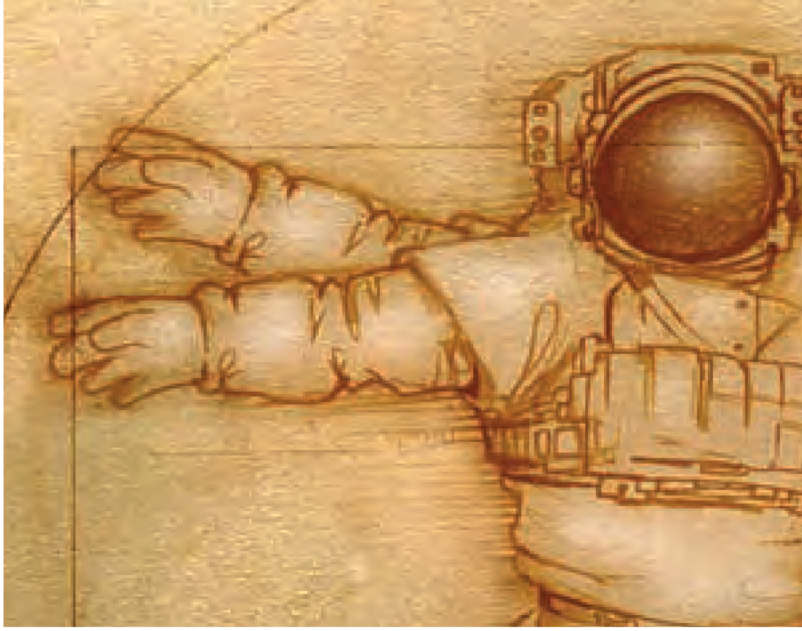
We have defined three categories of human system threats or issues:

1. Exposure to hypergravity or hypogravity environments
2. Remote deployment in space
3. Exposure to hazardous and closed environments

These three "parent threats/issues" potentially cause physiological changes, cause or contribute to medical events, provide environmental exposures (for example, to radiation), require appropriate considerations and countermeasures because of closed-loop life support systems (air and water), and require design of space habitats and vehicles and associated habitability systems appropriate for long-duration missions. Our efforts directly address human system considerations but also influence spacecraft design, development, and operations, including life support systems, monitoring systems, and astronaut workload.

At one time, we talked about human system risks in absolute terms, but we have found it essential and beneficial to consider human health and performance risks in context—linking the risk to a precipitating spacecraft or space environment condition or event and understanding how that affects human health and performance. The fact that mass and volume are very limited during space exploration missions potentially affects onboard





medical and environmental management capabilities. Those limitations are realities that must be factored into our human system risk-mitigation strategies.

Consider the example of one scenario for Orion, the new crew exploration vehicle under development: a catastrophic failure at translunar insertion that results in a depressurized spacecraft. From a purely medical point of view, the preferred response would be to re-pressurize the vehicle, but the craft will not carry enough consumables to do that. That reality refocuses the risk mitigation strategy for the crew on a solution set in which the crew would don their space suits and live in them until their safe return to Earth. Our responsibility becomes one of determining how long this scenario is really viable for crew survival and what the effects of a prolonged period in a suit would be.

The Forum in Action

The Human System Risk Forum and Board are where human health and performance scientists and physicians and human system engineers come together to discuss and integrate all elements of the human system. Started in May 2008, the forum provides a place to discuss high-priority risks thoroughly and exchange evidence-based information and data. Bringing together different disciplines can lead to more informed, balanced decisions than any one group would likely make on its own.

For example, a cardiovascular research lab that had been studying the risk and countermeasures for orthostatic intolerance (that is, a blood pressure drop leading to fainting when standing up after return to Earth) came to the forum with a problem and a question. The promising pharmaceutical agent they were testing interacted negatively with other medications used in space. Since they had stopped testing the specific pharmaceutical countermeasure due to the interactions noted, they asked the members of the forum—researchers, space medicine physicians, and other human system experts—whether they should look for alternatives that were free of the described troubling interactions. In other words, and not surprisingly, they were looking for a solution within their own area of expertise. But the space medicine representatives at the forum pointed out that orthostatic intolerance need not be addressed with pharmaceuticals: there are mechanical devices that astronauts can use to mitigate the problem. So forum members recommended that the specific countermeasure research effort be stopped entirely. Perhaps this was not the solution that was anticipated at the start of the meeting, but it was the consensus recommendation that was reached through multidiscipline discussion.

Recommendations made by the Human System Risk Forum concerning work required to close gaps in knowledge and technologies, to retire or mitigate risks, and to identify new risks are brought to the Human System Risk Board, where strategic decisions are made concerning our portfolio of work. The board does not duplicate routine, tactical decisions that we negotiate with the agency's programs. It is the place where we make strategic decisions about the recommended level of investment in high-priority human system risks. Both the forum and the board help us communicate and widely disseminate information and tactical decisions to the broader human health and performance community.

The human system may also have relationships to and interdependencies with other system and program risks. Mitigation strategies must therefore be worked collaboratively with other system owners. The Human System Risk Forum meets at Johnson on the second and fourth Tuesday of each month. Participation has been extended to the larger NASA community through the use of teleconferencing and WebEx capabilities.

Capturing and Documenting Human System Risks

Another important consideration in the Space Life Sciences implementation of the human system risk management effort has been to follow Continuous Risk Management (CRM) as defined by NASA and used throughout program and project management.

BRINGING TOGETHER DIFFERENT DISCIPLINES CAN LEAD TO MORE INFORMED, BALANCED DECISIONS THAN ANY ONE GROUP WOULD LIKELY MAKE ON ITS OWN.

In the past, we sometimes described human system risks using medical and scientific terminology that program and project managers had difficulty understanding and relating to the kinds of risk calculations they make in their work. Using the same nomenclature and following the same CRM processes facilitates communication of risks to those outside the human health and performance community. Using consistent CRM language and discipline to provide information allows others in the agency to balance human health and performance risks with technical development and operational risks, resulting in more informed decision making.

Integral to human system risk management has been the development and baselining of a human system risk master list that captures all the currently known human system risks and potential risks. As it matures, the list will provide the chief medical officer and the Health and Medical Technical Authority with a comprehensive description of all human system risks and their status.

To that end, we have developed an RMAT to capture detailed information for each human system risk, including the evidence supporting it. Intended primarily as a communication tool, the RMAT is formatted to facilitate the understanding of human system risks and allows comparison of existing standards, requirements, and mitigation strategies against known mission architectures and resources. Missions differ in duration, distance from Earth, resources, and onboard capabilities. It is vital that the information we collect using the RMAT format allow for the development of risk-mitigation strategies for each architecture and that differences in the likelihood and consequence of risks in different kinds of missions be taken into consideration.

The RMAT information will improve understanding of risks and their mitigation strategies in the human health and performance community and other, associated disciplines. We will use this approach as we work through human system health and performance risks over the next several years to ensure appropriate evidence and mitigation strategy development and eventual implementation. ●

JUDITH L. ROBINSON is associate director of Space Life Sciences at Johnson Space Center.

CONQUERING SPACE BY CAPTURING IMAGINATIONS

BY SVETLANA SHKOLYAR

Image courtesy 4Frontiers Corporation

Artist rendering of the settlement by Michael Carroll.

What do the rocket scientist Dr. Wernher von Braun, 1950s television programs and magazine articles, and an emerging corporation focused on the human settlement of Mars have in common? They all recognize that linking science and the media creates excitement and support. Their objective has been to inspire the rest of us that "Man Will Conquer Space Soon!" In the 1950s, this sentiment was conveyed by von Braun in a series of influential magazine articles. The 4Frontiers Corporation is making similar efforts today.

VON BRAUN WAS CONSIDERED TO BE THE “FATHER OF THE U.S. SPACE PROGRAM” NOT ONLY FOR HIS PIONEERING ROCKET SCIENCE, BUT ALSO FOR THE WAY HE PROMOTED THE SPACE PROGRAM, ESPECIALLY THROUGH HIS WORK WITH WALT DISNEY.

Capturing America’s Imagination

German-born von Braun developed the V-2 missile during World War II, but his real interest was in engineering rockets for space exploration, not war. Throughout his American career, during which he guided the development of the Saturn V launch vehicle and directed NASA’s Marshall Space Flight Center, von Braun worked tirelessly to convince the public that mankind should escape from what he called the “chains of gravity” that bind us to the earth. In the 1950s, *Collier’s Weekly*, which had a circulation of more than four million, asked von Braun to contribute articles about his vision for space exploration. Those articles included his concepts for a space station and spurred the movement to create one.

As space historian Randy Liebermann notes, “After twenty-five years of continuous and directed thinking and endless hours of experimentation, von Braun, the world’s leading rocket engineer, had the chance to come out of his sequestered military environment and, through a national magazine, inform the general public of his detailed blueprint for realizing manned space travel.”

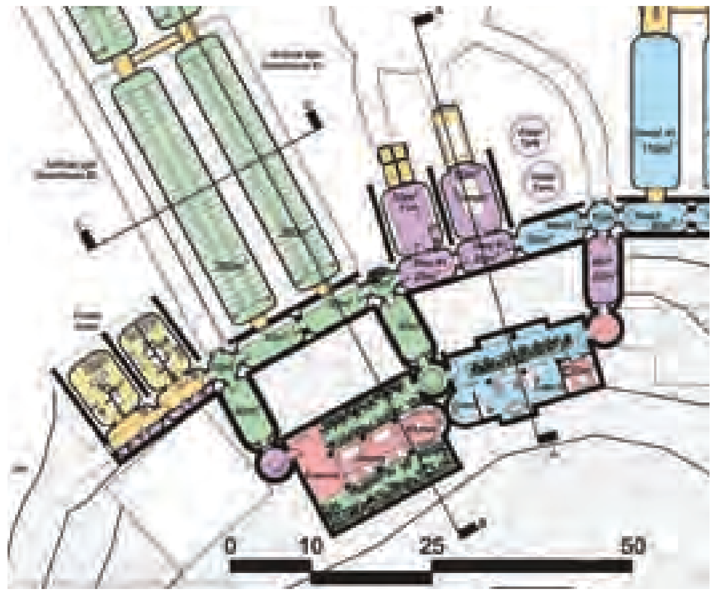


Image courtesy 4Frontiers Corporation

Close-up view of 4Frontiers’ site of the first permanent settlement on Mars.

Von Braun was considered to be the “father of the U.S. space program” not only for his pioneering rocket science, but also for the way he promoted the space program, especially through his work with Walt Disney. He worked as a technical director with Disney to create three space-related television films. Disney introduced “Man in Space” and “Man and the Moon” in 1955 and “Mars and Beyond” in 1957, seen by an estimated forty-two million viewers. Von Braun’s objective was to create what he called a “science factual” show.

Together, von Braun and Disney used the power of the new medium of television to convey to Americans just “how high man might fly on the strength of technology and the spirit of human imagination,” in the words of Marshall Space Flight Center historian Mike Wright.

These Disney films were the first to explain basic science in a vivid, humorous, and colorful way. “It was a matter of synthesizing the philosophical aspects into neat packages and solid statements which the public would buy,” wrote Erik Bergaust, von Braun’s biographer. Critics and commentators regarded the shows not as science fiction entertainment but rather as predictions of what emerging technology would make possible. Dr. Ernst Stuhlinger, a technical consultant for the shows, wrote that von Braun’s wish to see man conquer space meant turning not just scientists, industry, and politicians into supporters but also, most importantly, the public.

Applying Von Braun’s and Disney’s Techniques Today

Like von Braun in the 1950s, the 4Frontiers Corporation understands that although technical skills are essential, it takes public support as well as strengths in many other areas to “conquer” the ultimate frontier. Applying this understanding is key to their strategy.

In July 2005, 4Frontiers was founded at the Massachusetts Institute of Technology to help extend humanity’s reach to new frontiers, specifically the first human settlement on Mars. The four frontiers the founders envision are Earth orbit, the moon, Mars, and asteroids. While humans may not conquer Mars for

at least another decade, informative entertainment, Earth-based technology development, and consultancy are three business frontiers the company is working to master today. Efforts in these areas will lay the foundation needed to pursue their ultimate objective.

A crucial aspect of 4Frontiers' strategy is to engage the public through informative entertainment, sharing its vision and its latest innovations while translating public interest into support of the company's research and business operations. To do so, the company has been developing a number of unique ventures. Educational tour packages have been created for groups interested in space and U.S. culture, providing behind-the-scenes tours of space and science centers throughout the country. 4Frontiers is even planning a television reality show where groups of individuals compete as if they were early Mars settlers. New media such as Twitter and Facebook are being used to engage the public in 4Frontiers' efforts.

A second avenue being pursued is educational programming. 4Frontiers knows that educating and exciting today's youth will help to inspire tomorrow's pioneers. Fictional stories about the first family on Mars have been included in an interactive children's Web site, www.crazy4mars.com. Curricula have been developed for fifth- through seventh-grade classrooms that present the theme of Mars exploration. The company is also planning to open an Informative Entertainment Center that will house a museum, business center, and research facility for innovative space technologies.

4Frontiers recognizes that the pursuit of interesting technology alone is insufficient to permit the company to accomplish its goals. As Peter Collins, an intern for 4Frontiers, explains, "It is not just technical skills that will get us to Mars, but business skills also; projects need to be managed, funding obtained, and profits made along the way."

The third business segment that the corporation is exploring is consultancy. "The company is developing a solid client base for its space technology engineering consulting. Real value can be added in this area through cross-pollination between different technical disciplines," said Joseph Palaia, vice president and co-founder of 4Frontiers.

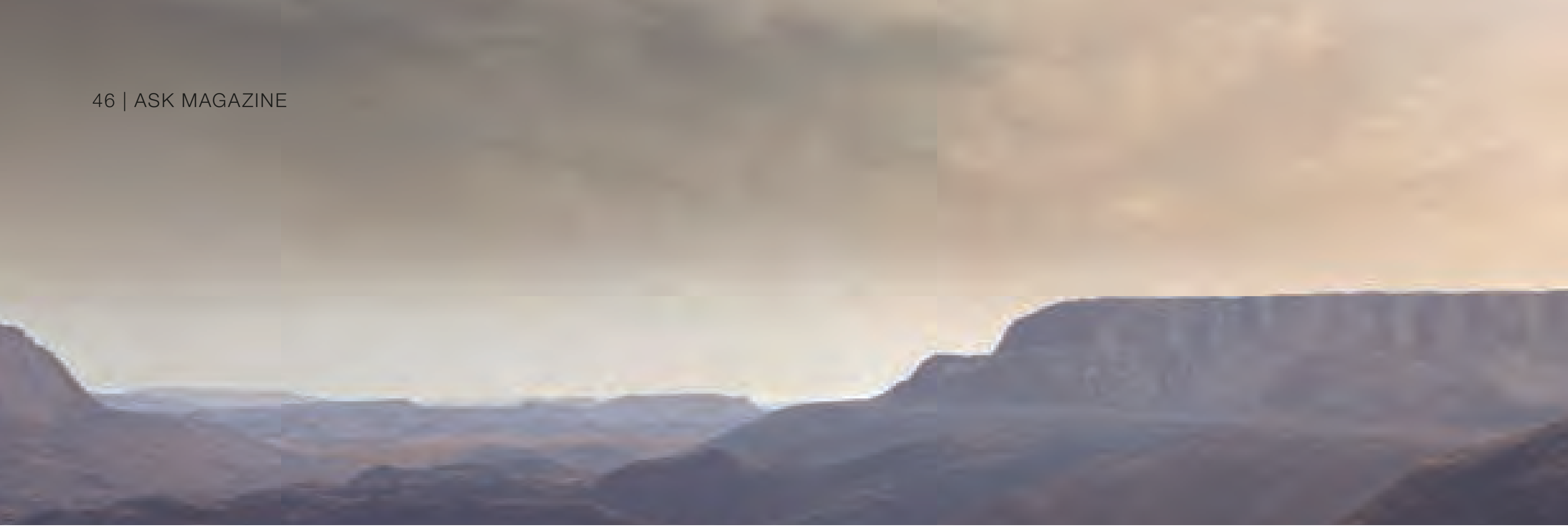
The company has provided consulting services for some organizations, including one researching advanced energy conversion technology in Florida and another manufacturing semiconductor equipment in Massachusetts. "Technical solutions we develop for the space frontier often have direct applicability here on Earth," said Palaia. The company has also consulted for Galactic Suite Limited, a company aiming to get an orbiting space vacation resort open in 2012. 4Frontiers even provided entertainment and education consulting services for high school students from New Delhi, India, including the development and execution of two custom tour package programs for them.

The Power of Diversity

The co-founders of 4Frontiers, CEO Mark Homnick and Vice President Palaia, both have engineering backgrounds. They have played leading roles in the company's Mars settlement design efforts, and they are strong proponents of bringing people with diverse skills together to develop inventive solutions to problems and rich visions of the future.

"Imagine if you were tasked with designing a city on another planet," Palaia said. "We cannot do that unless we are multidisciplinary." Indeed, the company has engaged some untraditional participants, including specialists in astrosociology, psychology, artistic rendering, and science fiction writing, alongside the more traditional technical disciplines. What enables communication between these individuals who would not normally interact is their interest and passion for 4Frontiers' mission. Through their brainstorming, whether face to face or via communication technologies, they can come up with ideas to solve technical problems relevant to Mars and here on Earth.

An example of this approach occurred during the Generation II Mars settlement programming study meeting in Atlanta in 2006. In one weekend, more than two dozen experts gathered to refine concepts for the first Mars settlement. No two members were from the same discipline. Those in attendance included, among many others, experts in aerospace engineering, medical factors, psychology, and architecture. The Generation II study helped 4Frontiers facilitate later investigations on settlement architecture and greenhouse material.



According to Palaia, progress in the coming decades will be driven by work from teams who cross the boundaries between disciplines. These diverse groups may discover new approaches to problems that have typically been handled exclusively by one discipline. 4Frontiers will engage partner organizations and individuals to execute project elements and move the work forward. The drawback to this multidisciplinary approach from a corporate perspective is closely related to what makes them successful: these teams tend to come up with very ambitious new ideas. "We are good at developing innovative cross-discipline solutions," said Palaia, "but then we need to engage teams outside our group to actively develop those ideas."

Within 4Frontiers, people use their own varied skills to work effectively. Homnick leveraged his engineering background and managerial skills to manage the Generation I Mars settlement programming study, which now serves as a foundational element of the company's Mars settlement research efforts. His expertise in project management for large-scale electronics projects was useful to the settlement study because elements of risk and incomplete information are common in both. He was able to use a well-understood project management process, apply it to this study about a topic that is not well understood, and achieve a meaningful result. Homnick led the study effort to identify the goals, objectives, and project needs, just as in a typical project management situation, to determine that a project like this was feasible.

The company looks continually for new ideas. Interns Alex Stimpson and John Truett, exploring various research grant opportunities during the summer of 2008, proposed using nanotubes to increase the permeability of fish eggs and embryos, enabling their cryopreservation. A research proposal is being developed to actively pursue this innovation.

New Frontiers

The very first press release put out by 4Frontiers explained why it is one of the few start-ups treading the ground of these new frontiers: "While a number of companies have set their sights on advancements in getting to Mars, few have laid out plans with technical reality and actual designs to quickly and affordably establish settlement."

"Lots of people tried just the technical approach. We don't think that'll work. It is too myopic," explained Homnick. "Others try education and tourism and don't develop technology. That's short-lived, too. We combined the two; that's how we created 4Frontiers—a symbiotic relationship between the elements."

The company is in the early stages of designing and building an Informative Entertainment Center, where visitors will be able to tour a full-scale Mars settlement replica. There, they can sample Mars algae snacks, buy tickets for space vacations and experiences from real space tourism companies like Virgin Galactic, and see technologies and systems being engineered for future use on Mars.

> … THE COMPANY HAS ENGAGED SOME UNTRADITIONAL PARTICIPANTS, INCLUDING SPECIALISTS IN ASTROSOCIOLOGY, PSYCHOLOGY, ARTISTIC RENDERING, AND SCIENCE FICTION WRITING, ALONGSIDE THE MORE TRADITIONAL TECHNICAL DISCIPLINES.

One final motivation inspires 4Frontiers. According to Palaia, "Human beings benefit from going into new environments. Here on Earth, we've run out of physical frontiers." Von Braun might have agreed. ●

SVETLANA SHKOLYAR is a science communication graduate student, researcher, and writer.

The Quest for Good IDEAS

Suppose you had to design a door within a lunar lander module that would shield the crew habitat from solar activity during a moon mission. Assuming this isn't already your day job at NASA, how would you begin to devise a solution?

BY MATTHEW KOHUT

IN THE WORLD OF DESIGN, NOBODY HAS A MONOPOLY ON THE ANSWERS. IT PAYS TO LOOK EVERYWHERE.

That's the question that two dozen participants wrestled with over a three-day period at Ames Research Center last fall. Their brainstorms, deliberations, drawings, and prototypes were the central group activity of Innovative Design Engineering Applications (IDEAS), a new course offered by the Academy of Program/Project and Engineering Leadership that focuses specifically on the challenge of design. IDEAS introduces a variety of tools that engineers can use to help conceive, develop, and test new design concepts. The emphasis on variety is deliberate because there is no single approach that works well in all contexts. "The design practice of systems engineering is more of an art learned through experience," said course instructor John Sturrock.

Day One: Divergent Tools

"Is brainstorming a soft or hard tool?" John Sturrock asked the class.

"Soft."

"How about Design for Six Sigma?"

"Hard."

Photo courtesy John Sturrock

Teams brainstorm, sketch, and build possible solutions for projects during the IDEAS course.

Sturrock hadn't defined "soft" or "hard." Participants shared common assumptions about what these metaphors meant. This wasn't terribly surprising since all were NASA engineers working in very similar organizational settings, but those same words could have different meanings to people in different contexts. His point: an over-reliance on verbal communication in the design process can introduce ambiguities or misunderstandings.

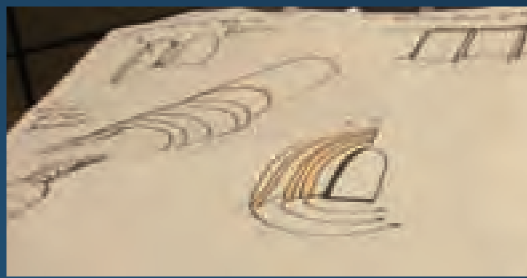
The class also examined visual thinking, which highlighted the importance of drawings and sketches. It explored kinesthetic learning through a case study focusing on the design of the astronaut seat for the Orion vehicle. The case recounts the experience of the lead designer of the seat, who was having trouble arriving at a design solution through the use of software-based visual tools such as Pro-Designer and AutoCAD. By building a prototype seat in his garage, he was able to touch and feel how the controls and handling worked, leading to new breakthroughs.

Day one emphasized divergent tools, which are a means of gathering a wide range of ideas. Brainstorming is a divergent tool. Selecting team members with diverse backgrounds who haven't worked together is another one. Divergent tools offer the promise of enhancing creativity but no guarantees. "Design is an unstable activity," said Sturrock. "Not only do we not know where we're going, but we change our destination as we go."

"Much time was spent on exercises meant to demonstrate that we never get a 'full picture' of possibilities and we are inherently biased in our focus of attention," said Silvano Colombano, a computer scientist in the Intelligent Systems Division at Ames. "A wider, more unbiased coverage of problems and solutions comes at a cost. The real difficulties in innovative design are the cost–benefit analysis associated with eliminating biases, and how to organize groups of people so that the best possible solutions can be obtained by their combined brain power."

Participants broke into small groups and began brainstorming designs for their lunar habitats, generating as

Design #2 Ranked
Interior Curtains filled w/ Regolith and/or water



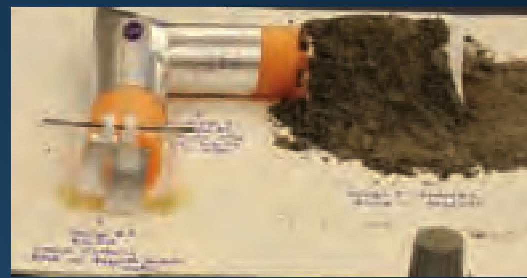


Photo courtesy John Sturrock

One team s initial rough sketch and model for the lunar habitat case.

many ideas as possible. Sturrock encouraged the groups to follow the practice of design firm IDEO and refrain from judgments or criticisms during these initial sessions: the goal was mass creativity. Water was a key design element because of its ability to act as a radiation shield. How about a revolving door with one side filled with water? A flexible water curtain? A water-filled sleeping bag for each crewmember? There would be time to sort, rank, and criticize the next day.

Day Two: Convergent Tools

The hard tools of design come into play at the point where creativity meets engineering rigor. Quality Functional Deployment (QFD) sets customer requirements alongside business processes to determine strong and weak correlations. The Pugh matrix (also known as a criteria-based matrix) offers a simple means of scoring and ranking concepts against requirements. Design for X (DFX) looks at design in terms of a certain functional aspect, such as "design for maintenance and serviceability," "design for reliability," or "design for manufacturing and assembly." These kinds of tools enable designers to converge on ideas that are worthy of further time and energy.

"Tools like the Pugh decision matrix, brainstorming, and innovation have their application to my everyday job. Many of the design decisions that get made are done so for specific reasons and require data to back them up," said Joe Matus, a systems engineer from Marshall Space Flight Center. "When designing a one-of-a-kind vehicle or experiment, or a limited quantity launch vehicle with critical performance parameters, it is important to weigh the myriad solutions that are available and to choose the one that makes the most sense in the overall scheme of things. Once a forward path is chosen, it can be quite costly to decide later that it is not the correct one."

Participants then used the convergent tools to score and rank their lunar habitat designs from the first day. The water sleeping bag would never pass muster with the crew. A revolving door or some sort of ball valve might work. The good designs would make it to day three.

Day Three: TRIZ, Open Innovation, and Final Projects

Participants spent the first part of day three discussing some other valuable techniques for spurring and guiding innovation. One is the Theory of Inventing Problem Solving. While working as a patent examiner in the Soviet Union in the mid-1940s, Genrich Altshuller, a Soviet engineer, developed a rigorous taxonomy of inventions, focusing on how patent applicants solved problems. He found that there were forty inventive principles that were used time and again, regardless of the industry or technical discipline, to solve common technical contradictions. This led him to the Theory of Inventing Problem Solving, which became known worldwide by its Russian acronym TRIZ.

Another is open innovation, one of the most dynamic developments in the design world over the past decade. The open-source software movement is the leading example, though the practice has spread to countless industries and manifested itself in multiple ways throughout NASA, ranging from the Innovative Partnerships Program to the Centennial Challenge competitions it has sponsored. In the world of design, nobody has a monopoly on the answers. It pays to look everywhere.

The final activity brought the small groups together one last time for a ninety-minute rapid prototyping session. The lunar habitat designs that had been brainstormed on day one and analyzed on day two took shape with Styrofoam, aluminum foil, paper plates, and Scotch tape. Each group made a short presentation to the class, and then participants voted for their favorites. Photos and sketches of the best designs would be shared with the lunar habitat design team at Johnson Space Center.

The IDEAS session at Ames marked the second time the course had been offered at NASA—it had been held earlier in the summer at Kennedy Space Center. It is easy to envision future sessions held specifically for newly formed design teams or new hires at the Agency. The challenge of developing innovative designs will be waiting for them. ●

Photo Credit: NASA Dryden Flight Research Center

SOFIA: GETTING AIRBORNE

BY KERRY ELLIS

As early as the beginning of the seventeenth century, when Galileo used his telescope to turn Ptolemy's geocentric theory on its ear, astronomers have continually sought better ways to look into the heavens to discern what exists in the depths of our star-studded universe. This scientific pursuit has resulted in numerous ground-based observatories and, more recently, space telescopes, but very few airborne observatories. The Stratospheric Observatory for Infrared Astronomy (SOFIA) is here to change that.

With several infrared telescopes currently in operation, including Mauna Kea Observatories in Hawaii, Kitt Peak National Observatory in Arizona, and NASA's Spitzer Space Telescope, adding one more may seem like overkill. But SOFIA offers some advantages the other observatories do not. To understand these benefits, it helps to first understand the unique advantages infrared astronomy offers over optical, or visible light, astronomy.

Due to the expansion of the universe, objects that are furthest away from Earth have their light shifted to longer wavelengths. Viewing the infrared wavelength allows us to observe visible light from stars in distant galaxies. Many interesting objects, such as the dusty gas clouds where stars are formed or planets outside our solar system, are also too cold to emit visible light, but they glow brightly in infrared. Also, dust can obscure many things in the visible light range, which is why the Milky Way appears to have dark, blank patches between its billions of stars. Stars do exist within those voids, and infrared wavelengths pierce through the dust obscuring them, allowing an infrared telescope to see what lies beyond.

However, infrared light is absorbed by moisture in the atmosphere, which is why infrared observatories are built high upon mountains or launched into space. Ground observatories are limited to what can be seen from a fixed location and get above only a portion of the water vapor in Earth's atmosphere, and space telescopes eventually run out of the cryogen needed to keep infrared instruments cold enough to operate. SOFIA eliminates most of these disadvantages.

Its infrared telescope is mounted in the rear fuselage of a highly modified Boeing 747SP aircraft, which will fly at about 40,000 ft. to get above 99 percent of the moisture in the atmosphere. It will be able to land each night for refueling, servicing, or even technological updates to keep the instruments cutting-edge. SOFIA's mobility will allow it to fly anywhere in the world to observe celestial events, including occultations, or eclipses of stars. A ground-based observatory may experience a dozen of these events out of the couple hundred that occur in a year, reducing the chances for valuable new discoveries. For example, the Kuiper Airborne Observatory, SOFIA's predecessor, discovered the atmosphere around Pluto by observing an occultation in which the light of a star behind the planet did not sharply drop off but instead slowly waned and waxed, refracting through Pluto's atmosphere.

Photo Credit: NASA

Two USRA technicians at NASA Ames Research Center are reflected in the coated SOFIA telescope main mirror suspended above them in the mirror coating facility.

Reorganizing for Success

The SOFIA project began about ten years ago. After several schedule delays and cost overruns that threatened to end the project before it flew, SOFIA changed from a contractor-led project with government oversight to a government-led model with contractor support.

Part of this change included moving the program office to Dryden Flight Research Center. Dryden's expertise includes development, testing and evaluation, and flight research, which benefit SOFIA's current development and testing phase. For the next few years, the program challenges will be finishing the system integration and testing numerous modifications and subsystems. The most significant of these is the structural change needed to accommodate the large hole in the fuselage for the telescope. The team extensively tested the modification in a wind tunnel, working to ensure the modified aircraft flies just like the unmodified aircraft. The proof will be in the flight test.

The reorganization also aligned the various organizations involved with SOFIA according to their strengths. For example, Ames Research Center and USRA became responsible for the science associated with SOFIA, while Dryden and its supporting contractors are responsible for the integration, testing, and operation required to turn the airplane into an observatory.

Before the move, the German space agency Deutsche Zentrum für Luftund Raumfahrt (DLR), which is contributing funding to the project and building the telescope, helped fight to keep SOFIA from being canceled. While the move changed the main points of contact for DLR, communication has helped maintain cohesion among the team.

In addition to weekly teleconferences involving the German and NASA program offices—which take place early in the morning since Germany is nine hours ahead of the west coast—the project leaders have created independent project teams, or IPTs, to help coordination and communication efforts. For example, the telescope has an IPT comprising NASA, DLR, and contractor team members to facilitate knowledge sharing and team cohesion.

Since SOFIA's hardware development and testing occur at Dryden, most of the DLR engineers work there. Michael Toberman, deputy project manager for SOFIA, also had the opportunity as part of his career development plan to work overseas in Germany at DLR for nearly four months and learn how the agency works. His experience has helped him better coordinate the SOFIA efforts back home.

Getting Ahead

While SOFIA is now ahead of the game on its cost and delivery schedule, its earlier delays disenchanted the science community. Lacking the support of its main audience, SOFIA again teetered on the edge of extinction.

To reinvigorate the scientists and regain their trust, the SOFIA team first listened to what the scientists wanted. They obtained feedback from the community through existing program reviews and other input. High-level NASA and National Research Council science advisory groups, such as the NASA Advisory Council, the Committee on Astronomy and Astrophysics, and the Astronomy and Astrophysics Advisory Committee, also regularly reviewed the SOFIA program. "The messages I received were (1) 'we want the science scheduled quickly' and (2) 'we want a credible cost and schedule to get there,'" said Bob Meyer, SOFIA's program manager. So the team brainstormed creative ways to get science from the first in-flight observations as quickly and credibly as they could. The program philosophy changed from finishing the observatory before testing began to an approach that pursued the minimum capability required to obtain limited science observations as early as possible. "It's a fly a little, fix a little, fly a little philosophy," said Meyer.

Once the team established the schedule, they set about proactively communicating it and providing updates on how they were meeting it. They published regular announcements on the mission Web site and sent speakers to meetings and departmental colloquia around the world, including regular American Astronomical Society (AAS) meetings, to speak directly with the scientists. Meyer added, "We also have independent science review teams, comprising people not involved with the program, come look at SOFIA once or twice a year. They have favorable feedback, and they share their observations with their colleagues."

Another concern for SOFIA was the age of its science vision, which was cutting-edge when the program began in the nineties. But a decade later, the team was worried about the science becoming stale, in large part because of new discoveries from the Hubble Space Telescope and new infrared observatories such as Spitzer. "We conducted workshops in conjunction with the biannual AAS meetings, looking at what science was current and where SOFIA could add the most value," said Meyer. "With the workshops and people seeing how close we are to flying with a science instrument, we've really turned the science community around."

The SOFIA team also announced to the world that the observatory had successfully flown from Waco, Texas, to Dryden during an event to unveil the airplane. Originally christened by Charles Lindberg's wife when the plane went into service for Pan Am, SOFIA still bears its original moniker of "Clipper Lindberg" on its side. The team invited Eric Lindberg, Charles's grandson, to rechristen the Boeing 747 for science. "That event marked a turning point; it showed that SOFIA had flown and was real," said Meyer.

Moving Forward

SOFIA has conquered many hurdles, and the team is doing everything within its power to carry out the mission's first science observation flight on schedule in 2009. Part of their preparation includes testing for and eliminating any acoustic resonance that may occur while flying with the telescope observation door open. "It's the same thing that happens when you blow air over the top of an empty bottle," explained Meyer. "Acoustic resonance would vibrate the structure and could put the mission at risk."

Acoustic resonance brought a Department of Defense (DoD) project to a standstill, so the SOFIA team spoke with the DoD to learn about its approach to flight tests. "We're doing more extensive wind tunnel and analytical testing than they did, and we don't believe we'll have the same issue," said Meyer. "It's a risk we carry until we fly with the door open for the first time, which should be in about three months."

With continued communication among the team and with the science community, SOFIA is sure to take off and bring to light new discoveries hidden behind the dust of space, such as how planets and stars form, how material is processed within and cycled through the spaces between stars, the composition and structure of planetary atmospheres, and the role of ultraluminous infrared galaxies in the formation of the early universe. ●

The SOFIA airborne observatory s 2.5 meter infrared telescope peers out from its cavity in the SOFIA rear fuselage during nighttime line operations testing.

Photo Credit: NASA Dryden Flight Research Center

ASK Bookshelf

Here is a description of a book that we believe will interest ASK *readers.*

The Powers to Lead, by Joseph S. Nye, Jr. (New York: Oxford University Press, 2008)

Joseph Nye, who has served as chairman of the National Intelligence Council and Assistant Secretary of Defense as well as dean of Harvard's Kennedy School of Government, has long been a proponent of "soft power"—the ability to get what you want by attraction, by co-opting rather than coercing others. That idea, along with Nye's recognition that both hard and soft power can play a role in achieving desired results, informs this brief, sensible, useful book on leadership.

Nye defines a leader as someone who "helps a group create and achieve shared goals." Implicit in that definition is his insistence that leadership is a *relationship*, both because leaders only exist in relation to followers and because success is more likely when goals and ways of working are shaped by leaders and followers together. Effective leaders have vision, communication skills, and emotional intelligence. This last quality includes a person's ability to master his or her own emotions and the empathy needed to understand and interact appropriately with others. Successful leaders also understand how the context of work influences the appropriateness of particular leadership strategies and styles. Leading in a crisis and leading a long development project may require different approaches—a different balance of hard and soft power, for instance, or more or less emphasis on inspiration or maintaining order.

While recognizing that hard and soft power both have value (he calls the combination of the two "smart power"), Nye emphasizes the value of soft power, perhaps because traditional ideas of leadership stress hard power, sometimes to the exclusion of any other kind. He admits that consultative leadership—soft-power asking and engaging—takes more time than issuing orders, but it has the advantage of giving leaders more information and gaining the commitment (not just the obedience) of followers.

Members of NASA project teams should find lots of useful insight in *The Powers to Lead*. The book gives project managers and other "official" leaders an opportunity to analyze their own behavior as leaders, evaluate their effectiveness, and add to their repertoire of approaches for their varied and challenging work. But team members not normally identified as leaders will also find value here. For one thing, being an effective follower is being an essential contributor to the leadership relationship. Also, as Nye points out, leadership in groups tends to be somewhat fluid, with different people becoming leaders in different situations, whether or not their taking on that role is formally recognized. Finally, Nye makes an important point about what he calls "leader attribution error"—the tendency to give leaders more credit for accomplishment and more blame for failure than they deserve. We often imagine leaders have influence and knowledge far beyond what they actually possess. Understanding leaders' limitations and seeing them as one factor among many in getting work done can also contribute to success, including successful leadership. ●

The Knowledge Notebook

Leadership and Knowledge

BY LAURENCE PRUSAK

I almost hesitate to write this column because I devoutly believe that too much is made of "leadership" in business curriculums and in the popular press. Organizational life in general and the activities involved in actually getting things done are profoundly social, never the work of one man or woman. Having said that, I recognize that we still mainly organize ourselves with hierarchical structures, archaic as they may seem. Given this fact, it does matter what the "leader" does or says. Organizational structures and the roles of leaders differ quite a bit from organization to organization, but it seems that leaders will have considerable power and influence for some time, though probably less than they think.

So what can a "leader" actually do to advance the cause of knowledge in an organization? Very few people would actually speak out against knowledge—though I have met one or two who have done just that—but benign neglect will not help organizations use knowledge more effectively and efficiently and develop and value new knowledge. Here are some things leaders can and should do.

One essential action is to talk about knowledge, making the case for the importance of knowledge to the organization with passionate conviction. Good ideas do not—I repeat, do not—succeed because of their internal logic or their obvious merit. They succeed because people fight for them, using their passion, their understanding, their political skill and guile, and their rhetorical powers to make the case for ideas they believe in. This involves finding cases and stories of how knowledge adds value. We all have seen this happen in varied circumstances and know how well it works when it is done well. One way any of us can help in this regard is to feed these cases to our leaders. It may seem a small thing to do, but it can be tremendously effective in helping leaders lead and advance the knowledge cause.

Another important leadership role is to use symbols and signals to show employees the value placed on knowledge. Symbols can be anything from awards for innovative uses of knowledge—BP used to give an award for what they called the "best stolen" idea—to encouraging employees to read and write, attend relevant meetings, subscribe to journals, and bring in guest speakers. In addition to the value of the activity, all these things convey a message, signaling the importance of the subject and showing that management values it enough to spend some funds on its behalf.

Probably the strongest signal about what an organization values and believes is sent by who gets promoted. Considerable research has been done on the power of promotion as a communication device. A promotion in essence says, "This person exemplifies the values we hold dear." Even if successful employees' vocational or educational histories are not relevant to you, you are likely to be aware of what sort of people they are, what values they represent, and how they advanced. If you don't know these things from direct observation, you will learn about them soon through the organizational grapevine that quickly spreads such news.

Let me give you an example. I have worked for five major management consulting operations in my too-long working life. All these firms claimed they were committed to developing new knowledge. They stressed this claim in their advertising and made it a central, vigorous part of their attempts to win and hold new clients. All but one of them, however, based promotions *only* on how many engagements individual consultants sold. Knowledge creation by consultants was never recognized or rewarded. Needless to say, this mismatch between words and deeds engendered cynicism in the staff about the importance of knowledge-development activities. If only sales were valued, one had better sell if one wanted to succeed.

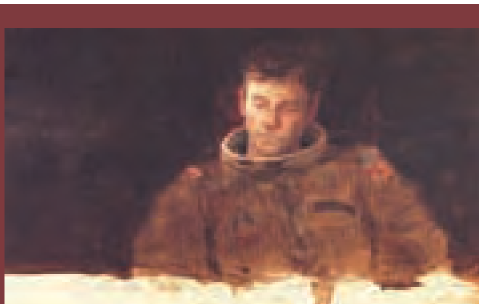
Now, I am not against promoting sales, but the result of telling one and all how much they valued knowledge and then not valuing it at all in action was that those firms seldom developed or transferred valuable knowledge. It is interesting to note that the only one of the five firms that exists and thrives today is the one that genuinely promoted knowledge activities.

The other very important thing leaders can do is lead by example. Our new president offers a case in point. What better way to promote literacy and clear thinking among our kids than to have a president—the ultimate leader—who has actually written two literate and clear-headed books.

When I read about a CEO or senior manager who genuinely encourages knowledge activities, the story stays in my memory mainly because it is so rare an event. A day may come when it is more common. Until then, I urge leaders who may be reading this to realize above all that your employees and peers watch both what you say and what you do and tend to adjust their own behavior accordingly. So talk about the value of knowledge but, above all else, show how much knowledge matters through your deeds and decisions. ●

GOOD IDEAS DO NOT—I REPEAT, DO NOT—SUCCEED BECAUSE OF THEIR INTERNAL LOGIC OR THEIR OBVIOUS MERIT. THEY SUCCEED BECAUSE PEOPLE FIGHT FOR THEM.

ASK interactive



When Thoughts Turn Inward," by Henry Casselli
Astronaut John Young reflects pensively as he suits up for launch on April 12, 1981. Casselli conveys a quiet, almost spiritual moment when the astronaut must mentally prepare for his mission. This was the first time that the newly inaugurated Space Shuttle would carry humans, in this case the two person crew of John Young and Robert Crippen.

Image courtesy the NASA Art Program

NASA Art Program

The NASA Art Program was founded by James Dean in 1962 to record the history of space exploration through different media and genres in order to reach, educate, and inspire a variety of audiences. Paintings, illustrations, photographs, poetry, and even songs have been commissioned by NASA from notable artists, including Norman Rockwell, Annie Leibovitz, Robert Rauschenberg, and Patti LaBelle. View some of the original artworks chronicling the wonders, risks, and triumphs of space exploration at http://www.hq.nasa.gov/copernica. The current curator, Bertram Ulrich, joined Dean to write a book celebrating the images for NASA s 50th anniversary. The book can be found in bookstores or online at http://www.amazon.com/NASA-ART 50 Years Exploration/dp/0810972875.

Learning and Exploration

Relive NASA's journeys to the moon through the personal stories of the astronauts, engineers, and flight directors who helped make man's journey into space a reality. The Discovery Channel site includes several clips from the six-part series *When We Left Earth* along with interactive features that highlight NASA's effect on our everyday lives, test your knowledge about the twenty-four men who went to the moon, allow you to interactively explore the universe, and more. Listen to the firsthand accounts of Mercury, Gemini, Apollo, and Space Shuttle at http://dsc.discovery.com/tv/nasa/nasa.html.

Web of Knowledge

The new year is often a time when people reflect upon what they accomplished the year before and how those experiences will help them face new challenges, and NASA is no different. Though the Agency recently celebrated fifty years of exploration, it also took time to review its discoveries and accomplishments during 2008. Among the top ten accomplishments for the year are the International Space Station's ten-year anniversary, Hubble's discovery of a planet circling a distant star, and completion of the successful Phoenix lander mission to Mars. Read about these and more at http://www.nasa.gov/externalflash/yir2k8/index.html.

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Additional information pertaining to articles featured in this issue can be found by visiting the following Web sites:

- **Mars Express:** http://www.esa.int/esaMI/Mars_Express/index.html
- **Phoenix:** http://www.nasa.gov/mission_pages/phoenix/main/index.html; http://phoenix.lpl.arizona.edu
- **SOFIA:** http://www.nasa.gov/mission_pages/SOFIA/

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