National Aeronautics and Space Administration

Academy Sharing Knowledge

ask

The NASA Source for Project Management and Engineering Excellence | APPEL

SPRING | 2007

Image Credit: NASA/John Frassanito and Associates

ON THE COVER

This artist's concept of the Ares V cargo launch vehicle illustrates the separation of its first and second stages in Earth orbit. The vehicle's propulsion system will be able to lift heavy structures and hardware to orbit or fire its engines for trans-lunar injection, a trajectory designed to intersect with the Moon. Such lift capabilities will enable NASA to carry robust science and exploration payloads to space and could possibly take future crews to Mars and beyond. For a detailed map of the mission architecture, see the special pullout in this issue.

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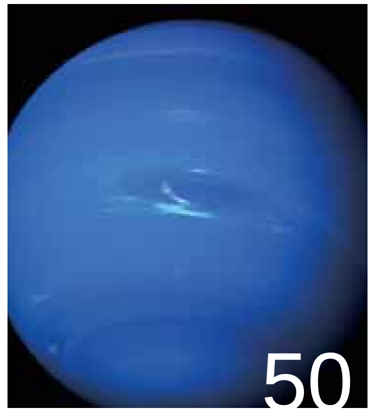

ask

Issue No. 26

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

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

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

A casual observer of NASA's accomplishments from Mercury and Apollo to the Space Shuttle, space telescopes, and interplanetary robotic missions would probably guess that those achievements depended on two things: technical knowledge and money. Those are essential, of course. But the ability to manage that complex, innovative work—to plan, guide, and evaluate efforts of many people in many places—has been equally important. Landing a man on the Moon required the combined knowledge and skills of several hundred thousand individuals working for tens of thousands of contractors and universities. It was as much an organizational triumph as a technical one.

The Agency's new mission—to build an outpost on the Moon and fly humans to Mars—is in many ways more ambitious than Apollo. It will demand decades of outstanding cooperative work from all ten NASA centers and many contractors. It too will be a managerial challenge of daunting complexity and scope. As NASA Administrator Michael Griffin notes in his column on the role of governance, it "will require as much ingenuity, hard work, and sustained commitment as NASA has ever brought to bear." This special issue of *ASK* is devoted to the Agency's efforts to develop the organizational structures, policies, procedures, and practices needed to organize and support that work and commitment.

A number of articles focus directly on the new NASA Procedural Requirement documents that establish the consistent processes and clear roles and responsibilities needed to carry out and coordinate the programs and projects that will turn the Vision for Space Exploration into reality. Chief Engineer Chris Scolese and Associate Administrator Rex Geveden emphasize the importance of the clarity and consistency of the procedures, especially as they relate to decision making and the balance between project authority and engineering authority.

Geveden also talks about the importance of a relentless focus on the mission, and Ed Hoffman describes the kinds of career-long training and education that the new vision will require. The framers of the procedural documents have striven to make them practical tools that support the mission, not bureaucratic abstractions of how programs and projects *should* be carried out. "Documented Experience" and Garry Lyles' "Enabling Exploration" describe some of their efforts to incorporate knowledge developed through long experience in the requirements and to test them against the reality of actual work. Bryan O'Connor ("Safety and Mission Assurance: Independent Yet Engaged") and Scott Pace ("Program Analysis and Evaluation: Clarity and Independence for the New Mission") describe how their organizations identify potential risks and problems in NASA programs but also look for solutions. Their aim, too, is to help accomplish the mission, not put roadblocks in the way.

Real-life experience is always more varied and surprising than even the most sophisticated plans and procedures can describe or predict. Rob Manning's conversation about the Mars programs he has worked on make that clear, and the historical perspectives provided by C. Howard Robins, Jr., and Roger Launius point out some of the continuing challenges of managing complex projects. Howard McCurdy argues that NASA must continue to innovate, not only in creating its spacecraft and launch vehicles but by finding new ways to work efficiently and well. The articles in this issue show how much thoughtful work has been done to ready NASA for the new era of space exploration, but they also make clear that we are only at the beginning of a long, demanding, and exciting journey.

Don Cohen
Managing Editor

From the Administrator

The Role of Governance

BY DR. MICHAEL D. GRIFFIN

We at NASA have the unique privilege of carrying out an enormously challenging program of exploration and discovery on behalf of the American people. The vision for Space Exploration, first announced by the president three years ago, has since become the law of the land with the passage of the NASA Authorization Act last year. The capabilities we are developing to satisfy the vision will enable us to explore new places, expand our understanding of the universe, and establish a human presence in other parts of the solar system.

The vision has given NASA its greatest mission statement since President Kennedy set the Apollo program in motion in 1961. Fulfilling our commitments to the International Space Station, retiring the Space Shuttle by 2010, and developing the Crew Exploration Vehicle and launch vehicles to carry out missions to the Moon, Mars, and beyond will require as much ingenuity, hard work, and sustained commitment as NASA has ever brought to bear.

The path ahead is difficult and risky to be sure. The next decade will present some of the greatest technical and management challenges NASA has ever known. Meeting them requires a solid organizational foundation that facilitates our ability to develop and successfully execute programs and projects. It is my responsibility to ensure that the Agency has a highly resilient management and governance framework, one that strikes a proper balance between flexibility and control, so we can thrive during this time of dynamic transition.

Governance in NASA refers to two things: oversight and approval of strategic, programmatic, and operational planning and the process for decision-making and appeals through the chain of command. The former manifests itself through the Strategic Management Council, the Program Management Council, and the Operations Management Council. Governance by council is reserved for matters in which decisions require high degrees of integration, visibility, and approval.

The latter is a natural feature of the way we are organized, in which the programmatic and institutional chains of command are clearly defined and intentionally separated until they reach the very top of the organizational chart. Generally speaking, decisions are the responsibility of line organizations, either programmatic or institutional. In some cases, where there is substantial disagreement, decisions will be appealed by one side or the other.

A good recent example is the launch decision for STS-121. In that case, programmatic authorities made the decision to launch, and institutional authorities appealed that decision in light of concerns about ice-frost ramp foam losses from the shuttle's external tank. In that case, the appeal came to the level of the Administrator because agreement could not be found at lower levels. And my belief is that decisions of that magnitude deserve the attention of NASA's top management, so our governance process worked well in that case.

It is necessary to have independent technical and programmatic lines of command at NASA, because there will always be a healthy tension between the programmatic imperative to accomplish tasks within cost and schedule and the technical imperative to do things perfectly, regardless of cost or schedule. Without this organizational separation, one imperative or the other must dominate, always to the detriment of either the project or the institution. This separation preserves the valid viewpoints of both, to the benefit of the program and the institution. This approach restores our ability to provide independent technical review of programs.

A central organizing principle of our work is that the people of NASA must assume the primary responsibility for making the vision for Space Exploration come to fruition. We are undertaking a multigenerational program of sustained exploration, and our intellectual capital should remain in house, where we can sustain the program's momentum and retain an institutional memory of the system, the cost trades that are made, and why the architecture is the way it is. Making our own engineers clearly responsible and accountable for our technical products at the system level will drive our team toward excellence.

Having decided this, we want to provide our engineers with sound requirements and processes that help them execute mission objectives with careful and sober attention to risk. First and foremost, we will continue to encourage our people to speak up whenever they have safety concerns. And through the governance framework we will listen to and respond to those concerns.

Since NASA is a highly decentralized organization that requires flawless integration of its complex systems, a uniform approach to program and project management is essential if we are to achieve the kind of technical excellence that is necessary to execute our long-term exploration program successfully. The same holds doubly true for systems engineering. I have said many times since joining NASA that we need to do better in this area. The requirements and processes spelled out in NPR 7120.5D and NPR 7123.1 are steps in the right direction for these disciplines.

Through efforts to strengthen our governance model, policies, and processes, we are working to establish standards of technical excellence that will enable a program of the complexity and promise of deep space exploration to move forward over a period of decades. It is a personal priority of mine to work with the senior management team to make sure that our organization enables the workforce to excel as it undertakes the tremendous tasks before us. ●

WE ARE UNDERTAKING A MULTIGENERATIONAL PROGRAM OF SUSTAINED EXPLORATION, AND OUR INTELLECTUAL CAPITAL SHOULD REMAIN IN HOUSE, WHERE WE CAN SUSTAIN THE PROGRAM'S MOMENTUM AND RETAIN AN INSTITUTIONAL MEMORY OF THE SYSTEM, THE COST TRADES THAT ARE MADE, AND WHY THE ARCHITECTURE IS THE WAY IT IS.

Documented Experience: Re-Defining Project Management Processes

BY DON COHEN

Tom Gavin of Jet Propulsion Laboratory (JPL) heads the team responsible for writing NPR 7120.5D, the document that defines the policies and requirements that will govern the programs and projects that will take NASA back to the Moon and on to Mars. Carrying out this complex, innovative, lengthy mission is as much an organizational challenge as a technical one.

The work of NASA Centers and contractors, and what is likely to be more than one generation of engineers and scientists, needs to adhere to consistent, well-defined processes to guarantee quality and safety and make it possible to coordinate those thousands of local efforts into intricate, integrated systems—think of a gigantic puzzle whose pieces must fit together perfectly. At the same time, the processes need to flexibly accommodate different kinds of projects and leave room for the creativity that will solve the myriad problems this new work will present. Most of all, these processes cannot be a bureaucratic abstraction of how work *should* be done; they need to be grounded in experience and embody the best of how work happens in the real world.

The 7120.5D team pulls together broad and deep NASA expertise, including members from each center and mission directorate, from the Office of the Chief Engineer and the Office of Safety and Mission Assurance, from Program Analysis and Evaluation, and several mission support organizations that provide experience in human space flight and robotic projects. Gavin, currently associate director of Flight Projects and Mission Success at JPL, brings a wealth of experience in establishing consistent flight project practices at that center, but he is quick to point out that 7120.5D represents the interests and expertise of stakeholders throughout NASA.

Many organizations run into problems with coordination and collaboration because they assume that everyone understands basic terms in the same way when, in fact, they mean different things to different groups. Those differences often only surface when they try to work together but end up working at cross purposes. Some of the most critical work of the 7120.5D team involved developing a common understanding of the words that define important processes. For example, Gavin notes, "People had different views about the meaning of 'independent.' We had to resolve that." NASA's governance model includes the principle that programs and projects do not review their own work, but what, precisely, does that mean in practice? Gavin comments: "Does 'independent' mean that a person on the review board can't be part of the project or funded by the project? Yes. Does it mean they can't work at the same center? No. The technical knowledge you need is at the centers."

Everything the team did was open to discussion. 7120.5D defines roles and responsibilities in part for the same reason it defines key terms: to reduce ambiguity and eliminate confusion generated by the assumption that "everyone knows" what project, center, and headquarters roles and responsibilities are, when in fact ideas about them are likely to be vague or contradictory. Orlando Figueroa, veteran of many projects and programs and now director of Applied Engineering and Technology at Goddard Space Flight Center, drafted a matrix of roles and responsibilities for 7120.5D and "everybody beat on it once it was out there" (according to a team member) to make sure the definitions were the right ones.

… THESE PROCESSES CANNOT BE A BUREAUCRATIC ABSTRACTION OF HOW WORK *SHOULD* BE DONE; THEY NEED TO BE GROUNDED IN EXPERIENCE AND EMBODY THE BEST OF HOW WORK HAPPENS IN THE REAL WORLD.

The document defines key decision points and makes clear what the minimum standard of accomplishment is for each

GAVIN CONCURS THAT OPENNESS—DEVELOPING THE REVISION "IN THE SUNSHINE" AND TESTING ITS PROVISIONS WITH THE NASA COMMUNITY—WAS CRITICAL TO THE QUALITY OF THE PROCESS AND THE DOCUMENT.

phase—what needs to be done before moving on to the next phase. So it mandates more project and program structure than in the past, when project approval was the main and sometimes the only formal decision point. But in keeping with the need for flexibility and in recognition of the professionalism of NASA employees and contractors, it focuses on *what* needs to be accomplished, not *how* a project team achieves those results.

The team's goal was to define a single, consistent, unambiguous process for all NASA programs and projects, but they recognized the need to maintain some process elements that have value for some kinds of projects and not others. Gavin says,

> The general structure is the same across the board, but we wanted to keep the things that were good about existing processes. For robotics, we do a post-launch assessment review with the standing review board. For human space flight, they have a mission management team meeting every day. We wanted to preserve that function, so we wrote that exclusion into the document.

The extensive hands-on experience of the team members gave them the ability to test 7120.5D against the realities of project work. They continually asked, "Could I have been successful on my project if I had to work to these requirements?"

The NASA community beyond the drafting group also had an opportunity to apply their experience and insight to the new policies and requirements. Team members distributed their draft document informally to program, project, and mission support practitioners at their centers or organizations, asking them to test the document's provisions and definitions against their own experience. They received 1,300 comments in response. A subgroup of the team then "holed up for three days," in Gavin's words, "and went through every single one of those comments." They decided collectively whether to accept or reject each criticism or suggestion and wrote down the rationale for their decisions. The comments helped clarify the life-cycle review process. Among those adopted were a new flow chart by Bill Hill of the Space Shuttle Program Office and an explanation of how a tightly coupled program like Constellation will negotiate between program requirements for mission success and center standards of how to perform work. Gavin remarks, "Sometimes we said, 'Yes, we blew it. You got it right.'" The decisions and rationales were discussed by a core team, which approved the document revision. In several instances the core team reached out to leading Agency experts for advice on a specific subject, such as new federal Earned Value Management requirements. Then the new version was put on NODIS, the NASA Online Directive Information System, to get comments from an even wider group of NASA practitioners. The posting drew another 370 comments. Those went through the same careful evaluation process to produce the final document.

Randy Taylor, a member of the 7120.5D team who also worked on the earlier 5A and 5B versions, notes that those documents took years to complete. "We did this version on a more aggressive schedule," he says, "which has real plusses: it meant continuity of membership, and it kept the momentum going." Probably the most important part of the process, he adds, is that "we did it in the sunshine."

Gavin concurs that openness—developing the revision "in the sunshine" and testing its provisions with the NASA community—was critical to the quality of the process and the document. He has nothing but praise for the group that devoted intense months of analysis and discussion to the task of defining the new policies and guidelines. "The operative word is 'team,'" he says. "They worked as a team. They were very constructive. Everybody brought their skills and their culture, and it all melded together into one document." ●

Lessons from COBE
About Processes and Procedures

BY DENNIS McCARTHY

Image Credit: NASA

COBE was launched into an Earth orbit in 1989 to make a full sky map of the microwave radiation left over from the Big Bang.

From 1983 to 1989, I was deputy project manager at Goddard Space Flight Center for the Cosmic Background Explorer (COBE), the spacecraft that enabled NASA scientist Dr. John Mather and his colleague Dr. George Smoot (University of California/Berkeley) to investigate the origin of galaxies and stars and offer the most conclusive evidence of the big bang theory to date. Mather and Smoot were awarded the 2006 Nobel Prize in Physics for this research.

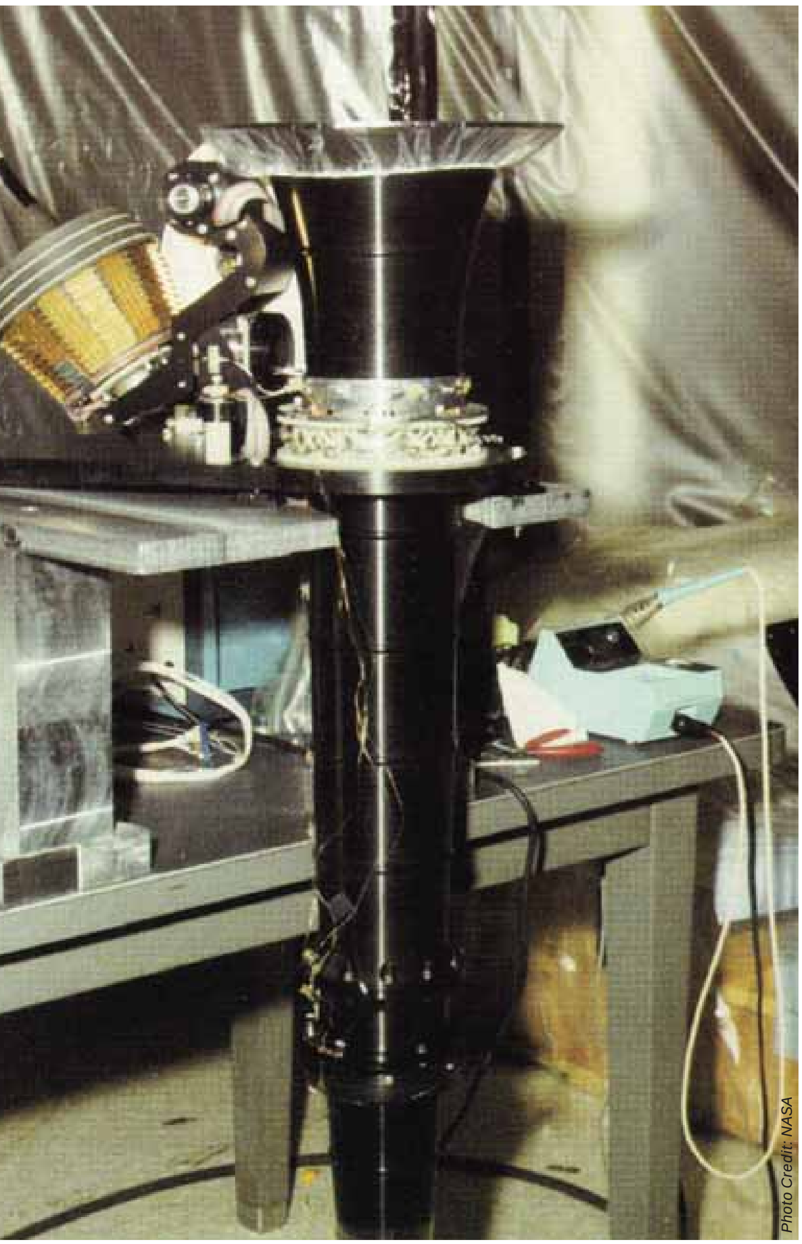


Photo Credit: NASA

A close-up of COBE's Far Infrared Absolute Spectrophotometer (FIRAS) horn antenna, which made a precise measurement of the spectrum of the cosmic microwave background radiation.

The COBE project was the most demanding of my career because it had to be so precise. To achieve its goal of measuring diffuse infrared and microwave radiation from the early universe, it had to be essentially perfect. We handled this almost impossibly stringent requirement by performing a lot of analysis. We analyzed every circuit and did Failure Modes Effects Analyses (FMEAs) of all the things we thought could possibly happen.

You could never have written a specification on a contract or a statement of work to have someone build COBE. It was Nobel Prize science that depended on groundbreaking technology. Nothing like the instruments we needed had ever been built before. We had a 100% failure rate along the way, when we put the instruments in test dewars and tried to test materials' properties and electronics. You couldn't afford to have a contractor do that.

Because COBE had cryogenic instruments with a dewar full of liquid helium cooled to a temperature of 2 kelvin (-271˚C), we had to be sure everything was right before we cooled it down; otherwise, it would have taken six weeks to warm it back up and then cool it down again. So we were very sensitive to developing plans and procedures to test the satellite and the instruments. Even though we didn't have all the requirements in the eighties that projects have today, we were very conscious of all the analyses required to ensure the spacecraft was noise-free and would perform the way we predicted it would.

COBE was designed to launch from Vandenberg Air Force Base on the Space Shuttle, which would insert it into a polar orbit. The *Challenger* accident forced us to completely rethink every aspect of the spacecraft's design, including moving from a shuttle launch to a Delta rocket. We'd already built a full-scale mock-up of the COBE spacecraft for a shuttle launch. After the accident, we had to do a lot of additional analyses to reconfigure the spacecraft for an entirely new launch vehicle and orbital insertion. The mock-up was actually used to integrate and test all spacecraft subsystems while we continued to develop the instruments in parallel.

The processes and procedures used to conduct the test program were extremely thorough. For example, when we finished the tests needed to qualify the complete satellite, we left it in a radio frequency clean room—a shielded environment that blocks extraneous electromagnetic signals—and let it run for two weeks. We were encouraged to do this to help scientists understand all the characteristics of the satellite. Because what they were trying to measure was so minute and the measurements had to be so accurate, they needed to be certain that their results reflected cosmic background radiation, not "noise" from the satellite. This two-week test gave the scientists the opportunity to learn the satellite's idiosyncrasies.

We also had an open-door policy that worked remarkably well. The project management team was very sensitive to the fact that we wanted everyone in the program to come to us at any time if they found something they didn't understand or if they didn't agree with our decisions. People could come talk to me whenever they wanted, and they did. We relied on the technicians, engineers, and designers to be our eyes and ears, keeping tabs on what went on every day. They were all empowered to feel it was their spacecraft. When the workforce feels they own the spacecraft, they take care of it, they test it adequately, and they don't take shortcuts.

I gave our quality assurance (QA) personnel the authority to shut down work whenever they felt the need. Once or twice they called me from the clean room to say they were going to shut down work for a day because the pressure of the project was causing someone to want to move on and not finish something or skip steps instead of being thorough. The QA team did a marvelous job. They had a lot to do with the success of this program.

In-house development is critical to building the skill base of the NASA workforce. Goddard Deputy Director Mike Ryschkewitsch and Director of Engineering Orlando Figueroa were each responsible for a part of COBE. There's no better proof of the value of hands-on work. The only way they could have developed their high level of engineering judgment was through work on an in-house program. In-house projects also make you a much smarter customer. You cannot go out and monitor prime contractors and distinguish what the problems are if you haven't done the work yourself.

False-color image of the near-infrared sky as seen by the Diffuse Infrared Background Experiment (DIRBE), a COBE instrument that obtained data that can be used to seek the cosmic infrared background radiation and study the structure of the Milky Way Galaxy and interstellar and interplanetary dust.

COBE is a success because the satellite led to a major discovery. Looking back, I can say it succeeded because of the team's talent and dedication, despite disagreements and misunderstandings caused by the absence of clearly spelled out roles and responsibilities, such as those provided by the new 7120.5D. There were people in the line organizations who thought they had more responsibility for COBE than I thought they should have, and as a result there were lots of conflicts. Clarity about who does what allows everybody to be more comfortable about expectations, which leads to a better working environment where the focus can remain on accomplishing the mission. ●

DENNIS McCARTHY was deputy project manager for the Cosmic Background Explorer (COBE) at Goddard Space Flight Center from 1983 to 1989. He remained at Goddard in 1990 as the associate director for the Space Sciences Directorate, moving in 1991 to NASA Headquarters to be the program manager for the Hubble Space Telescope. McCarthy was later vice president and director of Engineering Services and then director of Engineering at Swales Aerospace, where he was responsible for all engineering discipline support to NASA, universities, and industry until 2006.

A Relentless FOCUS on the

Artist's concept showing a coronal mass ejection sweeping past STEREO, which is one of NASA's many recent successful missions.

Image Credit: NASA

MISSION

BY REX GEVEDEN

As someone who has worn a lot of hats within NASA, I would be the last person to say that policies and procedures don't matter. They're absolutely critical if we're to do our jobs effectively. But it's not an accomplishment to put out a procedure or to reorganize. In this agency, there's only one kind of accomplishment that matters, and that is to carry out NASA's mission.

Of course the mission can take several forms—a space flight, a research activity, a wind tunnel test. The point is that these are all outcome-focused activities, the purpose of which is to satisfy NASA's mission. They are the reason NASA exists, that Congress appropriates money to us, and that taxpayers support us. Our job is to execute the nation's civilian aerospace program. Period.

If you're not doing the mission or something that supports the mission, then stop what you're doing and focus your energies on work that does support the mission. This applies to any organization. To take a non-NASA example, I used to get a utility bill that was a postcard in the mail with a perforation so I could mail back one half with my check and put the other half in my records. That was the system for years and years, and it worked fine. For the last several years, though, I've received a different kind of utility bill that comes in a bigger envelope. It still contains the card with the perforation, but it also has something else called the utility bill newsletter. I have never read the utility bill newsletter, and I never will. But I'm still paying three cents a month or so to contribute to the production and distribution of that newsletter. The mission of the utility company is to deliver kilowatts of power to my home, not a newsletter that I didn't ask for and don't want. In my view, the newsletter is just a distraction from the mission of the utility company.

One of the differences between the NASA of today and yesterday is that we have a much more focused and ambitious mission today than we've had in nearly forty years. We've been handed a vision with a scale that exceeds our budgets, so we have to use every penny we can possibly find, and we have to partner with international entities, commercial concerns, and others. To make all this happen, we can't afford to squander any resources on non-mission activities.

In the past couple of years, we've made sweeping governance changes, organizational changes, and procedural changes, but those are just a means to an end. They are all about the mission. If we have successful missions and we perform on cost and schedule, then we'll know that our governance, strategic management, and organizational principles mattered.

What many of these changes have done is put the pendulum back in the middle on the balance between project authority and engineering authority. There was a time when the engineering culture dominated the agency, and project managers had very little real authority. Later, probably starting in the mid-1990s, we developed a project management culture, which was a very positive development except that it took things out of balance. Today the project manager still has clear authority and accountability all the way down a well-defined chain of command. At the same time, however, technical authority now exists independent of that. If you're an engineer in the field, I think it's easier to get a technical issue raised by the management, and I think that's the way it should be.

Based on what we're seeing so far, those changes are manifesting very positively in mission success. The Flight Readiness Reviews for Space Shuttle flights STS-114, STS-121, and STS-115 were characterized by healthy debate, which of course became publicly known. I think we're a better agency for

WHAT MANY OF THESE CHANGES HAVE DONE IS PUT THE PENDULUM BACK IN THE MIDDLE ON THE BALANCE BETWEEN PROJECT AUTHORITY AND ENGINEERING AUTHORITY. THERE WAS A TIME WHEN THE ENGINEERING CULTURE DOMINATED THE AGENCY, AND PROJECT MANAGERS HAD VERY LITTLE REAL AUTHORITY.

it. We worked harder, we thought more deeply about technical issues, and in the end we got the best decisions we could get. And they contributed to mission success.

It's a sign of health, not illness, for an organization to institutionalize a process for constructive disagreement. Consensus-based management in which decision participants are pressed into agreement reflects, in my opinion, a state of poor health for an organization. If we don't respect or care about one another enough to disagree honestly and openly, then we're not healthy. In an unhealthy organization, disagreement creates discomfort, so at times of conflict you will hear things like, "Let's take that offline." Or, "We'll take an action item." In other words, disagreement is diverted and suppressed. Disagreement—civil, constructive disagreement, not destructive, personal disagreement—brings out the best in us. It causes us to think harder about our positions. It causes us to defend ourselves in a more comprehensive and professional way. And I think it leads to good decisions.

I'm proud of the culture we're creating within NASA. It's about accountability, responsibility, and success. It's a demanding culture, but it's one in which I think NASA and its partners can thrive and are thriving. It's a culture about truth, about being straight, about disagreeing when you need to, and about listening to disagreements and adjudicating them fairly. When we talk about technical authority and institutional independence, we're not just talking about engineering. We're also talking about a responsibility to be technically great in procurement, for example. If we're doing something that's risky or otherwise inadvisable, it's a procurement responsibility to raise that concern up the chain and challenge the program or project on it. It's a responsibility to be excellent in law, in accounting. Technical authority is not just about an engineering culture, though engineering is a big part of it.

In the end, it is all about the mission, and none of the organizational or cultural changes will matter if we don't fly successful missions. Just in the last year, we have flown a number of exceptionally difficult missions—the shuttle and station assembly flights, New Horizons, CloudSat/CALIPSO, STEREO, the Mars Reconnaissance Orbiter, and others. I think we are doing well. We must maintain our mission focus, because this is a hard and risky business, and it will require the best efforts we can offer. ●

Photo Credit: NASA Kennedy Space Center

STS-114 Mission Specialist Wendy Lawrence (right) learns about equipment inside the orbiter Discovery from Reina Winters, an engineer with Johnson Space Center. The Flight Readiness Review for STS-114 involved healthy debate, which led to better decisions for the mission.

REX GEVEDEN is NASA's Associate Administrator. In this position, he is responsible for all technical operations of the Agency. He works directly with the Administrator to develop strategy and policy and has direct oversight of all NASA's programs and field centers.

Developing Engineering Excellence for Programs and Projects at NASA

BY CHRIS SCOLESE

As a boy growing up, I was enthralled by all aspects of space exploration. I soon realized that the success of all space initiatives was the result of solid engineering. Today, while I serve as the NASA Chief Engineer, I am still in awe of our challenges and accomplishments. NASA is a great organization. Our work is literally the stuff of dreams. Themes of wonder, challenge, technology, and exploration are components of the work that we do. We sustain NASA's ability to inspire through our commitment to solid engineering.

When Mike Griffin asked me to serve as the Agency's Chief Engineer, it was clear that there was an overarching mission to create an organization that fostered excellence in engineering so our intellectual and mission products would be respected by our peers and the public. During the past two years, tremendous energy has been devoted to designing a governance model that will further promote mission excellence. Standards have been established that demand commitment to what we all know is the right way to succeed on complex engineering systems. These standards have been reinforced by increasing the power and responsibility of engineering and programmatic leaders working on our projects within the Agency. These increased authorities are further enhanced by an organizational commitment to new and improved training and development targeted for the individuals and teams working our missions. Taken together, these developments—the governance model, updated standards, clear lines of authority, open communication, and enhanced training—represent real steps forward in fostering engineering excellence.

This organizational transformation serves one purpose: to build our capacity for excellence. But engineering excellence goes beyond standards, communication, training, and structure. It comes down to personal responsibility for doing a job based on dedication and knowledge and speaking up about what is right and what is wrong. Such organizational and personal responsibility has always been a part of NASA, as it always is a part of great organizations.

I have been fortunate to work with great organizations and great people throughout my professional life. My career began in the navy nuclear submarine program, where I had the opportunity to work for Admiral Hyman Rickover, the father of the nuclear navy. Rickover understood better than anyone that people are the key to the success of any organization. "Human experience shows that people, not organizations or management systems, get things done," he once said. These words continually serve as a reminder to me that everything we do in the Office of the Chief Engineer is ultimately about people. I am dedicated to providing the best possible leadership and guidance for the technical workforce—both civil servants and contractors—that designs, builds, and operates our space flight systems. Everyone working with NASA knows that our missions rarely get second chances, and we have little margin for error. So what does it take to achieve this consistent level of mission success? It requires nothing less than excellence. The legendary Green Bay Packers coach Vince Lombardi once said, "The quality of a person's life is in direct proportion to their commitment to excellence, regardless of their chosen field of endeavor." On some level we all know this and are motivated by the pursuit of excellence.

With that in mind, how do we achieve engineering excellence? I see it in terms of four guiding principles: clearly documented policies and procedures, effective training and development, engineering rigor, and open communication. All are necessary to enable people to perform at their best in the unique context of NASA, a high-reliability organization that builds one-of-a-kind systems.

Given the complexity of the systems we will develop and deploy to fulfill the NASA mission, clear policies and procedures are essential. NPR 7120.5D *(NASA Program and Project Management Processes and Requirements*) represents our best thinking—drawing on NASA's nearly fifty years of experience in running space flight programs—about the essentials of program and project management and the engineering of complex systems. The existence of sound policies and procedures does not guarantee success, but their absence is a surefire recipe for disaster. As President Eisenhower, the crowning achievement of whose military career was commanding the Allied invasion of Normandy, once observed, "Plans are nothing; planning is everything."

Our policies, processes, and procedures must help us work collaboratively. That means allowing us to complete tasks effectively in a repeatable manner. This reduces costs and fosters designs that encourage collaborative problem solving, which is essential in an agency with ten field centers and thousands of private industry suppliers.

We all know that space flight projects are inherently risky ventures. So at its core, NPR 7120.5D will help us minimize risks that can jeopardize mission success. When we practice smart strategies at key knowledge decision points in the project life cycle, we minimize project risk. When we maintain a clear division between technical and program authority, we minimize both technical risk and performance risk. When we assign clear roles and responsibilities and strengthen accountability, we minimize the risk that an organizational weakness will lead to failure.

Engineering excellence is about more than risk reduction, though—again, it is about people. NASA is fortunate that the challenge and excitement of its mission allows it to attract and retain the most capable technical workforce in the world. After all, as President Kennedy said, "We do these things not because they are easy but because they are hard." NASA, in turn, bears responsibility for providing this workforce with the training and development necessary to carry out its missions. The Academy of Program/Project and Engineering Leadership (APPEL), which operates within the Office of the Chief Engineer, is responsible for the development of program, project, and engineering leaders and teams within NASA. Its programs must draw on industry, academic, other space agency, and NASA best practices; cutting-edge research; and the most sophisticated tools available to give our people the best possible preparation for their work. Professional development is more than a series of benchmarks that must be met in order to progress up a career ladder; it is a philosophy of growth through continuous learning that becomes a habit of mind for individuals who recognize its value and make it a personal priority.

Engineering rigor is a professional standard for scrutiny that individuals bring to their work. This has both a personal and an institutional component to it. On a personal level, all of us have an obligation to understand and believe that we are individually responsible for mission success. Each of us contributes, regardless of our position. What we do is so complex and unique that each and every component must work for us to be successful. On the institutional level, engineering rigor takes the form of independent technical authority, the implementation of which is spelled out in 7120.5D. We have learned the hard way what can happen when an engineering organization does not have a strong, independent voice. That independence cannot be sacrificed to schedules and budgets, just as programmatic concerns cannot be overlooked in the development of the technical approach for a given program or project.

Communication lies at the heart of all leadership and management challenges. Every major failure in NASA's history has stemmed in part from poor communication. Among the technical workforce, communication takes myriad forms: team meetings, discussion among peers, continuous risk management, knowledge management, knowledge sharing, dissemination of best practices and lessons learned, and continuous learning, to name but a few. The complexity of NASA's programs and projects demands an open, vigorous culture of continuous communication that flourishes within the context of policies and procedures while empowering individuals at all levels to raise concerns without fear of adverse consequences. NPR 7120.5D specifically addresses the importance of dissenting opinions, ensuring there is an orderly process for airing all viewpoints in an environment of respect, integrity, and trust.

Engineering excellence is a goal, not an objective that can be measured over a fixed period of time. Policies and processes, professional development, engineering rigor, and open communication are necessary means for achieving that goal, but they should not be mistaken for ends that offer any guarantees. Through the diligent practice of these principles, however, we will develop a way of working that will bring us closer to this goal and shape us into an engineering organization that can successfully execute the programs and projects that will take us closer to our vision of exploring the new frontier of space. ●

As chief engineer, **CHRIS SCOLESE** is responsible directly to Administrator Michael Griffin for the overall review and technical readiness of all NASA programs. The Office of the Chief Engineer ensures that the development efforts and missions operations are being planned and conducted on a sound engineering basis with proper controls and management.

INTERVIEW WITH

Rob Manning

BY DON COHEN

Rob Manning was chief engineer for the 1997 Mars Pathfinder project and is currently chief engineer for the Mars Exploration Program at Jet Propulsion Laboratory. He was one of the NASA practitioners asked to review and comment on a draft of the 7120.5D requirements and policies.

COHEN: I want to talk about your take on the 7120.5D processes and requirements, but let's start with the Mars program experience that has shown you how projects work.

MANNING: In late '92 or early '93, Brian Muirhead, the flight systems spacecraft manager of Mars Pathfinder, said, "I need a chief engineer who can deal with the software and electronics of this mission, because we're doing new things." Brian and Tony Spear, the Pathfinder project manager, were able to pull together a very young and energetic team peppered with old, wise people. Mars Pathfinder was among the first of the faster, better, cheaper missions. We modified the old way of doing business, trying to streamline it to make it faster and cheaper.

COHEN: It's hard to do more than two of "faster, better, cheaper."

MANNING: The trouble is, you need all three. Brian tried to get people very disciplined not just about cost control but scope control. You just can't make things cheaper by whipping people; you have to adjust scope, make things as simple as you can, but not too simple. For a while we were too simple. For instance, we didn't have a radar to detect when we were getting close to the ground. We had a 50-meter cable with a little touchdown sensor that sent a signal up to inflate the airbags, but the lander might land before the tether did, so we said that wasn't going to work. We added a low-budget radar we found. We tried to use a lot of commercial stuff, which was a mixed story. Sometimes you

“I LEARNED ON PATHFINDER THAT WHEN YOU **engineer something**, YOU HAVE TO ENGINEER **the whole story**. …YOU MIGHT HAVE TO **change the design** OF THE SYSTEM TO MATCH **the capability** OF THE PEOPLE WHO DO **the work.**”

spend more money convincing yourself that the off-the-shelf instrument will work than you would have spent had you built a unit ten times more expensive. Mars Pathfinder landed the fourth of July 1997, the first airbag lander, with its little Sojourner rover. For a while, Sojourner was treated like a parasite.

COHEN: In what sense?

MANNING: It was this funny thing bolted to the inside of the lander; we didn’t see where it would take us. The faster, better, cheaper mission paradigm was an experiment; the landing system was an experiment; the science that you could do with a rover was experimental. In the grand scheme of things, Mars Pathfinder will not be counted as the greatest scientific mission, but it broke a logjam. We hadn’t been to Mars since the very successful but very expensive Viking missions of the late seventies. The notion was that you couldn’t land on Mars without a substantial budget, maybe in the billions of dollars. So a $270 million mission, which was what Pathfinder turned out to be—including the launch vehicle, the operations, the science, the spacecraft, and the rover—seemed unbelievably low. The view that you could have a mobile platform on the surface of Mars to bring rocks right up to your nose had never been tested or taken seriously by the scientific community. Likewise, airbags. Who in their right mind would land a spacecraft and have it bounce around on the surface of another planet?

COHEN: So it was a proof of concept?

MANNING: It’s hard for human beings to accept new paradigms without experiencing them. In 1995, the World Wide Web was just starting. We wouldn’t have dreamed that, a few years later, we couldn’t do our work without it. People have to have a little taste.

COHEN: So faster, better, cheaper worked.

MANNING: Yes, but after Mars Pathfinder, the faster, better, cheaper model led to the sad state of affairs in 1998, when the Mars Polar Lander and Mars Climate Orbiter failed. The notion was, if Mars Pathfinder can do this mission for $270 million, we can do it again for half that. People overestimated what was possible. They didn't see how close to the edge we were financially and technically. The combined budget of the Mars Polar Lander and the orbiter equaled the Pathfinder budget. My view was, that team was probably better than we were, but I don't know if they're twice as good.

COHEN: Did they build on what you learned?

MANNING: Some. Mars Pathfinder was the first planetary mission to use a single-board computer with a commercial operating system. That's since been repeated over and over. It was the first mission to use C programming constructs that have now been ubiquitous for more than a decade. Much of the software on Pathfinder went on to fly on Stardust, Genesis, and Odyssey.

COHEN: Were there particular mechanisms for passing along what was learned?

MANNING: We used the NASA lessons-learned process to put particular lessons in the lessons-learned database, but that doesn't substitute for the people connection. You've got to connect with and talk to individuals who have gone through these experiences, either as review board members or team members or leaders of the follow-on mission. That's the only method I know that really works.

COHEN: Some companies use peer assist—conversations with people who have done similar work—to pass along project knowledge.

MANNING: We do that. In the case of Pathfinder, we hadn't landed on Mars in almost a quarter of a century, but the people who did it were still around. You go to Israel Taback, the chief engineer working for Jim Martin, and to Jim, the project manager of Viking. You go to Paul Siemers of the Viking project. They're worth their weight in gold. They'll say, "There's a paper written by so-and-so. Call that person. That's what I would do." Imagine having Jim Martin, Iz Taback, Gentry Lee, Duncan MacPherson, and John Casani all in the same review board staring you down. Jim Martin saying, "If you can't show me this entry-descent-landing system is going to work in the next four hours, this project is going to be over by noon. We shouldn't be wasting taxpayers' money if we don't know how to pull this off." The good news is that he and others had prepared us.

COHEN: You convinced them.

MANNING: We were the first in twenty-five years, and I think they wanted us to try. Convincing ourselves that it would work was touch and go. We had so many air bag failures, so many drop test failures, so many software problems. Literally two months before launch we were doing a full-up test of the entry-descent-landing system with the spacecraft and our test bed vehicle, and it crashed. We launched knowing that the software on board had a slim chance of working. We like to say, get our software done by launch, but it's never really done. That seven months after launch has paid off multiple times on almost all our missions.

COHEN: You couldn't delay the launch?

MANNING: You can launch to the outer planets with some regularity because you can fly by Venus and Earth a few times. But with Mars, you're stuck in a two-week launch window every twenty-six months.

COHEN: That will be true for manned missions to Mars.

MANNING: The pressure will be phenomenal. When we develop missions to go to Mars with people, you're going to see the same two-week window. All the launch pads are going to be in incredible use. One launch error or disaster potentially knocks the whole armada off.

COHEN: Do you see the Mars mission failures of 1998 as reality checks?

MANNING: In some respects, they were the best things that could have happened. They reminded us that we were on the edge. Had they not occurred, others would have. You can dance a long time on the edge of the cliff, but if you're that close, you're going to fall. Dan Goldin was encouraging us to do more for less and saying, "A failure or two won't hurt us," but two failures within two months is painful. They reminded us what about faster, better, cheaper is good and what is bad. When you cut a project down, it acts almost like an incompressible fluid. The pressure goes up astronomically as you reduce the volume. We squished those missions down until the risk squeezed way up.

COHEN: Do you think the experience taught both technical and management lessons?

MANNING: They're almost interchangeable in my mind. I learned on Pathfinder that when you engineer something, you have to engineer the whole story. You don't only engineer what it's going to look like and how it's going to work; you have to engineer the person who's going to design it and build it. You have to think about how they work with everybody else and make sure they have the tests, the resources, the space, the test time, the schedule. It all has to go together. You might have to change the design of the system to match the capability of the people who do the work. You think, the design's got to be what the design's got to be, but it turns out there's a lot of variability. You want to select a design approach that best uses the skills you have at your disposal.

COHEN: On Mars Pathfinder you had a lot of uncertainty to deal with.

MANNING: In the case of all landing systems on Mars so far, you don't know as you're designing it whether it's going to work because there are so many unknowns in the Mars environment and in the system interactions. There's just no way you can tell a review board, "I need 500 percent margin in my mass." They'll say, "You don't know what the heck you're doing." That's correct; we don't know because no one has done this before. Project managers at NASA want to stay on the road. Entry, descent, and landing comes along and suddenly the road stops. The whole team is driving across a field or a river valley that wasn't on the map. You end up taking the project off road because the road that you thought would take you from here to there has a big gap in it.

COHEN: I assume the Pathfinder experience laid the groundwork for the Mars Exploration Rover program.

MANNING: The whole MER premise was to take the Mars Pathfinder entry-descent-landing system, make the minimum necessary modifications in that detailed design, and fly a rover that's designed to fit. That lasted about three months as a paradigm. It's June 2000 and the launch date is June 2003. Projects need four years: one to do preliminary design, another to do detailed design, another to do fabrication and assembly, and the fourth year to test and launch. Three years is not enough, if you design from scratch. Even before we started seeing these changes, we got a phone call from Dan Goldin's office saying, "Why aren't you doing two?" We said, "No one asked. We don't know that we can't, and it might help us." It turned out that it did. We wouldn't have launched any had we only done one.

COHEN: How did it help to do two?

MANNING: When you're building an assembly line of aircraft, you typically build one and put it through its paces to qualify that system design. Would you do that same lengthy test program for the tenth aircraft you build? No. You put it through an acceptance test program to certify that it matches the first one. With two vehicles, we put one through the set of qualifications for its cruise and entry-descent-landing phases and the other one, in parallel, through the surface phase qualification and split the acceptance testing. That knocked a couple months off our schedule, which allowed us to launch on time.

COHEN: Is there a key lesson this MER story teaches?

MANNING: In the case of these super-complicated systems, give yourself a test program that gets you the answers you don't want to hear early and have the team get into the test mode as soon as possible. Things that you build often don't work to specifications and oftentimes the *environment* doesn't operate to specification. We wrote requirements on Mars; she failed to live up to them. You have to be willing to accept new information, new discoveries from the scientific team that say, for instance, "Hey, Rob, winds are much worse than you thought." But once you know about a problem, it becomes remarkably easy to fix it if you've given yourself the time. When people say, "I'm doing my testing at the end," they're asking for trouble unless it's a system

IN THE CASE OF THESE **supercomplicated systems**, GIVE YOURSELF A **test program** THAT GETS YOU THE **answers** YOU DON'T WANT TO HEAR EARLY AND HAVE THE TEAM GET INTO THE **test mode** AS SOON AS POSSIBLE.…ONCE YOU KNOW **about a problem**, IT BECOMES REMARKABLY **easy to fix it** IF YOU'VE GIVEN YOURSELF **the time**.

that they already know very well. There's no crime in being wrong. The crime is not giving yourself elbow room to fix the problems.

COHEN: Let's talk about 7120.5D and how it reflects some of your experience.

MANNING: There are three legs of program management. Program-level management focuses on the program/project objectives and the resources needed to get the job done. Mission assurance provides an independent view of safety and quality assurance, and makes sure we follow the approved processes and get certification for the systems that we build. The third leg, which has always been there—we just haven't made it official before—is the engineering leg. It's the technical authority processes that start with the Office of the Chief Engineer and work all the way down to the projects and through the engineering line organizations at the NASA Centers. The line organizations and the lead engineers and project systems engineers have an independent technical say, almost a technical ombudsman role, going all the way up to the chief engineer in the event programs deviate from good engineering practice. We've been doing much of it unofficially for many years. 7120.5D makes it official. It allows people—especially new people who come to work for NASA—to understand how the processes work and the right methods for talking about engineering quality.

COHEN: Can 7120.5D do that without introducing a lot of bureaucratic paperwork?

MANNING: We have developed a lot of checklists; there are new processes involved. But some of the older processes have been streamlined. In the past, who was on your review board and how many different review boards you had was unclear. You might have a preliminary design review with one group and then a month later an independent review with a different group of people going through the same material. We said, "Let's combine them." Many of the processes and procedures we've been doing in an ad hoc way are now being codified: this is specifically what you need for this review; you only need to do it once. There's new terminology—for example, the term "key decision point" describes the gate to get from one phase of the mission to another. That's also been murky in the past. The new version attempts to clarify that.

COHEN: Do you think it will be equally appropriate for different projects?

MANNING: It's tuned to different classes of projects. Constellation is a collection of projects that are very closely coupled. There's a certain review process for that kind of program versus the Mars program, which is a more continuous program that has projects that are somewhat coupled, but not as closely as Constellation. If we find a process is cumbersome, we'll tune it. This is a work in progress. The first projects to use it will find holes in it. We'll try to fix them in version E. Some people may argue that it's great for big projects, but what about little projects? We'll spend all our time doing documents and writing certification and flight readiness reports. We say, "Yes, you have to do it, but appropriately for your project." That's part of the balancing act that's still to come.

COHEN: You've mentioned new terminology. Tom Gavin has talked about 7120.5D helping to standardize shared vocabulary.

MANNING: We still are not consistent about how we define terms and rules of engagement across the Agency. Having things written down really makes a difference.

COHEN: Will 7120.5D require people to document project learnings?

MANNING: I don't think that's its intent. It's an attempt to define the minimum requirements of projects to ensure that the system being built will meet its objective on budget and schedule with the appropriate level of quality, mission assurance, and safety. Because budgets are tight, it's still a problem to write down what you've done and why you did it.

COHEN: Which could be a problem for future missions.

MANNING: We have relied on Viking documentation to an extraordinary extent. Because there was a twenty-five-year hiatus between Mars missions, we could never have done Pathfinder and MER without the Viking documentation. The same thing is happening with Constellation and Apollo. The Apollo documentation has really helped people understand what happened in the 1960s. It's helped them get a dose of experience they would not have gotten at this phase of the program otherwise. It has been healthy for the Agency to study the knowledge that was developed at that time.

COHEN: What do you think is the best way to present new documents to make clear they're not just a bureaucratic annoyance?

MANNING: It would be useful for somebody to create a presentation that explains where it came from and why it's the way it is. We tried to put as much information in as small amount of space as possible. 7120.5D has a long, rich history. Laying down rules and making a list of them is important, but when you first get them, you shouldn't get them as rules, you should get them as stories so you can understand the context behind the rules. If you're just following the rules without being aware of why you're doing what you're doing and why it's important to your success, you're being an automaton. Reading the document will probably confuse a lot of people unless they're steeped in the stories behind it. There's a logic behind the document that's very deep and rich. If you read it without the context, it looks bureaucratic, but it's based on crisp and well-thought-out project and program management issues: How is money assigned? How does NASA avoid throwing good money after bad? How is programmatic and technical risk communicated? How do we make sure that our cost estimates will be close to being right? A lot of it has to do with controlling the future, which is a notoriously difficult thing to do. It represents the best we've got so far. ●

For more of our conversation with Rob Manning, read the full interview online at http://appel.nasa.gov/ask.

Safety and Mission Assurance: Independent Yet Engaged

BY BRYAN O'CONNOR

When I was a test pilot at the Naval Air Test Center, I worked closely with the engineers designing the first American version of the British Harrier, a vertical/short takeoff and landing (V/STOL) fighter, for two years before the first flight of the prototype. The main aim of my involvement, based on my own cockpit experience, was to keep the pilot's workload at a manageable level, especially during takeoff and landing. I worked with the engineers on the design of the head-up display, which projects vital information into the pilot's field of view, and the design of the throttle and stick to minimize circumstances that required the pilot to let go of them.

LIKE GOOD TEST PILOTS, MEMBERS OF THE SAFETY AND MISSION ASSURANCE COMMUNITY SPEND A LOT OF TIME THINKING ABOUT "WHAT IF" SITUATIONS (WHAT IF THE ENGINE QUITS? WHAT IF ONE OR ANOTHER SYSTEM FAILS?), TRYING TO REDUCE THE SET OF POSSIBLE PROBLEMS THAT NO ONE HAS THOUGHT ABOUT YET AND TRYING TO MAKE SURE THERE IS ALWAYS A WAY OUT IF SOMETHING GOES WRONG.

As NASA's Chief Safety and Mission Assurance Officer, I apply and promote a lot of the lessons I learned then as a test pilot and later as a Space Shuttle pilot and director of the Space Shuttle program. One of them is the value of drawing on different perspectives and types of expertise early on, as with the development of the American version of the Harrier. We have a history in the Agency of not involving the safety and mission assurance (SMA) community during the entire project life cycle. No one disagrees with the idea, but they tend to think of SMA as the "back-end folks." An important element of the new 7120.5D practices and policies is that they give safety and mission assurance an explicit, active role from the beginning of every project.

"Can Do" vs. Caution

Like good test pilots, members of the safety and mission assurance community spend a lot of time thinking about "what if" situations (what if the engine quits? what if one or another system fails?), trying to reduce the set of possible problems that no one has thought about yet and trying to make sure there is always a way out if something goes wrong. NASA's culture is a famously optimistic, problem-solving, and goal-oriented one; the SMA community is supposed to look for potential problems and question engineering and operational assumptions. In so doing, its members can sometimes be seen as naysayers. Over time, this perception can wear down a motivated SMA engineer. I have seen people burned out by the stress of this negative role.

I think part of the responsibility for resolving the tension between can-do optimism versus problem-seeking pessimism lies with the SMA team itself. "No, because" is a legitimate starting point for safety and mission assurance. We need to take a realistic, unbiased look at barriers and assumptions. But "no" shouldn't be the last word. "Yes, if" is an important goal in an organization like NASA. In other words, we need to be not only knowledgeable enough to know when there is a safety or reliability problem but persistent enough to help the larger team define the solutions to the problems we uncover. SMA engineers must be engaged from the beginning as part of the design team, figuring out how to make things work, not just explaining why they might not and then leaving the scene.

A tension also exists between being fully and actively engaged in projects from the beginning, as safety and mission assurance will be under 7120.5D, while at the same time maintaining the independence of perspective and action we need to do our work well. Our job is to

challenge and test the assumptions of design engineers, providing the checks and balances needed to ensure safe, successful missions. So we need to look at project plans, analysis results, design options, and other project elements with independent eyes and ensure design engineers are not drinking their own bathwater. We at NASA can sometimes get carried away by an overabundance of confidence in ourselves, but I think of the advice Tommy Holloway gave me while we were working on the space station together: “Remember, you’re not as smart as you think you are.” No matter how good you are, you can’t think of everything, foresee every problem, or recognize all the potential weaknesses in your assumptions, so reach out for the independent look.

I remember a clear example of skilled professionals being led astray by an excessive belief in their competence in the late seventies. We arranged training dogfights between a dozen navy F-14 pilots and an equal number of marines flying the AV-8A, the first American version of the British V/STOL aircraft. The first F-14 pilot to face a Harrier unswept his aircraft’s wing to lower its speed and increase maneuverability, but he couldn’t match the Harrier, which had vectored thrust capability and could be almost stationary by comparison. The Harrier easily dropped behind the F-14 and “destroyed” it. Although the second and third F-14 pilots saw what happened, they tried the very same thing, with the same result: they also lost their dogfights. Why didn’t they learn? They assumed they were better pilots than the ones who had failed and ignored the possibility that the tactic itself was faulty.

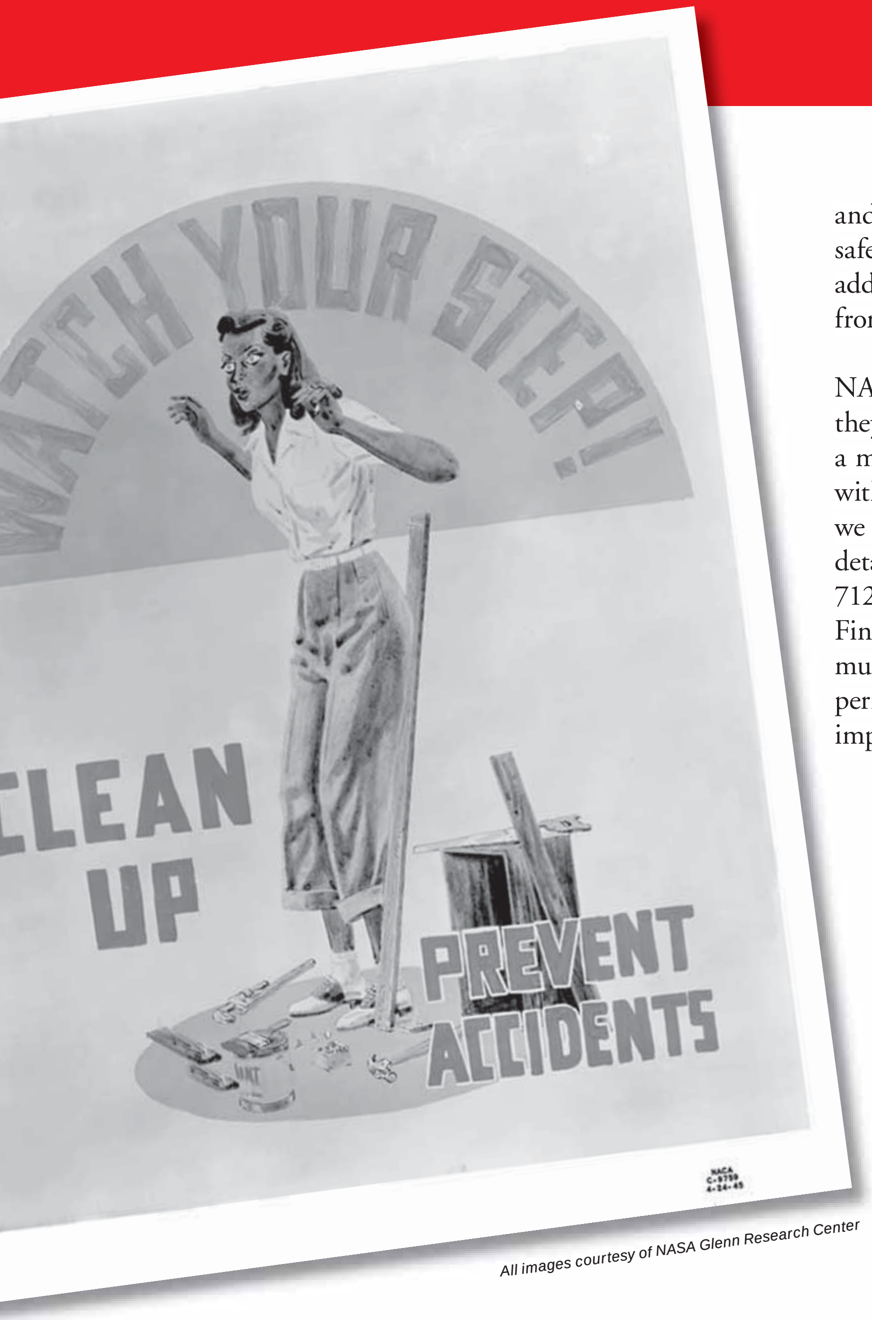
Learning from Mishaps

A similar overconfidence factor may get in the way of NASA’s ability to learn from mistakes. The Agency is required to investigate all occurrences of damage and injury. Investigating close calls is encouraged but not required, so they are often ignored. In the past, when we experienced a close call, we tended to focus on the one thing that saved us (and our own skill at avoiding disaster) rather than the three that almost killed us. But close calls are a gift—an opportunity to learn important lessons without scraping bodies from the floor. We are doing better, though. I recently sat in on a class B–level mishap investigation final report briefing, not for a class B mishap, but for a close call. A young worker was knocked down but not injured when he cut through a “hot” electrical wire that had 22,000 volts of electricity running through it. The focus of the investigation was not on what saved his life—the fact that the ground was dry, that he was wearing gloves, that he was young enough to tolerate the jolt—but on what caused the accident—bad procedures, out-of-date drawings, inadequate supervision. The center director, through the mishap board, made the best of this “gift” and allowed the center to take steps toward preventing similar, possibly fatal mishaps in the future.

Safety and Mission Assurance and 7120.5D

The safety and mission assurance community has been deeply involved in the process of rewriting 7120.5D, with some members spending almost all their time on the work. Their contribution helps ensure that SMA, one of the three legs of the check-and-balance “milk stool” that supports programs and projects, has as well-defined a role as program management

SMA ENGINEERS MUST BE ENGAGED FROM THE BEGINNING AS PART OF THE DESIGN TEAM, FIGURING OUT HOW TO MAKE THINGS WORK, NOT JUST EXPLAINING WHY THEY MIGHT NOT AND THEN LEAVING THE SCENE.



All images courtesy of NASA Glenn Research Center

and engineering. The new processes make clear that system safety, reliability, maintainability, and quality assurance are not add-ons that come toward the end of projects but are integral from the beginning.

The Columbia Accident Investigation Board concluded that NASA lacked the discipline needed to avoid serious accidents; they pointed to navy submarine requirements and discipline as a model. 7120.5D takes a step toward the necessary discipline without mandating processes that are too rigid. One of the ways we have tried to keep from getting bogged down in excessive detail is to look for the optimal mix of processes spelled out in 7120.5D and references to other policy and process documents. Finding the sweet spot between not enough process and too much is not easy. 7120.5D alone is not going to create that perfect balance—that's where good people come in—but it's an important step in the right direction. ●

BRYAN O'CONNOR is a former Marine Corps test pilot and aeronautical engineer. He served at NASA as a Space Shuttle commander and program director and is currently serving as the Agency's Chief of Safety and Mission Assurance.

Program Analysis and Evaluation: Clarity and Independence for the New Mission

BY SCOTT PACE

NASA Administrator Michael Griffin established the Office of Program Analysis and Evaluation (PA&E) to supply independent studies and assessments of NASA programs for the Office of the Administrator. To ensure its objectivity, the office has no operational line authority or direct responsibility for any mission areas—it is a staff function. We don't say "go" or "no go;" we come up with observations and options that help those who do make decisions make them on the basis of the best available information and "full disclosure" of alternatives.

PA&E consists of five divisions: studies and analysis, strategic investments (which focuses on budget planning and programming), cost analysis, an independent program assessment office, and mission support that administers resources for PA&E. We are not an auditing organization—that is, our aim is not to find fault or mistakes but to offer clear, objective analysis that includes alternative solutions to potential problems. For instance, if we have doubts about a program having sufficient reserves of money and time to achieve a critical technical objective, we may identify possible responses such as conducting tests to demonstrate technical readiness, adding reserves, or accepting the identified risks.

To do their jobs effectively, PA&E staffers need multidisciplinary expertise. They need to see the "big picture" and understand areas such as economics and statistics as well as engineering. They regularly supplement their own technical knowledge with the expertise of NASA and industry engineers, including those working on the programs being evaluated, since they are the ones likely to be closest to the problems. Throughout the analytical process, we have to manage the tension between independence and collaboration. We work closely with program teams to understand their work and help them succeed, but we must simultaneously maintain enough distance to avoid the blind spots and optimism that often accompany deep engagement. Optimism is good—it is one source of NASA's success—but it can lead to a failure to recognize and adequately allocate resources to areas of risk. Cost and schedule seem especially susceptible to optimistic thinking, so it is important for PA&E to provide reality checks wherever possible. As Michael Griffin has said, "You shouldn't grade your own homework."

Recent Examples

Some recent decisions based on PA&E's work have helped avoid unnecessary expense and delay. The office studied the question of whether RS-68 rocket engines could be used for the new exploration mission, or whether it would be preferable to use Space Shuttle Main Engines. At first, technical experts were skeptical about using the RS-68, but careful analysis showed that, given some launch vehicle modifications, it would be able to provide the necessary performance. The decision to go with the RS-68 will save several billion dollars over several decades.

PA&E also examines infrastructure needs. The groups developing the James Webb Space Telescope and the Crew Exploration Vehicle were originally planning to use the same thermal vacuum chamber at Johnson Space Center. A PA&E team, working with the centers and mission directorates, analyzed the potential impact of common needs for the same testing facility and worked to develop new plans to avoid conflicts that could have delayed or compromised the technical performance of both programs.

PA&E, 7120.5D, and New Missions

Mark Saunders, the PA&E director of the Independent Program Assessment Office, has been directly involved in developing the new 7120.5D guidance on program and project management. The new clarity the document provides regarding the review process, defining and standardizing when major reviews occur and what must be accomplished before a project or program can move on to the next stage, also clarifies when and how PA&E will carry out its analyses and make recommendations. But 7120.5D leaves room for the flexibility that different kinds of programs require. A research program shouldn't be treated the same way as a flight project, for example. The aim of 7120.5D is mission success, not making everything fit the same template.

WE NEED TO BASE OUR DECISIONS ON CLEAR, CONSISTENT PRIORITIES. NOT EVERYONE WILL BE HAPPY WITH EVERY DECISION, BUT IF THE SUPPORTING LOGIC IS FULLY AND CLEARLY EVIDENT, I BELIEVE THOSE DECISIONS WILL BE RESPECTED BY THE NASA COMMUNITY, OUR PARTNERS, AND STAKEHOLDERS.

The projects and programs that make up NASA's new space exploration mission are extremely complex and interrelated, with each element building on the one before and laying the foundation for those that follow. Choices—some of them very difficult choices—will have to be made with the overarching challenges and aims of the mission in mind, so the level of analysis needed to make informed decisions will be especially great. Making the best possible decisions based on the best possible information will be doubly important as NASA prepares to send human beings away from the Earth for long periods of time.

New missions of exploration to the Moon, Mars, and beyond will make great demands on all involved projects and programs and will undoubtedly create tensions in the management of requirements, resources, and schedules. We need to base our decisions on clear, consistent priorities. Not everyone will be happy with every decision, but if the supporting logic is fully and clearly evident, I believe those decisions will be respected by the NASA community, our partners, and stakeholders. We are mindful that the Columbia Accident Investigation Board complained that NASA has been too much a "PowerPoint culture;" the limitations of that tool sometimes obscured information needed for decisions. PowerPoint has legitimate uses, but it is no substitute for detailed analysis that explains not only what was decided but why that choice was made. PA&E's job is to contribute to mission success by helping the senior leadership of the Agency make better decisions through analysis and thereby enhance the credibility, trust, and cooperation we need to explore new worlds. ●

SCOTT PACE is the Associate Administrator for Program Analysis and Evaluation at NASA. In this capacity, he is responsible for providing objective studies and analyses in support of policy, program, and budget decisions by the NASA Administrator.

Lunar Mission Profile

www.nasa.gov/mission_pages/constellation/main/index.html

1. The cargo launch vehicle, Ares V, lifts off.
2. Solid Rocket Boosters (SRB) separate from Ares V.
3. Earth Departure Stage (EDS) performs Earth orbit insertion.
4. Payload shroud separates to expose the Lunar Surface Access Module (LSAM).

1a. The crew launch vehicle, Ares I, lifts off.

2a. First stage separates from Ares I.

5. Ares I upper stage performs Earth orbit insertion.
6. Crew exploration vehicle, Orion, docks with LSAM and EDS; EDS fires for lunar destination.
7. Orion and LSAM separate from EDS.
8. Orion and LSAM enter lunar orbit.
9. LSAM lands on the lunar surface.
10. Astronauts perform lunar surface activities.
11. LSAM ascent stage lifts off from lunar surface.
12. LSAM ascent stage and Orion dock for crew transfer.
13. Orion burns for Trans Earth Injection (TEI).
14. Orion and surface module separate and re-enter Earth's atmosphere.
15. Orion decelerates through Earth's atmosphere.
16. Parachutes open for landing and recovery.

ASK Magazine would like to extend special thanks to Beth Dickey from the Office of Public Affairs and Derek Wang from the Exploration Systems Mission Directorate for their assistance.

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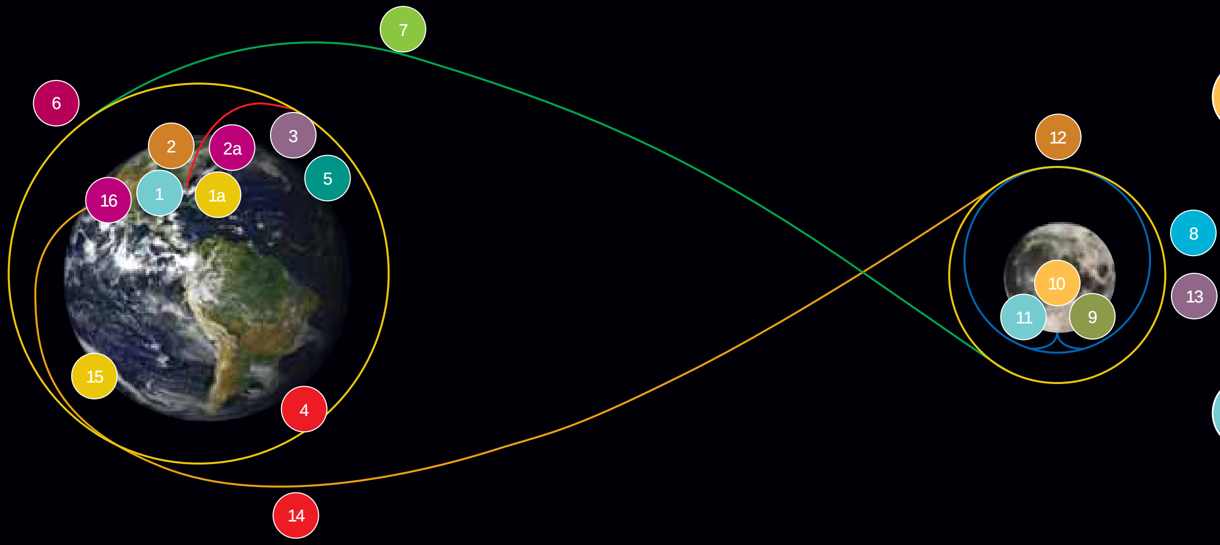

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All images courtesy of NASA/John Frassanito and Associates

NASA's
Exploration Architecture

When undertaking a long journey to a new place, it helps to have a road map to guide you. NASA's new space exploration program is such a journey, one whose length, complexity, and challenges make a good map especially important. The new *Program and Project Management Processes and Requirements* (NPR 7120.5D), which outline the policy and processes designed to ensure project success and knowledge sharing at NASA, are part of that map. Taken together, those requirements and this special pullout of the Agency's exploration architecture—a map of milestones for the Constellation program—show where we are going, the important stages of the journey, and what we have to do to reach our destination. We hope this map brings into focus what we need to accomplish today and tomorrow to achieve our ambitious goals.

The mission we are beginning now will span decades. We need to define, record, and communicate the path we take to ensure we—those of us working today and those joining the program in the future—are all working with the same vision in mind. NASA's new policies and the exploration architecture offered here are part of this process, providing the maps we and our successors will refer to and refine as we expand human exploration in space.

The Vision for Space Exploration

There is nothing so far removed from us to be beyond our reach, or so far hidden that we cannot discover it.
RENÉ DESCARTES

We shall not cease from exploration and the end of all our exploring will be to arrive where we started...and know the place for the first time.
T.S. ELIOT

It is difficult to say what is impossible, for the dream of yesterday is the hope of today and reality of tomorrow.
ROBERT GODDARD

In the long run men hit only what they aim at.
HENRY DAVID THOREAU

Where there is no vision, the people perish.
PROVERBS 29:18

The Moon is the first milestone on the road to the stars.
ARTHUR C. CLARKE

The important thing is not to stop questioning.
ALBERT EINSTEIN

For I dipped into the Future, far as human eye could see; saw the vision of the world, and all the wonder that would be.
ALFRED, LORD TENNYSON

I had the ambition to not only go farther than man had gone before, but to go as far as it was possible to go.
CAPTAIN COOK

The greatest gain from space travel consists in the extension of our knowledge. In a hundred years this newly won knowledge will pay huge and unexpected dividends.
WERNHER VON BRAUN

The past is but the beginning of a beginning, and all that is and has been is but the twilight of the dawn.
H.G. WELLS

We are at a point in history where a proper attention to space, and especially near space, may be absolutely crucial in bringing the world together.
MARGARET MEAD

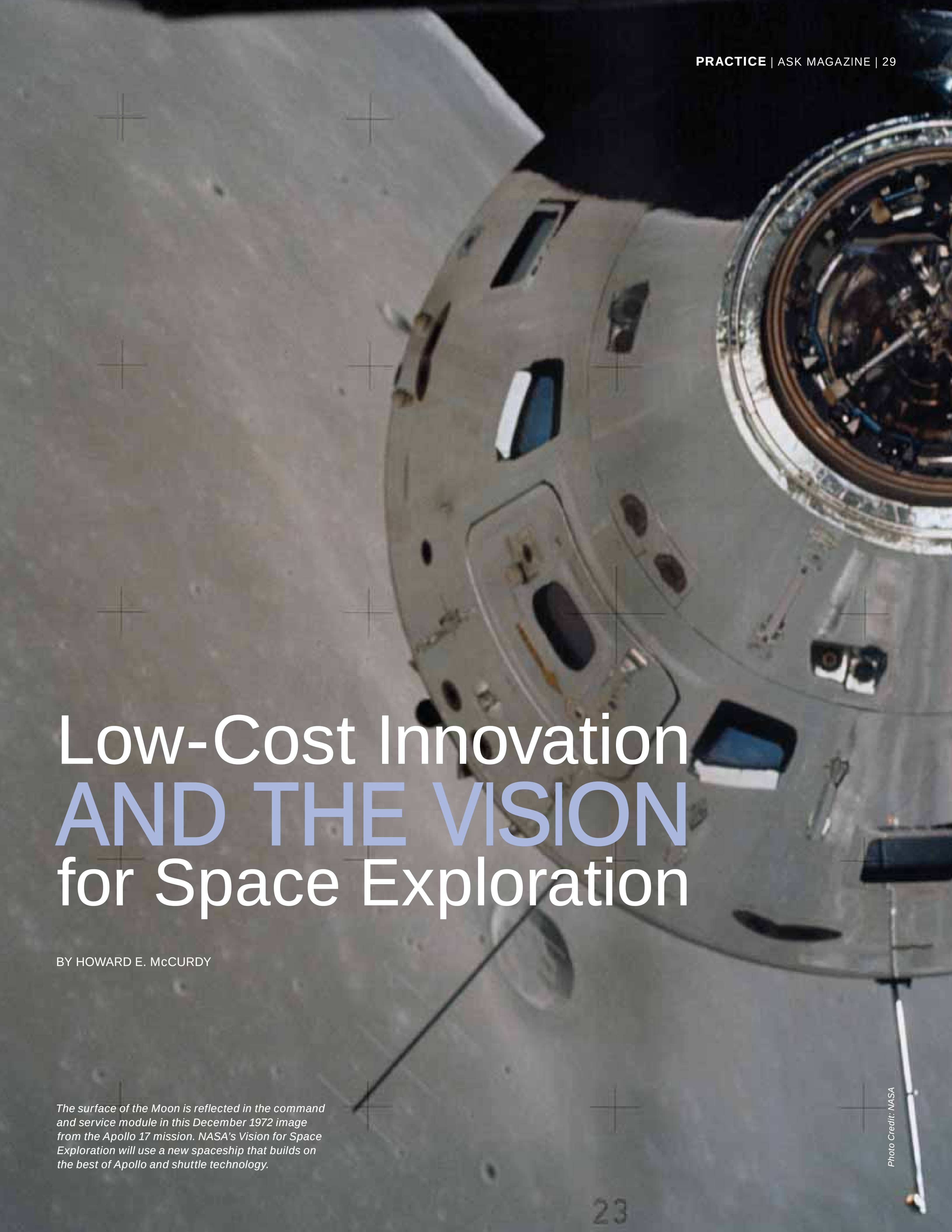
Freedom lies in being bold.
ROBERT FROST

To set foot on the soil of the asteroids, to lift by hand a rock from the Moon, to observe Mars from a distance of several tens of kilometers, to land on its satellite or even on its surface, what can be more fantastic?
KONSTANTIN E. TSIOLKOVSKY, FATHER OF RUSSIAN ASTRONAUTICS

Destiny is not a matter of chance. It is a matter of choice. It’s not a thing to be waited for—it is a thing to be achieved.
WILLIAM JENNINGS BRYAN

A sense of the unknown has always lured mankind, and the greatest of the unknowns of today is outer space. The terrors, the joys, and the sense of accomplishment are epitomized in the space program.
WILLIAM SHATNER

In my own view, the important achievement of Apollo was a demonstration that humanity is not forever chained to this planet, and our visions go rather further than that, and our opportunities are unlimited.
NEIL ARMSTRONG



Low-Cost Innovation AND THE VISION for Space Exploration

BY HOWARD E. McCURDY

The surface of the Moon is reflected in the command and service module in this December 1972 image from the Apollo 17 mission. NASA's Vision for Space Exploration will use a new spaceship that builds on the best of Apollo and shuttle technology.

Photo Credit: NASA

Nearly every project that NASA scientists and engineers undertake requires some degree of innovation. Project managers generally employ proven technologies as a means of reducing risk, but invariably some innovation occurs. Most engineers who work in the realm of space flight enjoy innovating and are not content to build the same system over and over again. The desire to innovate is part of NASA's organizational culture.

The first phase of the Vision for Space Exploration—wherein humans and their machines return to the Moon—is no exception. NASA officials could dust off old blueprints and return to the Moon using 1960s technology. That path is well known. Yet any attempt to repeat the lunar landings using Apollo techniques would degrade one of the primary objectives of the return—the desire to develop technologies that eventually will carry humans beyond the Earth–Moon system toward Mars.

Of these potential innovations, few are more important than those affecting cost. When quizzed on the affordability of the Vision for Space Exploration during its consideration in 2003, NASA officials assured White House aides that a return to the Moon could be accomplished using Apollo-style technology for less than the cost of landing the first humans on the Moon in 1969.

NASA officials pointed out that they would not need to incur the expense of constructing the Johnson or Kennedy space centers or a new tracking network. They would not need to charge the cost of excess equipment used for future missions against the first, as Apollo program managers had done. By using tested technologies, they could save money on the crew exploration vehicle, the lander, and a new launch vehicle. The total savings, NASA officials estimated in 2003, would amount to about half of the inflation-adjusted $147 billion spent to send the first humans to the Moon. The estimated savings have varied from study to study, and recently shrunk, but the underlying principle remains the same. Using Apollo-style technology, the United States can return to the Moon for a sum that fits within projected NASA budgets. It will not be easy, but it can be done.

Now take that analysis one step further. Suppose the United States, with its international partners, attempts to use Apollo techniques to send humans to Mars. In other words, the expedition uses chemical-fueled rockets, small capsule-shaped spacecraft, a Martian orbit rendezvous, a mission length of 900 days, and Apollo-style project management in which every element of the mission and its possible interactions are triple-checked before the first astronauts leave. The cost of a mission of such complexity rapidly approaches $1 trillion. Could the United States afford to organize such an expedition? Yes, it could. Is Congress likely to provide the necessary funds? No. In short, any attempt to return to the Moon using Apollo-style techniques is likely to defeat the ultimate purpose of the undertaking, making the next Moon landing an end in itself rather than a means to a more spectacular objective.

ANY ATTEMPT TO REPEAT THE LUNAR LANDINGS USING APOLLO TECHNIQUES WOULD DEGRADE ONE OF THE PRIMARY OBJECTIVES OF THE RETURN—THE DESIRE TO DEVELOP TECHNOLOGIES THAT EVENTUALLY WILL CARRY HUMANS BEYOND THE EARTH–MOON SYSTEM TOWARD MARS.

What can NASA officials do to resolve this conundrum? As a first step, they can seek inspiration from the people who organized Project Apollo. When President John F. Kennedy challenged Americans to race to the Moon in May 1961, no one in NASA knew how to do it. NASA engineers had not yet invented lunar-orbit rendezvous. Wernher von Braun's rocket team had not yet perfected the hydrogen-burning J-2 engines that would propel the Saturn V rocket's second stage. NASA officials had yet to embrace consolidated or "all-up" testing, one of the practices that allowed the space agency to meet its end-of-the-decade deadline. More significantly, few people in NASA knew how to organize projects as big as Apollo. NASA scientists and engineers had plenty of technical capability, lots of hands-on skill, and plenty of experience with small projects. People in the newly created space agency had practically no experience, however, managing an undertaking as interactive and complex as Project Apollo.

To resolve the management challenge, NASA Administrator James Webb looked outside the Agency. He turned to the U.S. Air Force and its supporting contractors, where people working on the crash program to deploy a fleet of intercontinental ballistic missiles (ICBMs) had spent the previous decade developing a technique called large-scale systems management. Webb recruited people like George Mueller and General Sam Phillips from the air force ICBM program to help reorganize NASA. They introduced techniques like configuration control, concurrent development, progressive design freezes, and systems integration studies to produce an agency organizationally capable of reaching the Moon. Historian Stephen Johnson has called these techniques "the secret of Apollo." Without large-scale systems management, the lunar landings would not have occurred—certainly not with the degree of reliability that the United States achieved.

So where can NASA officials turn for the next round of innovations, in particular for the low-cost innovations necessary to take humans beyond the Moon? To start, they can look within their own organization. This may seem like a strange suggestion for an agency that has struggled for thirty years to meet cost and schedule goals on the Space Shuttle and International Space Station. Yet NASA program managers have accumulated many years of experience with low-cost innovation, including experience from projects that worked (like Mars Pathfinder and NEAR-Shoemaker) and ones that failed (like Mars Climate Orbiter and CONTOUR).

The techniques used to manage a succession of "faster, better, cheaper" projects during the past fifteen years may not scale up well to projects as complicated as human expeditions to the Moon, but they contain valuable lessons nonetheless. One profound lesson is the importance of centers of integration. The low-cost projects that worked best possessed focused centers of integration in which the same team of technically competent people designed, built, and flew the spacecraft. Team leaders used contractors to build spacecraft components, but the teams did not distribute their core functions. Low-cost projects that got in trouble invariably did, with results like those afflicting Mars Climate Orbiter, with one team working with English units of measurement and another using metrics.

Photo Credit: NASA/Johns Hopkins University Applied Physics Laboratory

NEAR-Shoemaker approaches asteroid Eros in this artist's concept. NEAR is one of many successful projects that helped program managers gain experience in low-cost innovation.

A preference for work packages and extensive contracting characterizes NASA's preferred approach for large-scale project management. It worked well for Project Apollo, accompanied as that was by a strong center of systems integration and plenty of in-house technical capability. Yet the approach is very expensive, prohibitively so when one considers it as a method for sending humans to Mars. To get to the Moon and beyond on a budget, NASA officials might consider reestablishing single centers of systems integration with very strong technical capabilities. It would be nice if those centers were inside the Agency, but they could be outside as well so long as they are concentrated and technically strong.

Next, NASA officials can look beyond the Agency to innovations taking place in the private sector and elsewhere in government. The aerospace contractors on whom NASA project managers have traditionally relied are not a good source in this regard. They exist in a business environment that provides few incentives for cost innovation. The reverse is true in the highly competitive electronics and information sectors, where firms face incredible pressures to innovate or perish. Backed by entrepreneurs from these sectors, innovators like Burt Rutan are seeking new and economical ways to accomplish the first steps in space that NASA officials took forty-five years ago. The management techniques and technologies they use are often radically different from the ones NASA pioneered.

Government leaders insist that the new vision for space exploration will be carried out by humans and robots exploring space together. Some of the most innovative work in this regard is taking place in the U.S. Department of Defense, especially the Defense Advanced Research Projects Agency (DARPA). The defense department is working to reengineer one-third of its transport vehicles so they can be driven by robots by 2015. One of the lessons to be gathered from this activity is the importance of prizes. DARPA officials have used contests such as the 132-mile Grand Challenge for robot vehicles across the Mojave Desert to encourage innovation in pursuit of this goal.

Finally, NASA can learn from its international partners and competitors, especially Russia and China. Both nations conduct space programs at a fraction of the NASA enterprise expense. They accomplish less, but what they do produce (like the Soyuz launch system) costs far less than U.S. counterparts. The difference cannot be explained entirely by lower labor costs. The adoption of production line methods may account for a significant portion of the cost reductions achieved on the Russian vehicles.

When President Kennedy assigned NASA the task of sending humans to the Moon in the spring of 1961, agency officials were not capable of doing the job. Yet eight years later Americans stood on lunar soil. Through two major reorganizations and frequent innovations, NASA founders transformed their young agency. Most of the transformations were painful; many were controversial. The desire of NASA officials to achieve their goal outweighed their pain. The NASA that dispatched Americans to the surface of the Moon in the summer of 1969 little resembled the organization that started the journey eight years earlier.

In a similar fashion, if NASA employees and their contractors succeed in returning humans to the Moon and dispatching them and their machine companions to Mars, the organization that completes the work will bear little resemblance to the one that exists today. Innovation will occur again. The NASA that completes the new challenge will be as transformed as the NASA of 1969 was relative to itself in 1961. ●

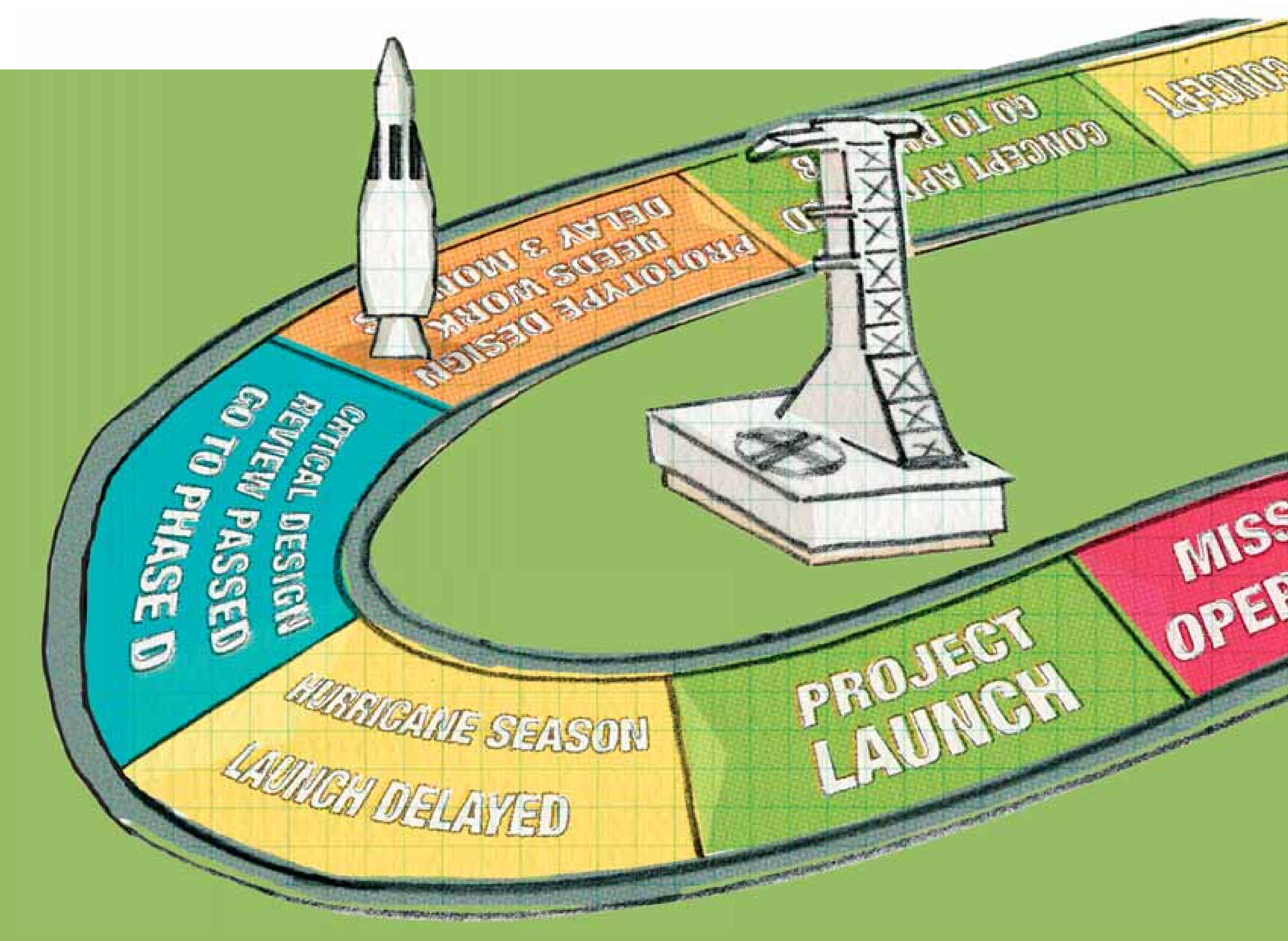
SO WHERE CAN NASA OFFICIALS TURN FOR THE NEXT ROUND OF INNOVATIONS, IN PARTICULAR FOR THE LOW-COST INNOVATIONS NECESSARY TO TAKE HUMANS BEYOND THE MOON? TO START, THEY CAN LOOK WITHIN THEIR OWN ORGANIZATION.

HOWARD E. McCURDY is a professor in the School of Public Affairs at American University in Washington, D.C., and author of six books on space policy, including *Faster, Better, Cheaper: Low-Cost Innovation in the U.S. Space Program* and *Inside NASA*, a study of the Agency's changing organizational culture. He is currently completing a book with Roger Launius on human and robotic flight.

A Look Under the Hood of NPR 7120.5D

BY MIKE BLYTHE

NASA's space flight programs and projects are highly visible national priorities. The Agency's strategic plan articulates these space flight goals and the timetable for reaching them. Program and project management translates the strategy into the actions needed to achieve these goals. So NPR 7120.5D, which defines the requirements for effective program and project management, is an essential contributor to the Agency's ability to fulfill its mandate.



COMMON PROCEDURES AND TERMINOLOGY ACROSS CENTERS WILL INCREASE OUR EFFICIENCY AND REDUCE THE RISK OF ERRORS DUE TO MISUNDERSTANDINGS. THEY WILL ALSO LAY THE GROUNDWORK FOR TIGHTLY INTEGRATED ROBOTIC AND HUMAN MISSIONS ON THE MOON, MARS, OR THE INTERNATIONAL SPACE STATION IN THE FUTURE.

Why Revise 7120.5D?

The new revision of NPR 7120.5D is part of a realignment of governing documents within NASA designed to increase accountability and general clarity about management process requirements. When NASA revamped its governance model in 2005 in response to the long-term challenge posed by the Vision for Space Exploration, it became essential to bring NPR 7120.5D into conformance with the Agency's new direction.

Some of the changes to the document respond to external reviews of NASA's performance over recent years. For instance, the establishment of a technical authority and the protection of dissenting opinions have their roots in the findings and recommendations of the Columbia Accident Investigation Board Report. Defining and standardizing key decision points in the project approval process acknowledges the Government Accountability Office's recommendations about best practices in knowledge-based acquisition. Most important, though, the thorough internal review process that accompanied this revision makes it a compendium of NASA's nearly fifty years of knowledge about the most successful practices for space flight program and project management.

How Does the Governance Model Affect Programs and Projects?

The NASA governance model describes a management structure that employs checks and balances between key organizations to ensure that decisions have the benefit of different points of view and are not made in isolation. NASA has adopted two basic authority processes: the programmatic authority process and the technical authority process. The programmatic authority process is largely described by the roles and responsibilities of the NASA Associate Administrator, Mission Directorate Associate Administrators, and program and project managers.

The technical authority process provides for the selection of individuals at different levels of responsibility who offer independent views of matters within their areas of expertise. The term "Technical Authority" refers to such an individual, but it is also used (without capitalization) to refer to all elements of the technical authority process taken together. A key aspect of the technical authority process is that Technical Authorities (TA) are funded independently of programs and projects. Their responsibilities include approving changes to, and waivers of, all TA-owned requirements; and serving as members of program/project control boards, change boards, and internal review boards. The technical authority process ensures that the golden rule of the governance model—projects don't check their own work—has sound implementation through processes and procedures.

What Is Different This Time?

Beyond supporting the new governance model, the new 7120.5D accomplishes a number of "firsts." For the first time in NASA's history, the program/project life-cycle and milestone reviews that occur across the Agency have been integrated for both human and robotic missions. There is also now a common set of terms, so a critical design review (CDR) means the same thing at one center as it does at another.

This does not mean that the milestones for human and robotic missions are now identical in every phase across the life cycle; manned missions will still have Mission Management Team meetings, for instance, while robotic missions will not. But the missions are standardized and synchronized to the greatest extent possible. This will offer myriad benefits for NASA. Common procedures and terminology across centers will increase our efficiency and reduce the risk of errors due to misunderstandings. They will also lay the groundwork for tightly integrated robotic and human missions on the Moon, Mars, or the International Space Station in the future.

Program and project reviews are essential for approving, conducting, managing, and evaluating space flight programs and projects. In preparation for these reviews, programs and projects conduct internal reviews to establish and manage the program/project baseline. These internal reviews are the decisional meetings where the programs/projects solidify their plans, technical approaches, and programmatic commitments.

Major technical and programmatic requirements and performance metrics are assessed along with the system design and other implementation plans. After completing the internal work, a Standing Review Board (SRB) conducts independent life-cycle reviews. Independent reviews are conducted under documented agency and center review processes.

The document also offers a phase-by-phase breakdown of all program and project management requirements across the life cycle, so every requirement includes answers to the questions "who," "what," and "when," defining roles and responsibilities along with their places in the life cycle. NPR 7120.5D defines two types of requirements—programmatic requirements and management process requirements—that apply to programs and projects. Programmatic requirements focus on the space flight products to be developed and delivered and specifically relate to the goals and objectives of a particular NASA program or project. These requirements flow down from the Agency's strategic planning process. Management process requirements focus on how NASA does business and are independent of any particular program or project.

How Do Projects Get Approval?

The new 7120.5D introduces two new concepts: key decision points, when approval is given to proceed to the next life-cycle phase, and the Decision Authority, the responsible official who provides that approval.

The key decision point (KDP) is defined as the event where the Decision Authority makes a decision on the readines of the program/project to progress to the next phase of the life cycle. KDPs serve as gates through which programs and projects must pass. Within each phase, the KDP is preceded by one or more reviews, including the governing Program Management Council review. For programs and Category I projects, the Associate Administrator is the Decision Authority. For Category I projects, this authority can be delegated to the Mission Directorate Associate Administrator. For Category II and III projects, the Mission Directorate Associate Administrator is the Decision Authority. Category assignments are based on a project's life-cycle cost estimate and their priority level.

How Are Dissenting Opinions Protected?

NASA teams must have full and open discussions based on all relevant facts in order to understand and assess issues. In keeping with NASA's core values of teamwork and integrity, diverse views are to be fostered and respected in an environment of integrity and trust with no suppression or retribution. Unresolved issues of any nature—programmatic, safety, engineering, acquisition, or accounting—should be quickly elevated to achieve resolution at the appropriate level. At the discretion of the dissenting person(s), a dissenting view is identified and presented to the next level of programmatic and/or technical management. If the dissenter is not satisfied with the process or outcome, he or she may request referral to the next highest level of management. The dissenter has the right to take the issue upward in the organization, even to the NASA Administrator if necessary. Dissenting opinions raised by a Technical Authority are handled by the technical authority process.

How Is Compliance Ensured?

Center management holds the primary responsibility for ensuring programs/projects comply with NASA institutional documents such as 7120.5D. Each center does this by preparing and documenting its institutional engineering, program/project management, and safety and mission assurance standards and practices. At a minimum, each Center Director is responsible for preparing and executing a center implementation plan for

- Project management standards and practices
- Engineering standards and practices
- Safety and mission assurance standards and practices
- Technical authority standards and practices
- Traceability and conformance of center standards and practices to NASA policies and procedures
- The system used to verify that these standards and practices are employed by programs and projects at the center

How Does This Fit Within the Big Picture?

The intent of all these changes is to clarify lines of authority, to streamline processes and procedures across the Agency, and ultimately to give NASA the program and project management structure it needs to implement the Vision for Space Exploration. Given the thoroughness of the review process that accompanied this revision, the team has done its best to devise a document that helps program and project teams do their jobs, rather than adding levels of unworkable bureaucratic interference. The real test of its effectiveness lies ahead. ●

MIKE BLYTHE serves as the Program Executive for Program and Project Management in the Office of the Chief Engineer. Prior to coming to NASA Headquarters, he was deputy project manager for the CALIPSO project at the Langley Research Center.

A Common Language for Systems Engineering: NPR 7123.1

BY STEPHEN J. KAPURCH

Winston Churchill once famously remarked that the United States and Britain are two great countries separated by a common language. That's a useful metaphor for thinking about the discipline of systems engineering. If you ask any two systems engineers to define the job, chances are that you'll get two very different answers.

Part of the reason there's so much disagreement about the definition of systems engineering is because of the difficulty of measuring its value. If you're a structural engineer or a thermal engineer, success is easy to measure: the system sustains all the loads and performs as predicted or the spacecraft reenters the atmosphere with no problems. In systems engineering, if you use a good, consistent approach, you reduce the system risk and rework. It's difficult to calculate the resources you save by doing things right the first time.

A common misconception about systems engineering is that it is an "up-front" activity that takes place only in the requirements definition phase of a program or project life cycle. That view doesn't properly account for the complexity of engineering and integrating systems. As systems are added and modified over the course of development, the number and complexity of interfaces increases in a nonlinear fashion. Problems resulting from conflicting or missing interfaces are the norm, not the exception. The only way to deal with this type of dynamic environment is by adopting an end-to-end, logical systems approach that emphasizes robust modeling and simulation, verification, and validation testing. These rigorous systems processes must be repeated throughout the life cycle of a system to detect unexpected consequences that can flow from even small design changes.

Given the complexity of the systems that NASA is now designing for the Vision for Space Exploration, it's essential that we have a shared understanding and a common language that will enable us to do our jobs effectively across organizational lines. To address this need, the Office of the Chief Engineer has undertaken an overall systems engineering excellence initiative. Its objective is not to define what a systems engineer does; rather, it is to transform systems engineering from a task performed by individuals to a logical systems approach performed by multidisciplinary teams.

A systems perspective does not just belong to the person who wears the "systems engineer" badge. Even though you might be a thermal engineer, you need to understand the requirements that are allocated from the system above and flow down to the subsystem below your system. You need to know what your margins are and how you fit into the overall project. That way, when you conduct trade studies or select a design, you understand how your system operates within a bigger whole. Educating just systems engineers is insufficient. NASA as a whole is adopting a systems approach.

This multidimensional problem calls for a multidimensional approach. The Office of the Chief Engineer's systems engineering excellence initiative has three dimensions: common technical processes, tools and methods, and workforce training

THE CHALLENGE IN DEVELOPING IT WAS TO TARGET THE RIGHT LEVEL OF DETAIL—NEITHER TOO DETAILED NOR TOO GENERAL—AND CREATE SOMETHING THAT ADDS VALUE.

and development. By integrating processes, tools, and training, this approach aims to create an engineering culture in which continuous improvement is the norm.

NPR 7123.1 is the result of an extensive, iterative effort to define the common technical processes of systems engineering. The team that developed the document represented all NASA Centers and mission directorates. Before the writing began, the 7123.1 team held a series of workshops with both NASA stakeholders and external experts, including officials from government agencies, private industry, and professional organizations. Their perspectives helped us survey the state of systems engineering both within and outside NASA and identify common practices. Most importantly, though, the workshops made clear that promoting a systems approach across all engineering disciplines will require a change in culture that won't happen overnight. It will take time, persistence, and support from senior management.

The document itself describes at a relatively high level what to do, not how to do it. The challenge in developing it was to target the right level of detail—neither too detailed nor too general—and create something that adds value. There are important differences in the types of projects that NASA conducts. Within that range, the NPR defines a standard design review approach that conforms to the common life-cycle definition spelled out for programs and projects in NPR 7120.5D, and it lays out a systems engineering process that can be applied to any system, regardless of scope or scale.

Once the team completed a draft, we ran it through four tabletop simulations involving the Constellation program, satellites, ground systems, and research projects. These exercises led to significant changes that made it more practical and user-oriented. It's no secret that if the document doesn't help people do their jobs, it's going to be shelfware.

In short, NPR 7123.1 is part of a larger initiative to develop and implement a common systems engineering framework at NASA. The missions and systems ahead demand a revolutionary advancement in our capability. The only way to get there is through a continuous improvement process that is well understood, consistently applied, and flexible enough to meet the diverse needs of our programs and projects. ●

STEPHEN J. KAPURCH is currently assigned to the Office of the Chief Engineer at NASA Headquarters. In this position he directs the Engineering Excellence Initiative to assess and improve NASA systems engineering processes and the Advanced Engineering Environments Program.

EXPLORATION SYSTEMS MISSION DIRECTORATE AND 7120.5D: ENABLING EXPLORATION

BY GARRY LYLES

In the past, Agency-wide requirements documents for program and project management at NASA have typically been shaped by contributions and advice from the field centers, the mission directorates, and people who have been involved in past programs. 7120.5D represents a new approach because the team that developed it also received real-time input from a program currently being formulated—Constellation, NASA's largest new program. The Constellation program and the Exploration Systems Mission Directorate (ESMD) have collaborated with the 7120.5D team to develop realistic, workable processes and procedures early in the game. This provided an important reality check for the document's usability and created a sense of ownership of this critical process document within the program, which represents the direction of human space flight at the Agency for the foreseeable future. Everybody involved wanted to take advantage of this opportunity to get the processes right the first time. NASA's future accomplishments will depend on it.

As the 7120.5D team worked on the policies and requirements spelled out in that document, the Constellation team developed requirements for its program. At the request of the Constellation program manager, the Office of the Chief Engineer established a technical requirements team to help determine processes to apply to the new governance model established by NASA Policy Directive 1000.0. This team would also provide information to the 7120.5D team that would allow them to properly document these processes, which define the working relationship between the program and projects and the technical authority as well as the role of the technical authority within the program's management structure. Processes for managing selections, changes, and waivers to institutional engineering requirements (specs and standards) as well as dissenting opinions between the program and the technical authorities were established. These processes were tested in the real program environment as Constellation developed its requirements. For example, this testing within the Constellation program helped establish the method for effectively integrating technical authorities into a program's requirements development, configuration management, and control processes. The program contributed to the scope and definition of the Standing Review Board to provide oversight at each critical review to support key decision points throughout the program life cycle. The process for handling dissenting opinions was also established and clearly documented within 7120.5D.

Since NASA has never had a requirements document for systems engineering in the past, Constellation will benefit from the requirements and common definitions captured in NPR 7123.1. The same good systems engineering practices are applicable to small science missions and large human space flight programs like Constellation. The processes defined by 7123.1 will give systems engineering a structure for formulating, designing, verifying, and operating a whole range of Constellation system elements that must work together to successfully accomplish a mission. For the lunar

Test engineer Alonzo Frost prepares a Constellation program crew launch vehicle model for testing in the Marshall Space Flight Center Aerodynamics Research Facility. Constellation played an important role in testing NASA's new NPR 7120.5D policy.

Photo Credit: NASA Marshall Space Flight Center/D. Higginbotham exploration mission, for instance, the Orion crew exploration vehicle system will function in cooperation with the Ares I crew launch vehicle, the lunar surface access module (LSAM), and the extra-vehicular activity systems. The LSAM, in turn, will function integrally with the lunar surface habitation and surface mobility systems. There are a tremendous number of systems that will be developed to perform the complex mission of establishing a lunar outpost. Successfully managing the complex interactions within and between Constellation systems demands clear, consistent, effective systems engineering across the board. Under these new NASA procedural requirements, systems engineering will function as a clearly defined process designed to manage and simplify the complexity inherent in the Constellation program while allowing for the unique characteristics of robotic and human missions.

An important aspect of both 7120.5D and the newly formulated systems engineering processes and requirements of 7123.1 is their blending of best practices for robotic and human space flight missions. These documents bring together the experience and knowledge of the entire Agency in a form that establishes guidelines and sets boundaries for future programs and projects and will increase the probability of successful space flight missions. These boundaries will help program and project managers and systems engineers avoid the pitfalls of the past. Based on the real-world lessons taught by extensive experience, the new requirements for program/project management and systems engineering represent the best guidance the Agency can give its programs.

The Constellation program is tasked with nothing less than translating the Vision for Space Exploration into real accomplishments that will expand the bounds of human endeavor, developing the transportation systems, infrastructures, and power and communication systems for human and robotic missions. The challenges of achieving the goals of returning humans to the Moon, establishing a permanent presence there, and then preparing for human exploration of Mars and beyond are complex and beyond anything ever attempted in human history. NPR 7120.5D and NPR 7123.1 provide the glue that brings the unique experience and capabilities of all ten NASA Centers together in one integrated set of system design, development, test, and operation activities that will enable humans, working in collaboration with robotic systems, to explore and add to our scientific knowledge of the solar system. ●

UNDER THESE NEW NASA PROCEDURAL REQUIREMENTS, SYSTEMS ENGINEERING WILL FUNCTION AS A CLEARLY DEFINED PROCESS DESIGNED TO MANAGE AND SIMPLIFY THE COMPLEXITY INHERENT IN THE CONSTELLATION PROGRAM WHILE ALLOWING FOR THE UNIQUE CHARACTERISTICS OF ROBOTIC AND HUMAN MISSIONS.

GARRY LYLES is currently the Exploration Systems Mission Directorate (ESMD) chief engineer. His responsibilities include broad technical cognizance, insight, and oversight of all ESMD programs and responsibility to establish, approve, and maintain technical requirements, processes, and policy. ESMD is responsible for directing the design and development of new capabilities necessary to achieve the nation's new exploration vision—human and robotic missions to the Moon, Mars, and beyond.

Managing NASA's Complex Space Flight Programs:

THE APOLLO EXPERIENCE

BY ROGER D. LAUNIUS

Engineers inspect and test a boilerplate Mercury space capsule. Project Mercury spanned five years and achieved the goal of orbiting Earth in a manned spacecraft. Former NASA Administrator T. Keith Glennan remarked about Mercury that he had been associated with "one of the best organized and managed" programs.

When Congress passed the National Aeronautics and Space Act of 1958 and President Dwight D. Eisenhower signed it into law, few politicians understood the magnitude of the complexity required to carry out the broad mandate it had given the new National Aeronautics and Space Administration (NASA). It directed the space agency to expand human knowledge about the cosmos, develop and improve the performance of space technology, and make the "most effective utilization of the scientific and engineering resources of the United States, with close cooperation among all interested agencies of the United States in order to avoid unnecessary duplication of effort, facilities, and equipment." Congress did not, however, tell NASA how to accomplish those difficult tasks. The Agency has been working ever since to develop approaches to management that achieve those objectives.

Initially, NASA applied principles of management learned during nearly fifty years of experience in the National Advisory Committee for Aeronautics (NACA), whose members made up the majority of NASA in its first years. This government institution, with its three research centers and single flight test facility, had a breadth of experience undertaking aeronautical research, but by far its largest management effort to date had been the X-15 hypersonic flight research project begun in the latter 1950s.

Its approach to the X-15 as well as to its other programs had been to empower an authoritative project manager to oversee all aspects of the effort and to rely on that individual to organize resources as deemed appropriate, to acquire personnel seen as necessary to the project, and to bring it to successful operational status. In the case of flight research projects, this involved building the research vehicle and conducting a measured program of research and technical publication preparation. The method worked well for the relatively modest projects of NACA.

The newly established NASA followed basically the same approach in 1958 during its first human space project, Mercury, placing it under the direction of Robert Gilruth's Space Task Group at the Langley Research Center and giving Gilruth virtually total control to ensure its success. This proved a difficult but "doable" task, as Gilruth had to structure the project to involve other teams at different NASA Centers, something not common in the NACA experience.

Just six days after NASA was established on October 1, 1958, Administrator T. Keith Glennan approved plans for Mercury. On October 8 he gave Gilruth authority to proceed. Thirty-five key staff members from Langley, some of whom had been working on the military human space flight plan, were transferred to the new Space Task Group, as were ten others from the Lewis Research Center near Cleveland, Ohio. These forty-five engineers formed the nucleus of the more than 1,000-person workforce that eventually took part in Project Mercury. As Glennan wrote in his diary, "The philosophy of the project was to use known technologies, extending the state of the art as little as necessary, and relying on the unproven Atlas. As one looks back, it is clear that we did not know much about what we were doing. Yet the Mercury program was one of the best organized and managed of any I have been associated with."

Such a small program, imbued with outstanding leadership from Robert Gilruth and staffed by a dedicated team of engineers, succeeded well. But its relatively unstructured approach would not do for the massive Apollo program that took Americans to the Moon in the 1960s and 1970s. Instead, NASA borrowed the program management concept used by the Department of Defense in building the first intercontinental ballistic missiles (ICBM). To accomplish its goal, NASA had to meld disparate institutional cultures and approaches into an inclusive organization moving along a single, unified path. Each NASA installation, university, contractor, and research facility had its own perspective on how to go about the task of accomplishing Apollo.

The central figure in implementing this more rigorous approach was U.S. Air Force Major General Samuel C. Phillips, the architect of the Minuteman ICBM program before he came to NASA in 1962. Answering directly to the Office of Manned Space Flight at NASA Headquarters, which in turn reported to the NASA Administrator, Phillips created an omnipotent program office with centralized authority over design, engineering, procurement, testing, construction, manufacturing, spare parts, logistics, training, and operations.

One of the fundamental tenets of the program management concept was that three critical factors—cost, schedule, and reliability—were interrelated and had to be managed together. Many recognized that if program managers held cost, for instance, to a specific level, then one of the other two factors, or both of them to a somewhat lesser degree, would be adversely affected. This held true for the Apollo program. The schedule, dictated by the president, was firm. Since humans were involved

Neil Armstrong sits in the X-15's cockpit in this 1960 photo. The X-15 hypersonic research project was one of NASA's largest management efforts.

in the flights, and since the president had directed that the lunar landing be conducted safely, the program managers placed a heavy emphasis on reliability. Accordingly, Apollo used redundant systems extensively so failures would be both predictable and limited in their effects. The significance of both of these factors forced the third factor, cost, much higher than might have been the case with a more leisurely lunar program such as had been conceptualized in the latter 1950s. As it was, this was the price paid for success under the Kennedy mandate, and program managers made conscious decisions based on knowledge of these factors.

The program management concept was recognized as a critical component of Project Apollo's success in November 1968, when *Science* magazine, the publication of the American Association for the Advancement of Science, observed the following:

> In terms of numbers of dollars or of men, NASA has not been our largest national undertaking, but in terms of complexity, rate of growth, and technological sophistication it has been unique.… It may turn out that [the space program's] most valuable spin-off of all will be human rather than technological: better knowledge of how to plan, coordinate, and monitor the multitudinous and varied activities of the organizations required to accomplish great social undertakings.

Understanding the management of complex structures for the successful completion of a multifarious task was an important outgrowth of the Apollo effort.

Under Phillips, this management concept orchestrated more than 500 contractors working on both large and small aspects of Apollo. For example, the prime contracts awarded to industry

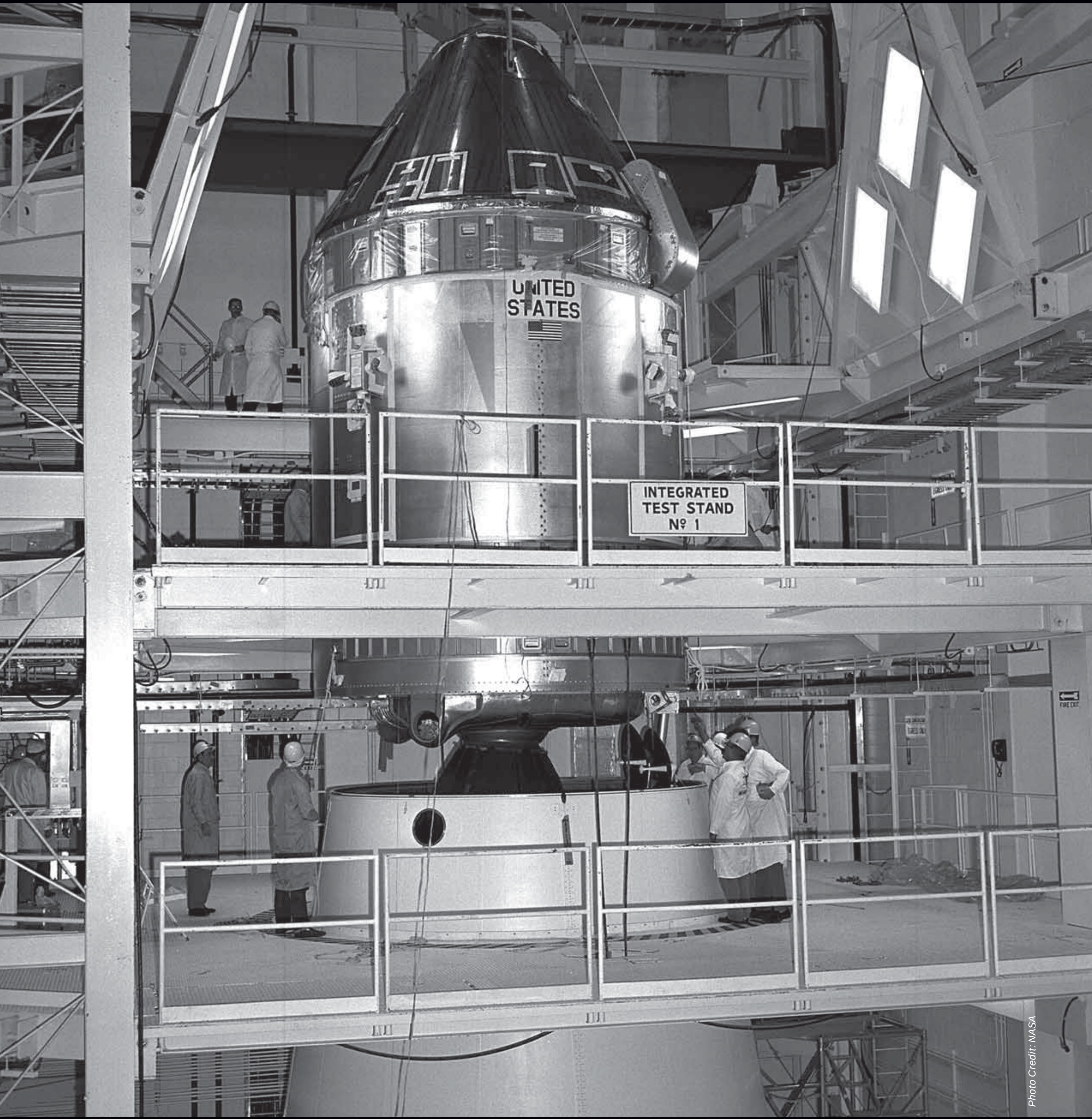


Photo Credit: NASA

The Apollo 11 Command/Service Module is mated to the Saturn V Lunar Module Adapter. NASA borrowed the program management concept used by the Department of Defense to establish a strong management model for Apollo.

ONE OF THE FUNDAMENTAL TENETS OF THE PROGRAM MANAGEMENT CONCEPT WAS THAT THREE CRITICAL FACTORS—COST, SCHEDULE, AND RELIABILITY—WERE INTERRELATED AND HAD TO BE MANAGED TOGETHER.

for the principal components of just the Saturn V included the Boeing Company for the S-IC, first stage; North American Aviation, S-II, second stage; the Douglas Aircraft Corporation, S-IVB, third stage; the Rocketdyne Division of North American Aviation, J-2 and F-1 engines; and International Business Machines (IBM), Saturn instruments. These prime contractors, with more than 250 subcontractors, provided millions of parts and components for use in the Saturn launch vehicle, all meeting exacting specifications for performance and reliability. The total cost expended on development of the Saturn launch vehicle was massive, amounting to $9.3 billion. So huge was the overall Apollo endeavor that NASA's procurement actions rose from roughly 44,000 in 1960 to almost 300,000 by 1965.

Getting all the personnel elements to work together challenged the program managers, regardless of whether or not they were civil service, industry, or university personnel. Various communities within NASA differed over priorities and competed for resources. The two most clearly identifiable groups were the engineers and the scientists. As ideal types, engineers usually worked in teams to build hardware that could carry out the missions necessary for a successful Moon landing by the end of the decade. Their primary goal involved building vehicles that would function reliably within the fiscal resources allocated to Apollo. Again as ideal types, space scientists engaged in pure research and were more concerned with designing experiments that would expand scientific knowledge about the Moon. They also tended to be individualists, unaccustomed to regimentation and unwilling to concede gladly the direction of projects to outside entities. The two groups contended with each other over a great variety of issues associated with Apollo. For instance, the scientists disliked having to configure payloads so they could meet time, money, or launch vehicle constraints. The engineers, for their part, resented changes to scientific packages added after project definition because these threw their hardware efforts off kilter. Both had valid complaints. They had to maintain an uneasy cooperation to accomplish Project Apollo.

The scientific and engineering communities within NASA were not themselves monolithic, and differences among them thrived. Add various other groups representing industry, universities, and research facilities, and the result was widespread competition among parties at all levels striving to further their own scientific and technical aims. The NASA leadership generally viewed this pluralism as a positive force within the space program, for it ensured that all sides aired their views and encouraged the honing of positions to a fine edge. Competition, most people concluded, made for a more precise and viable space exploration effort. There were winners and losers in this strife, however, and sometimes ill will was harbored for years. Moreover, if the conflict became too great and spilled into areas where it was misunderstood, it could be devastating to the conduct of the lunar program. The head of the Apollo program worked hard to keep these factors balanced and to promote order so NASA could accomplish the presidential directive.

Another important management issue arose from the Agency's inherited culture of in-house research. Because of the magnitude of Project Apollo and its time schedule, most of the nitty-gritty work had to be done outside NASA by contractors. As a result, with a few important exceptions, NASA scientists and engineers did not build flight hardware or even operate missions. Rather, they planned the program, prepared guidelines for execution, competed contracts, and oversaw work accomplished elsewhere. This grated on those NASA personnel oriented toward research and prompted disagreements over how to carry out the lunar-landing goal. Of course, they had reason for complaint beyond the simplistic argument of wanting to be "dirty-handed" engineers; they had to have enough in-house expertise to ensure program accomplishment. If scientists or engineers did not have a professional competence on par with the individuals actually doing the work, how could they oversee the contractors creating the hardware and performing the experiments necessary to meet the rigors of the mission?

One anecdote illustrates this point. The Saturn second stage was built by North American Aviation at its plant at Seal Beach, California, shipped to NASA's Marshall Space Flight Center in Huntsville, Alabama, and there tested to ensure it met contract specifications. Problems developed on this piece of the Saturn effort and Wernher von Braun began intensive investigations. Essentially his engineers completely disassembled and examined every part of every stage delivered by North American to ensure it had no defects. This was an enormously expensive and time-consuming process. The stage's production schedule ground almost to a standstill, jeopardizing the presidential timetable.

When this happened, then–NASA Administrator James E. Webb told von Braun to desist, adding, "We've got to trust American industry." The showdown came at a meeting where the Marshall rocket team was asked to explain its extreme measures to Webb. While doing so, one of the engineers produced a rag and told Webb that "this is what we find in this stuff." The contractors, the Marshall engineers believed, required extensive oversight to ensure they produced the highest-quality work. A compromise emerged that was called the 10 percent rule: 10 percent of all funding for NASA was to be spent to ensure in-house expertise and in the process check contractor reliability.

The project management of the Apollo program involved these major features:

- A well-staffed headquarters group with strong systems engineering and integration capabilities
- Strong field centers using extensive in-house technical capability
- Independent contractors relied upon to do their work effectively
- Extensive checks and balances, inspections, safety reviews, systems engineering, and configuration management
- Recruitment of exceptional engineers and scientists, allowing them wide latitude in taking initiative and responsibility
- Hands-on engineering at all levels
- Extensive research and testing of components and systems
- Practices that encouraged constant learning (such as creating new challenges on each flight and learning through failure)

NASA added to that an aggressive program-planning effort that ensured clear objectives, well-defined lines of authority/accountability, and consistent and objective management. It also necessitated complex systems integration emphasizing orderly, clear, reliable, and consistent oversight, configuration control, decision making in a timely and effective manner, and omnipresent communication and accountability.

The program management concept worked well, but it was enormously expensive. NASA officials realized at the conclusion of the Apollo program that they would never again have the resources that had been made available for the Moon landings, and they had to find another means of accomplishing their projects without such a broad effort. Perhaps most important, the experience of Apollo suggested that this approach was fragile and could easily become flawed if its managers failed to manage practices strictly. In the face of conflicting organizational demands, the practices so successful in Apollo would tend to disappear. Maintaining such practices requires constant vigilance and adjustment. ●

ROGER D. LAUNIUS is chair of the Division of Space History at the Smithsonian Institution's National Air and Space Museum in Washington, D.C. Between 1990 and 2002 he served as chief historian of NASA.

PROFESSIONAL DEVELOPMENT FOR THE MOON, MARS, AND BEYOND

BY ED HOFFMAN

From the beginning, the Academy of Program/Project and Engineering Leadership (APPEL) and its precursors have been shaped by direction from NASA's senior management at major turning points in NASA's history. In 1989, in response to the *Challenger* accident, then–Deputy Administrator J.R. Thompson called for the creation of an organization within NASA that would provide training in program and project management. That was the first step toward the establishment of today's Academy.

Our current focus is similarly driven by the challenges of the day. To ensure that NASA's technical workforce has the capability to execute the missions that will comprise the Vision for Space Exploration, Administrator Michael Griffin and Chief Engineer Chris Scolese directed us to do for systems engineering what we have done over fifteen years to build program and project management capability at NASA. We merged the Academy of Program/Project Leadership (APPL) with NASA Engineering Training (NET) to create APPEL, and over the past year we have conducted an intensive requirements-driven process to address systems engineering development.

This is the most dynamic time at the Agency since I arrived in 1982. The portfolio of human and robotic missions required to implement the vision is on a scale that has never before been attempted. These missions will span more than a single generation, so our strategic planning for professional development has to include developing multigenerational capability. Given the complexity of the missions ahead, it's essential for NASA to provide its workforce with the professional development opportunities it needs to succeed.

Budgets are already tight, and there's skepticism outside NASA about the real cost of these missions. As a result, we can't afford to be anything less than optimally efficient; a trial-and-error approach won't suffice. For its part, APPEL has focused its efforts on developing the technical excellence of the workforce on three levels: individuals, project or engineering teams, and the institution as a whole.

At the individual level, APPEL offers an updated, integrated core curriculum that addresses program/project management and systems engineering at all stages of a career: entry-level, mid-career, and executive. Teaching new hires about electrical engineering or propulsion systems is not APPEL's job. Members of our technical community come to NASA with a great deal of education and often with previous professional training, and APPEL is not a substitute for either. Rather, we address a unique need by delivering NASA-specific knowledge to our practitioners. For example, our course for new hires, "Foundations in Aerospace at NASA,"

Making Sure People Know What They Need to Know

APPEL has developed a conceptual framework for building project team capacity that focuses on four essential elements of success: teamwork, leadership, process utilization, and knowledge. APPEL addresses these elements through a variety of approaches, from coaching to coursework to online learning.

While the new NPR 7120.5D clearly concerns process, it also represents a compendium of NASA knowledge about the practices for space flight program/project management that are most likely to result in mission success. It strives to facilitate better leadership by clearly delineating roles and responsibilities across the project life cycle and to foster teamwork—one of NASA's core values—by establishing an open environment in which all opinions are heard and respected. To varying degrees, it touches all the bases that enable team success.

Most of us, and perhaps most particularly NASA program and project managers, live in habitual "time starvation." It seems there is never enough time to deal with the urgent matters of the day, much less educate ourselves on the content of documents like 7120.5D. Yet, if program/project team members fail to understand and then implement the policies and processes covered in the document, they may place their endeavors in peril.

To address this dilemma, we built a quick-response online learning tool (available at http://teambuilding.4-dsystems.com/public). Our team converted the most important 7120.5D information into about 190 question-and-answer (Q&A) sets, with each question requiring about thirty seconds. Ninety minutes is an acceptable amount of time to dedicate to this important subject.

covers topics including the NASA governance model; the roles and responsibilities of the field centers and headquarters; NASA's vision, mission, and history; awareness of agency directives, policies, and procedures; the essentials of systems engineering; and an introduction to the various engineering disciplines. At the mid-career level we offer "Project Management and Systems Engineering" for subsystem managers and engineers and advanced versions of each for system-level leaders. Our executive-level course is designed to give emerging senior leaders realistic simulations of top-level issues such as launch decisions. We also offer in-depth courses tailored for specific needs in areas such as risk management, requirements development, system architecture, verification and validation, program control, and project planning and scheduling.

For project or engineering teams, APPEL offers support at any phase of the project life cycle. Team members begin by completing an online assessment that takes no more than ten minutes to fill out. The team then typically has a three-day workshop, followed by one-on-one coaching sessions for individuals who request them. Expert practitioners with decades of experience in every discipline within NASA are also available for consultations on subjects ranging from instrument development to cost estimation. Follow-up assessments after workshops, coaching, and consultations show that these services produce measurable team improvements.

On an institutional level, APPEL seeks to build, maintain, and share knowledge that will be critical for this multigenerational effort. To do this, we are developing a series of online tools to measure knowledge and process utilization, the first of which is an online assessment of NPR 7120.5D. (See "Making Sure People Know What They Need to Know" below.) Process tools will cover areas such as acquisition management, safety and mission assurance, and requirements management. We also facilitate knowledge sharing through storytelling at the PM Challenge conference and invitational Masters Forums, and through *ASK Magazine* and the *ASK* OCE e-newsletter.

The challenge of establishing a permanent lunar base and sending humans to Mars and beyond is daunting, but as Wernher von Braun said, "I have learned to use the word 'impossible' with the greatest caution." Our success in accomplishing these objectives will depend on many things, ranging from sound financial management to sustained political support, but without technical excellence the rest is irrelevant. Through our efforts to develop individuals, project teams, and our institutional knowledge base, APPEL is committed to helping NASA develop the technical excellence required to make the vision a reality. ●

The Q&A set for 7120.5D has three components. The first dozen questions address the salient parts of NPD 1000.0, the *NASA Strategic Governance and Management Handbook*. The next hundred address core concepts from parts 1, 2, and 3 of 7120.5D. The last eighty or so address part 4, which covers the program/project life cycle.

The tool has no evaluative scoring. At the start, all Q&As are displayed in a bucket labeled "These Remain." The tool moves correctly answered Q&As into "I Know These." Incorrect answers move into "Still Need to Learn These." When "These Remain" is empty, the tool resets by moving all the "Still Need to Learn These" into "These Remain," and the process continues. All answer screens show the correct answer, so anyone with persistence can complete the learning process.

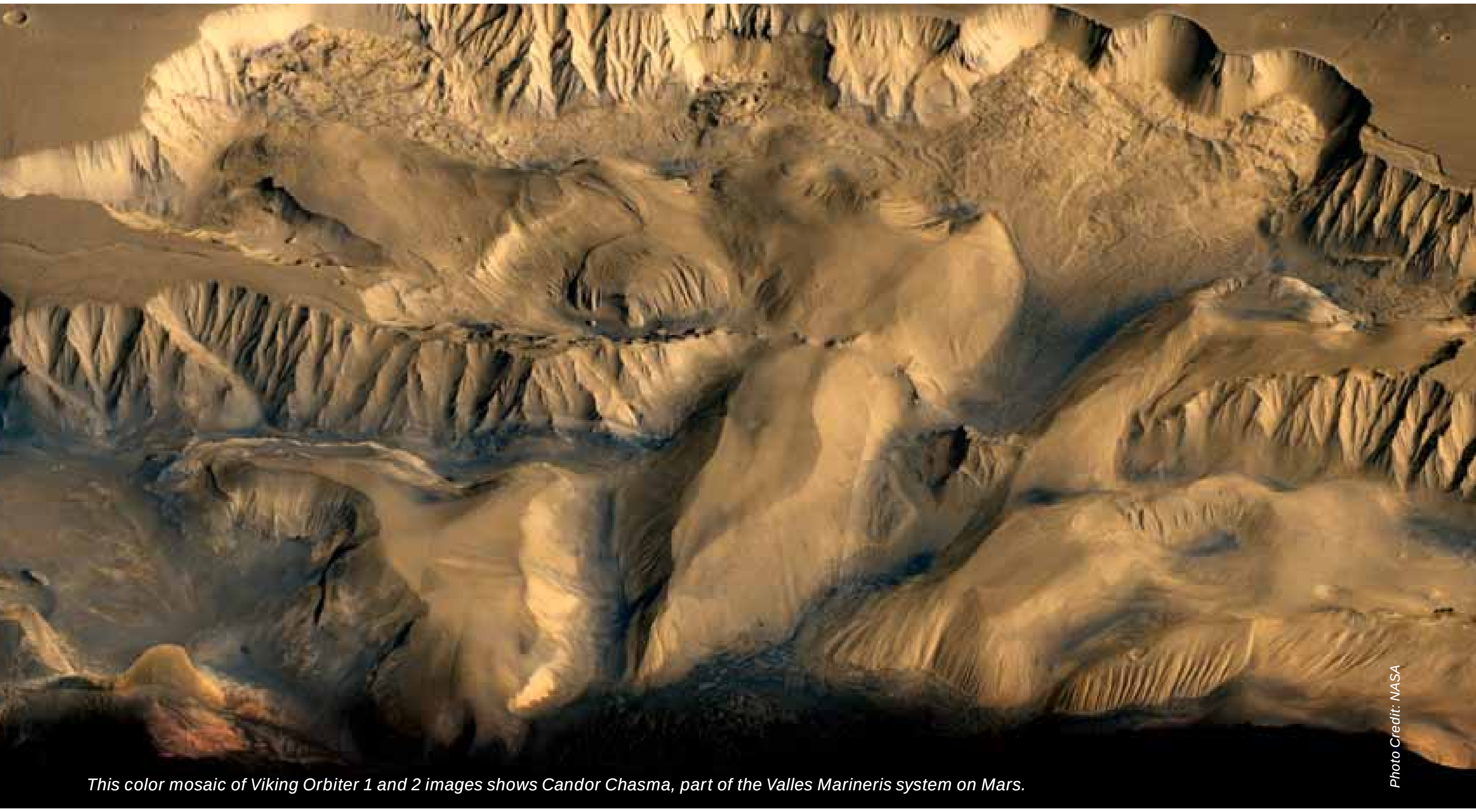
Team leads or management selects participants. The system automatically issues status reports indicating whether individuals have started and how far along they are. (Individuals can also voluntarily take the assessment.) The system does not routinely generate reports for management other than the team leaders; its primary purpose is education, not evaluation. It can, however, mine the data if needed.

Every answer page offers an opportunity to comment with a box to check if people want to remain anonymous. We also anticipated that there might be Q&As that people think are incorrect or annoying. Rather than force them to give a "correct" answer, there is a radio button choice labeled "Flawed question—I'll comment instead of answering." They must enter text into the comment box, and the question is removed from their process.

We have tested the system with several groups, and people consistently reported that they enjoyed taking the assessment. The online 7120.5D knowledge tool is Web-based, self-directed, and easy to use, all of which make it an appropriate way to reach a vast workforce of civil servants and contractors at ten geographically dispersed centers. It is a key part of APPEL's effort to support the rollout of 7120.5D and, in doing so, build project team capacity for NASA. ●

Program and Project Management Improvement Initiatives

BY DR. C. HOWARD ROBINS, JR.



This color mosaic of Viking Orbiter 1 and 2 images shows Candor Chasma, part of the Valles Marineris system on Mars.

The primary factor in project success is the quality of program and project management. Quality begins with excellent human resources, but effective processes are also critical. Since NASA's founding in 1958, the Agency has undertaken various efforts to develop, maintain, and improve program and project management policies and processes to help ensure project success. These efforts can be grouped in four eras: an aggressive initial development in the Apollo era; maintenance-level actions during the post-Apollo era of the 1970s and 1980s; a proactive period of reformulation in the faster, better, cheaper era of the 1990s; and the current era, which began with a recognition of the limitations of faster, better, cheaper and is establishing processes to help achieve the Vision for Space Exploration.

The Apollo Era: 1958–1969

NASA's first formal system of program/project management was introduced in three stages between 1960 and 1968 in response to the need for standards and discipline in managing the complex, expensive, and ambitious programs of the Apollo era. The first stage saw the introduction of the Program Management System (PMS) in 1960. Basically a reporting system, the PMS was NASA's first disciplined system to address program management.

The second stage came in 1961, with the development of the Project Planning and Implementation System (PPIS). This primarily added authorization to the existing PMS and was created partly in response to external reports recommending that procurement be strengthened and project management be tightened. The PPIS also created policies and processes for agency-level approval and for project planning and implementation. The system was modified several times to include the Program Evaluation and Review Technique (PERT) and the Program Approval Document (PAD), along with changes to simplify the system and to integrate time and cost, a major step in establishing a total project management system.

The third stage was marked by the introduction of Phased Project Planning (PPP) in 1965. Previously informal practices were formalized via a NASA Policy Directive (NPD) as one of several responses to significant 1964 problems: major delays in Apollo and the fourth consecutive *Ranger* failure. The formal guidelines were intended to make practice more uniform and to give management an additional intervention point in the project life cycle. The PPP policy was not fully established until 1968, the year of Administrator James E. Webb's departure, through a revision to the NPD and issuance of a handbook. This policy has been attributed to Webb's determination to regain control of the Agency, which he believed he had lost sometime before the Apollo 1 fire of 1967.

The success of the effort to develop these policies and processes can be primarily attributed to Webb's strong focus on agency organization and program management and his determination to establish a disciplined program management system. Most of the program/project management staff from that era I have spoken with feel that discipline in adhering to policy and processes was maintained, and program and project managers were very much in charge of their respective programs and projects. By the end of the era, mission success (technical performance) had improved.

The Post-Apollo Era: 1970–1991

The policies and processes of the Apollo era underwent minor revisions in 1972 and again in 1977, but significant reevaluation did not occur until Congressional concerns arose in the late 1970s over both Space Shuttle program management and the cost and schedule performance of robotic flight projects. These concerns resulted in three studies: the 1979 Shuttle Program Management Assessment, the 1980 NASA Colloquium on Project Management, and the 1981 NASA Project Management Study of robotics missions. Collectively, these studies found problems in almost every area of program/project management, and the latter two indicated needs for policy revisions.

The 1979 Shuttle Program Management Assessment, performed in response to cost increases and schedule delays, found budgeting, management, and personnel problems. These findings included clear violations of good program/project management practice. However, follow-up was essentially limited to strengthening the program budgeting staff.

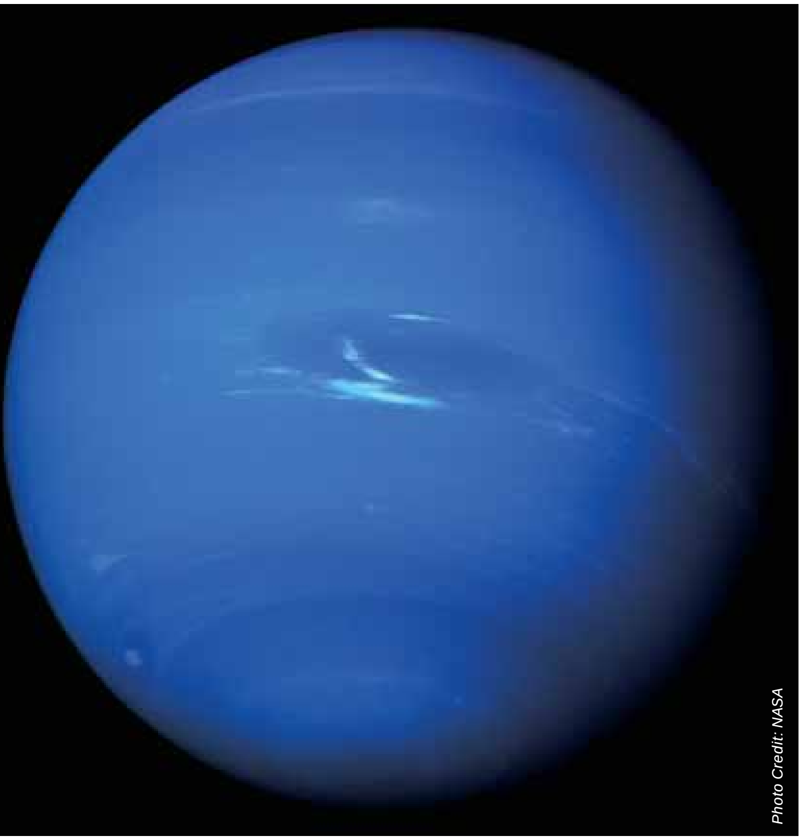
The 1980 Colloquium on Project Management was held to prepare for restarting the Program Management Shared Experience Program (PMSEP), the first agencywide program/project management training program. The colloquium identified a number of problems, but some of its recommendations were not implemented until thirteen years later.

The 1981 Project Management Study, colloquially referred to as the "Hearth Study," would come to be viewed within NASA as a landmark. It was undertaken in response to Congressional requests resulting from concerns about cost and schedule performance problems. It was the first multiproject study of program/project management by the Agency and also the first study of the topic by an agencywide NASA team. At the direction of NASA Administrator Robert Frosch, Langley Research Center Director Donald P. Hearth led a team that

NASA HAS NO TROUBLE IDENTIFYING ITS WEAKNESSES. THE "USUAL SUSPECTS" APPEAR REPEATEDLY IN THESE ASSESSMENTS … THIS REPEATED IDENTIFICATION OF THE SAME PROBLEMS INDICATES THAT ADDITIONAL TOP-LELVEL AGENCY MANAGEMENT ATTENTION TO PROGRAM/PROJECT MANAGEMENT IMPROVEMENT IS ESSENTIAL TO THE SUCCESS OF THE VISION FOR SPACE EXPLORATION PROGRAMS.

studied thirteen robotic projects, including projects such as Viking and Voyager, undertaken over a twenty-two-year period. Hearth was chosen at least in part to minimize the potential for center bias; Langley did not have any space flight projects in development at the time.

The study found significant problems, including inadequate project definition, overoptimism during advocacy, and low contractor bids. However, it also found NASA performance was good overall, that cost growth may have increased but the evidence was inconclusive, that agency inability to estimate project cost was not a problem when a project was well defined, and that no new management tools or layers were required. Of particular note, the team stressed the importance of good people, continuous top management verification of the application of sound management principles, and the use of available management tools.



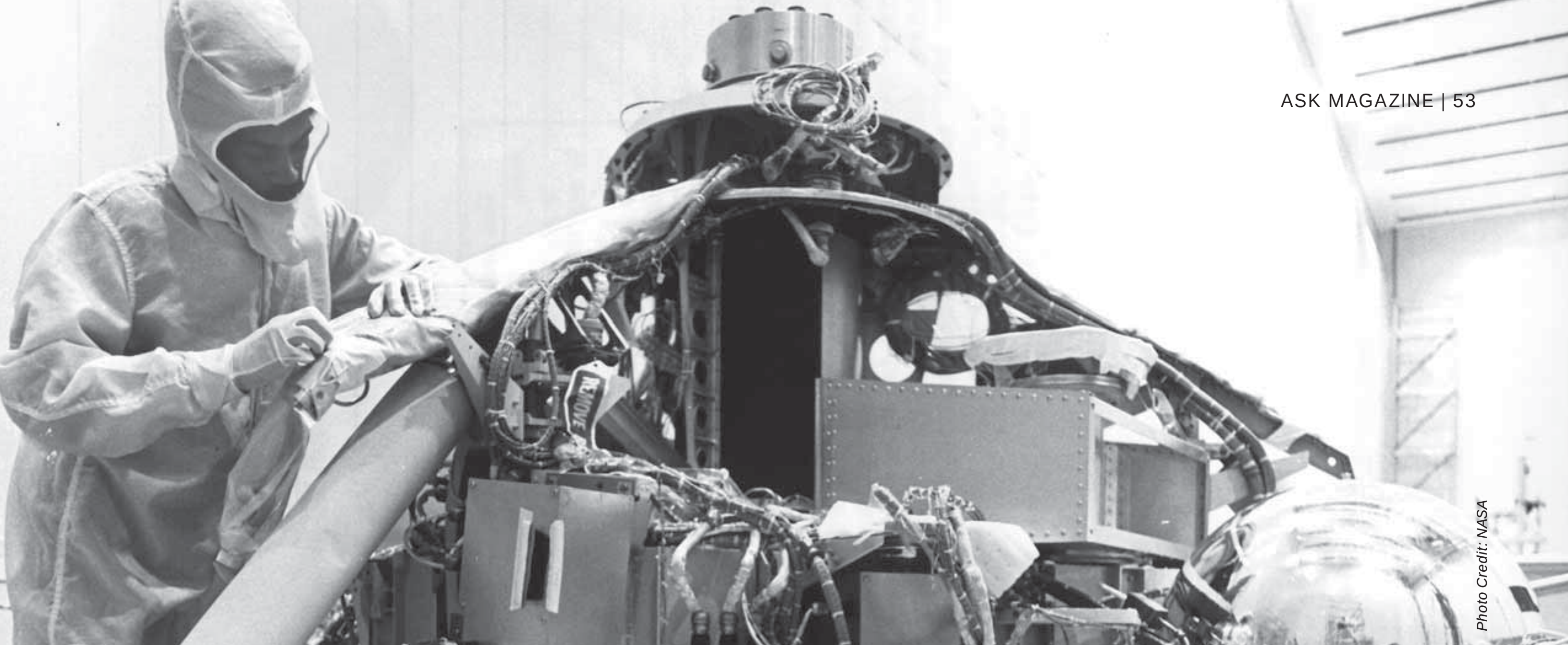
This picture of Neptune was produced from the last whole planet images taken through the green and orange filters on the Voyager 2 narrow angle camera.

The study made nine recommendations, one of which was to "reexamine, revise, and reissue" the NASA Management Instruction (NMI) that covered program/project management policy. Although the initial policy update was ready a year later, the NMI revision was not issued until 1985—four years and two months after the study had been completed—due to poor follow-up by senior management. The revision was completed only after Hearth himself took it on as a short-term special assignment immediately prior to his retirement.

After the Hearth Study, no significant activity occurred in formal project and program management processes until after the 1986 *Challenger* accident. The loss of *Challenger* spurred three studies: a 1986 study of NASA organization and management, a 1988 study of NASA Headquarters, and a 1989 study of program control. They were sponsored by Administrator Dr. James Fletcher, who was brought in following the accident. All were performed under the auspices of the National Academy of Public Administration and led by former NASA Headquarters executives who had played key program/project management roles while at the Agency. Many recommendations accompanied these studies, including improving discipline and responsiveness of the program/project management system, but follow-through was generally poor. A notable exception was the establishment of a formal program and project management training program, which continues to function today.

The Faster, Better, Cheaper Era: 1992–2001

In the early 1990s, cost overruns and schedule slips, which were forgiven in the Cold War era if mission performance requirements



The Viking 1 lander is shown in a cleanroom during assembly.

were met, became unacceptable. Daniel Goldin was appointed Administrator in 1992 with a mandate to change the Agency. He introduced the "Faster, Better, Cheaper" (FBC) concept at NASA as well as thirteen continuous improvement initiatives, including one devoted to program/project management improvement.

The program/project management improvement initiative included a 1992 internal study that identified eight major factors driving program cost and technical risk. Of particular importance, it noted the issue of problem repetition: similar findings had been widely documented over the past fifteen years, and many had been reflected in NASA policies and processes. This persistence of previously identified problems signaled to senior management a breakdown in policy/process discipline. In 1993 this led to a major revision of basic program/project management policy, establishment of the Agency Program Management Council (PMC), and reassignment of ownership for these policies and processes to the Office of the Administrator. The follow-up actions did not include an effort to determine the specific causes of the breakdowns in discipline in policy/process implementation, however.

Extensive reviews, audits, and investigations throughout the 1990s on the Space Shuttle, International Space Station, and Mars programs found that these lapses continued. Most importantly, a number of these studies also found that many of the problems would not have occurred if existing policies and processes had been followed.

Prior to completion of the 1992 study, Goldin established a Program Excellence Team (PET) to strengthen, streamline, and consolidate the policies and processes governing management of major system development projects. In my role as deputy associate administrator for Space Systems Development, I led the PET, which consisted of senior headquarters and field center program/project management executives. The team developed a consolidated NASA program/project management policy (NMI) and supporting handbook (NHB) for implementing policies and processes that were approved in late 1993 and subsequently underwent the most extensive rollout to date. The new NMI consolidated existing program/project management policies and processes, eliminated artificial separations that existed between program/project management and acquisition, and placed responsibility for the integrated policy with the deputy administrator in his role as the Agency's senior acquisition official.

These new policy/process documents reflected the results of all studies, colloquia, reviews, investigations, and audits subsequent to the 1981 Hearth effort. Extensive policy changes included the introduction of life-cycle costing, reestablishment of PPP, selection of "Down Select" (narrowing the field for selection of a contractor through successive competitive phases) as the normal acquisition mode, and establishment of requirements for independent reviews and cost estimates. Even these changes did not meet all policy needs.

In developing the new program/project management policy and handbook, the PET found problems in every aspect of the program/project management function: policy, implementation, and training. The team also found that the repetition of program/project management problems was due to the stress of performing in a very difficult environment combined with a lack of senior management ownership of policy documentation. The new policy addressed this issue by assigning overall program/project management responsibility to the deputy administrator. Acting Deputy Administrator General John Dailey subsequently established a PMC Working Group (PMCWG) and used the Office of the Chief Engineer, a part of the Office of the Administrator, to support him in meeting this responsibility.

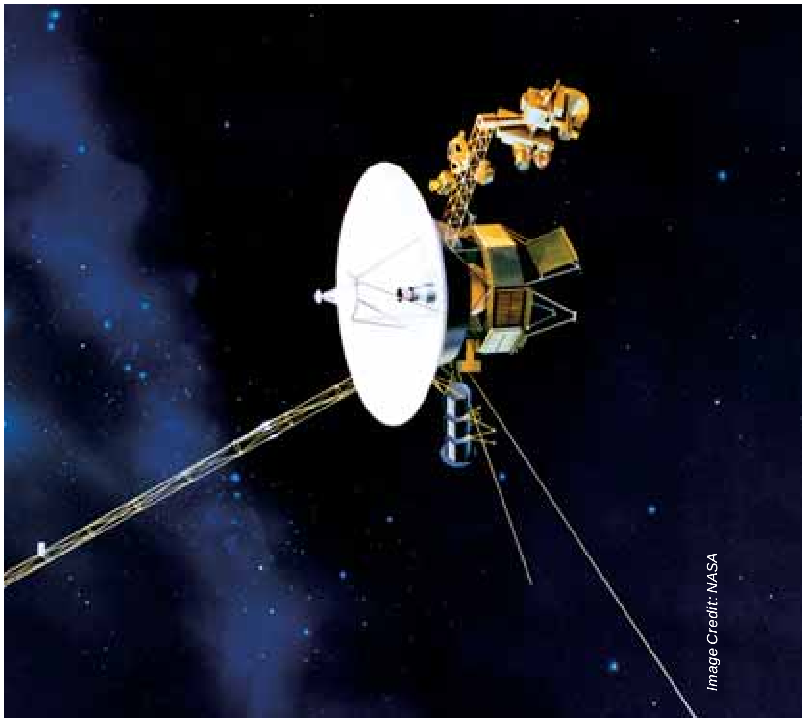
Shortly after the PMCWG was established, the Administrator made two decisions that would necessitate a major revision of the new program/project management policy: program management responsibility would shift from headquarters to the field centers, and NASA was to implement a strategic-planning process that would eliminate the existing life-cycle approach to program/project management.

The program/project management policy revision needed to effect these changes was developed by the PMCWG and issued in 1996 as a NASA Policy Directive (NPD 7120.4A). This revision expanded the policy scope to all agency programs and projects and replaced the five phases of the life cycle with the four component processes of the strategic management process for program/project management. It was significantly briefer than the PET-generated version it replaced, with the expectation that the deleted material would be updated and included later in the needed revision of the *Program/Project Management Handbook*. However, when the PMCWG updated the handbook in 1998, much of the deleted material was not included. The review rollout process for NASA Procedures and Guidelines (NPG) 7120.5A, the precursor to today's 7120.5D, was personally led by the acting deputy administrator and was the most comprehensive ever.

Lessons for the Road Ahead

What can be learned from reviewing these efforts? First, NASA has no trouble identifying its weaknesses. The "usual suspects" appear repeatedly in these assessments: inadequate program/project definition, complex or unclear roles and responsibilities, budget instability and inadequate resource reserves, inadequate program/project control, inadequate risk management, poor implementation of management and engineering processes and practice, and poor communication. Other persistent problems include discipline breakdowns, a lack of agency buy-in, inadequate training resources, inappropriate management approaches, organizational fragmentation, and deficiencies in the policies and processes themselves. Where problems are concerned, there is nothing new under the sun.

Second, this repeated identification of the same problems indicates that additional top-level agency management attention to program/project management improvement is essential to the success of the Vision for Space Exploration programs. The increased attention that NASA Administrator Dr. Michael Griffin is devoting to the improvement of program/project management and systems engineering is very encouraging. The breadth and depth of the ongoing improvement efforts and their strong support from the Administrator are the critical prerequisites to their success, as were the similar efforts of Administrator James Webb on behalf of the Apollo program.



An artist's impression of the Voyager spacecraft.

DR. C. HOWARD ROBINS, JR., spent more than 40 years with NACA/NASA, retiring in 1994 as deputy associate administrator for Space Systems Development. He currently serves as a consultant in program and project management.

ASK Bookshelf

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

The Secret of Apollo: Systems Management in American and European Space Programs (New Series in NASA History), by Stephen B. Johnson (Baltimore: Johns Hopkins University Press, 2006)

Using case studies, including the development of the intercontinental ballistic missile, the Jet Propulsion Laboratory's (JPL) entry into space projects, the Apollo program, and the creation of the European Space Agency, Stephen Johnson—a space historian and engineer at Marshall Space Flight Center—demonstrates that systems management sustained large projects and led to mission success:

> Social and technical concerns drove the development of systems management. … Investigation of the technical issues led to the creation of stringent organizational methods such as system integration and testing, change control, quality inspections and documentation, and configuration management. Engineers led the development of these new technical coordination methods, while managers intervened to require cost and schedule information along with technical data … The result of these changes was systems management, a mix of techniques that balanced the needs and issues of scientists, engineers, military officers, and industrial managers.

The case studies he chooses reveal how the organizational methods emerged as responses to problems within projects and became the discipline now called systems management. He also examines how JPL shifted from an army contract missile laboratory to a successful NASA Center conducting lunar and planetary space flight missions, noting that "recognition of the 'systems concept' marked JPL's transition from research to engineering development. Systems engineering, which began as coordination between technical divisions and between JPL and its contractors, became a hallmark of JPL." JPL learned from its mistakes on the Ranger and Surveyor programs about the need for stronger project management, better change control, and progressive design freezes. The highly successful Mariner project became a model for the lab:

> JPL engineers repeatedly found that many technical problems could be solved only by using organizational means. Problems with missile reliability demanded engineering design changes, parts inspections, and test procedures. Systems engineers solved interface problems by maintaining interface drawings, mediating subsystem disputes, and chairing change control meetings to track and judge design modifications.

The lessons from these early successes and failures eventually contributed to JPL's reputation as the world's leader in deep space exploration.

Although NASA's organizational structure and procedures proved successful during Mercury and Gemini, the Apollo program faced increasing cost pressures as the program developed. Apollo program director Brig. Gen. Samuel C. Phillips brought helpful Air Force Systems Command methods into the NASA organization, such as configuration control and the Program Evaluation and Review Technique. As the new chief in the Office of Manned Space Flight, George Mueller also quickly realized the need for better cost prediction and control. Johnson credits Phillips and Mueller with reforming the management of the Apollo program:

> Mueller forced MSC [Manned Space Center] and MSFC [Marshall Space Flight Center] to adopt stronger project management, institute systems engineering, expand ground testing, and report more thoroughly to headquarters. Phillips instituted configuration management and project reviews throughout Apollo to control technical, financial, and contractual aspects as well as the scheduling of the program. Air force officers brought in by Mueller and Phillips propagated the reforms and transformed OMSF's organizations into project-oriented hierarchical development organizations.

NASA's successful approach to the Apollo program did not go unnoticed. Johnson shows how the Europeans applied American managerial practices to successfully create the ESA after the embarrassing failure of the European Space Vehicle Launcher Development Organization (ELDO). While ELDO had revealed significant communication and interface problems among the British, French, and Germans, the European Space Research Organization borrowed from NASA's successful practices to produce a series of scientific satellites.

The Secret of Apollo provides a valuable historical perspective on the importance of good systems management in the development of large-scale projects and programs, lessons that remain relevant to this day. ●

The Knowledge Notebook

The Communications Challenge

BY LAURENCE PRUSAK

The complexity of NASA's projects and the challenge of coordinating and communicating among the centers and organizations that do the work have parallels in enterprises that flourished long before the beginning of the space age. In the late nineteenth century, large-scale organizations began to emerge in the United States, Western Europe, and Japan. Driven by the first and second waves of the industrial revolution, along with concurrent changes in demographics, they were unlike anything seen before. The work of these firms, which produced railroads in the United States, textiles in the United Kingdom, chemicals and steel in Germany, and weaponry in Japan, was far more complex than that of the firms that preceded them. A hallmark of these new organizations was that their work was spread out over space and therefore also over time, since contact and communication were not instantaneous. The thinking that went into running these new-fangled enterprises also began to be divided and distributed. Functions such as operations, finance, and sales migrated to separate departments and the well-known advantages of dividing labor into specialized components made themselves quickly obvious.

In those expansive and functionally divided organizations, discussions and conversations about how work would be done were no longer as direct and "hands-on" as they had been in the smaller, localized organizations of the past. Many of those instructions needed to be communicated through written directives or schematic plans, often unaccompanied by a person who could explicate them and see that they were properly applied.

Of course, large-scale enterprises existed before the later nineteenth century. The East India Company was already an effective institution by the mid-seventeenth century, running global trade with a mere handful of employees. The Dutch also had similar organizations whose aftereffects are still with us. Even further back, the Roman and Chinese empires were examples and models of extremely large organizations, as was the Roman Catholic Church. But much of the work of those early "global" organizations was fairly routinized and varied only slightly over time. Tasks were well defined, and technology—especially rapidly changing technology—played no significant role in how the work was done. So there was limited need for long-distance communication explaining how to deal with novel and ambiguous situations.

At the end of the nineteenth century, however, we began to see large, dispersed organizations that had to learn to deal with increasing complexity and change. Today complexity and change have become fundamental facts of life. Technologies, both hard and soft, come at us with ever-greater rapidity. Waves of new ideas sweep over organizations like tsunamis, causing disruptions as well as creating opportunities. The remarkable dispersion of cognition that is enabled by communication technologies means that much knowledge is widely shared but also that the knowledge needed to accomplish many tasks is widely scattered. Like fish that never notice the water they swim in, we give little if any thought to this volatile, fragmented environment, but it must be taken into account for us to work and live successfully.

The trends toward complexity, change, and dispersion increase the need for managers at every level to focus on communication—on how to convey instructions and communications with the greatest possible effectiveness and sticking power. Fundamental to that effectiveness, of course, is the quality of that communication, its relevance to work it is meant to guide. But process matters as much as content. Words alone, especially when conveyed over great distances, are ambiguous and easily distorted. A policy statement, memo, or e-mail offers few if any opportunities for the negotiation of meaning that is so critical to any effective knowledge transfer. Without that negotiation—without, for instance, conversation about what the words imply—what the creator of a document means and what its readers understand are likely to differ dramatically. Communication is not a one-way activity limited to sending a message. It is a social process, a shared refining of ambiguities and distortions and building of context and understanding to create meaning.

This brings us to a few of the lessons that practitioners and researchers have learned about how to structure effective communication. Here they are in a digestible form:

- Believe in "ground truth" and local truth—the experiential knowledge of those who do the daily work. People can tell from a long way off if a communication is dictated from on high with little input from those who have the real know-how about what is being communicated. Lack of trust and an unwarranted belief that all wisdom resides at the top can impede the use of this critical source, especially in hierarchical organizations.
- Think of communication as a process, not a message. Without mechanisms for discussion, debate, and demonstration, even the most carefully crafted instructions will probably be misunderstood or ignored.
- Communicate with stories. They provide the context and emotion that rules cannot convey. We are wired to understand things through narrative. Storytelling is slowly becoming the norm in many organizations. To its credit, NASA was one of the first organizations to institutionalize this practice.
- Do not be cynical or skeptical. Most employees can recognize good advice and will use it if it helps them do their work. They are, as the social scientists like to say, intendedly rational. That is, they make purposeful choices that they believe will help them achieve their goals. ●

COMMUNICATION IS NOT A ONE-WAY ACTIVITY LIMITED TO SENDING A MESSAGE. IT IS A SOCIAL PROCESS, A SHARED REFINING OF AMBIGUITIES AND DISTORTIONS AND BUILDING OF CONTEXT AND UNDERSTANDING TO CREATE MEANING.

ASK interactive

The History of NASA

Lessons from the past can help solve problems today, and the NASA History Division is a treasure trove of important lessons. Established in 1959, the NASA History Program documents and preserves the Agency's remarkable history through a variety of products. The History Division serves two key functions: fulfilling the mandate of the 1958 Space Act, which called for NASA to disseminate aerospace information as widely as possible, and helping NASA managers understand and benefit from the study of past accomplishments and difficulties. The History Division has an array of resources available on their Web site, http://www.history.nasa.gov, including a list of interesting and helpful publications. One of their new books, *Critical Issues in the History of Spaceflight*, is a collection of essays that analyzes some of the perennial issues in the history of the Space Age. Edited by NASA Chief Historian Steven J. Dick and Roger D. Launius, former NASA chief historian and current chair of the Division of Space History at the Smithsonian Institution's National Air and Space Museum, the essays examine some of exploration's perpetual questions: What are the motivations for space flight? Is human space flight necessary when robotic spacecraft are cheaper? This collection is available to read online at http://history.nasa.gov/SP-2006-4702/frontmatter.pdf.

Learning and Development

The Academy of Program/Project and Engineering Leadership (APPEL) has updated its curriculum offerings. The APPEL Program Management and Systems Engineering development structure includes three major components: core curriculum, in-depth courses, and outside-the-classroom development experiences. Evaluating the quality and results of this curriculum—and providing for its continuous improvement—is a high priority of the APPEL team. For more information, visit the newly revised site at http://appel.nasa.gov/node/28 or e-mail APPELcourses@asrcms.com.

Web of Knowledge

Find the new NASA *Program and Project Management Processes and Requirements* (NPR 7120.5D) and more in the NODIS library at http://nodis.hq.nasa.gov/main_lib.html. The NASA Online Directives Information System (NODIS) is a searchable online library that contains agency-level directives, reports, other policy documents, and useful links to other executive orders, standards, and more. Since its inception in October 1986, NODIS has earned its reputation as a simple, efficient, and user-friendly service. Prior to NODIS, NASA relied heavily on telephones and the postal service for disseminating information and fulfilling data requests. NODIS played an instrumental role in revolutionizing information dissemination and request coordination at NASA. It won the 1992 Federal Leadership Award, co-sponsored by the Federal Open Systems Conference Board and the *Federal Computer Week* newspaper.

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Exploration Systems Mission Directorate (ESMD): http://www.exploration.nasa.gov/

The Hearth Report: http://www.klabs.org/richcontent/Reports/NASA_Reports/hearth/index.htm

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