National Aeronautics and Space Administration

Academy Sharing Knowledge

ask

The NASA Source for Project Management and Engineering Excellence | APPEL

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Image courtesy of the Smithsonian Center for Folklife and Cultural Heritage

ON THE COVER

This image was used during the 42nd Annual Smithsonian Folklife Festival in 2008 to showcase NASA's history and continuing exploration. Represented are some of NASA's discoveries and pursuits in planetary and lunar exploration. Earth's moon appears behind an astronaut helmet on the left and Mars appears on the right, followed by Jupiter, Saturn, Uranus, and Neptune cascading toward the background. Between them is the Ares I crew launch vehicle, currently being developed as part of the Constellation program and NASA's Vision for Space Exploration.

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

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

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In This Issue

In his "Knowledge Notebook" piece, Laurence Prusak notes that the past experiences of organizations influence how they behave now and how they will behave in the future. The truth of this is complex. It means that what an organization learns from its successes and failures—both technical knowledge and knowledge about how to organize work—can be put to use, past accomplishments serving as the foundation for future ones. It also means that unproductive old habits and beliefs tend to persist even when the damage they do is recognized. As Stephen Johnson suggests in "Success, Failure, and NASA Culture," elements of organizational culture are often the root cause of failures, but culture is hard to understand and change.

Still, Prusak is right that understanding the past is essential preparation for the future. This issue of *ASK*, which commemorates NASA's fiftieth anniversary, is one attempt among many to look at and learn from the space agency's first half century. Some of what you will find here is pure celebration. That is appropriate, because great achievements should be celebrated and because the joy of achievement is one of NASA's essential and defining strengths. Some of the articles here take a hard, analytical look at what the Agency has been as a way of exploring what it needs to become to accomplish its new mission. Some practitioner stories of past projects offer advice that can be applied to future work.

So what do these articles teach us? One repeated theme is the influence of the political and social context on the space agency's work. NASA is in the business of solving technical problems, but it would be a mistake to think that technical solutions are the sole or even the main source of the shape and success of projects. James Burke's description of competition with the Russians in the late fifties and early sixties and Jim Odom's "Lessons from Shuttle Development" are among the articles that show how powerfully politics affect budgets, schedules, and even the goals of missions. In the Apollo era, the Cold War space race meant that NASA programs were very well-funded but under tremendous schedule pressure. After the United States won that race, financial support weakened, leading to changes in the shuttle design and the successes and failures of "faster, better, cheaper." Among their other skills, successful program and project managers need the ability to read the political situation, as well as the determination and flexibility to find new ways to achieve their goals when external factors threaten their plans.

The contribution of good management to project success is additional proof that creating technological marvels is not just a technical challenge. Johnson points to the essential role of project management and systems management expertise in NASA's early achievements. In "Lessons from the Past," Howard McCurdy attributes the Agency's success in landing men on the moon to technical expertise, excellent management techniques, *and* effective relationships with contractors. And Kerry Ellis's article on Viking shows how strong, smart leadership and good teamwork are vital to success. Landing on Mars and sending back pictures and information from the surface required technological innovation but also innovation in management, such as the creation and use of a data system that helped members of the large project team share information.

The value of skilled management is a familiar *ASK* theme. So is the importance of learning and knowledge exchange. NASA must be a learning organization because so much of what it does has never been done before. It has to learn new things to do new things. Several articles make clear that we learn best from hands-on experience. In his recollection of being a young engineer at Marshall in the early sixties, Glen Robinson talks about how much he learned working on rocket test stands and how much he learned *from* people who had little advanced education but lots of practical experience. Greg Lofgren tells how doing geology on Earth prepared Apollo astronauts for doing it on the moon. Ed Hoffman's brief history of project management development at NASA emphasizes the importance of making the real experience of practitioners the basis of what is taught about managing projects. Jim Odom recalls how valuable it was to have engineers with Apollo experience working on the shuttle and argues for a smooth, well-planned transition to Constellation that will similarly draw on expertise developed over decades of shuttle and International Space Station work.

Looking to the future, many of our authors insist that finding ways to give engineers and managers more hands-on experience will be essential to NASA's future. Some of the themes Prusak and I touch on in "NASA and the Future of Knowledge"—respect for local knowledge, the value of personal networks as knowledge sources, and understanding how learning happens—are implicit in these stories of knowledge and learning.

Several articles here consider NASA's history of scientific discovery. Beginning with Explorer 1, launched before NASA came into existence, doing science has been an integral part of the space program. Noel Hinners and James Garvin draw on their long experience of space science to describe the factors that contribute to successful scientific missions and the decisions that must be made to do the best possible science within the constraints imposed by financial and engineering realities. Scientist-astronaut Joe Kerwin details the important medical research done on Skylab, and MIT's Laurence Young argues for the medical research he believes should be done at the planned lunar outpost.

This issue of *ASK* is one small part of NASA's fiftieth anniversary observations and barely scratches the surface of what the Agency has done in the past. I hope, though, that this brief look at some NASA experiences and accomplishments will contribute at least a little to its readiness to reach its goals for the future.

Don Cohen
Managing Editor

Lessons from the Past: How NASA's Early Culture Informs Current Challenges

BY HOWARD E. MCCURDY

Imagine for a moment that high-ranking government officials enthusiastically embrace a plan to send Americans to the moon as part of an effort that will lead eventually to human expeditions to Mars. The officials charge NASA with the task of mobilizing the nation to achieve this goal. At first, the Agency struggles to achieve it. Efforts to produce a succession of robotic precursors falter. The rocket selected to dispatch the crew is not safe. The crew's space capsule cannot land as planned. The program suffers cost overruns and schedule delays. The White House and Congress refuse to provide extra funds; support for ventures beyond the moon dwindles. The Agency reorganizes itself.

Peering from the Apollo 11 hatch while conducting a crew compartment fit and functional check in their command module are, from left, Neil Armstrong, commander; Michael Collins, command module pilot; and Buzz Aldrin, lunar module pilot. Lessons from Gemini and large-scale project management aided Project Apollo's success.

Photo Credit: NASA

W.C. Sleeman, Jr., inspecting a model of the paraglider proposed for use in Project Gemini. The wing suffered a number of problems and was later canceled, but the team learned from the failure, which helped Project Gemini's eventual success.

Photo Credit: NASA

Does this sound familiar? Although it may seem to describe the current challenges facing NASA employees as they attempt to launch the Vision for Space Exploration, it is in fact a recounting of the difficulties encountered nearly fifty years ago as the original race to the moon began. The response of NASA officials at that time contains important lessons for efforts under way now.

In recalling what is often termed NASA's "finest hour," people tend to mythologize the Apollo landings and the successful efforts to overcome difficulties—most notably those that afflicted the flight of Apollo 13. Yet the effort to surmount earlier difficulties, especially those affecting the Gemini flight program, had a much greater effect upon NASA and transformed the Agency in ways that made the lunar landings possible.

Project Gemini, approved in late 1961, served as a bridge between the Mercury project and the larger goal of reaching the moon. NASA flew ten piloted Gemini missions in 1965 and 1966. Concurrently, NASA dispatched nine Ranger spacecraft to the moon, robotic precursors to the human missions that would follow. Both projects endured significant troubles from the start. The resolution of those difficulties reshaped NASA and enhanced its capacity for effective project management. The NASA that reached the moon in 1969 was significantly different from the institution that began Project Gemini in late 1961.

Government officials approved Project Ranger as a means of obtaining close-up pictures of the lunar surface. The first six Ranger spacecraft failed to complete their missions. Balky rockets, faulty spacecraft, and inaccurate trajectories produced six successive mishaps. Congress launched an investigation and blamed the failures on deficient project management.

NASA officials selected the Titan II launch vehicle, being developed as an air force missile, to carry the Gemini astronauts into space. The rocket oscillated badly. Half of the first twenty test fights failed to meet expectations. Officials at the Johnson Space Center (then the Manned Spacecraft Center) called the rocket unfit for human flight. For the return to Earth, engineers designed a paraglider that would inflate upon descent and guide the space capsule to a smooth touchdown on land. When the test program produced more wing-load problems than controlled descents, NASA officials installed parachutes and reenlisted the U.S. Navy for another series of retrievals at sea.

The cost of Project Gemini grew by more than 40 percent over early estimates. NASA Administrator James Webb asked President John F. Kennedy for extra funds to help the program achieve its objectives. Kennedy rejected Webb's request and Congress cut NASA's appropriation by 3 percent. As Congress and the White House cut, NASA planners began to formulate a post-Apollo space program that would include a 1986 human expedition to Mars. In 1964, Webb prepared President Lyndon Johnson for the financial commitments that this effort would entail. Johnson refused to be drawn in. He provided the funds to complete the objective of landing Americans on the moon but declined to provide any significant funding for activities beyond.

Commenting on the troubles faced by the people working on Project Gemini, the authors of the comprehensive history *On the Shoulders of Titans* conclude that "this picture of a smoothly meshed team moving from success to success, although true enough for the last six months of the program, slighted the obstinate technical and managerial problems that had to be surmounted before the happy outcome was reached."

Developing NASA's Culture

How did NASA officials respond to these problems and setbacks? At the start, the Agency relied upon a strong tradition of in-house technical capability. It had an extensive corps of government employees who understood the intricacies of spacecraft design, landing systems, rocketry, and aerodynamics. NASA officials sustained this technical capability by completing a certain amount of work in house, recruiting what they thought to be exceptional people, giving them a great deal of discretion,

TOGETHER, THESE PRACTICES FORMED WHAT CAME TO BE KNOWN AS THE NASA ORGANIZATIONAL CULTURE: IN-HOUSE TECHNICAL CAPABILITY, APPROPRIATE MANAGEMENT TECHNIQUES, AND CAREFULLY MAINTAINED, CLOSE RELATIONSHIPS WITH CONTRACTORS.

allowing them to take risks and fail, and providing them with new and challenging assignments.

In-house work encouraged NASA employees to be technically competent. Most people remember the extensive training that astronauts received before their voyages, but NASA's leadership trained its engineers and scientists as well. Engineers and scientists practiced their technical skills by working on real hardware, conducting tests, training astronauts, operating spacecraft, and doing research. As a result, NASA maintained a corps of professional employees who knew as much—if not more—about space flight and rocketry than any other group of people on the planet.

Second, NASA executives like James Webb looked outside the Gemini and Apollo projects for management practices that could be used to control schedules, monitor costs, regulate design changes, and ensure performance. They learned that complex projects worked best when governed by a single center engaged in systems integration. Webb turned to the U.S. Air Force ballistic missile program, which had the strongest tradition of large-scale systems management, and imported a succession of air force officers and contract employees who knew how the system worked. It took two major reorganizations and plenty of perseverance to install the system in NASA, but by the mid-1960s the Agency was institutionally prepared to complete the Gemini project and move toward the moon landings.

Third, the Agency maintained a special relationship with its contractors. Agency policy dictated that NASA employees use private contractors to build the spacecraft, rockets, landing systems, and other components of Project Gemini. Yet NASA employees did not defer to contractors. Relying upon the technical capability inside NASA and the strong centers of in-house systems integration, NASA managers penetrated and controlled contractors to an unusual degree. One rocket scientist likened the relationship between NASA and its contractors to what one would expect to find between a professor and his or her students.

Together, these practices formed what came to be known as the NASA organizational culture: in-house technical capability, appropriate management techniques, and carefully maintained, close relationships with contractors. If a healthy organizational culture consists of the practices and values that help the organization accomplish its tasks, then NASA's culture was unquestionably a healthy one. It helped the Agency complete the moon landings—on schedule and within the estimated cost—and supported a succession of successful missions to the moon, Mars, and the outer planets using robotic spacecraft.

Maintaining NASA's Capabilities

When NASA strays from these practices, it invites trouble. The temptations to stray are considerable. Bureaucratic procedures, excessive oversight, aversion to risk, independent field centers, and unwarranted confidence all conspire to undermine healthy cultures. A recent survey conducted by NASA's History Office confirms that agency employees worry about issues such as these, although employees still view the Agency as an exceptional place.

History suggests that there is no substitute for in-house technical capability. It is the foundation upon which all other practices rest. Without it, NASA would cease to be a research and development organization. In the 1960s, people like Max Faget, Christopher C. Kraft, Robert R. Gilruth, George M. Low, Wernher von Braun, Eugene F. Kranz, George Mueller, and many others helped preserve that capability. Respondents to the 2006 History Office survey believe that NASA still recruits exceptional people but does not give them enough hands-on work to keep them sharp. By a six-to-one margin, NASA professional employees agree that the Agency "has turned over too much of its basic engineering and science work to contractors."

Experience also reveals that individual space missions suffer when they lack a single strong center of program integration. Large-scale systems management provided such a center for the moon race, transforming the troubles of Project Gemini into the achievements of Project Apollo. Historian Stephen Johnson has characterized the use of large-scale systems management during the moon race as “the secret of Apollo.” Yet it is not the only way to achieve program integration. A recent succession of low-cost projects demonstrated that “skunk works” techniques provide a worthy substitute for the more formal practices associated with systems management. Scientists at NASA’s Jet Propulsion Laboratory used skunk works techniques to complete the Pathfinder project; officials at the Applied Physics Laboratory used them to complete the NEAR-Shoemaker mission. Space entrepreneurs have adopted them in pursuit of goals like the X PRIZE. Basically, the skunk works approach substitutes small, tightly organized teams with a high capacity for interpersonal communication for the formal control strategies contained in systems management. Lots of organizations use it.

NASA’s relationship with contractors is still evolving. In the beginning, when space exploration was new, NASA attracted a disproportionate share of the world’s best spacecraft engineers and rocket scientists. Today, that talent is more widely dispersed, and NASA officials face substantial pressure to contract out their work. External organizations have substantial technical capability, but their institutional practices do not always match those found in NASA. I recently completed an analysis of twenty-three low-cost NASA projects conducted between 1992 and 2005. One-third of the projects were completed in house; two-thirds were completed by contractors. Projects that followed NASA’s historic practices had a 100 percent success rate. They possessed a single center of program integration, funding commensurate with project complexity (not too little given the complexity of the mission), and a culture of technical competence. Where projects violated two or more of those precepts, they failed 50 percent of the time. Violation of the precepts occurred far more frequently on projects contracted out than ones done in house.

A half-century of space flight has created a storehouse of experience that can be applied to future challenges. There are many ways to manage a space expedition and only a few ways to do it right. The civil space program has been well served by its tradition of in-house technical capability, strong centers of integration, and the insistence that contractors follow sound practices. Yet the temptation to compromise remains strong. Where that occurs, trouble invariably follows. NASA has the opportunity to achieve great new goals. Its history suggests that this will not be easy, but it is feasible. As President Kennedy noted in launching the modern space program, we do these things “not because they are easy, but because they are hard.” ●

HOWARD E. MCCURDY is a professor in the School of Public Affairs at American University in Washington, D.C., and author of seven 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 recently completed a book with Roger Launius, *Robots in Space*.

EARLY LUNAR MISSIONS: A MEMOIR

BY J. D. BURKE

Technicians prepare the Ranger 4 satellite for use at the Parade of Progress show at the Public Hall in Cleveland, Ohio.

Photo Credit: NASA

An audience at NASA's Jet Propulsion Laboratory listens to a description of the final moments of Ranger 6 in 1964. Ranger 6 impacted the moon as planned on February 2, 1964, but a malfunction disabled its camera system.

When the world changed with Sputnik on October 4, 1957, we at the Jet Propulsion Laboratory (JPL) were jubilant. Yes, we had been beaten in a race, but we now knew that our fondest hopes would be realized. Soon we and the Wernher von Braun U.S. Army team gained permission to launch Explorer 1, and we were planning missions to the moon.

On January 2, 1959, the Soviets' Luna 1, Mechta (Dream), escaped into interplanetary space. To me, this was the real watershed. NASA had been founded in 1958, and JPL, transferred from army sponsorship, had become one of its field centers. We agreed that lunar and planetary exploration should be our central goal. Of course Earth satellites were important, destined, among other things, to found a huge new industry in telecommunication satellites, but these were regarded as not appropriate pursuits for a research laboratory in a university setting. So we decided that JPL should plan to work at the farther frontier and develop Earth satellites only for science missions.

The first American lunar attempts were unsuccessful. Pioneer 4, a tiny, spinning Tin Woodsman's hat, did follow Luna 1 into interplanetary space, but it and other U.S. lunar missions in 1959 returned no data from the moon. Meanwhile, Luna 2 hit the moon and Luna 3 ended centuries of speculation by imaging its far side. By 1960 we were into serious planning for more ambitious missions to the moon and Venus. Despite its tempting aspect as the first chance in history for humans to send something to Mars, we abandoned that year's October Mars launch window as unattainable, given our capabilities at the time.

The Soviets did try for Mars. On October 10, 1960, at the instant when Tyuratam was brought by Earth rotation into alignment with a minimum-energy path to Mars, a vehicle lifted off carrying a far greater weight than any ever before lofted by rocket. Intercepted telemetry showed that the loaded upper stages weighed more than thirty tons. A new upper-stage engine started, but its turbine did not reach a stabilized full speed. Four days later, again at the exact right instant for a departure to Mars, another heavy vehicle lifted off. Again the upper-stage engine failed.

These flights, though not announced at the time in either the Soviet Union or the United States, were a powerful stimulus to our efforts. We now knew beyond doubt that we were in competition with determined and well-supported colleagues in the otherwise feared and mistrusted Soviet Union. Today I am privileged to enjoy the friendship of some of them who have survived up to now. Indeed two, Mikhail Marov and Nikolai Tolyarenko, are fellow faculty members of the International Space University.

During that same month, October 1960, I was appointed project manager of Ranger, the first American effort to place scientific instruments on the surface of the moon. Our technical work proceeded in an environment of managerial and political commotion as the army, navy, and air force jockeyed for position in the new space game and NASA struggled to be born.

The Eisenhower administration had a good fundamental policy: the U.S. civil space program would be done in the open, with secrecy only where it was absolutely needed, such as how the Atlas guidance system worked. There were also deeply secret space programs, such as the one openly labeled Discoverer—known in the secret world as Corona and managed by the CIA—to obtain reconnaissance information on Soviet strategic capacities. The military services naturally wanted a piece of the action, and the air force thought it should own the U.S. space program. The navy laid claim by asserting it needed to have important navigation satellites. The army was already launching satellites, and JPL had been connected with the army until NASA was formed. So all three military branches were campaigning against each other in this important national strategic opportunity.

Below this high-level struggle, we had huge arguments about who would be in charge of what—for example who had authority to launch or stop a launch. We also had one part of the science community wanting to obtain scientific information about the earth and its surrounding magnetosphere, creating another controversy. To me, this was a competition with the Soviet Union and getting to the moon for lunar science was the paramount objective; magnetospheric science was secondary. But to the non-lunar scientists, their science was primary. They would say to us, "If my instrument isn't ready, you should wait until it is." Our lunar scientists never gave us this problem.

Until things settled down around 1963–64, when the roles and missions became clear and everyone buckled down to do the job, we found a few good people scattered throughout the system who were prepared to work together and ignore the uproar going on around us. U.S. Air Force Major Jack Albert, who by policy might have been an opponent, was a proponent of our team and helped us in many ways. Harold Luskin at Lockheed also collaborated wholeheartedly with us. Having real people, separate from theoretical policies, made things work. Instead of adversaries, they were collaborators.

Despite all the turmoil, we were able to launch five Rangers during 1961 and 1962. All reached orbit and one crashed on the moon, but none returned useful scientific data. As Cargill Hall states in his book, *Lunar Impact*, "Experience soon drove home the point that project management had to be delegated to a project manager at the pertinent field center, JPL. Experience also made clear the advantages of bringing together agency scientists and engineers both at Headquarters and in the field laboratory." I was succeeded as project manager by my admired JPL friend Harris M. (Bud) Schurmeier, who took the project through one more failure and on to three triumphant successes in 1964 and 1965.

I remained with Ranger and saw it become the success I had always intended it to be. Hall points out, "The things for which he [Burke] struggled—straightforward, unchanging project objectives; experiments that could not be altered at a scientist's whim; recognized authority and responsibility in and from all the agencies participating—Burke won all these in defeat. NASA and JPL leaders granted all these to his successor, Schurmeier, who, with new test facilities and procedures, used them skillfully to the advantage of Ranger."

While we were preparing Ranger 1 in the spring of 1961, President Kennedy announced Apollo, launching the great moon race. Ranger and JPL's Surveyor lunar soft-landing project came to be regarded as precursors to Apollo, with their original science objectives retained but with a new focus on getting early results. Also, a new project managed by Langley Research Center, Lunar Orbiter, was started to obtain images in support of Apollo.

Photo Credit: NASA

Dedicated in May, 1964, the new Space Flight Operations Facility used state-of-the-art equipment for mission operations and communications with JPL's unmanned spacecraft. One of the first missions to use the facility was Ranger 7.

MOST OF THE SOVIET TROUBLES RESULTED FROM FAILURES OF MANAGEMENT. THE KIND OF MANAGEMENT DISPUTES WE HAD EARLY ON DID NOT GET RESOLVED IN THEIR CASE.

Meanwhile our Soviet competitors were having a terrible time. At the Venus window in February 1961, they launched two more heavy rockets. One achieved Earth orbit but failed to eject its payload toward Venus. The other, Venera 1, failed on its way to the planet. In 1962 they launched six of their enormous rockets, three to Venus and three to Mars, but only one spacecraft, Mars 1, went on its way and eventually it, too, failed en route. At that opportunity JPL mounted two Venus missions. One launch failed, but the other sent Mariner 2 to Venus, yielding the first data on the planet's hellish atmosphere.

A long and frustrating period of Soviet lunar attempts followed. Beginning on January 4, 1963, and continuing through the next two years, they launched at least ten missions with only two partial technical successes and no lunar scientific results except the far-side images from Zond 3, a planetary spacecraft sent past the moon. At last, on February 3, 1966, Luna 9 landed and began sending facsimile panoramas from the lunar surface.

Most of the Soviet troubles resulted from failures of management. The kind of management disputes we had early on did not get resolved in their case. For example, their launch vehicles were operated by Soviet armed forces in a military institution that did not have science among its primary objectives. They would launch vehicles before they were ready, and they would fail. They also faced a technical problem that we had to learn about, too, by bitter experience: it's very difficult to start a rocket engine in microgravity because propellants do not remain where they are needed. Design ingenuity is required to get the liquid into the pumps before an engine can start. One reason the Soviet R-7/Soyuz rocket was so successful and is still used is that all engines are running on the launchpad before liftoff.

By 1966 we had been collecting telemetry from the Soviet missions for several years. When Luna 9 landed, we were recording the spacecraft's signals at our station in Eritrea and three other collaborating sites. The Doppler showed retrorocket braking of the descent all the way to the surface. Then the signal went off the air. Another failure? We waited anxiously. Then all of a sudden a new signal appeared: a scratchy, pulsing heartbeat. Wow, it was a fax! We were joyful to see the result of their ingenious system designs and persistent, patient overcoming of successive failures. Soon the American Surveyors, too, began landing on the moon and returning television images and, later, chemical data.

The next Soviet lunar spacecraft was stranded in low-Earth orbit, but then the USSR team achieved another historic milestone by placing the first spacecraft, Luna 10, in lunar orbit. From then on, the Soviet robotic lunar program advanced steadily, with much larger spacecraft launched by the huge Proton rocket, eventually returning small samples of lunar soil and delivering the two Lunokhod rovers to the moon.

On the larger stage of human lunar missions, the preparations for Apollo moved America ahead. We watched with overhead imaging while monstrous facilities for the giant N-1 rocket were built at Tyuratam, and when the four attempted launches of the N-1 failed, we were downcast at the thought that this would bring human lunar exploration to an end—as indeed it did. The greatest N-1 failure wiped out parts of the USSR launch facility on July 4, 1969, just before Apollo 11. When the Soviets decided to cut their losses and give up competition with Apollo, keeping lunar missions going was no longer a priority in either country. Soviet circumlunar human-precursor missions in the late sixties, labeled Zond 4 through 8, had demonstrated ingenious design and execution but did not lead anywhere. By 1976 it was all over.

What should we now conclude about this wonderful and never-to-be-forgotten experience? Both we and our competitors were in too much of a hurry at the beginning, and we had to learn that robotic lunar and planetary exploration is barely achievable even with great effort and care. In spite of their many failures, the Soviets did pull down each of the world's historic firsts at the moon: the first escape, the first lunar impact, the first far-side images, the first lunar landing, and the first lunar orbit. But when it came to the great contest with Apollo, they could not keep up the pace.

They had funding, they had good people, they had policy support, but they did not have a coherent and stable management system. Apollo succeeded because the whole nation rose to the challenge. With Mercury and Gemini building human confidence and skills in orbit, the robotic craft finding needed information at the moon, the giant Saturn V building upon decades of experience in the von Braun team, and the human lunar spacecraft being created with broad skills in industry, the colossal enterprise was rigorously managed all the way to its end in 1972. ●

J. D. BURKE, a Caltech alumnus and former U.S. Navy aviator, was employed at Jet Propulsion Laboratory from 1949 to his retirement in 2001 after serving in many lunar and planetary projects. He was a member of Paul MacCready's team, winning the Kremer Prizes for human-powered flight. Now in retirement, his main professional activities are with The Planetary Society and the International Space University.

1. R. Cargill Hall, *Lunar Impact*, (Wahington, D.C.: NASA History Office, 1977), NASA SP-4210.
2. J. D. Burke, "Seven Years to Luna 9," *Studies in Intelligence 10*, Summer (1966, declassified 1994).

THE APOLLO ERA:

Working at Marshall in the Sixties

BY GLENN A. ROBINSON, JR.

Photo Credit: NASA

This photograph depicts a view of the test firing of all five F-1 engines for the Saturn V S-IC test stage at the Marshall Space Flight Center.

I graduated in 1963 with a degree in aerospace engineering from North Carolina State University and immediately went to work at the Marshall Space Flight Center. At that time, all of us young engineers were assigned to work on smaller pieces of the Saturn V.

As you can imagine, I was a fresh-out with no experience at all. My first week at Marshall, I was told, "We're building this testing facility, and you're going to be the engineer on it." I knew nothing about building facilities, let alone aerospace test facilities. But based on that experience and similar experiences, I would strongly recommend that a young engineer who goes to work for NASA or an aerospace firm start in a test area. It teaches you that you cannot build things overnight. Materials must be ordered and delivered. Planning and initial work must be done.

Working on that test facility at Marshall, I understood some simple realities. The electricians could not do anything until we had a structure. We could not build the structure until the foundation was in place. We learned to establish realistic schedules for that up-front work. Hardware was the same. We started with an idea, defined it, and then drew it on paper (no CAD-CAM in those days). Some people may believe that such things can be built quickly, but it takes time to do everything.

Hands-On Knowledge

At Marshall in 1963, there were a number of people who were "wage-board employees." Almost all of them were World War II veterans, most in their forties and fifties. The majority of them had no college education, but they had incredible knowledge. I don't believe we could have accomplished what we did without them. We also had a complete machine shop in our building. If we did not have something that we needed, these veterans would go into the shop and build it. It was obvious to me how we won World War II when I watched these guys. If something was not immediately available, they'd build it from scratch.

When I first came to Marshall, I had ten wage-board employees working for me, building a Saturn V model engine test-firing stand to evaluate building a Saturn V launch platform over water. These guys had a wealth of accumulated, hands-on knowledge and common sense. When we finished building the test stand, our first test was to fire a model of the F-1 engine. These were LOX/RP1 engines (liquid oxygen and jet fuel). As part of the testing, we had to do valve timings to make sure that the propellants came in at the correct time.

While we were putting the facility together, one of the wage-board employees said to me, "Robbie, if we set these valves up like they're telling us to set them up, I think we're going to burn that engine up."

I asked, "Why?"

He said, "Well, they've got us coming in with an oxidizer lead."

I said, "Well, the guys who configured it are supposed to know what they're doing." Of course, I was an inexperienced, twenty-one-year-old kid; I didn't really know what I was doing. But I decided to discuss his concern with some of the senior engineers. They concluded that it was not a problem. I went back and told the technicians.

They said, "Don't worry about it. After we melt the first one, we'll fix it."

Sure enough, in the first test firing we burned up an injector. So I went back to the technician and said, "Henry [Henry Hilton was his name], how did you know that this was going to happen? I have an aerospace engineering degree, but we never studied anything like this at NC State."

Henry answered, "It's very simple. I looked at it like an acetylene torch."

"What do you mean?" I asked.

Henry said, "An acetylene torch will do one of two things. You can either solder with it—melt stuff to put it together—or you can cut with it. If you're running oxidizer rich, guess what: you cut with it." He explained that all we had done was to create an acetylene torch, which caused a meltdown of the injector. I was a relative youngster with an engineering degree, but since I could admit that I didn't know everything and was willing to ask questions, I gained the respect of the team working with me. I continued to benefit from their knowledge over the next few years as we worked together testing different parts of the Saturn rockets.

In those early days of human space flight, NASA built and assembled a lot of the flight and test hardware, then built the facilities for all the experimental testing we did. Much of the

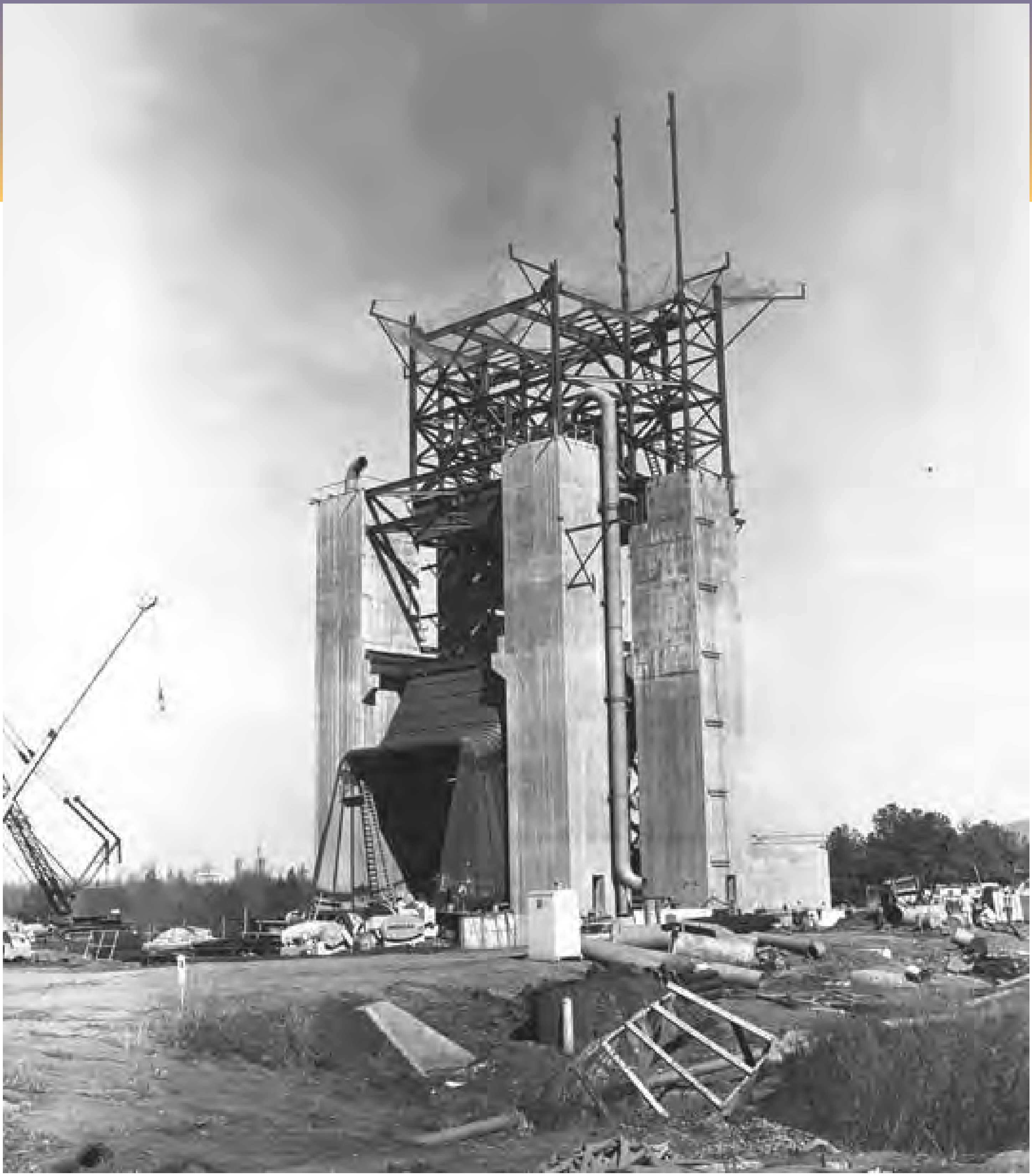


Photo Credit: NASA

At its founding, Marshall inherited the army's Jupiter and Redstone test stands, but much larger facilities were needed for the giant stages of the Saturn V. From 1960 to 1964, the existing stands were remodeled and a sizable new test area was developed. The new comprehensive test complex for propulsion and structural dynamics was unique within the nation and the free world, and it remains so today because it was constructed with foresight to future as well as current needs.

Photo Credit: NASA's ASK Magazine

The 138-foot-long first stage of the Saturn V is lowered to the ground following a successful static test firing at Marshall Space Flight Center's S-1C test stand.

I BELIEVE THAT PART OF THE PROBLEM THAT EXISTS AT NASA TODAY IS THAT THE OLD AND EXPERIENCED ENGINEERS (INCLUDING ME) MOVE UP INTO MANAGEMENT AND NO LONGER HAVE THE OPPORTUNITY TO DO MUCH TECHNICAL WORK WITH THE YOUNG EMPLOYEES WHO ARE COMING ABOARD.

Saturn hardware was designed at Marshall. Today, most of it is designed and built by contractor teams at their facilities. It's a very different environment. I believe that part of the problem that exists at NASA today is that the old and experienced engineers (including me) move up into management and no longer have the opportunity to do much technical work with the young employees who are coming aboard. These new, young engineers work with other young engineers. I consider it to be a shame that we, who have had the experiences and the knowledge gained from many failures and successes, have not gotten more technically involved with our younger, less-experienced employees.

Working for Von Braun

Wernher von Braun was a fascinating individual. If he met you once he would remember your name. Over the years, I had opportunities to fly on the Gulf Stream with him. The director's seat was always at the back. People would get to the Redstone airfield early so they could sit near von Braun. He was fun and exciting to be around. He could talk on almost any subject; he was extremely knowledgeable. It didn't matter whether you were a fresh-out twenty-one-year-old engineer or someone who had been around for twenty years; he was always willing have discussions with you. He was very open-minded, listened to what people had to say, and considered their recommendations. But once he made a decision, the decision was made and the decision was his.

Von Braun would come down to the test stand that I was running as a very young test engineer and ask my permission to go out on the stand. His attitude was, “This is your environment, and you’re in charge.” Away from the test stand, there was no question: he was the center director, and he was in charge.

We did much of the S1B testing at Marshall. Back then, we didn’t have the computers that we rely on today. We used consoles with switches to manually operate all the valves and strip charts with ink pens to record measurements and data. A number of us were asked to support one of the S1B firings by monitoring some of the redlines. As I recall, the chamber pressure for the H-1 engine was 1,000 psig and the redline was slightly above that.

Those of us watching critical redlines were given cut-off switches. About two minutes into the test, the needle touched the redline on the chamber pressure of the engine I was monitoring and then went slightly above. I punched my button and shut down the test. Of course, it became really quiet in the room. Everyone was looking around to see who had shut it down. I admitted being the “culprit.” An investigation followed. The more senior people asked, “Why did you shut it down?”

Needless to say, I acknowledged that I had shut down the test because the chamber pressure exceeded the redline by a couple of psi. The senior engineers asked, “Couldn’t you see it was stable and it wasn’t going anywhere?” They were going on and on like that, as typical engineers do. Von Braun had been sitting in the back during this “inquisition.”

After a few minutes of intense inquiry he spoke up and asked, “What did you tell my young engineer to do?”

They answered, “We told him to shut it down if it hit the redline.”

Von Braun asked, “Did it hit the redline?”

“Well, yes, it exceeded the redline by a couple of psi.”

Von Braun responded, “Well, the young engineer did what you told him to do. Quit criticizing him. Change your redlines if they’re wrong and leave my young engineers alone.” Only he said it with a little bit more explicit language. That ended that, and, no, the redlines were never changed.

The Apollo Spirit

During that exciting time, money was not an issue like it is today. Our only challenges were technical. We all worked six or seven days a week to accomplish our mission of landing a man on the moon within the decade. We were very close, committed to our work and to each other. It is very difficult to describe the camaraderie. We played softball together; we worked together; we went fishing together; we vacationed together. Our environment was very much like being on a college football team. Our coaches were von Braun and the management team at Marshall. I believe that the only problem we had then was that we took greater risks than we should have. For example, we lost a couple of guys on a tank that blew up. They had been leak-checking the tank while it was pressurized at a level that was too high. We had a few other accidents along the road to our successes. Nobody heard much about those events. Our environment said, “We’re going to do this.” We were all gung ho. I don’t think there was anything that we thought we couldn’t do. Our accomplishments are a national legacy. Our spirit is part of the legacy, too, but it came with a silent price. ●

After graduating with a degree in aerospace engineering, **GLENN A. ROBINSON, JR.**, went to work at Marshall Space Flight Center, where he remained for the first twenty years of his forty-four-year career with NASA. In 1983 he spent a year on detail at NASA Headquarters for the Space Station Task Force. He was detailed to Johnson Space Center in April 1984 to work in the Space Station Skunk Works, where he stayed until retiring from NASA in 2007.

Teaching Geology to

Astronaut James B. Irwin, lunar module pilot, uses a scoop to make a trench in the lunar soil during Apollo 15 EVA. Mount Hadley rises above the plain in the background.

Photo Credit: NASA/David Scott

Apollo Astronauts

BY GARY LOFGREN

I came fresh out of graduate school to the then Manned Spacecraft Center (MSC—later Johnson Space Center) in 1973, prepared to build a laboratory to study the formation of basaltic rocks. Little did I know what was to come. I became a member of the Geology Branch. One of our primary activities was to train Apollo astronauts how to do geology on the moon. I eventually built the science laboratory and accomplished all I hoped to do when I came. My participation in the Apollo program, however, has been the highlight of my science career.

It is difficult to describe my excitement when I was about to see rocks from the moon for the first time. Apollo 11 went to a mare area, the Sea of Tranquility. We expected that basaltic lavas would be the most common kind of rock in the so-called lunar seas, and they were. The other kind of rock, the soil breccias, were a surprise and were our initiation to the rocks produced during the many impacts evident on the moon.

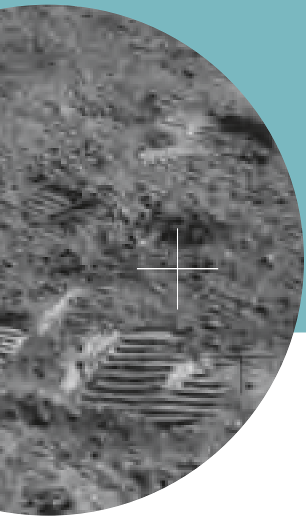
Shortly after the samples were returned, I was asked to participate in the process of distributing them to scientists for study. Many scientists needed samples of a definite shape—a cube, for instance. Such samples would have to be cut with a saw, but no saw suitable for the task existed. Rocks are usually sawn with water as a lubricant and coolant, but using water or any liquid that would have contaminated the samples was unacceptable. One of the scientists developed a saw that used a diamond-impregnated wire to cut the samples dry. It was a delicate machine that needed constant attention. I was given the task of learning the saw and doing all the cutting for the initial Apollo 11 allocation of samples that required sawing. This gave me a chance to study the samples at my leisure. I used this opportunity to record my observations, which later became part of an introductory paper in the proceedings of the first lunar science conference. I went on to study the lunar basalts in my laboratory for the next ten years.

Teaching Geology to Astronauts

Far and away the most memorable aspect of my Apollo experience was working as part of a team of geologists that taught the astronauts geology. Being a rookie, I began working with the backup crew for Apollo 13, John Young and Charlie Duke, who eventually flew on Apollo 16. Training began in earnest when I was assigned to work with the Apollo 15 crew as the MSC representative. Apollo 15 was the first of the long-stay "J" missions. They would have three extra-vehicular activities (EVAs) on the surface totaling more than twenty hours. In addition, they would have a vehicle, the Lunar Rover, to extend the area over which they would conduct scientific experiments. Clearly the science effort was becoming huge. Dave Scott, the mission commander, recognized that fact and dedicated a large block of his and Jim Irwin's time to becoming field geologists. They would land on basalt flow with Mount Hadley, part of the early lunar highland crust, a short distance to the east of the landing site. This would be the first landing with an objective to sample the primitive lunar crust. Training would have to prepare Dave and Jim to recognize and sample both basalt and lunar crustal rocks. They would set a standard for geologic fieldwork that would spur on the later crews.

The spectacular scientific success of the A-15 mission and Apollos 16 and 17 to follow—with their cumulative total of approximately sixty hours on the lunar surface—was in large part a result of extensive geologic field training. The geologic objectives for these missions were complex. What made the training so successful, in addition to great teachers and dedicated astronauts, is worth noting for future missions.

A-15 was a turning point in the length and intensity of the training in geology. Training included sixteen to eighteen



field exercises of two to three days each over eighteen months, augmented by limited classroom study. Every attempt was made to train in geologic settings that simulated some aspect of the scientific objectives of the mission. Apollo 15 would land between Hadley Rille and Mount Hadley on the edge of the Imbrium Basin. The crews were asked to systematically observe everything from the far distance to the near field and ultimately developed astute observation skills and a geologic vocabulary in common with the geologists in the mission science backroom. Most of the field exercises were focused on specific mission objectives to give the astronauts the background they needed to fully understand the scientific objectives and their rationale. One of the most important classroom activities was to learn basic lunar rock types by direct observation of Apollo lunar samples in the Lunar Receiving Laboratory. Because I was at MSC and close to the lunar samples, I took on the task of familiarizing the crew with the lunar samples we already had collected on previous missions.

The primary teaching technique that evolved during the early training was perfected during the Apollo 15 training under the tutelage of Lee Silver, a Caltech professor who had been teaching field geology to students for years and was strongly encouraged to participate by Jack Schmitt. Jack would be on the A-17 prime crew and was on the backup crew for A-15. The training traverses were designed to mimic what would happen on the moon as closely as possible. Routine tasks such as sample collection and documentation were practiced on all traverses until they became second nature, freeing the astronauts to observe their surroundings. Every effort was made to visit terrestrial geologic localities that mimicked the geologic problems at the lunar landing sites as closely as possible.

Traverses were designed by knowledgeable geologists with a definite path to follow and specific science objectives to be achieved at designated stations indicated on the traverse. The real mission capcoms, astronauts Joe Allen (prime) and Bob Parker (backup), acted as a communication link between the crew in the field and a science backroom comprising geologists not familiar with the geology that would be encountered by the astronauts. During these exercises, Joe and Bob developed their ability to prod and guide the activities of the crew to complete their designated tasks. The most important part of this training exercise was the face-to-face debriefing where the crew, together with the capcoms and the science backroom geologists, walked over the entire traverse and discussed the degree to which the crew had been able to communicate the geology they were seeing in the field.

In the early exercises the gap was large, but with repetition over many field trips that gap disappeared and a common language was born. The capcoms developed an intimate knowledge of how the crew worked, what limitations were imposed by the rigor of the defined traverse, and how to best interact with the crew to get the job done. The geologists learned how difficult it would be to communicate with the crew and how best to make that happen. Most importantly, the crews had the opportunity to learn how to communicate with the geologists effectively and how and when to ask for advice. I believe this activity alone is primarily responsible for the success of the geologic traverses. These debriefings forced everybody to recognize their deficiencies and to eliminate them. Ultimately, this activity formed the cohesive team that succeeded so well. I know also that if I were to teach students field geology, I would use many aspects of this training with my students.

More than anything else, though, the work succeeded because the crews took ownership of the missions and dedicated themselves to their success.

Dave Scott was an innovative commander. It was his idea that he and Jim Irwin would put on their space suits and open the docking hatch on the top of the Lunar Module to view the area. From this vantage point, approximately 20 ft. above the surface, the view was spectacular. He was able to find all the major landmarks noted on their traverse maps, describe the geology in the distance, and evaluate the surface mobility. An exciting moment

Photo Credit: NASA Johnson Space Center

Astronauts David R. Scott, left, and James B. Irwin, right, join Manned Spacecraft Center geologists in looking at some of the first Apollo 15 samples to be opened in the Non-Sterile Nitrogen Processing Line in the Manned Spacecraft Center's Lunar Receiving Laboratory. Holding the microphone and making recorded tapes of the two Apollo 15 crewmen's comments is Dr. Gary Lofgren.

came during the second traverse, when Dave spotted a white rock on the surface whose cleavage surfaces reflected the sunlight and caught his attention. He retrieved the rock and quickly identified the white mineral as plagioclase feldspar. This was why they came to the base of Mount Hadley—to find a piece of the primitive lunar crust. One major mission objective accomplished.

They made another equally important discovery there. We were also looking for olivine-rich rocks. Olivine is a green mineral, and they saw some rocks with a green cast. These ultimately proved to contain not olivine but a green glass brought to the surface by a basaltic fire fountain. This green glass from deep in the moon revealed much about the nature of its source and the interior of the moon.

Late one night, near midnight, I left the building where I had been in a science backroom to support the crew after this EVA. There was a nearly full moon shining overhead. I looked up and realized that the two guys I had just watched collect some great rocks were on that moon. It was one of those moments you never forget.

There were other moments. In the Lunar Receiving Lab (LRL) where the samples were returned and the first three crews quarantined, I remember Dave and Jim's excitement when they first saw the rocks they had collected on the lunar surface in the calm of the laboratory. They recounted how they noticed these important crustal rocks and gave us a better picture of their setting on the surface. There were several rapt geologists gathered around. I felt that the many training hours showing the crew the lunar rocks had paid dividends.

Preserving and Protecting Lunar Geology

Thirty years after the mission and a long career studying first lunar basalts and then meteorites, I returned to Apollo. I became the curator of the lunar samples. They were now in my care. After thirty years, the samples have lost some of their scientific luster to many people but not to me. I rededicated myself to preserving the Apollo lunar sample heritage. A new building to house the samples was finished in 1979, and it has served them well. They are well protected from Earth's environment, which would quickly destroy the lunar character of the samples. But a nearly twenty-five-year-old building needed renewing. That became my mission. Now, after ten years of effort and nearly $3 million, that renewal is nearly complete. But preserving the building is only part of the job. The documentation of forty years of processing lunar samples needed to be preserved in a useful, accessible form.

The story of the lunar database is a story of the development of the digital age from the late sixties to the present. The first version was contained in a primitive computer that was accessed with a 300-baud phone modem, the kind that had you put the phone receiver in a cradle. It went through the stage of punch cards and then magnetic tapes. Eventually we reached a critical stage when the database was still on an outmoded VAX computer for which no spare parts existed. The transition to a modern database was a more demanding task than I ever envisioned. I hoped to get $50,000 to make this transition. The cost was ultimately closer to $1 million and took five programmers fourteen months to accomplish. Without this effort, we would have been nearly out of the business of allocating samples if the VAX failed. We would have had to go back to the days of pencil and paper. I am comfortable now that all the necessary changes have been made or are currently in process to house and care for the samples properly for decades to come. They are indeed a national treasure.

GARY LOFGREN is a senior planetary scientist and the Lunar Curator, where he oversees the preparation of lunar material for distribution to scientists for study, to museums for display, and for educational purposes. He has been a research scientist and principal investigator in the NASA Cosmochemistry program since 1968.

A Brief History of Project Management Development at NASA

BY ED HOFFMAN

Thinking about this special issue of *ASK* focusing on NASA's fiftieth anniversary, it occurred to me that there is a story from my own experience that is worth sharing. I came to NASA in 1983, at what is now the midpoint of its history, and over the past twenty-five years I have witnessed a wholesale change in the Agency's approach to developing its project managers and engineers.

When I arrived at NASA, the Agency had one approach to professional development: people learned on the job. Period. There were no training courses, no formalized coaching sessions or consultations with retired expert practitioners, no *ASK Magazine*. It was very much a sink-or-swim environment, just as it had been for decades. NASA focused primarily on a few large programs and projects—this was the era of the Space Shuttle and Hubble—with relatively long life cycles. They created opportunities for new people to learn as members of large teams of experienced practitioners.

In 1986, the *Challenger* accident happened. It was a watershed event for NASA. Enormous energy and thought went into understanding what had gone wrong and what it would take to repair the NASA legacy of project excellence. Numerous committees, boards, and tiger teams worked to figure out what needed to be done to improve project management.

One idea that came out of these activities was the Program and Project Management Institute (PPMI), the precursor to today's Academy of Program/Project and Engineering Leadership (APPEL). PPMI was sponsored by then-Deputy Administrator J. R. Thompson, who assigned it an initial $2 million training budget and one civil servant. (If you judge an organization by its number of civil servants, then not much has changed: today APPEL has two.) PPMI was a training program. It focused on developing a curriculum that would provide a baseline of knowledge and competence, and it did so under the assumption that training would account for only a fraction of an individual's development; the rest would take place on the job, as it always had.

I became involved with PPMI in 1991 when I interviewed with Frank Hoban, its director, for the position of deputy director. Frank was a straight shooter. At first he didn't want me because I knew little about the real world of project management. Once we met, though, Frank decided that I had the right attitude and a willingness to learn, and he hired me straight away.

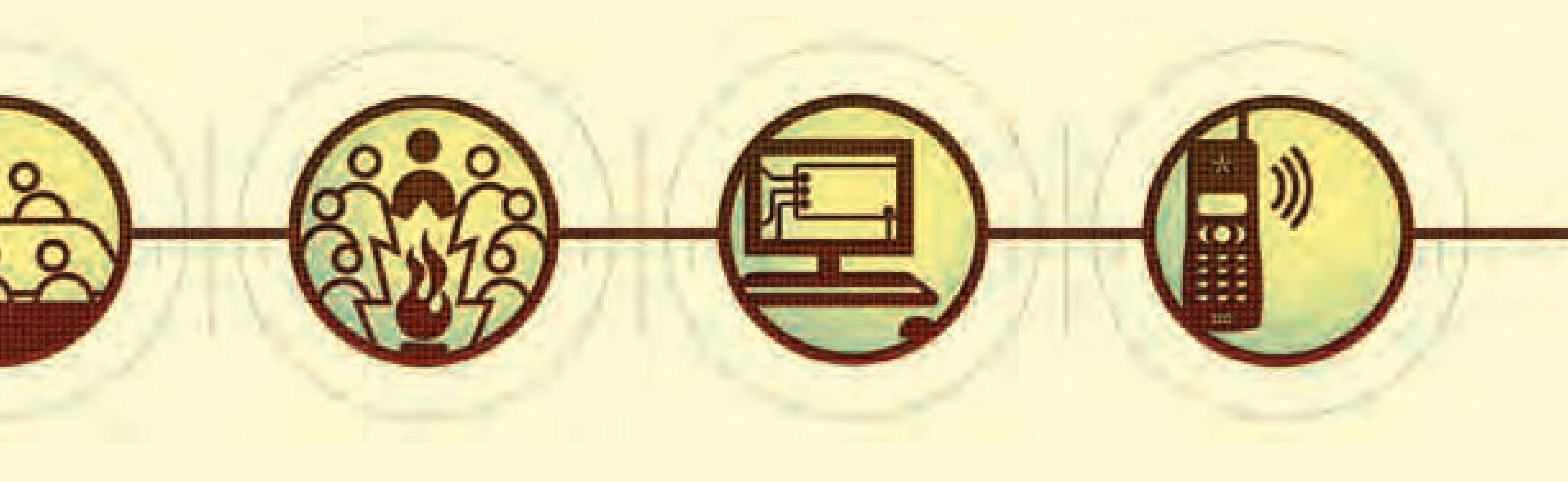
Frank understood that PPMI had to be more than a training course. He emphasized the importance of identifying the competencies required for project management and then using those competencies as a basis for building a curriculum. He knew that there were multiple ways to do project management successfully, and that our efforts depended on respecting and listening to practitioners. Training that worked had to be based on what experienced practitioners did, not on an abstract theory of what they should do.

Frank set up working groups on project management, program control, systems engineering, and other technical disciplines, and he talked to everybody. He taught me the importance of field research, of spending time visiting the centers and talking to practitioners about what they did and what they needed. He knew we could not do our job sitting behind a desk.

He also initiated the practice of writing down what we'd learned. PPMI began publishing *NASA Issues in Program and Project Management*, a journal that is still available online through the NASA Technical Report Server (NTRS) archive. He believed we had to write about what we were doing and clearly document our efforts. He got questions about that: "Why are you doing a journal about training?" His reply was that it was not about training, it was about improving the development of project practitioners. In Frank's mind, we existed to serve as a resource for the technical community as a whole. Our work had to be aligned with the NASA mission and it had to reach as much of that community as possible.

Just a few months later, Frank did something that shocked me: he left NASA. I protested that I was not ready to take over, but he assured me that I would be fine, that I was asking the right questions and pointing in the proper direction. So I ended up taking over project management development for NASA three months after arriving at Headquarters. It happened under the most improbable circumstances, and now I had to deliver.

The other landmark in professional development at NASA was the arrival of Dan Goldin as NASA Administrator. Nobody who worked for Dan would ever say he was an easy boss, but he made things happen. He became known, of course, for instituting the "faster, better, cheaper" era, but he was also deeply concerned about the development of NASA project managers. Dan looked at what PPMI was doing and said, you have a lot of courses, but you don't have a framework. He wanted us to adopt a competency-based framework for developing project managers over the course of their careers. This became the basis for the Project Management Development Process (PMDP). We researched and identified the competencies needed at each stage of a career, and we came up with a career learning strategy to attain those competencies. To this day, PMDP remains the bedrock on which our current career development framework



HE TAUGHT ME THE IMPORTANCE OF FIELD RESEARCH, OF SPENDING TIME VISITING THE CENTERS AND TALKING TO PRACTITIONERS ABOUT WHAT THEY DID AND WHAT THEY NEEDED.

is built. This is when our efforts became truly professional, culminating in the establishment of the Academy of Program/Project Leadership (APPL) in 1997.

The back-to-back failures of the Mars Polar Lander and the Mars Climate Observer in 1999 represented the next big challenge and opportunity for APPL. Dan was furious that we were doing nothing to support our project teams in the field. As painful as this was, his criticism set us in a new direction. We began offering direct support to project teams by sending them expert practitioners who could tell when a project had gone off course and help steer it back to health. To date, APPEL has sponsored hundreds of performance enhancement engagements with NASA project teams, and these services now consume the largest part of our budget.

Around the same time, I began to focus heavily on the importance of stories in NASA's project-based environment. *How* you communicate matters, and stories are a powerfully effective way to communicate real-world expertise and build professional communities. We created *ASK Magazine* as a journal for practitioners to share their stories, lessons learned, and best practices. A report by the Government Accountability Office (GAO) found that NASA needed to do a better job of sharing lesson learned, and this provided us with an opportunity to expand our knowledge-sharing efforts. Shortly after starting *ASK*, we held the first Masters Forum to provide senior practitioners with a venue where they could share stories, build cross-agency relationships, and take time to reflect on what they had learned from their experiences. We followed the Masters Forum with the first Project Management Challenge conference, which represented the first opportunity to gather a sizable percentage of the project community in one place. The last two PM Challenge events have each had more than 1,000 attendees.

Our recent developments—our leap into the present—came about when Mike Griffin became NASA Administrator. One of his first initiatives was getting the Agency's governance model right. Though that may sound like an abstract bureaucratic exercise, it had enormous importance because it determined how decisions would be made about work getting done at the project level. It set out clear lines of authority and refocused the Agency on one goal: mission success.

APPL merged with the NASA Engineering Training (NET) program to form today's APPEL, an integrated organization that has responsibility for the development of the entire technical workforce, not just the project community. Our professional development strategy now reflects a much broader focus than training. We provide a range of competency-based activities—including project team support, knowledge-sharing conferences and publications, and training—that are all linked to a career development framework. We have revamped the training curriculum to include a four-level core curriculum as well as in-depth offerings in specific technical disciplines. We place a renewed emphasis on sharing best practices and lessons learned through our e-newsletters and case studies, and we support the Agency's efforts to work with the Office of Management and Budget and the GAO on the implementation of common project standards across government agencies.

Through meeting my colleagues in other government agencies and professional organizations like the Project Management Institute, I have come to learn that NASA is seen as a leader in project team development. Many organizations are just now starting project academies to deal with the challenges that NASA had to undertake years ago, and they are hungry to learn about what we have done.

What will the next fifty years hold for NASA? I do not place much stock in forecasts for the future, but I am comfortable making this one: we live in a project world today, and we will continue to live in a project world for the foreseeable future. We have made a lot of progress at NASA, but the need for constant learning and professional growth will continue and be an ongoing challenge. ●

Some NASA Moments

We asked some long-time NASA people to describe events during their careers at the Agency that they consider especially vivid or meaningful. We got a range of responses—from personal evocations of a moment of inspiration or crisis to descriptions of the challenge of saving a threatened project or the satisfaction of years of scientific discovery. What they all express in common, though, is a passionate commitment to the mission of space exploration.

"THERE IS A **feeling of unreality** AS YOU STRAP INTO THE SPACECRAFT, AND THEN THE FIRST STAGE LIGHTS AND THE ACCELERATION AND VIBRATION JUST SEEM TO GROW AND GROW AND GROW. FOR THE FIRST TWO MINUTES, I WAS MORE A PASSENGER THAN A CREWMEMBER. HAD WE HAD A MAJOR PROBLEM, I'M NOT SURE HOW WELL I WOULD HAVE RESPONDED. BUT THE FIRST STAGE CUTS OFF; YOU COME FORWARD IN THE STRAPS; YOU LOOK AROUND. THE SECOND **stage lights**, AND IT'S VERY GENTLE. YOU TAKE A DEEP BREATH AND **all your training comes back**. THE EXPERIENCE OF LAUNCH; THE FEELING OF WEIGHTLESSNESS, OF BEING A SATELLITE ON YOUR OWN FLOATING INSIDE ANOTHER, LARGER SATELLITE; AND THE VIEW OF THE EARTH AS YOU GO AROUND ARE THE THREE WONDERS OF THAT TRIP. I HOPE THAT ONE OR MORE OF THESE COMMERCIAL ENTERPRISES THAT ARE UNDER WAY TAKE OFF, HAVE SUCCESS, AND BRING THE PRICE DOWN TO WHERE IT'S IN REACH OF A GREAT MANY PEOPLE."

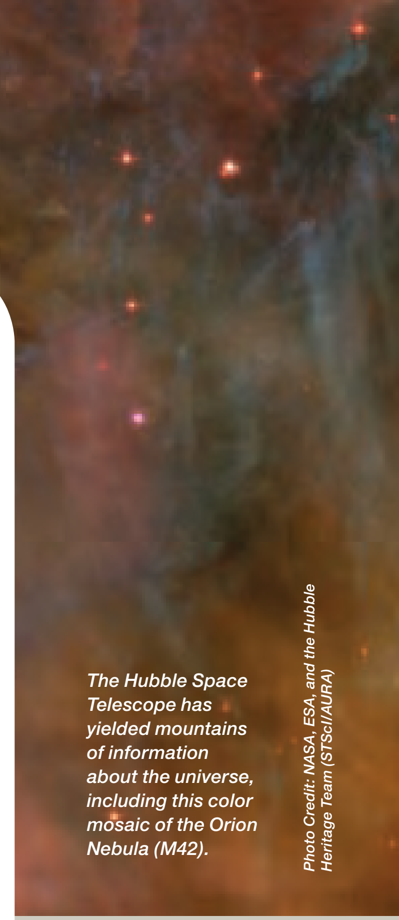
– Joe Kerwin, physician and former NASA astronaut, and the first physician ever to be selected to be an astronaut

In 1977, while I was Associate Administrator for Space Science, the Hubble Space Telescope and the Galileo mission to Jupiter were both presented to Congress for funding. James Fletcher, NASA's Administrator at that time, told me I wasn't going to get both missions and to pick one. I told him I thought we could get both. Delightfully, he let me try. The House appropriations subcommittee had approved Hubble but deleted funds for Galileo. But the House authorizing subcommittee had approved the Jupiter mission, so the disagreement needed to be resolved by a floor vote of the full House.

I went to the Hill to watch it. After a long, intense discussion, the vote was taken: 280 in favor of Galileo; 131 opposed; 22 abstentions. We had won. I went back to the administrator that same afternoon and said, "Jim, I told you we could do it." He looked at me and said, "Noel, you may live to regret that." Indeed, the following year at the House appropriations subcommittee hearing the chairman, Edward Boland, really took after me. He was still angry and extremely frosty.

It was worth it! We got Hubble and an incredibly exciting planetary mission, two of the highlights of my five years as Associate Administrator for Space Science.

– *Noel Hinners, formerly NASA's Associate Administrator for Space Science (1974–1979), director of Goddard Space Flight Center (1982–1987), and director of the Smithsonian National Air and Space Museum (1979–1982)*



The Hubble Space Telescope has yielded mountains of information about the universe, including this color mosaic of the Orion Nebula (M42).

Photo Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

"I was managing Galileo, which had been rescheduled several times due to external factors, mainly related to the shuttle program. It was originally scheduled for launch in 1982, then 1984, then 1986. Each change involved major reprogramming requiring different upper-stage configurations and different spacecraft configurations. Keeping the project intact through it all was programmatically and technically challenging. For the '86 launch our plan was to use the shuttle with the wide-bodied Centaur upper stage to send Galileo on to Jupiter. In January of '86, we were at the Cape readying the spacecraft for launch in May. The project had been stable and undisturbed for a couple of years, and it looked like we were finally on track for a May launch.

Then the *Challenger* accident happened. We knew that would mean a long delay before there would be another shuttle launch. Later we had other bad news. NASA decided that the Centaur was potentially too dangerous to fly on the shuttle. We were left with the much less energetic IUS (Inertial Upper Stage), which we 'knew' couldn't get us to Jupiter.

I encouraged people to think of anything and everything that might work. We began to explore the possibility of launching on the Russian Proton rocket, though that clearly would involve political issues. One day, a young engineer came to my office and suggested a new, radically different trajectory that would work with the lower-power upper stage. It would mean getting gravity assists from a Venus flyby, followed by an Earth flyby, going out to the asteroid belt, then back for a second Earth flyby, and then on to Jupiter. I immediately saw that this was a viable solution. We would have to make a few changes to the spacecraft. It would need new heat shielding because it would travel closer to the sun than in the original mission plan. It would need a second low-gain antenna to give coverage on the aft side of the spacecraft, because Earth would be on the aft side during the time the spacecraft was traveling inside the orbit of Earth. Thanks to my earlier work on the Mariner 5 and Mariner 11 projects, I knew these changes were doable. Galileo launched in 1989 and arrived at Jupiter in 1995.

For me, the lessons of this often-challenged project were

- Don't ever give up
- Be open to innovative solutions and ready to try things that have never been tried before

Years later, a colleague said the word back then was that, 'Casani lives in a world without corners,' meaning that, in spite of all the programmatic and technical challenges faced by Galileo, the project always found a way to slip out of the corner."

– *John Casani, currently special assistant to the director at the Jet Propulsion Laboratory; previously managed Voyager, Galileo, and Cassini*

Many scientists would be happy to make a discovery every year. Those of us on the Voyager team were fortunate to have participated in floods of discoveries: one surprise after another that have changed and deepened our understanding of the solar system.

The two Voyagers were launched in 1977. For over a year they traveled toward the outer planets with only some of the scientific instruments returning data. Then, as Voyager 1 approached Jupiter, increasingly better information poured in day after day. Every afternoon for more than a week, the science team met to discuss what had arrived in the previous twenty-four hours, what we were learning, and what we did not yet understand about the data. The following morning we would have a press conference to announce our new insights into the planet. That afternoon, we would examine more new data in another science meeting and the process would repeat itself.

The surprises kept coming. Images of Io, one of Jupiter's four moons, showed hundreds of black spots. Although it had just been proposed that Jupiter's moon would experience tidal heating from the gravitational pull of the giant planet, until we actually saw a volcanic plume, we couldn't take the leap and acknowledge that those spots were calderas. We had discovered hot lava lakes and nine active volcanoes on Io. That was the end of the old idea that the further reaches of the solar system would be cold and dead.

We experienced those intense, illuminating seven- to ten-day periods of discovery in the years following as the Voyagers flew by Saturn, Uranus, and Neptune and their satellites. The wealth of new information also gave us opportunities to engage the public and share the excitement of the many discoveries. In those days before the advent of the World Wide Web, we sent real-time pictures to planetariums around the country. Crowds gathered to glimpse these first close-up images of what had been, until then, little-known points of light in the sky.

Even today, more than thirty years after the twin Voyager spacecraft left Earth, we are still learning and still surprised. Voyager 1 is approaching the heliopause, the extreme outer edge of the bubble of solar wind ions that envelope the solar system. It is already in the area where a shock forms as the million-mile-per-hour outbound wind of solar ions abruptly slows as it presses outward against the external interstellar wind. We expected that shock would heat the solar wind ions but found that the energy of the collision mainly heats ions coming from outside the solar system—another surprise we are striving to understand.

In another seven years or so, Voyager 1 will leave the solar bubble and begin traveling through material that comes from other stars. The scientific adventure—and the learning—continues.

– Ed Stone, former director of the Jet Propulsion Laboratory (1991–2001), Voyager project scientist, and currently professor of physics at Caltech

My most vivid moment was my time as mission director on Viking and landing on Mars. No one had ever landed a spacecraft on Mars—or any planetary body other than the moon—and had it successfully operate afterward. We were doing something no one had ever done before. It was an extraordinary engineering challenge, but even more than that we had the opportunity to learn firsthand about a planet that had been shrouded in mystery and intrigue for decades. The science was exciting, and the engineering was exciting. It was tough to do and had no certainty of being successful.

As we approached Mars orbit, one of the first things we ran into was a helium leak in the propulsion system. The helium pressurized the fuel in the rocket onboard the orbiter, and if we didn't do something about the leak, the pressure would build up and it would explode. We had two possible courses of action: we could blow a pyrotechnic valve that would seal off the helium so it wouldn't leak anymore, or we could burn the engine periodically, doing a large number of midcourse maneuvers to relieve the pressure. The easy thing to do was to blow the pyrotechnic valve. The problem was it would leave us to rely on only one working pyrotechnic valve. If that one didn't work, the mission would fail. So we chose the hard way, the series of midcourse maneuvers. This meant a lot of work for all of us on the flight team, but it worked.

As we got even closer to Mars, we began to worry that the preselected landing site was too rough. Now, the smallest thing we could see was the size of the Rose Bowl, but all the geologists and people who really understood Mars knew enough to worry about the site. We took time looking for a new landing site. We were originally supposed to land on July 4, 1976, to celebrate America's bicentennial, but we never hesitated one second to abandon the 200th anniversary. We never considered taking extra risks to meet that date.

The lander was finally ready to land. The landing went as expected, and I remember the feeling of relief, excitement, and anticipation when it landed and we confirmed we were really on the surface and things were working well. At that point it was an engineering success. But we didn't go there for an engineering success, we went there to learn about Mars.

It was a fantastic feeling, but we had yet to learn what Mars looked like. I remember watching as the first picture came in. The resolution was such that you could see something as small as a blade of grass. Seeing that picture come in was the fulfillment of the eight or nine years I spent working on Viking.

– Tom Young, mission director for Viking

"There were tremendous people in the mission planning and analysis division who developed all the information about when to conduct burns, how long they would be, and the spacecraft's attitude during the burns. Starting with Apollo 8, they did a fantastic job building on the experience of the robotic missions. I still marvel, back then and to this day, at their accuracy. Everything came out almost to the second.

It was our job in flight planning to fit in all the crew activities and procedures so things happened when they were designed to happen. When we flew those Apollo missions, we had a set of simulators here at Johnson Space Center—a command module simulator and a lunar module simulator. There was a duplicate set at Kennedy Space Center (KSC), and the set in the training facility at KSC was kept in the absolute configuration of the flight so that, late in the game, whatever changes were made were implemented at KSC. The crews spent the last couple of months training at KSC, and we would go down there and do all the final flight planning and procedure adjustments out of a little office at KSC.

I had that duty for Apollo 11. I was there with a couple of other people working on all the things leading up to the mission. It was quite a task because there were so many possible adjustments to the procedures and the flight plan. We made 1,100 changes in the last two months. Some of the adjustments came from refinements of the trajectory. Even more of them came from a more detailed understanding of how systems might operate in the lunar environment. And we made some changes late in the game having to do with the settling of the spacecraft on the lunar surface and whether any propellants would be trapped in the nozzle of the engine and therefore be an explosive hazard. So we developed procedures to bleed off residual propellant. We had to verify all these changes, carry them out in the simulators, and validate that they were ready to go. We worked with the flight control team back in Houston to make sure that it was all squared away with them.

You can imagine that we stayed a little nervous, hoping everything was the way it was supposed to be to carry out this mission. When Apollo 11 landed, we felt tremendous accomplishment but also concern about how things would go on the surface and then how they would go when we had to lift the ascent module off the moon and rendezvous with the command module for the trip home. Once they had rendezvoused and the command module and crew were on the way back, we breathed a little sight of relief. There wasn't total relief until those three parachutes were out there and they were descending to the ocean.

We had such gifted managers in the program. The secret of Apollo was the capability of the management team and the hard work of all the supporting people trying to make it happen. Their dedication, conviction, and enthusiasm were unbelievable. No one left work. They might go home for a while, but no one left work."

— John O'Neill, chief of the Flight Planning Branch during Apollo 11 and deputy director of the Mission Operations Directorate during Apollo 13

As a very young child, I had a strong interest in space exploration and pursued it with all my intellectual curiosity. I was also a co-founding member of our fourth grade science club, and I hoped that someday I could contribute to this great endeavor, however unlikely that seemed at the time.

Then along came "reality"—the draft, Vietnam, and the Tet Offensive—and those visions were lost to the **insanity and turbulence of that age.** Little did I realize that when I returned from that life-changing experience, I would experience another within less than a year.

Like most of the other billion-plus people who witnessed it, the most vivid and moving NASA moment for me was watching Neil Armstrong and Buzz Aldrin take those first steps on another world. I also had a deep interest in journalism and interpretive reporting—the human stories behind the news. I watched Walter Cronkite become speechless at the sight of the first human lunar landing. He turned to Eric Sevareid, who commented that, because of what we are witnessing today, "I now have hope that humankind will endure in the cosmos, despite what we may do to ourselves here on this Earth." I knew, at once, that I had heard a fundamental truth. That visual experience, those compelling words, that seminal moment touched me, rekindling the curiosity and drive that would help a child's distant, and **seemingly unreachable goal, become a reality**—to somehow contribute, in however small a way, to this amazing, inevitable adventure.

– Lewis Peach, former vice president for Exploration and Technology and chief engineer for USRA, director of Advanced Programs in the Office of Space Flight at NASA, deputy director for space station engineering, and associate director for computational physics and supercomputing

Shaping the Space Age: The International Geophysical Year

BY MATTHEW KOHUT

It's a story so familiar it has achieved popular status as NASA's creation legend: when the Soviet Union launched Sputnik in October 1957, it shocked the flat-footed United States into action, locking the Cold War gladiators into a space race. Like most legends, there is a kernel of truth in it, but the full story is more complex. The United States had been working fervently for years to develop its own capability to reach space, most famously through the efforts of Wernher von Braun's group of rocket scientists at the Army Ballistic Missile Agency. More than two years before Sputnik, the United States had already announced its intention to launch a satellite that would collect scientific data "to benefit scientists from all nations." The launch would be the centerpiece of the United States' participation in the first International Geophysical Year (IGY), an oft-overlooked event that helped set the stage for space exploration.

Despite what its name suggests, the IGY was an eighteen-month period from July 1, 1957, through December 31, 1958, during which scientists around the world conducted coordinated observations in eleven earth science disciplines. The IGY began with forty-six participant countries; sixty-seven ultimately became involved. Both Sputnik and Explorer I, the U.S. satellite launch that followed four months later, took place during the IGY. The IGY helped define aims and values that have characterized much of our first fifty years in space: an emphasis on science missions whose results are shared with international communities of scientists. One of the three elements in NASA's mission statement describes a goal similar to that of the IGY, though grander: "To advance and communicate scientific knowledge and understanding of the earth, the solar system, and the universe."

The genesis of the IGY has also become something of a legend. It was the inspiration of Lloyd Berkner, an American physicist who worked at the nexus of the scientific and national security communities in a career that seemingly fused Indiana Jones with "The X-Files." He was an adventurer who accompanied Richard Byrd on his Antarctica expedition in 1928. During World War II, he worked for the U.S. Navy on the development of advanced radar technology. After the war, he became the executive secretary of the Joint Research and

Photo Credit: NASA

Jet Propulsion Laboratory Director Dr. James Pickering, Dr. James Van Allen of the State University of Iowa, and Army Ballistic Missile Agency Technical Director Dr. Wernher von Braun triumphantly display a model of the Explorer I, America's first satellite, shortly after the satellite's launch on January 31, 1958.

Simulated Van Allen Belts are generated by plasma thruster in Electric Propulsion Laboratory tank #5 at the Lewis Research Center, now Glenn Research Center. The discovery of the Van Allen Belts has been widely recognized as the greatest scientific contribution of the International Geophysical Year.

Development Board that advised the Department of War and the navy on integrating science and technology into military research and development.

In April 1950, Berkner raised the idea of the IGY at a dinner party held by physicist James Van Allen, who worked at the Applied Physics Laboratory at Johns Hopkins University. The British geophysicist Sydney Chapman was also at Van Allen's that night, and he latched on to Berkner's suggestion, noting that a period of high solar activity climaxing in 1957–1958 would be an ideal time for observations. All three scientists shared an interest in the potential uses of rockets to expand the reach of atmospheric research.

Berkner suggested the IGY as a broadening of the International Polar Year (IPY), which had been held twice before, in 1882–1883 and 1932–1933. During the first IPY, twelve countries participated in fifteen expeditions to the Arctic and Antarctica. The second IPY focused on the newly discovered "jet stream" and saw participation expand to forty nations. Two years after conceiving the idea at Van Allen's house, Chapman and Berkner formally proposed the IGY to the International Council of Scientific Unions (ICSU). Once the ICSU approved it, Chapman and Berkner became president and vice president, respectively, of the ICSU's special committee set up to manage the event. The IGY took place concurrently with the third IPY in 1957–1958.

A U.S. National Committee operating under the guidance of the National Science Foundation coordinated U.S. involvement. The National Science Foundation and the National Academy of Sciences made the case in Washington in favor of developing an Earth satellite, and by July 1955, the White House announced its intent to launch one during the IGY.

On the eve of the IGY's kickoff, President Dwight D. Eisenhower said that "… the most important result of the International Geophysical Year is the demonstration of the ability of peoples of all nations to work together harmoniously for the common good."

Eisenhower's desire for cooperation faced a severe test four months later when the Soviet Union launched Sputnik on October 4, 1957. Within six weeks, the Senate Armed Services Committee, led by the chairman of the Preparedness Investigating Subcommittee, Senator Lyndon B. Johnson, began an "Inquiry into Satellite and Missile Programs."

On January 31, 1958, two months after the hearings began, Explorer I was launched. Though Sputnik beat the U.S. satellite into space, it returned nothing of scientific value. Explorer I achieved the true goals of the IGY. Through the use of a cosmic ray detector that flew on Explorer I, James Van Allen discovered a radiation belt around Earth, which was later named for him. This has been widely recognized as the greatest scientific contribution of the IGY.

Despite the competitive dynamic between the superpowers, cooperation remained a key consideration for the United States as it developed its civilian space program. NASA's first Administrator, T. Keith Glennan, appointed a director of the Office of International Cooperation as part of the new Agency's management team in October 1958. Within a year, this position went to Arnold Frutkin, who had recently served as deputy to the executive director of the U.S. Committee for the IGY at the National Academy of Sciences. Frutkin's experience with the IGY directly shaped NASA's early approach to international cooperation. He went on to write *International Cooperation in Space*, a seminal work on the topic.

The IGY's legacy was vast. In addition to the first satellite launches, it resulted in significant scientific gains. Research conducted in Antarctica helped pave the way for ratification of the 1961 Antarctic Treaty. The World Wide Data Centre was established to collect and share atmospheric measurements. Perhaps most importantly, though, the IGY set a precedent for peaceful international scientific collaboration that has been emulated through events such as the International Year of the Quiet Sun of 1964–1965, during which NASA launched Explorer 30 and a number of ship-based sounding rocket experiments. The clearest evidence today of the IGY's enduring legacy is the fourth International Polar Year, which began in March 2007 and runs through March 2009. ●

NASA'S FIRST SCIENTIST-ASTRONAUTS

BY JOE KERWIN

We who were not test pilots were delighted when NASA announced it was going to hire scientist-astronauts, that is, people with PhD or MD degrees that might prove useful in space flight. We didn't think too much about what NASA's plans were in detail. We just went for it.

The scientist-astronaut program was a little vague at the beginning. When we arrived, we found that NASA had given in to pressure from a scientific community that looked forward to what then seemed an infinitely expanding space program. There was lots of optimism in the early and mid-sixties about what we would do in the next ten or fifteen years. But NASA didn't have a very clear idea of what to do with scientist-astronauts once they had them.

My first visit to the astronaut office after being hired was illustrative. Three of the guys were off being trained as pilots. Curt Michael, an air force pilot and theoretical astrophysicist, and I were there, sitting in the back of the room at the Monday morning pilots' meeting. Al Shepherd mentioned that we'd been hired and said that NASA had given the OK to hire another group of astronauts next year. Dick Gordon asked, "Are they going to be pilots?"

Al said, "I certainly hope so."

It's not that the welcome we got was cold; it was just sort of quizzical. There were some valid questions, like, "Are you going to put a guy on a mission to the moon who hasn't got the kind of experience managing aircraft and spacecraft that test pilot–astronauts have got?" In fact, no scientist flew in Apollo until Jack Schmitt flew on Apollo 17.

Three of us flew on Skylab missions, which were considered less adventurous in terms of the piloting skills they required—that certainly was true—and more important as far as scientific output was concerned. All three of us—Owen Garriott, a PhD electrical engineer with wide-ranging interests in science; Ed Gibson, whom we considered our astronomer; and myself—believed that we contributed significantly to the success of the program on a number of fronts. The Skylab program began development a couple years after we showed up. Working Skylab support along with our training for space flight and other duties, we were able to contribute a lot to the development of equipment and procedures for the program.

The Skylab mission was the first that gave space medicine top priority. The in-flight medical support system—that is, the doctor's bag flown on Skylab—was considerably more sophisticated than would be needed or could be justified if the crew were just pilots. What pilots would need was a first aid kit with maybe a few extra items that they were trained to use. We had a lot of drugs, we had laboratory equipment, and we had minor surgical stuff. The very fact that physicians were allowed to put that stuff on the manifest and then develop it and test it and fly it put them ahead of the game for the follow-on programs.

I think the principal investigators of the life sciences experiments might agree, if any of them are still around, that having a physician-astronaut as their interface to the operational world was a good thing. They achieved more cooperation and a much higher level of priority working with Dr. G. Donald Whedon on his complete intake and output study, which required us to weigh and measure any uneaten food; to adhere to a very rigid diet preflight, in flight, and post-flight; and to collect all the urine and feces. It was a dog of an experiment. I doubt that it will ever be repeated because it was so much work. But we did it, and we did it well.

The other major science area on Skylab was the solar physics package, the so-called ATM (Apollo Telescope Mount), which was a state-of-the-art package of six or seven telescopes and cameras, all focused on the sun. Owen and Ed were in charge of operating it and were able to get us all intensive training and bring us up to the level, not of scientists—not in my case—but of graduate students, able to do an intelligent job at that console. As the missions went on, they were given more and more autonomy. They had the right to turn on cameras and focus on specific phenomena they were seeing on the solar disc. We went pretty much by rote on my flight, but Owen and Ed, on their two-month and three-month flights, were really turned loose. They did a lot of excellent work, just as Jack Schmitt did on the surface of the moon. The result was a wonderful harvest of scientific data. I think we showed a positive role for scientists in space.

The second scientist-astronaut group, eleven folks hired in 1967, didn't make out very well. Shortly after they arrived at NASA, they dubbed themselves "the excess eleven" because the program had already taken a downturn in budget and future prospects. There was a huge gap between Skylab and the shuttle, and the majority of them couldn't sit around for ten years or longer. Many of them left.

The next step in this process was preparing for the shuttle program, including making determinations and agreements with the science community on scientists' roles. There was a lot of fuss, bother, and argument during the seventies—the period when the shuttle was in development—to determine who should be on shuttle crews. The result, eventually, was a three-part crew definition: the pilots, the mission specialists, and the payload specialists. It hasn't always been religiously adhered to, but it's been the core for the whole shuttle program. The mission specialists are the career astronauts, some scientists and some engineers, who have the experience and responsibility to ensure the operability of the experiments and, with their scientific backgrounds, often to be productive in science as well. But when you really need a scientific expert, you hire a payload specialist, often from the community or the university that is sponsoring an experiment, and send him or her up. They fly with their experiment. They're not career people. Most of them fly once, some two or three times. I think that layout has given NASA and the scientific community the flexibility they have needed to do good work in science on the shuttle.

Having science on board is part of NASA's culture now. It's helped by the fact that not everybody needs to be a pilot on larger vehicles like the shuttle. That should be the case on the International Space Station (ISS). Unfortunately, we haven't yet gotten to a point where we can put more than three people up there for long durations.

I report with a mixture of pride and disappointment that the Skylab medical results are still, by a good margin, the best that have ever been done in space in terms of understanding human physiology and measures to counter the effects of living in space. They should have been surpassed by the space station. ISS offers a wonderful opportunity to get significantly sized crews up and do advanced experiments with enough numbers to get statistically significant results, but it hasn't happened yet due to many problems in the space station program.

Learning from Skylab

The first and most amazing surprise on our flight was the fact that, after three to seven days, depending on the individual, you become immune to space motion-sickness. That is a significant, unexpected finding. It gives us hope that humans will tolerate unusual acceleration environments quite nicely, even a rotating spacecraft with artificial gravity. I think they will be able—this is an unproven assertion—to live in a rotating spacecraft with an inertially stable core and transition from one to the other without any trouble once they get used to it. We had a rotating chair in Skylab designed to measure the response of the vestibular system—the inner ear—to weightlessness. One of three or four major parts of that experiment was to spin that chair up at a pretty good rate and make head movements guaranteed to make you motion sick and see whether the number of head movements it takes was more, the same, or less in weightlessness than it was on the ground. In our case, because we had problems with the vehicle, it took several days to cool off and activate Skylab to the point where we could start doing that test. The first time we did it, day seven or eight, we had no symptoms of motion sickness at all.

Skylab was the engineers' opportunity to excel because that was a mission in which the Skylab itself, the orbiting workshop,

Astronauts Joseph Kerwin (left) and William Lenoir familiarize themselves with equipment aboard the Spacelab mockup during a 1976 visit to the Marshall Space Flight Center.

Photo Credit: NASA

Photo Credit: NASA

After Skylab's launch, the large, delicate, meteoroid shield on the outside of the workshop was ripped off by the vibration of the launch. Engineers worked frantically to develop solutions to this and other problems and designed a protective solar sail to cover the workshop. Here astronauts practice deploying the protective solar sail in Marshall Space Flight Center's Neutral Buoyancy Simulator. Astronauts Conrad and Kerwin were able to complete the needed repairs to Skylab, salvaging the entire program.

was seriously damaged during launch by the loss of the heat shield, the loss of one solar panel, the closed pinning of the other solar panel, the overheating in orbit, and the inadequate electrical power. People worried about losing the whole program. The engineers got to work and in ten days devised three different ways of getting the temperature down and got an advance handle on the equipment we might need to free up the solar panel. We went up and did all that stuff and saved the program.

When we launched on Skylab, there was a lot of fear about spending even twenty-eight days in space. "Can they go twenty-eight days?" People worried, "Will they even be able to stand up afterward? Will they all die if they have to egress the spacecraft?" Now we don't have those worries any more.

Exercise is a necessary and sufficient countermeasure to muscle weakness and possibly cardio-vascular deconditioning in space flight. We saw that develop from the first to the second and third missions. After the twenty-eight days of our flight, we came back with significant weakness in both the arms and the legs—mostly the legs—despite the fact that we had a bicycle ergometer and used it pretty much every day. The second flight doubled the exercise time and added some isometric exercise. They did as well in two months as we did in one. The third crew added a poor man's treadmill and gave another half hour a day to exercise. They were up there for almost three months and came back in better shape than the second crew, slightly better than ours, and their appetites improved; their weight loss was less than either of the other two crews. That was the combination of findings that really gave us confidence to build the space station and say, "Humans are going to be able to go to Mars because a combination of the proper diet and proper exercise is going to keep us fit long enough to get there."

The Future of Life Sciences in Space

In the future, I think we need to be open to the opportunities and the adventures and discoveries that we make, many of which will be unexpected. In life sciences, what we've learned about human physiology is very interesting, but we're talking about adult human beings in space for periods of one to six months. What is going to happen to animals that are born and grow and reproduce in weightlessness over a number of generations? Let's fly a Noah's Ark some day when we're ready and fly and raise a bunch of animals in weightlessness and see what happens to their physiology, to their anatomy, to their DNA. Will we produce different species? Will adaptation take place? I think there's a world of discoveries open in that direction. ●

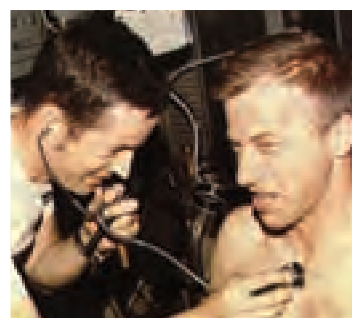
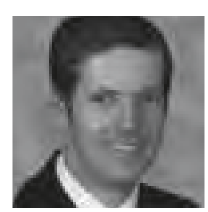


Photo Credit: NASA; Charles Conrad, Jr.

Astronaut Paul J. Weitz, Skylab 2 pilot, gets a physical examination by a fellow crewman during the twenty-eight-day Skylab 2 mission.



JOE KERWIN is a physician and former NASA astronaut. He was the first physician ever to be selected to be an astronaut.

Using the Moon to Learn About Living on Mars

BY LAURENCE R. YOUNG

So we are going back to the moon, this time with more people staying for longer periods. The lunar outpost has been envisioned as a substantial home base—if not a settlement—to house and supply astronauts as they explore the lunar surface. It needs to be more than that. Since one of the principle arguments in the Vision for Space Exploration is to use the moon to prepare for further exploration of the solar system (read Mars), we should be planning how to take advantage of this new opportunity. If we concentrate our efforts solely on maintaining the health and safety of the crew, we will miss out on a unique chance to understand the challenges to human survival on Mars.

The major issues in reduced gravity are well known from our experiences in orbit from Skylab and Spacelab through Mir and the International Space Station. Bones lose strength and size when deprived of the regular compressive forces associated with walking, and muscles atrophy when no longer required to support body weight. The cardiovascular system, which regulates blood pressure, volume, and flow, is no longer challenged by "standing up," and we are likely to faint when standing erect back on Earth. Posture is disturbed by the absence of a steady pull on the vestibular organs that regulate balance. The open question for us is the extent to which such potentially hazardous disruptions would also be present in the partial gravity of Mars, with its attractive force only three-eighths that of Earth.

One might conjecture a linear relationship for physiological parameters, between the values at 1 g (Earth gravity) and those at 0 g, making it simple to predict the results at 3/8 g. But biological processes are almost never linear. Doubling the input rarely doubles the output. Instead, we commonly see thresholds, saturations, hysteresis (or lagging effects), and other non-linearities, which make it folly to imagine we can predict effects between those two values. However, if we can insert reliable measurements at some third g level

Photo Credit: NASA

At Moses Lake, Washington, in June, astronauts, engineers, and scientists wore demonstration spacesuits, drove prototype rovers, and simulated scientific work to test some of the tasks that NASA studies have identified as possible in future lunar exploration.

THE LUNAR LABORATORY WOULD PROVIDE INVALUABLE INFORMATION, NOT ONLY ABOUT THE ABILITY TO SURVIVE THE CHALLENGES OF LIVING ON THE MOON, BUT ALSO ABOUT THE LIKELY DIFFICULTY OF LIVING IN MARTIAN GRAVITY.

between 0 and 1, we might better be able to predict the physiological effects of gravity throughout the range. If we add measurements of human deconditioning at lunar gravity (1/6 g) to our existing 0 g and 1 g data, we will be in a much better position to anticipate the experience of 3/8 g. Our outpost on the moon will present exactly that opportunity. All that will be required is a well-equipped lunar laboratory, along with careful scientific protocols and the commitment of astronauts to adhere to the testing requirements.

For example, bone density and imaging, muscle size and strength, cardiovascular regulation, and postural stability would need to be measured periodically during a stay of three to six months on the surface. Exercise and other countermeasures would need to be specified and monitored. Extravehicular activity in particular would need to be recorded and monitored to see whether the exercise associated with work in a pressure suit alone would provide sufficient protection, and a control group would eventually be required as well. The lunar laboratory would provide invaluable information, not only about the ability to survive the challenges of living on the moon, but also about the likely difficulty of living in Martian gravity.

If it turns out that simply living and working at lunar gravity is sufficient to maintain fitness, then we can be confident that Martian gravity will be similarly adequate, and no special countermeasures will be called for on Mars. On the other hand, if living at 1/6 g produces bodily deconditioning like that seen at 0 g in orbit, then we probably should prepare a range of countermeasures to assist our Martian explorers during their stay on the planet. The lunar outpost can be a true space laboratory and offer a unique opportunity to learn how to protect human beings as we venture into the solar system. ●

LAURENCE R. YOUNG is the Apollo Program professor of astronautics and professor of health sciences and technology at the Massachusetts Institute of Technology.

Photo Credit: Ed Quinn

Space Science: Forty-Five Years of Thinking and Tinkering

BY NOEL HINNERS

Starting in 1963, I have witnessed in amazement the science discoveries made by the nation's human and robotic space program. I also had a direct hand in those discoveries, first on Apollo and subsequently as NASA's Associate Administrator for Space Science and director of Goddard Space Flight Center. As director of the Smithsonian National Air and Space Museum, I saw firsthand the impact our space and aeronautics programs have on the public, and at the University of Colorado's Laboratory for Atmospheric and Space Physics and its aerospace engineering sciences department, I've witnessed their power to inspire students. NASA, especially in its forays in space science, has the capability to expand our knowledge and understanding not only of the universe around us but also of our own planet. The science done by exploring space is, at its core, an extension of physics, astronomy, geology, and chemistry—things we've done terrestrially for well over a hundred years. But leaving the confines of our own atmosphere has materially advanced our knowledge in those areas and offered boundless material to inspire practical applications and our imaginations.

When I started my specialty of planetary science in the early sixties, the moons and other planets were simply interesting little blobs in space. But each time we take a closer look, we find out how incredibly fascinating and complex they all are. We've seen evidence of geologic processes unlike those that have occurred on Earth, and what we see on Titan may mirror the most primitive beginnings of our solar system, going back to when organic chemistry was being formed. Organic chemistry, along with water, is the key to life, and the search for life remains a driver of space science. Cassini's results at Titan have taken on incredible priority because they may give us a clue about how life started in the solar system. The recent findings of abundant past water on Mars have also invigorated the new field of astrobiology.

The complexity and incredible diversity of geologic processes that we're seeing in the solar system beat anything we imagined in the early sixties. Getting above our atmosphere and seeing light wavelengths that are typically obscured have broadened what we know about the evolution of the universe, galaxies, dark energy, and black holes—knowledge that helps us solve more of the mysteries about our own planet and how it fits into the grand puzzle.

Where we can explore is, as far as we know, limitless. So choosing our destinations and experiments is not an easy task. Picking one foray from among thousands—or millions—of possibilities requires coordination between NASA and the external science community, an ongoing collaboration that has been one of NASA's major strengths.

Deciding Where to Go

Deciding which endeavors to pursue requires first asking, "Is it good science?" The proposals NASA receives come from scientists who make a career out of thinking about what's exciting in space and how to find out more, so they can answer that question well. But there is always more science to do than can be accommodated.

NASA, like Gaul, is divided into three major parts: human space flight, aeronautics, and space and earth science. I headed up the space science part of NASA as associate administrator from 1974 to 1979, and my job was both to manage the programs we had taken on from a Headquarters perspective and to initiate new programs. Each endeavor requires being both a proponent and a

This montage of the nine planets and four large moons of Jupiter in our solar system is set against a false-color view of the Rosette Nebula. Most of the planetary images in this montage were obtained by NASA's planetary missions, which have dramatically changed our understanding of the solar system in the past thirty years.

Image Credit: NASA, Arizona State University

manager. The Agency works closely with the National Academies' Space Studies Board to help decide what priorities should be, asking, "Is it forefront science? Is it potentially a breakthrough? Does it add materially to our store of knowledge?"

Science prioritization was and is an important job at Headquarters. It was easier to do for small missions, because the big ones, like Galileo and Hubble, required so much of the budget it made them tougher to get approved. A big part of my job was selling the big science programs that had major science payoffs while keeping the little ones that also contributed invaluable science going. COBE was one of those small programs, and it is NASA's only Nobel Prize–winning mission.

Beyond Science and Engineering

NASA's collaboration with the external science community doesn't end once a destination has been chosen. Once we have a destination, we have to figure out how to get there and achieve the science experiment. After all, the experiments—and a means of getting them into space—still need to be created. Communication between scientists and engineers is essential for a project to succeed. These two communities speak different languages, however, and it's not always easy for them to understand one another. By having a quality in-house science community, NASA has been able to forge a better link between its engineers and the academic science community.

Excellent engineering and science are the *sine qua non* of mission success, and NASA has the skills to solve technical issues, but these alone are insufficient. Failure reviews from *Challenger, Columbia,* and the Mars '98 missions consistently point out how a lack of genuine communication is often a major contributor to problems. Communication is in and of itself an art form that must be cultivated. We must ask, are we talking to one another in terms we understand? Are we listening with intent to hear? Have we properly aligned roles and responsibilities so we're not getting in each other's way? Are we working in a cooperative mode where everybody is providing the skills and capabilities that bring a project together? Communicating, understanding one another, and defining roles and responsibilities are essential necessities for project success. NASA clearly recognizes this and actively supports team development to hone communication skills and should continue this practice.

Once the right team is in place and communicating well, many missions face the budget hurdle. Stringent budgets have been with NASA continually, even during the latter part of Apollo. This presents the challenge of figuring out how to do missions more economically, do them more quickly, get more for the investment dollars, and push the boundaries without falling into the downside of faster, better, cheaper. I was involved in the infamous faster-better-cheaper era, which resulted in the Mars mission failures of the late nineties. But they didn't fail because faster, better, cheaper is inherently a bad concept. When you take the practice to extremes and try to do things for too little money, though, you get into trouble. We should have been smart enough not to push ourselves to attempt things that didn't make good engineering sense. It was a painful lesson and one we need to transmit to those who are coming into the business today.

From Discovery to Further Exploration

Mars has long been high on the list of places to go. It has had a special place in science programs and in dreams about human exploration. Much of this fascination was driven by both the fantasy and actual potential for finding life. The early Mariner flybys and orbiters set the stage. And then, in 1976, Viking landed with a prime goal of searching for evidence of life on Mars. While obtaining a lot of geologic and atmospheric information that significantly improved our understanding of the Mars environment, it detected no evidence of life. This is not because there never was or never might have been primitive life, but because all the evidence we've gathered so far shows that Mars has a very chemically active, oxidizing surface, which destroys organic molecules. This active surface remains today, even at the Phoenix site. It is one of the most intriguing and damning aspects of Mars. The surface is so oxidizing, I wonder if humans can cope with it. Can we devise life support systems for astronauts that will enable them to be safe? This is a major question as regards future human exploration of Mars.

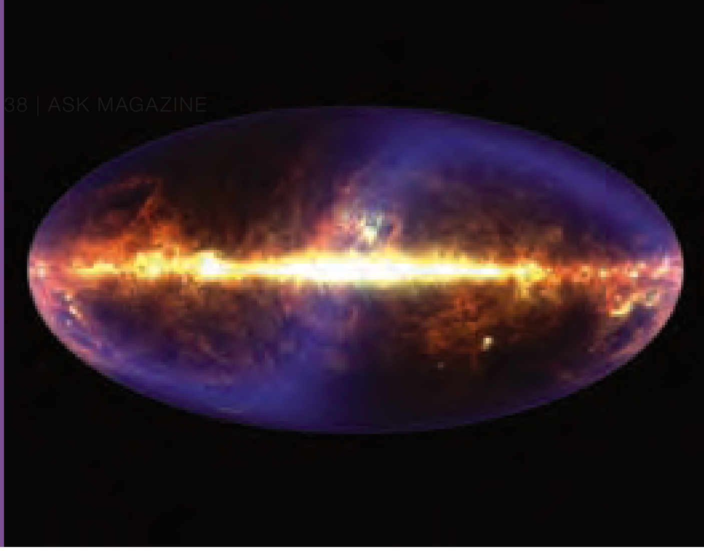


Photo Credit: NASA

Small explorer missions like the Cosmic Background Explorer (COBE) contribute to space science as much as the larger missions, like Hubble. COBE won a Nobel Prize and helped prove the big bang theory. The above image, in representative colors, is a projection of the entire infrared sky created from years of observations by COBE.

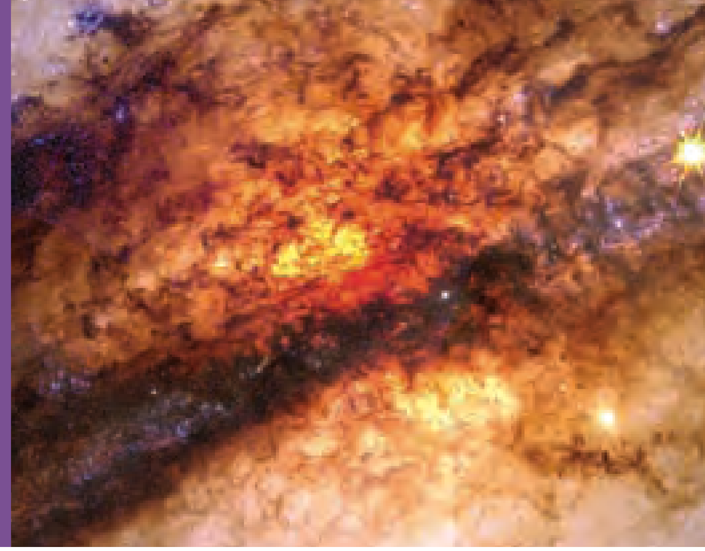


Photo Credit: NASA, E.J. Schreier (STScI)

Balancing larger missions with smaller ones is an ongoing process at NASA. Larger missions require more money and can be tough to get approved, but the dividends are worth it, as shown by this image of the Centaurus A galaxy from the Hubble Space Telescope.

A Mars sample return (MSR) mission has the potential to significantly advance our understanding of all aspects of Mars, especially the life question. Getting a sample back will enable more precise and detailed science in a terrestrial laboratory than we can possibly do remotely today. While remote-sensing experiments improve, they're always ten to fifteen years behind what we can do in a terrestrial lab; it simply takes time for an instrument to evolve from lab use to a flight experiment. With that detailed science, we can better understand the oxidizing surface awaiting us on Mars, an issue that must be resolved before we can be serious about sending humans. MSR is also an opportunity to begin structuring a round-trip mission to the red planet. In that sense, the sample return mission is a prototype for potential human exploration.

To achieve MSR, of course we'll need the obvious: the right leaders, science team, and budget. It will be an expensive mission, on the magnitude of the big astronomy missions: what Hubble has been and the James Webb Space Telescope will be. One way to help tackle the budget challenge is to use international cooperation. The European Space Agency and others are very interested in MSR, and NASA is working with potential partners to see what kind of cooperative MSR mission would make sense.

Looking into the Future

No one can accurately predict NASA's next fifty years. Look back at the fifties and sixties and see what people were predicting then. Wernher von Braun's Collier articles envisaged monster orbiting space stations and humans on Mars. Those things haven't happened. On the other hand, we totally underestimated the direction things would take and the advances in technology that are, in large part, unpredictable beyond a decade or so. Our robotic capability has improved unbelievably over the past fifty years. Even forty years ago, few conceived of doing some of the things we do today robotically.

I did a thought experiment and concluded that today we could do robotically most of what Apollo did. As proof of this concept, note that the Spirit and Opportunity rovers on Mars exceed in capability the geologic exploration capability of Apollo in many ways. There's no reason at all that our progress in robotics will do anything but continue to evolve, which brings up a major challenge for NASA: how to balance human exploration with things you can do robotically at one-tenth or one-hundredth of the cost. And while robotic approaches may be more cost-effective, humans have special capabilities that are incredibly useful in exploration. The Hubble repair and refurbishment activities are a prominent example. We need to do a much better job of understanding how to integrate NASA's human and robotic worlds. Finding the right mix of humans and robotics is a major challenge that the agency needs to face.

In the future as in the past, NASA will have to choose how best to use scarce resources. Good communication and strong engineering and science skills within NASA, industry, and academia will all remain important. Although it's not possible to predict exactly where we'll be decades from now, I think it's safe to say that NASA will continue to make astounding, unexpected, and valuable scientific discoveries. ●

NOEL HINNERS consults for NASA, the aerospace industry, and 4-D Systems, which supports the NASA Academy of Program/Project and Engineering Leadership. He has been on and chaired several space-related committees and has published on NASA programs. He currently serves on the executive committee of NASA's Mars Exploration Program Analysis Group and chairs the External Advisory Board of the University of Colorado Aerospace Engineering Sciences Department. He is also the executive secretary of the NASA Chief Engineer's Management Operations Working Group.

Discovery-Driven Science

BY DR. JAMES B. GARVIN

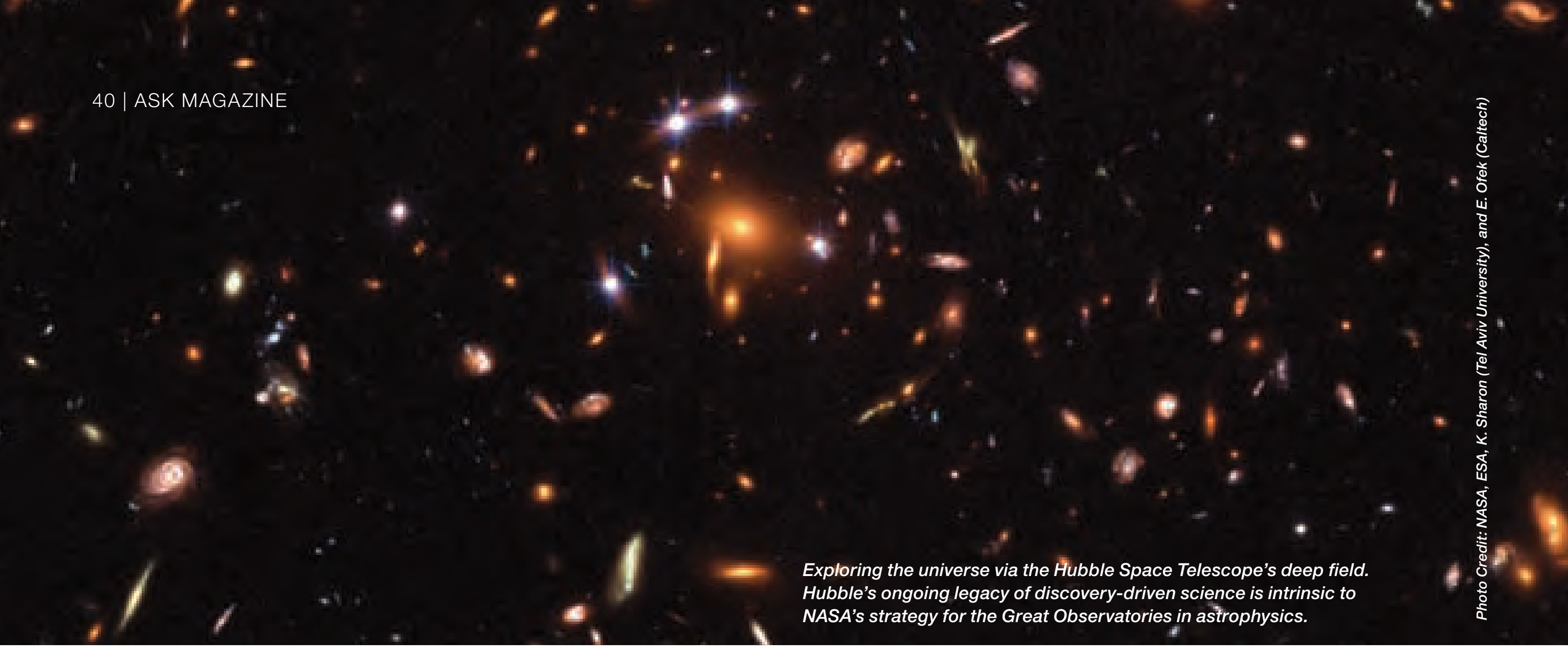
For fifty years, NASA has promoted scientific investigations enabled by the space-borne vantage point it has pioneered. Beginning with the first scientific measurements made in space by Explorer 1, major discoveries have been made about the workings of the universe, our home planet Earth, the sun, and our solar system, many of which were never imagined prior to the so-called Space Age. Were the groundbreaking discoveries of NASA robotic and human missions of exploration an anticipated consequence or a side benefit of the classical scientific method applied to space exploration?

NASA's missions are often described as technology-enabled and science-driven. This has been the hallmark of such icons of discovery as the Hubble Space Telescope, the Earth Observing System, the Cassini mission to Saturn, and the Mars Exploration Rovers (MER). Many of the breakthrough paradigm shifts in scientific understanding of the earth, universe, solar system, and sun have been catalyzed by particular missions with an emphasis on "discovery-driven science," which provides a tightly interwoven blend of technology-enabled measurements and broad, reconnaissance-level questions. Not all NASA missions, whether human-based or robotic, can be characterized as "discovery driven," but many have achieved unanticipated discoveries. A review of those NASA missions that best embody discovery-driven science suggests that attention to the discovery impact potential of breakthrough measurements in space will characterize NASA's next fifty years of scientific exploration.

NASA's flurry of "first-ever" missions during its first decade of existence were intended to provide initial surveys of the universe using instruments that had never before flown in space. Because such missions were our first foray to these targets, the path-finding measurements they provided established the basis for fundamental changes in scientific knowledge about the planets and the wider universe. Missions such as Ranger, Surveyor, and Lunar Orbiter were NASA's initial reconnaissance of the moon, and they blended engineering requirements with scientific measurements. Profound discoveries resulted in each case, with critical demonstrations of enabling technological capabilities essential to the later success of the Apollo lunar surface missions.

The concept of discovery-driven science may have been intrinsic to NASA's first missions to the frontiers of space, but it probably did not emerge as a powerful theme until the pioneering wave of planetary reconnaissance missions that began in the 1970s and continue today. Missions such as Mariner 9 (Mars), Viking (Mars), Voyager (outer planets), Pioneer Venus, and the Landsat series (Earth) were conceived to revolutionize our scientific understanding of key aspects of the universe using robotic spacecraft equipped with next-generation instrumentation. Due in many cases to the unknown character of the target destinations, the measurements acquired were often broad in scope and addressed key environmental issues. These 1970s missions helped define the era of discovery-driven science that blossomed from the catalytic results they achieved.

We can define discovery-driven science in several ways. First, it embodies scientific investigations with measurement capabilities that go beyond the scope of basic scientific hypotheses that are the primary focus of any given mission. An example is any astronomical observatory in space that employs its imaging ability to "see" at new spatial and spectral scales. Second, it specifically outlines areas of high science-discovery potential tied to one or more scientific questions for which there are multiple possible outcomes, including those that cannot be considered prior to the mission. While all scientific investigations can potentially "discover" new aspects of the physical universe,



Exploring the universe via the Hubble Space Telescope's deep field. Hubble's ongoing legacy of discovery-driven science is intrinsic to NASA's strategy for the Great Observatories in astrophysics.

Photo Credit: NASA, ESA, K. Sharon (Tel Aviv University), and E. Ofek (Caltech)

some are inherently more focused on quantifiable, incremental improvements in the state of knowledge associated with a small number of specific questions or issues. Discovery-driven science goes beyond this approach to embrace more ambitious measurements of the unknown or, as it is sometimes called, "the previously un-measurable."

Virtually all of NASA's early scientific missions demonstrated key aspects of discovery-driven science, but it was not until the past fifteen years or so that NASA has explicitly addressed the need for missions that emphasize this approach. In addition, human exploration missions to deep space that include discovery-driven science are now being considered in response to NASA's implementation of the Vision for Space Exploration.

The Apollo missions to the moon dramatically demonstrated how human activities can accentuate discovery-driven science, thanks to the intrinsic adaptability of the human explorer "on site." The Apollo J-series missions were guided by scientific objectives with abundant discovery potential and may have been the very first intentional discovery-driven science investigations implemented by NASA. These breathtaking missions of discovery catalyzed an era of unprecedented robotic reconnaissance of the solar system, including the Viking missions to Mars and the Voyager "grand tour" mission to the outer solar system.

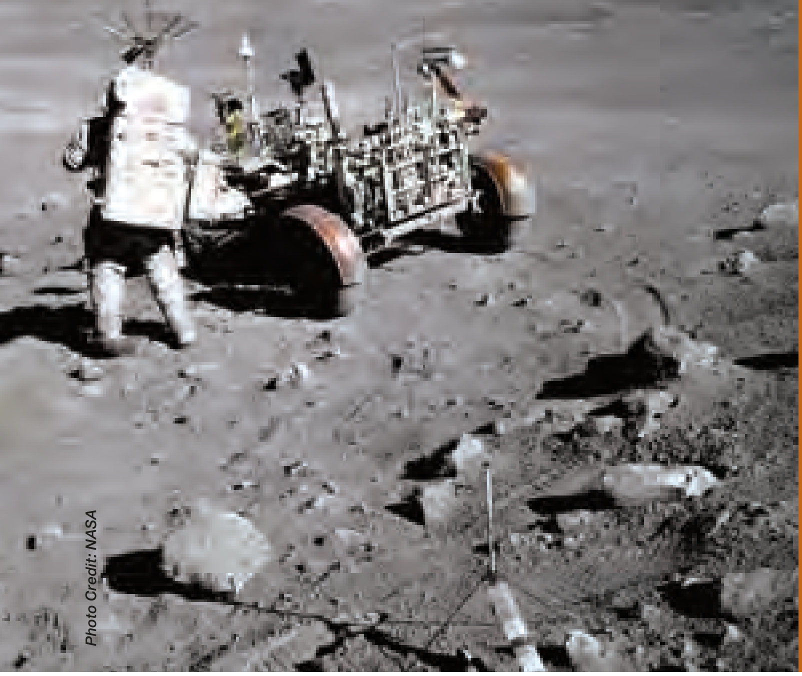
Discovery-Driven Science in Action

A few specific examples illustrate well the benefits of an exploration strategy that embodies discovery-driven science.

Perhaps the epitome of discovery-driven science is the Hubble Space Telescope, which has pioneered the space frontier for nearly twenty years and, in doing so, has produced multiple major discoveries about the accessible universe. The power of Hubble has always been its incredible "agility"—its ability to do many things well—which is a hallmark of discovery-driven science. In addressing fundamental questions within astrophysics and planetary sciences, it has produced observations that have changed viewpoints about basic processes, extending from the earth's moon to the so-called deep field. Hubble is an astronomical reconnaissance system capable of using its vantage point to pursue discovery-guided questions for which there are few, if any, preconceived ideas as to what will be observed. It has been able to discover new truths about objects in our own solar system, including dwarf planets such as Pluto, main-belt asteroids such as Ceres, and even the moon and Mars.

In an unprecedented use of its unique ultraviolet "vision," NASA directed Hubble to investigate the lunar surface in 2005 to better understand its resource potential. It was able to remotely measure the elusive signature of titanium-dioxide-bearing soils that extended far beyond those directly sampled by the crew of the Apollo 17 mission in 1972. Oxygen could be readily harvested from such soils for exploration-related uses, and their identification could prove to be of strategic value when NASA's human exploration of the moon resumes by 2020. The ultimate legacy of Hubble's rich array of scientific discoveries can be measured by the voluminous record of publications that have resulted from its observations. The Hubble-related scientific publication record is testament to its role as a leading example of intentional discovery-driven science in action.

The NASA Earth Observing System (EOS) was originally conceived as a "Mission to Planet Earth" in the late 1980s. It was designed to provide dozens of fundamental measurement sets that describe the earth "system" with adequate fidelity to constrain and amplify physical models of the behavior of the system, models that could help us improve the quality of life on Earth. While measuring the variables of our home planet via a constellation of Earth-orbiting platforms, EOS was also intended to catalyze discovery-driven scientific investigations related to climate variability. The massive amount of decision-relevant information that has been produced by the EOS suite of spacecraft has had a revolutionary impact on our understanding of the short-term climate of our planet, including the dynamics of ice cover and its relation to sea-level rise. Clearly, NASA's Earth science observations have produced dramatic discoveries.



Apollo 16 astronaut Charles M. Duke Jr. stands near the lunar roving vehicle during the second Apollo 16 extravehicular activity at the Descartes landing site. Apollo surface missions such as Apollo 16 provided ample opportunities for discovery-driven science in action by means of human explorers "on site" adapting to what they observed and refining their activities accordingly.

NASA's first competed Earth system science mission, GRACE, exemplifies a new flavor of discovery-driven science by measuring the intricacies of time-variable gravity as it relates to heat flow in the oceans and the changing ice sheets of our planet. NASA is poised to continue its legacy of groundbreaking Earth science in the years ahead using discovery-driven science approaches for both small and large missions.

Perhaps the other most visible example of discovery-driven science at a NASA program level is the past approximately eight years of the Mars Exploration Program (MEP). After program restructuring around 2000, the resulting new architecture embraced discovery-driven science in multiple ways, including an openly competed Mars Scout program element, as well as via specific strategic missions. Specific attention to maximizing discovery potential was established as a MEP guiding philosophy. This enabled decisions that resulted in uniquely discovery-driven missions such as the Mars Exploration Rovers Spirit and Opportunity, the Mars Reconnaissance Orbiter (MRO), and the 2009 Mars Science Laboratory, presently under development at the Jet Propulsion Laboratory.

The MRO mission was developed to specifically address discovery-oriented questions about Mars for which there were no easy answers. The search for mineral evidence of the history and persistence of water in the geologic history of Mars had historically proven to be an elusive one, but MRO's instruments have discovered new possibilities that were previously unsuspected. MRO involves three new classes of remote-sensing instruments that have dramatically increased resolution on surface and subsurface processes, and measurements from them have demonstrated the value of high-discovery potential experiments at the edge of the science frontier. The first Mars Scout mission, Phoenix, also illustrates substantial attention to discovery potential in its choice of a landing site in the high latitude polar plains as well as its inclusion of instruments such as an atmospheric lidar and the first atomic force microscope in space. These new measurement systems have probed previously unknown aspects of the local Martian "system" and, in doing so, have discovered important aspects of how Mars operates at scales as fine as nanometers. The current and ongoing Mars program within NASA provides ample evidence of the positive influence and value of discovery-driven science as a guiding philosophy.

The Past and the Future

NASA's first fifty years have included a variety of missions that embody the philosophy of discovery-driven science. Monumental icons to science such as Hubble, EOS, and MEP, among others, present dramatic evidence of the value of this approach. New scientific paradigms have been established by discovery-driven scientific missions of exploration, starting with the Apollo lunar surface missions and continuing today with ongoing missions of discovery such as Cassini at Saturn, MESSENGER at Mercury, Phoenix on Mars, and the EOS constellation in Earth orbit. The next fifty years of NASA missions can sustain the lesson of discovery-driven science by propagating the philosophy into the upcoming era of more tightly integrated human and robotic exploration missions, starting with our return to the moon. The science frontier is vast. Deploying innovative approaches for extending the discovery-driven science of NASA missions in the next decades will assuredly continue to expand our understanding of the universe in which we live. ●

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A HALF CENTURY OF NASA PHOTOS

BY GEORGE MICHAEL (MIKE) GENTRY

You might think I would take my work for granted after almost forty years of working with NASA photos. I never have, and even to this day I occasionally pinch myself. The same thrill I had dealing with the Apollo 11 photography when it was fresh, right after the moon landing in 1969, continues today when I see a great picture of the International Space Station over a panoramic spread of terrain or a new picture of some interesting part of the universe from the Hubble Telescope. From Apollo through early shuttle, we waited for astronauts to complete their space missions and bring back bags of film, which required lab processing and lots of other work prior to release to the media. I enjoyed receiving a large stack of moon photos from our photo lab that still had the smell of a darkroom on them for distributing to media, and then actually seeing them in collated sets, the sense of smell quickly giving way to the sense of sight. With their beauty just jumping up to smack you in the face, we felt like Santa Claus packaging up shiny new toys for the children of the world.

No smell of dark room chemicals and no more 8 x 10 paper prints greet us in 2008, but digital imagery looks just as impressive as it pops up in a gallery of thumbnails on the computer screen for captioning and editing. The digital capabilities we now have mean we can release a photo the very same day a space-walking astronaut has taken it. That may not impress the younger generation, but it still amazes us greybeards, with our memories of darkrooms and rushed courier trips from the airport. Many who read this will someday be able to take for granted new leaps in technology now unknown that will communicate NASA's future adventures and discoveries.

Here are a few of the many great images that help tell part of the story of NASA's first fifty years.

Photo Credit: NASA

There are no photos of President Dwight D. Eisenhower signing the National Aeronautics and Space Act on July 29, 1958. According to Public Papers of the Presidents, *he released a statement upon signing the bill. This usually means that he did not deliver the statement in person, so there was no ceremony. The other two men in the photo are T. Keith Glennan and Hugh L. Dryden. The photo was taken at the swearing-in ceremony for Glennan as administrator of NASA and Dryden as deputy administrator that took place in the White House Conference Room on August 19, 1958.*

This photograph of the Gemini 7 spacecraft was taken from the hatch window of the Gemini 6 spacecraft during rendezvous and station-keeping (maintaining a specific orbit) maneuvers at an altitude of approximately 160 miles on December 15, 1965. The two spacecraft are just a few feet apart. Inside the Gemini 7 spacecraft are astronauts Frank Borman and James A. Lovell. The December 1965 flight was followed three years later by a historic Apollo 8 flight, also in December, which included the same two astronauts as part of a three-man crew.

Photo Credit: NASA

The first three Americans to fly in space were, from left to right, John H. Glenn, Jr.; Virgil I. (Gus) Grissom; and Alan B. Shepard, Jr. They posed for this photo in 1961 while anticipating their flights of Mercury-Atlas 6, Mercury-Redstone 4, and Mercury-Redstone 3, respectively. They personified the Thomas Wolfe–coined term, "the Right Stuff." Glenn was the first American to orbit the earth, while Shepard was NASA's first astronaut to go into space. Grissom, who six years later lost his life in the Apollo 204 (also known as Apollo 1) fire at Cape Kennedy, flew a suborbital mission, launched between the flights of Shepard and Glenn.

Photo Credit: NASA

Several years ago I was at Fair Lanes Bowling Alley, participating in a NASA mixed Tuesday night league, when I got a page from the main desk telling me I had a phone call. It was John Denver. He was here in Houston, having just completed a battery of medical tests at Johnson Space Center because he wanted to fly in space.

He said, "Hi, John Denver here … got your name from PAO [the public affairs office], and they said you were probably at the bowling alley. I'm looking to do a hologram based on the Apollo 17 Earth photo, and I wanted to talk to you about that. I want to use it as a huge icon for my future concerts."

It is by far the most asked for image in the NASA collection. It so inspired a Canadian teacher twenty years ago that she took on the mission of distributing the image worldwide. The name of her project was "The Earth in Every Classroom."

I have traveled to various parts of Mexico and Japan and in about thirty states in the United States. I don't think there's been a trip I've taken that I didn't see the Apollo 17 Earth view on TV or on a billboard or in some medium or other.

Photo Credit: NASA

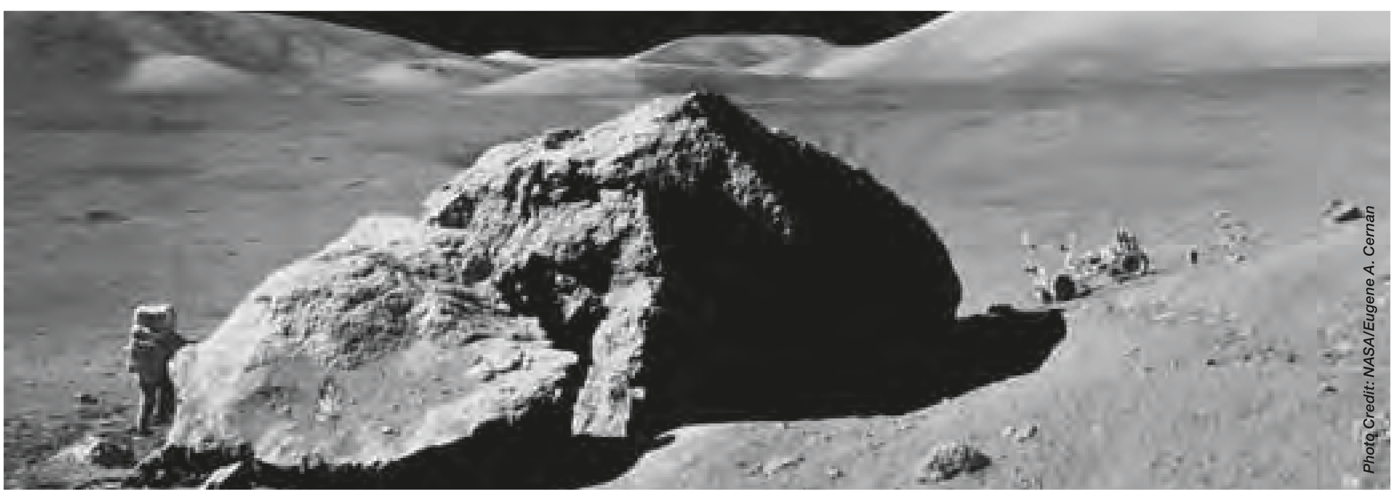


Photo Credit: NASA/Eugene A. Cernan

A view of Harrison H. Schmitt, Apollo 17 lunar module pilot, at the Taurus-Littrow landing site during the mission's first spacewalk. Note the lunar roving vehicle on the right side of the giant rock, from which chip samples and other pieces were taken for return to Earth and subsequent scrutiny by scientists. Schmitt was the only geologist to walk on the moon. Eugene A. Cernan took the handful of pictures that make up this mosaic.

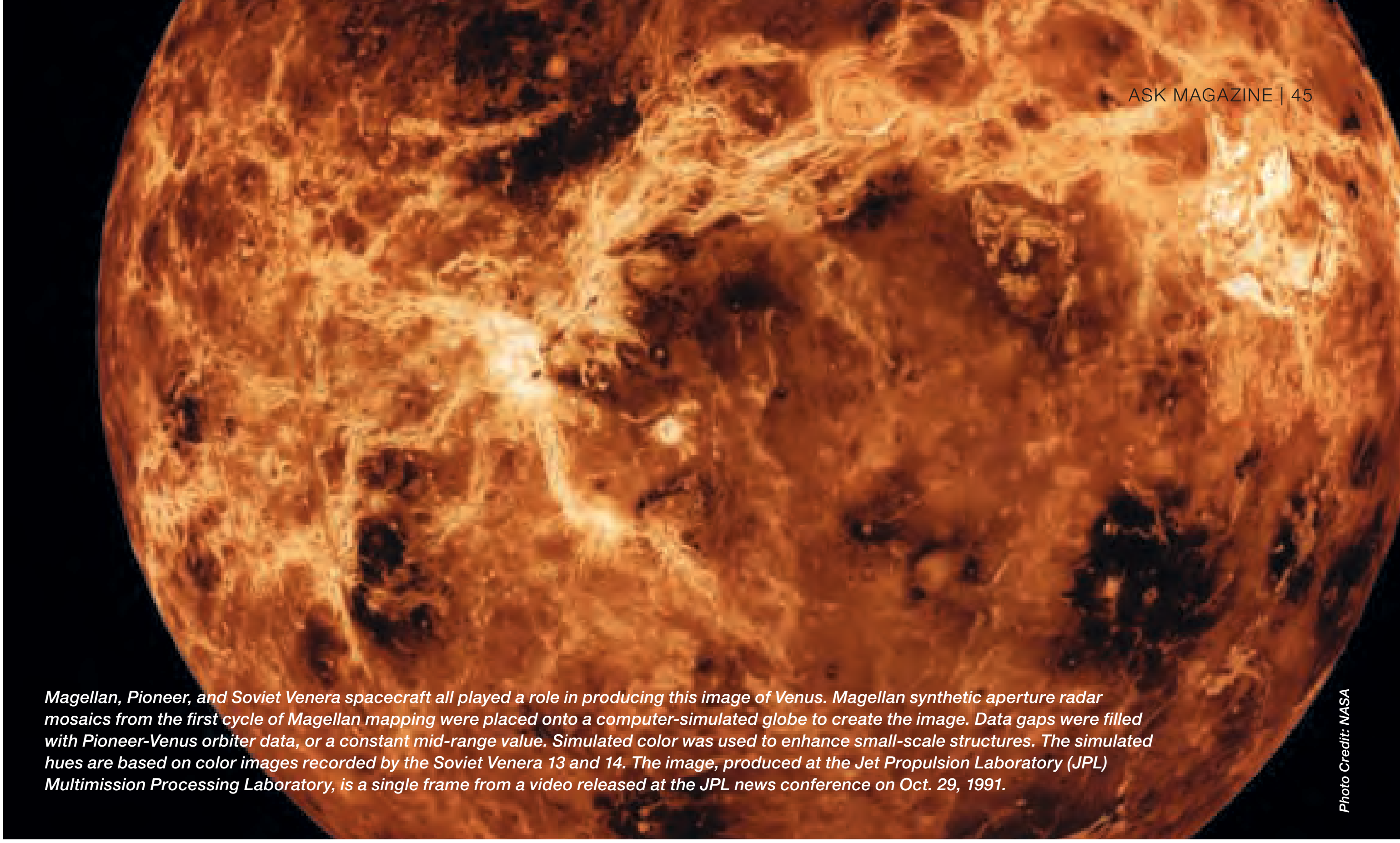


Photo Credit: NASA

Magellan, Pioneer, and Soviet Venera spacecraft all played a role in producing this image of Venus. Magellan synthetic aperture radar mosaics from the first cycle of Magellan mapping were placed onto a computer-simulated globe to create the image. Data gaps were filled with Pioneer-Venus orbiter data, or a constant mid-range value. Simulated color was used to enhance small-scale structures. The simulated hues are based on color images recorded by the Soviet Venera 13 and 14. The image, produced at the Jet Propulsion Laboratory (JPL) Multimission Processing Laboratory, is a single frame from a video released at the JPL news conference on Oct. 29, 1991.

Photo Credit: NASA

The International Space Station was photographed against the topography of the Canadian province of Quebec on April 29, 2001, following separation from the Space Shuttle Endeavour. *An impact feature known as the Manicouagan Reservoir is almost directly beneath the orbital outpost. One of several impact craters on Earth, Manicouagan's unique crab-like shape makes it easily recognizable from 220 statute miles above Earth. The 35mm frame was exposed by one of the STS-100 crewmembers onboard the shuttle.*

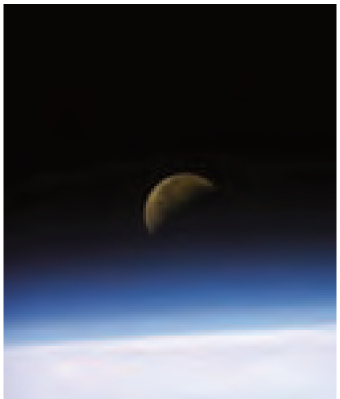


Photo Credit: NASA

This picture of a half-moon over a relatively small section of Earth and its atmosphere is not a rarity, because many space travelers have encountered similar scenes, but this particular image was captured by the final Space Shuttle Columbia *crewmembers prior to their deaths on February 1, 2003. Although it was recorded with a digital still camera and downlinked from space, much of the crew's filmed imagery was recovered in very good condition among the* Columbia *debris in North Texas after the mission's end.*

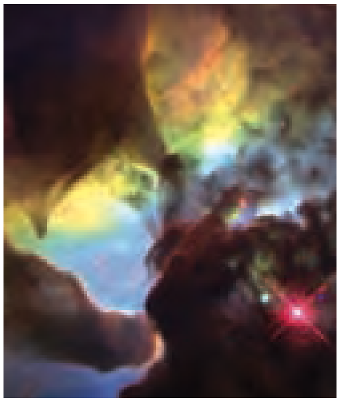
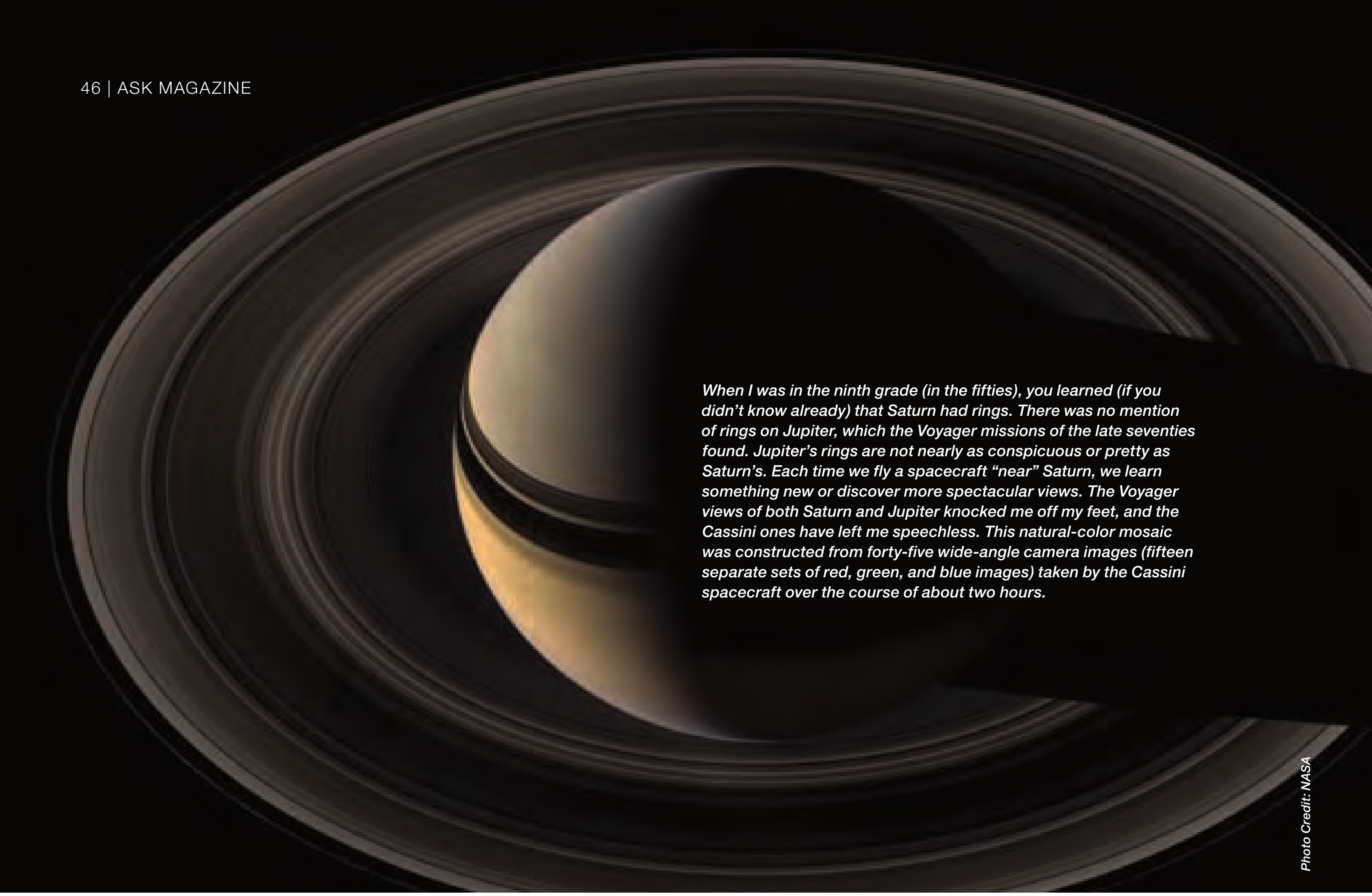


Photo Credit: NASA

This eleven-year-old Hubble image reveals a pair of one-half light-yearlong interstellar "twisters"—eerie funnels and twisted-rope-like structures—in the heart of the Lagoon Nebula (Messier 8), which lies 5,000 light-years away in the direction of the constellation Sagittarius. The Lagoon Nebula and nebulae in other galaxies are sites where new stars are being born from dusty molecular clouds. These regions are the "space laboratories" for astronomers to study how stars form and interactions between the winds from stars and nearby gases. These color-coded images are the combination of individual exposures taken in July and September of 1995, with HST's Wide Field Planetary Camera 2.



When I was in the ninth grade (in the fifties), you learned (if you didn't know already) that Saturn had rings. There was no mention of rings on Jupiter, which the Voyager missions of the late seventies found. Jupiter's rings are not nearly as conspicuous or pretty as Saturn's. Each time we fly a spacecraft "near" Saturn, we learn something new or discover more spectacular views. The Voyager views of both Saturn and Jupiter knocked me off my feet, and the Cassini ones have left me speechless. This natural-color mosaic was constructed from forty-five wide-angle camera images (fifteen separate sets of red, green, and blue images) taken by the Cassini spacecraft over the course of about two hours.*

Photo Credit: NASA

Photo Credit: NASA/Eugene A. Cernan

Scientist-Astronaut Harrison Schmitt, Apollo 17 lunar module pilot, is photographed next to the U.S. flag at the Taurus-Littrow landing site during extravehicular activity of NASA's final lunar landing mission in the Apollo series. The photo was taken by astronaut Eugene A. Cernan, commander and the last man of the twentieth century to have walked on the moon. The highest part of the flag appears to point toward our planet Earth in the distant background. This is one of a very few pictures from the moon that show both a human being and Earth in the same frame.

Photo Credit: NASA

View of Astronauts Robert L. Curbeam, Jr., (left) and Sweden's Christer Fuglesang of the European Space Agency, both serving as STS-116 mission specialists, as they work at the forward side of the starboard 1 truss on the International Space Station during the first extravehicular activity session on the flight. This breathtaking view represents the hundreds of hours thus far spent by astronauts assembling the orbital outpost. New Zealand is visible in the background.

GEORGE MICHAEL (MIKE) GENTRY was reared on the Texas–Oklahoma border and educated at The University of North Texas. He was a newspaperman in that area until coming to NASA's Public Affairs Office to work with photos for the news media in 1969.

NASA and the Future of Knowledge

BY LAURENCE PRUSAK AND DON COHEN

NASA is unquestionably a knowledge-intensive organization. Among government agencies, it is probably the *most* knowledge intensive. Its work depends on acquiring and applying the sophisticated knowledge of fields including engineering, science, and mathematics, as well as knowledge about how to organize immensely complex projects. Knowledge is also one of the agency's essential products. It is a major source of new knowledge about the earth, the solar system, and the universe. Its mandate specifically includes generating and sharing knowledge, aims articulated in two of the three parts of NASA's mission statement:

- To advance and communicate scientific knowledge and understanding of the earth, the solar system, and the universe.
- To research, develop, verify, and transfer advanced aeronautics and space technologies.

Effective knowledge organizations substantially rely on structures and practices that differ from the command-and-control hierarchies of many traditional manufacturing firms. We want to look briefly at how NASA stacks up as a knowledge organization and what it may still need to do to meet the knowledge demands of its future missions. We acknowledge our limitations—NASA is a large, complex, varied organization that we are still in the process of exploring. But we think we have learned enough to make some useful observations.

The Knowledge Organization

Knowledge organizations behave differently because knowledge is different—from information, from data, and certainly from the material resources that dominate manufacturing firms. Knowledge is often *local*, originating and having meaning in the context of particular work and a particular place. It is *social*, created, understood, and used mainly by groups of people who work together or share the same profession. It is largely *tacit*—that is, embedded in work practices and bound up with the experience, judgment, and understanding of experts and therefore impossible to capture fully in a document or diagram. Because it is local, social, and tacit, its effective use is *voluntary*, depending on the full engagement of people and their willingness to tap their inner resources and challenge themselves and each other.

Successful knowledge-intensive firms—private-sector examples include McKinsey and Company, Northrup Grumman, Google, and W. L. Gore and Associates—encourage practices and values and organize and manage themselves in ways that recognize the special nature of knowledge and support its creation, sharing, and use. Here are some of the most important characteristics of knowledge-intensive firms and our sense of how well NASA exemplifies them.

Extensive and Durable Informal Networks

A lot of organizational knowledge travels through informal networks, the personal connections that people establish in the course of their careers. We all have people we go to for knowledge or help or because we think they can connect us with someone else who has the knowledge we need. Organizations that have strong networks give people opportunities to meet and mix, understand the value of informal conversation, and have cultures that value both asking for and giving advice.

NASA gets high marks for its informal networks. Its employees tend to have long careers at the Agency, so they have time to build extensive networks of people they can call on to help solve problems. Members of project teams form ties that persist even after they move on to other work. NASA retirees and older employees—the "greybeards" who worked on Apollo and Viking, for instance—often retain connections with the Agency and are called on, informally and formally, to offer their expertise and advice.

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Most important, that kind of knowledge sharing is the norm at NASA. Of course there are people who want to defend their territory and engineers whose desire to solve problems themselves leads them to reject ideas that are "not invented here," but we see most NASA personnel readily seeking advice from people whose expertise they respect and responding to requests for their expertise.

Trust (and Mission)

Effective knowledge work requires a high level of trust. People will not share or seek knowledge from others or work effectively together on collaborative knowledge-intensive projects unless they believe that their colleagues are trustworthy: not only that they will be reliable providers and users of knowledge, but that they will share credit appropriately and not use their own knowledge for political or professional advantage.

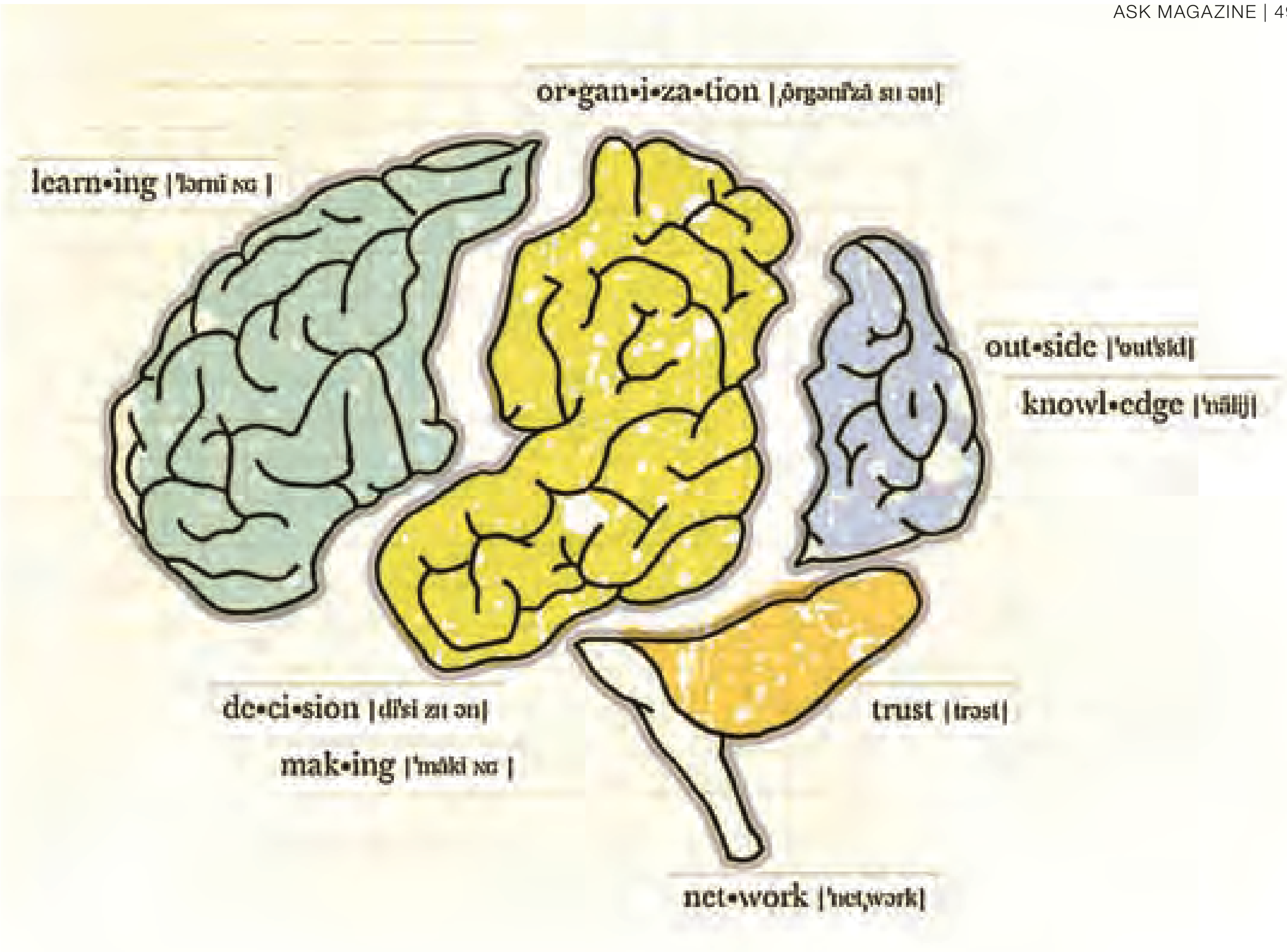
Trust has many sources, including the trustworthy behavior of leaders and managers. Shared values and a shared sense of mission powerfully contribute to trust at NASA. In project after project, the tensions and disagreements that are an inevitable part of doing difficult work together are offset by recognition of a shared commitment to an important and noble goal: the safety of astronauts and advancing human knowledge of the earth, the solar system, and the universe.

Respect for Local Knowledge

The localness of knowledge—its origin and use in the context of particular work—means that leaders and managers can never know everything they need to know to make good decisions. They must consult with and sometimes defer to people engaged in the daily "hands-on" work of the organization. W. L. Gore and Associates offers a striking example. Recognizing that innovation comes from the people directly engaged in research, the company gives individual researchers full authority to start new projects if they can convince enough people of the value of their ideas to form a project team.

Historically, NASA has a mixed record in this area. The *Challenger* and *Columbia* accidents arguably resulted from failures to pay enough attention to individual or local knowledge, either because of poor communication, a failure to give minority views serious enough attention, or a then-common cultural barrier to speaking truth to power.

NASA's new governance model, described in its recently revised "Program and Project Management Requirements" document (NPR 7120.5D), attempts to address this issue by providing a structure for dissenting opinions to be heard and to



rise to the highest level of management if they are not satisfactorily resolved at a lower level. This change matters, both as a process and as a signal that management *wants* different opinions. To ensure that the process works, though, the organization needs to continue to demonstrate a commitment to carefully evaluating diverse ideas and opinions.

Shared or Distributed Decision-Making

Genuine respect for local knowledge means putting some decision-making power in local hands—giving people the authority to make choices that only they are qualified to make because only they have the relevant knowledge. Clearly, it would not be appropriate for groups working on NASA's complex, highly integrated projects to make local decisions without regard to their effect on the bigger picture—it's the job of systems engineers and project managers to make decisions based on the system as a whole. But effective project managers talk about making clear to team members what has to be done and giving them the freedom to decide how to do it, based on their experience and expertise. Good NASA project leaders involve a broad range of project participants in "trade studies" that evaluate the effects of possible design changes so that local needs and knowledge can be heard and weighed.

The 7120.5D processes and requirements document, which specifies project roles and milestones, is an interestingly mixed story in relation to shared decision making. Writing and reviewing the document, the Agency worked hard to incorporate practical knowledge so that it would reflect some of the wisdom of real experience, not just a theoretical idea of how the work should be done. In many organizations, important knowledge is embedded in the processes and routines used to get work done, and 7120.5D tries to capture and promote that embedded knowledge. The document also recognizes the need for flexibility within the guidelines to respond differently to different projects and situations. At the same time (as in any large, complex organization) a tension exists between, on the one hand, the need for standards to support coordination, efficiency, and an expected level of quality and, on the other hand, the freedom to respond creatively to unusual and unexpected circumstances. Time will tell whether the new processes and requirements successfully balance these two needs.

Learning

Effective knowledge organizations make sure their employees keep learning, sometimes through support for formal education but especially through appropriately challenging work experience (often guided by mentors and more experienced colleagues). Many of these organizations also recognize and encourage learning opportunities that are neither formal education nor work per se: observing and talking to colleagues, hearing and telling stories that capture the realities of work.

A strength of NASA's formal educational programs is that they often use these multiple learning modes. Course offerings from the Academy of Program/Project and Engineering Leadership (APPEL) and APPEL's Masters Forums combine storytelling and conversation with more traditional instruction. Goddard's Systems Engineering Education Development program, Ames's Project Excellence Systems Engineering Development program, and Glenn's Space Missions Excellence program all combine classroom instruction, mentoring, and guided project experience.

Long-time NASA employees often talk about how much they have learned from their project work. Many describe being given significant responsibility for a project element as soon as they began work at the Agency and talk about how much that early hands-on experience taught them and how it ensured their commitment to NASA. But many people we have spoken to—people within NASA and NASA observers—worry that current and future generations of employees will not get enough hands-on design and engineering experience to develop their expertise and keep their interest. NASA projects have always involved both civil servants and contractors; many are concerned that the civil servants may spend too much time overseeing technical work done by others and not enough doing the work themselves. The result, they fear, will be difficulty attracting the most talented engineers and scientists and insufficient technical expertise within NASA.

Pursuit of Outside Knowledge

Successful knowledge-intensive organizations look outside their borders for the some of the knowledge they need. As part of its "connect and develop" strategy, Procter and Gamble has more than fifty "technology entrepreneurs" who are responsible for seeking knowledge outside the company. Organizations that cut themselves off—from arrogance or in an effort to protect their knowledge from outsiders—wither and die.

NASA works cooperatively with universities and foreign space agencies (as well as industry) in part to share the cost of expensive missions but also to get the benefit of outside expertise. The International Space Station is the most visible example of multinational cooperation, but far from the only one. NASA also sponsors competitions—Centennial Challenges—to encourage outsiders to apply their knowledge and skill to technical challenges. In 2007, Peter Homer won the Astronaut Glove Challenge, designing a more dexterous spacesuit glove. NASA is now sponsoring a lunar lander challenge, administered by the X PRIZE foundation.

ACQUIRING, SHARING, AND PRESERVING THE GENERATIONS OF KNOWLEDGE NEEDED FOR [NASA'S] NEW HUMAN EXPLORATION MISSIONS WILL REQUIRE SUBSTANTIAL ONGOING ATTENTION TO GOOD KNOWLEDGE PRACTICES.

There are some limitations on these collaborations. The International Trade in Arms Regulations sometimes create barriers to international knowledge sharing. NASA's relationship with private space entrepreneurs is at an early stage, so the extent and importance of knowledge sharing remains to be seen.

Knowledge About Knowledge/Knowledge Roles

Many organizations spend significant time and money on knowledge development, transfer, and use. Leaders and others understand how knowledge works, make knowledge part of the organizational conversation, and recognize the importance of investing in knowledge. McKinsey and Company, for instance, employs hundreds of people whose job is to facilitate knowledge exchange and provide essential context for documents and other resources. Intel has used "knowledge harvesters" to identify valuable project knowledge and help communicate it to other project teams that can use it.

At NASA, a relatively small number of people devote their time explicitly to knowledge work—in APPEL, for instance, through knowledge programs at the Jet Prolusion Laboratory and Goddard, and in recent Exploration Systems Mission Directorate efforts to link knowledge sharing to risk management. As in many organizations, though, there is more knowledge work to be done than there are people to do it, and the Agency may need to do more to preserve and share its project knowledge. NASA knowledge personnel should also perhaps practice what they preach by getting together to share their knowledge about knowledge more frequently and systematically.

The Future of Knowledge at NASA

On balance, NASA displays many of the characteristics of a healthy knowledge organization. Its mission-oriented, generally high-trust culture; its robust informal networks; its emphasis on learning; and its reasonable openness to outside knowledge all contribute to knowledge effectiveness. Formal and informal mentoring and long careers with the Agency foster individual and group expertise.

We believe the extraordinary challenges of NASA's future missions—both their technical demands and their duration—will require extraordinary efforts to develop and transmit knowledge. The future of knowledge at NASA should include continued attention to learning, with an emphasis on learning from hands-on experience. It should mean continuing efforts to understand and respect local knowledge and bring it into the decision-making process. It should continue and strengthen the trend toward seeking and using outside knowledge. And it should include additional investment in the practices that preserve and communicate valuable project knowledge. Acquiring, sharing, and preserving the generations of knowledge needed for its new human exploration missions will require substantial ongoing attention to good knowledge practices. From its earliest days, NASA has developed ways to create and coordinate vast amounts of knowledge to accomplish its innovative missions. It can and must continue to do so if it is to succeed in the future. ●

Success, Failure, and NASA Culture

BY DR. STEPHEN B. JOHNSON

When humans first went to space in the 1950s and 1960s, many rockets and satellites failed, leading to the development of processes and technologies to reduce the probability of failure. The extreme harshness of the space environment required novel technologies, but it also drove conservative design to prevent or mitigate failures. In NASA's formative years, these contradictory requirements deeply influenced its organizations and processes. The novelty of NASA's missions, along with the fact that they were generally unique or few of a kind, led to the adoption and refinement of project management and systems engineering to develop and build rockets and spacecraft.

Photo Credit: NASA

Workers study Hubble's main, eight-foot (2.4 m) mirror. The flaw in the Hubble Space Telescope's optics was due in part to reductions in testing to save money.

While Wernher von Braun's experienced rocket team at Marshall Space Flight Center eschewed systems engineering, NASA's other field centers developed that discipline to ensure proper communication and design reviews. In the 1950s and 1960s, the introduction of systems engineering, along with other related innovations such as redundancy and environmental testing, generally reduced system failure rates from around 50 percent to around 5 to 10 percent for robotic spacecraft and better than that for human flight. Von Braun's team seemed anomalous, for it attained very high reliability with its Saturn rockets without systems engineering. However, von Braun's team, which held together for nearly four decades, had learned its trade through three decades of tests and high failure rates from the 1930s in Germany through the 1950s in the United States. Only after the retirement of the German rocket team in the 1970s and the diversification of Marshall beyond rocketry did systems engineering begin to make significant inroads there.

Improvement in system reliability came with increased bureaucracy, as systems engineering put a variety of cross-checks and reviews in place. System dependability improved, but these processes and technologies increased the cost of each vehicle. Eventually, and in response to pressures to decrease costs, engineers and managers cut back on safety and reliability measures. Also, as Henry Petroski explains in *To Engineer Is Human* and *Success Through Failure*, success encourages engineers to reduce performance and safety margins to reduce costs and to create more elegant, optimal designs. Not surprisingly, these cutbacks, exacerbated by overconfidence, lead to failures. Failures in turn lead to increased attention to reliability and safety, pushing the pendulum in the other direction.

We see these pendulum swings in NASA's history. By the 1980s, as NASA faced increasing pressures to reduce costs, many aspects of its bureaucracy, including systems engineering, came under scrutiny. Many outsiders and some insiders began to question the need for all the "red tape." Citing a variety of examples, such as Total Quality Management (TQM) from Japan's automotive manufacturing and the Skunk Works model from Lockheed's aviation organization, critics believed NASA could build and operate its systems more quickly and less expensively by cutting back or changing its management and organization.

Faster, Better, Cheaper

After the *Challenger* accident in 1986, the human flight program was able to reestablish a focus on safety for a number of years. This shifted the cost-cutters' attention to robotic spacecraft programs, however. By the late 1980s, NASA began to experiment with a number of these management ideas, including TQM and reengineering. At the same time, traditional projects came under criticism. For example, the Cassini probe came under fire, parodied as "Battlestar Galactica" because of its size, complexity, and cost, and was frequently cited as an example of what NASA should not do. Failure of the Mars Observer in 1993 demonstrated again that projects managed with traditional methods sometimes failed. The 1990s became the era of "faster, better, cheaper" (FBC) during Dan Goldin's administration. Projects such as Mars Pathfinder, which landed on Mars for significantly lower costs than the 1970s Viking project, were touted as proof that the new methods worked (and hence that the old techniques were unnecessary).

Funding cuts and experiments to reduce the bureaucracy led to occasional success but also to increased failure rates. The flaw in the Hubble Space Telescope's optics was due in part to reductions in testing to save money. A series of failures in Earth-orbiting projects and most prominently in the Mars Polar Lander and Mars Climate Orbiter projects in 1999 led to a rethinking of the FBC strategy. By the early 2000s, the Mars program had retrenched and returned to more conservative and traditional management with significantly more funding than its recent predecessors. Managerial innovations like TQM, reengineering, and FBC were being reconsidered or rejected in favor of a return to classical systems engineering and systems management.

In the 1980s and 1990s, the debates about NASA's organization and its relation to system success or failure had been couched in terms of management methods, in particular systems engineering and management versus a variety of other techniques that usually originated outside the space industry. The loss of *Columbia* in February 2003 changed the debate. What caught the attention of the *Columbia* Accident Investigation Board (CAIB) and others was the resemblance of the decisions and factors leading up to the accident to those behind the *Challenger* accident seventeen years earlier. Ominously, the problems seemed to exist *within* the structures and processes of classical systems engineering and management. These inherent problems posed, and still pose, a much more serious threat to NASA than the attempts to impose new and arguably ill-suited techniques from outside the space industry. Instead of failures to follow rigorous systems engineering methods, as had been the usual earlier diagnosis, the CAIB identified NASA's *culture* as a primary cause of the *Columbia* tragedy.

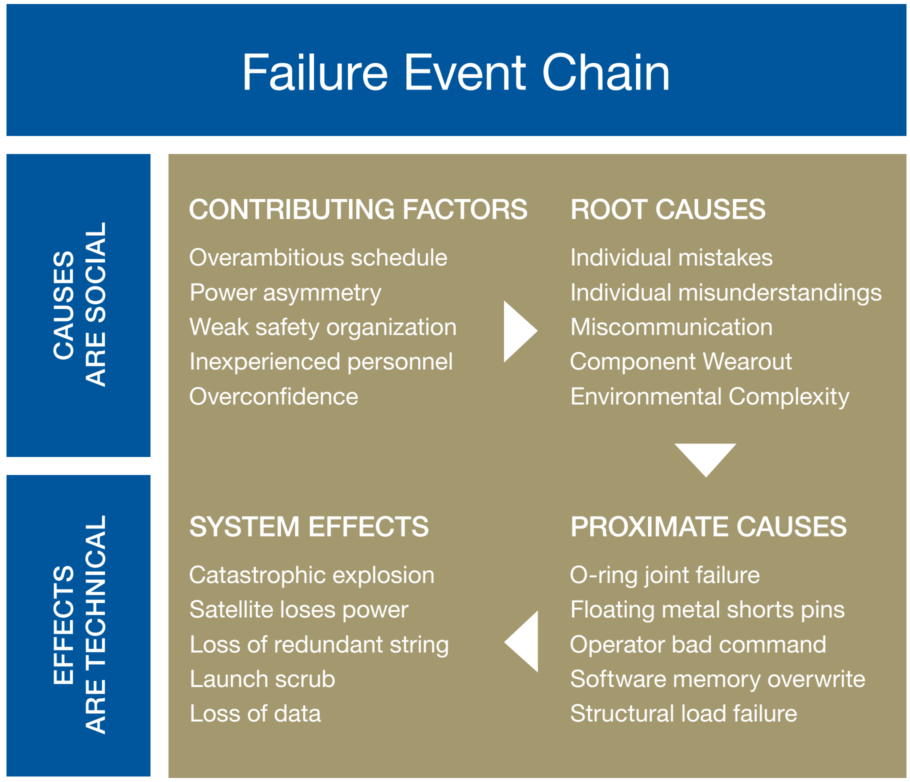
Photo Credit: NASA Kennedy Space Center

The Cassini spacecraft is mated to the launch vehicle adapter in Kennedy Space Center's Payload Hazardous Servicing Facility. Cassini was once frequently cited as an example of what NASA should not do because of its size, complexity, and cost.

The Challenge of Culture

This diagnosis was problematic for NASA for at least two reasons. First, it was not clear what "culture" really meant, as it is a famously holistic and ambiguous term, even for social scientists who use it in their day-to-day work. "Culture" covers a lot a ground, including patterns of human knowledge, beliefs, behaviors, and social forms. Out of the full set of NASA's human knowledge, beliefs, and behaviors, what is it exactly that NASA needed to change? Second, whatever NASA's culture actually is, it is not geared toward soft and squishy concepts about people but rather toward precise, technical assessments of things. Any action to address social issues would be difficult.

NASA's first response to the *Columbia* accident was to determine and fix the technical causes and implement operational procedures to minimize the risks; for instance, ensuring that shuttle missions always had means to inspect the thermal tiles and repair them if necessary. Addressing the cultural issue was more difficult. Knowing that internal



expertise was lacking, NASA hired Behavioral Science Technology, Incorporated, (BST) in 2004 to lead the culture-change effort. BST promised to assess NASA's culture through surveys and then implement changes that could be quantitatively measured. This experiment lasted only one year, however, as NASA's executive leadership decided that NASA had the skills to implement cultural change in house.

Another of the CAIB recommendations was to implement an Independent Technical Authority. This was duly accomplished. In February 2006 it was replaced by a new directive to move to a "Process-Based Mission Assurance" system. Behind these changes was the implementation of a renewed and restrengthened matrix management system, where engineers were responsible to the engineering technical authority for the technical effectiveness of their work and to their project management for day-to-day direction. One major goal was to ensure that if engineering opinion was rejected through one line of management, engineers had another line through which to communicate their concerns. Safety reporting systems remained in place and were reemphasized to ensure that safety-related problems could be reported separately from either of the project or engineering management chains. At present, these activities form the bulk of NASA's top-down cultural changes, albeit without the "culture change" label. In addition, educational efforts at NASA's Academy of Program/Project and Engineering Leadership (APPEL) are under way to address some of the cultural issues brought forward by CAIB, as education is a key component of long-term generational change in the workforce.

Is there still a need for "culture change" at NASA? I believe the answer remains "yes." The reinvigorated matrix structure is a move in the right direction, multiplying communication channels and delineating responsibilities for technical excellence. APPEL's new and updated engineering and management curriculum, if properly focused, is also a significant step. However, the core issues that relate NASA's "culture" to improvements in system dependability and safety have so far, in my opinion, only been marginally addressed. If the CAIB had any message for NASA regarding culture, it is that something in NASA's social organization and processes leads to technical failure of systems. To directly address the CAIB's concern, we must determine the connection between culture and failure.

To make this connection, we need to understand the nature of faults and failures. Failure is generally the outcome of a chain of events that are made more likely by various contributing factors. Failure investigations start from the end of the failure process: the final failure effects, which can include complete system loss, like the Space Shuttle *Columbia* burning up in the atmosphere, or can be more benign, such as the scrub of a launch. The proximate causes are generally the technical items that malfunctioned and led to the failure effects: O-ring failure of the *Challenger* accident, or the foam that fell off the external tank and hit *Columbia*'s wing during ascent. But proximate causes have their genesis in root causes, such as human-induced errors in the application of the foam to the external tank in the *Columbia* case, the decision to launch *Challenger* on a morning when the temperature was lower than rated environmental limits, or human error in creating the shuttle's original, flawed Solid Rocket Booster segment-joint design. Finally, there are contributing factors, such as pressures to launch the shuttle on an accelerated schedule, pressures to lower costs, or use of a teleconference instead of a face-to-face meeting contributing to miscommunication.

Frequently, we find that the failure effects and the proximate causes are technical, but the root causes and contributing factors are social or psychological. Successes and failures clearly have technical causes, but a system's reliability strongly depends on human processes used to develop it, the decisions of the funders, managers, and engineers who collectively determine the level of risk. In the terms of an old cliché, "we have met the enemy, and they are us!" We humans make mistakes, either individual cognitive or physical mistakes, or as groups through lack of communication or miscommunication.

Although the statistics have not been studied fully, my sense, from experience in the field and discussions with other experienced engineers, is that 80 to 95 percent of failures are ultimately due to human error or miscommunication. Most of these are quite simple, which makes them appear all the more ridiculous when the investigation gets to the root cause and finds, for example, that it is due to a missed conversion factor of English to metric units, a simple error in a weld, a reversed sign in an equation, or one person not knowing that another person had a piece of information needed to make a proper decision. The mundane nature of the causes is precisely what makes them so hard to catch. We constantly carry out simple daily tasks and communications. Thousands of such tasks and communications happen every day on a project, and any one of them can be the cause of tomorrow's dramatic failure.

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Systems management and systems engineering reduce failure rates by providing formal cross-checks that find and fix most potential mission-ending faults. Skunk-works approaches can succeed through the extraordinary hard work of a cadre of experienced personnel, but over the long run, they are not repeatable. That is because we humans are unable to maintain our focus for long periods. Eventually we become lax and forget some key detail or skip a critical process because "we know" that we have done the right things and don't need to double-check. Systems management and systems engineering cannot guarantee absolute success either, but history shows that they do significantly reduce project failure rates. This should be no surprise, because that is what they were created to do.

How can NASA make progress directly addressing the CAIB recommendations? The first step is recognizing that technical failures have individual and social causes. Evidence for this is overwhelming, and we do not need to look further for some elusive "cultural issue." The second step is to take action. While there is no single solution to this problem, there are many ways we can improve. We can perform research to better understand how humans make mistakes and what circumstances increase our "natural error rates." We can use this research to change the environment in which we operate and communicate, and we can educate ourselves to reduce the probability of making individual mistakes or miscommunicating with others. We can improve the relationships between engineering, operations, and safety organizations, and we can create design and operational engineering disciplines to better engineer our systems to tolerate the inevitable failures.

Above all, NASA needs to make tackling the individual and social causes of failure a priority. It should put a plan in place to start the research and to plan, coordinate, and assess organizational and educational innovations specifically targeted to improve dependability. Individual education, organizational change, and technical improvements will all be part of this plan. All these methods, and the efforts of all of us, will be needed to tackle this, one of NASA's most difficult and deep-seated issues. ●

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The Societal Impact of Space Flight

BY STEVEN J. DICK

NASA's founding document, the National Aeronautics and Space Act of 1958, specifically charged the new agency with eight objectives, including "the establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes." Although the Space Act has been often amended, this provision has never changed and still remains one of the main objectives of NASA.[1] Despite a few early studies, the mandate to study societal impact has largely gone unfulfilled as NASA concentrated on the many opportunities and technical problems of space flight itself.

As NASA celebrates its fiftieth anniversary, it is time to take up the challenge once again. Multidecade programs to explore the planets, build and operate large space telescopes and space stations, or take humans to the moon and Mars require that the public have a vested interest. But whether or not the ambitious space visions of the United States and other countries are fulfilled, the question of societal impact over the past fifty years remains urgent, and may in fact help fulfill current visions, or at least raise the level of debate.

It seems obvious that certain turning points in the history of space flight must have had an impact: Sputnik, the moon landing, the Space Shuttle disasters, and so on are etched in memory for better or worse. But unpacking the nature and extent of that impact is no simple task. Secondly, a commercial and economic component to space flight is undeniable. It ranges from a far-reaching aerospace industry to the famous (and sometimes literally legendary) "spinoffs;" it is a part of national and international political economy; and it has sometimes measurable, but often elusive, effects on daily life and commerce. Economic impact is closely related to a third area: applications satellites, which are in turn often inseparable from environmental issues and national security.

Imaging Earth from space and global space surveillance have played an arguably central role in the increasingly heated debate over global climate change and have changed the manner in which national security issues are understood and interpreted. Just how central is a matter that only historical analysis can reveal. In a fourth domain, that of social impact, space activities have affected science, math, and engineering education; embodied questions of status, civil rights, and gender, among other social issues; and led to the creation of "space states" such as California, Florida, and Texas. Finally, space flight has affected culture in multiple ways, ranging from worldviews altered or completely transformed by the images of Earth from space and the spectacular views of space from Earth-orbiting spacecraft, to a sense of our place in the universe made possible by studies of cosmic evolution and the search for extraterrestrial life, and the embodiment of these and other themes in literature and the arts.

These overarching themes raise further questions. What is the difference between social impact and cultural impact? What is the interplay between space flight and those enduring American values of pioneering, progress, enterprise, and rugged individualism? How does this interplay differ from experiences in the Soviet/Russian, European, or Chinese milieu? How has space flight affected conceptions of self and others, as well as our understanding of our purpose in the universe?

Despite the importance of the subject, very few systematic studies of the societal impact of space exploration have been undertaken over the past fifty years. One exception that stands out from four decades ago is *The Railroad and the Space Program: An Exploration of Historical Analogy*. Funded by NASA through the American Academy of Arts and Sciences, *The Railroad and the Space Program* focused on the uses of historical analogy to illuminate the problem of societal impact. Confident in the use of historical analogy as suggestive, but not predictive, of the future, the authors of the volume elaborated on two technological events whose beginnings were separated in time by 150 years. The railroad was, they said, an engine of social revolution that had its greatest impact a full fifty years after the start of the railways in America. As a transportation system, the railway had to be competitive with canals and turnpikes, and twenty years after the start of railways in America, more miles of canals were being built than railroads. It was not initially clear that railroads could be economically feasible. In the course of the nineteenth century, they represented human conquest of natural obstacles, with consequences for humans' view of nature and our place in it. Moreover, secondary consequences often turned out to have greater societal impact than the supposed primary purposes for which they were built. And though many technological, economic, and managerial hurdles needed to be overcome, railroads are still with us.

The space program has had, and still has, its technological challenges, and the economic benefits may be even longer term than the railroad. But by conquering the dimension of space as aviation did to a small extent in the thin skin of Earth's atmosphere, and as the railroad did on the surface, in the long run the space

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program's impact may exceed that of the railroad. Although originally suspicious of parallels with the past, present, and future, the authors in the end saw "the possibility of moving up onto a level of abstraction where the terrain of the past is suggestive of the topography of the present and its future projection."[2] They cautioned that in taking such an approach as much empirical detail should be used as possible, and that analogies drawn from vague generalities should be avoided. Four decades later, *The Railroad and the Space Program* still makes for relevant reading.

In addition to that early study, there have been other, sporadic forays. On the occasion of the sixtieth anniversary of the British Interplanetary Society, NASA was heavily involved in a special issue of its journal devoted to "the impact of space on culture."[3] There NASA scientists Charles Elachi (now director of the Jet Propulsion Laboratory) and W. I. McLaughlin, as well as historian Sylvia Kraemer, among others, discussed the impact of space endeavors on space science, politics, the fine arts, and education. In 1994 the Mission from Planet Earth program in the Office of Space Science at NASA sponsored a symposium entitled, "What is the value of space exploration?" A variety of speakers ranging from Carl Sagan to Stephen Jay Gould discussed the scientific, economic, cultural, and educational impact of space exploration.[4]

More recently, in 2005 the International Academy of Astronautics (IAA), which has a commission devoted to space and society, sponsored the first international conference on space and society in Budapest, Hungary. The IAA and the European Space Agency jointly sponsored a study published as *The Impact of Space Activities upon Society*,[6] in which well-known players on the world scene briefly discussed their ideas of societal impact, ranging from the practical to the inspirational.

The authors of more general studies of space flight have on occasion tackled the subject of societal impact. In her book *Rocket Dreams: How the Space Age Shaped Our Vision of a World Beyond*, Marina Benjamin argues that space exploration has shaped our worldviews in more ways than one. "The impact of seeing the Earth from space focused our energies on the home planet in unprecedented ways, dramatically affecting our relationship to the natural world and our appreciation of the greater community of mankind, and prompting a revolution in our understanding of the earth as a living system," she wrote. Benjamin thinks it no coincidence that the first Earth Day on April 20, 1970, occurred in the midst of the Apollo program; that one of the astronauts developed a new school of spiritualism while others have also been profoundly affected spiritually; or that people "should be drawn to an innovative model for the domestic economy sprung free from the American space program by NASA Administrator James Webb." Space exploration shapes worldviews and changes cultures in unexpected ways; by corollary so does lack of exploration.[7]

Others have demonstrated the complex relation of space goals to social, racial, and political themes. One such study is De Witt Kilgore's *Astrofuturism: Science, Race, and Visions of Utopia in Space*, where the author examines the work of Wernher von Braun, Willy Ley, Robert Heinlein, Arthur C. Clarke, Gentry Lee, Gerard O'Neill, and Ben Bova, among others, in what he calls the tradition of American astrofuturism.[8]

All these topics are discussed in the volume *Societal Impact of Spaceflight*, recently published in the NASA History series. It is available online at http://history.nasa.gov/sp4801-part1.pdf and http://history.nasa.gov/sp4801-part2.pdf. As NASA moves forward with its new vision for space exploration, understanding the societal impact of space flight may prove essential for sustaining its programs during the next fifty years. ●

1 The National Aeronautics and Space Act and its complete legislative history may be found at http://www.hq.nasa.gov/office/pao/History/spaceact-legishistory.pdf. The passage quoted here is on page 6.

2 Bruce Mazlish, ed., *The Railroad and the Space Program: An Exploration in Historical Analogy,* (Cambridge, MA: MIT Press, 1965).

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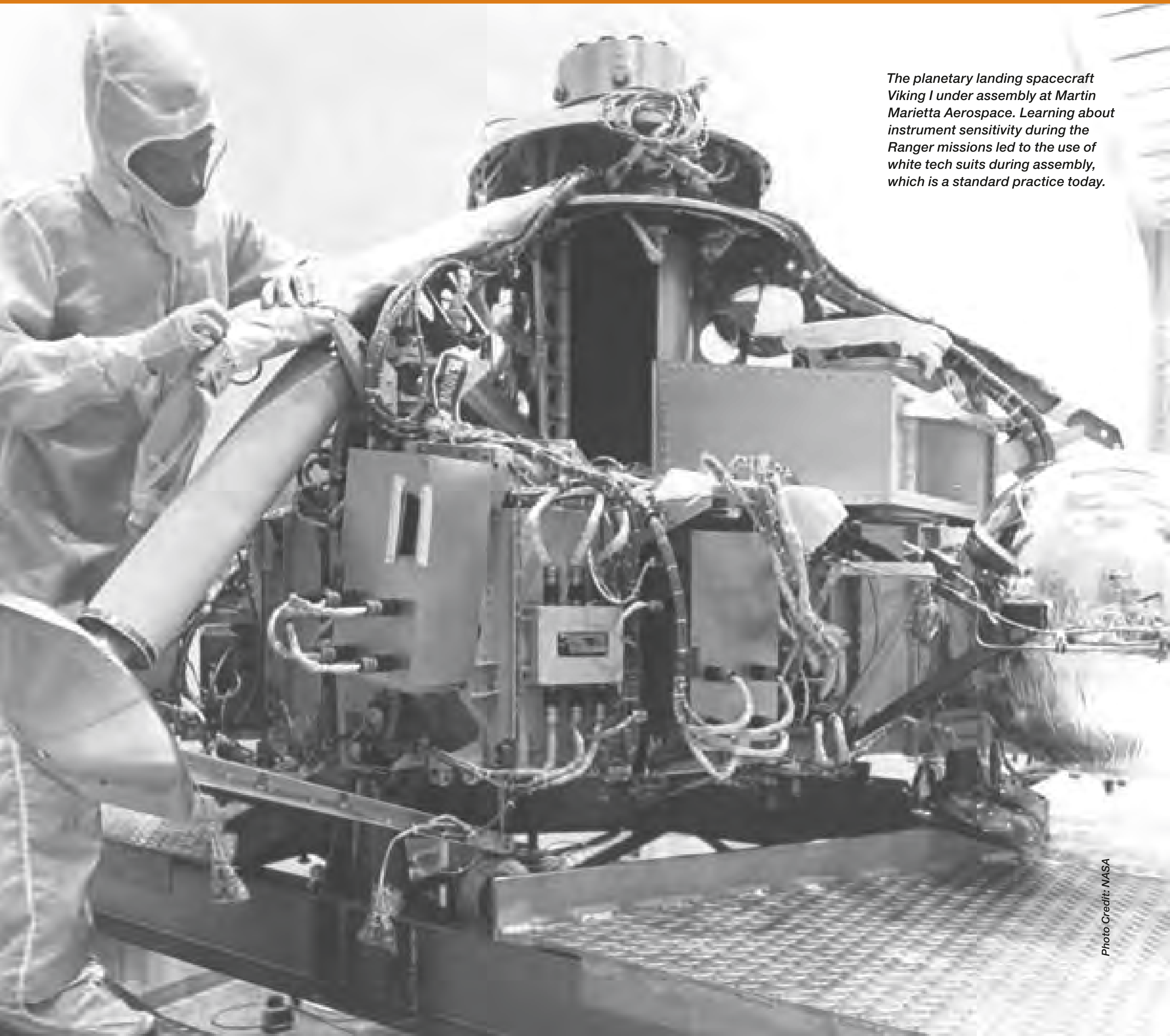
STEVEN J. DICK is NASA's Chief Historian.

Leadership, Teamwork, and Focus: VIKING'S LANDING ON MARS

BY KERRY ELLIS



The planetary landing spacecraft Viking I under assembly at Martin Marietta Aerospace. Learning about instrument sensitivity during the Ranger missions led to the use of white tech suits during assembly, which is a standard practice today.

Photo Credit: NASA

Since the advent of space exploration, Mars has been a tantalizing goal. Astronomers had been peering at Mars for centuries, trying to discern its features; science-fiction novels had been filling the human imagination with ideas of life on the red planet's harsh surface for fifty years before the first orbiter attempts were made. But Mars did not make it easy for us to approach. Between 1960 and 1974, the U.S. and Soviet space programs made twenty-two attempts to reveal some of the planet's secrets. Fifteen of those missions failed.

The U.S. Mariner missions provided glimpses of the planet. Mariner 4 accomplished the first successful Mars flyby and returned the first images of another planet from deep space. The images were taken from orbit, which gave too broad a view to distinguish small surface details—data necessary to determine safe landing sites. "We had no visibility and no imagery," said Viking project manager Jim Martin. "Look at the first color picture, and you see 'Big Joe' 25 to 30 feet away. If we'd hit that rock, Viking would have been smashed. We had no visibility. Just a lot of luck."

Along with luck, the Viking team had talent, intelligence, and an avid desire to solve the mysteries of Earth's near neighbor. A key driver and source of excitement for those involved was the burning question of whether life existed, or could exist, on Mars. The search for life presented its own difficulties, including the sterilization of all lander parts to avoid bringing Earth contaminants to Mars. This requirement eliminated about 90 percent of standard industry parts they could use for fabrication, according to Ansel Butterfield, the Viking parts coordinator. Creating technology that did not yet exist, finding cost-effective solutions, and explaining requirements to manufacturers became additional hurdles.

Butterfield recalled a conversation he had with a man from General Electric (GE), which was producing televisions at the time. While comparing notes about an electronic voltage amplifier, which would cost $50 each for Viking, the GE representative claimed he could get them for 50 cents. "I explained they were a bit different," said Butterfield in a NASA interview. "When he asked, 'What's the difference between your electronics and mine?' I told him, take your television set, stick it in the oven and bake it at 250 degrees for twenty-four hours, put it in a deep freeze for a year, then snap it and roll it down a flight of stairs, dump it out a second-floor window, and expect it to play."

The Viking orbiters and landers were not going to have an easy journey.

Designing, Fabricating, and Testing

Viking was a huge undertaking consisting of two orbiters carrying two landers. The orbiters would capture and relay information about the Mars surface that would allow the mission team to determine safe landing sites for both landers. It was a complex mission to design and fly, especially considering the technology available in the late sixties to early seventies.

Creating the landers presented a larger challenge. While engineers designing the orbiters could pull from their experience designing Mariner, the lander team was breaking new ground. The Viking landers were heavier and more complex than NASA's earlier lunar lander, Surveyor. They also needed to travel much farther than the earth's moon and had to descend safely through the Martian atmosphere. The relative thinness of the atmosphere made that, in some ways, a more difficult challenge than reentry into Earth's atmosphere, which had been solved during Apollo. These factors would affect the overall design and fabrication of the Viking landers, as well as the scientific instruments. Martin made certain the science team was involved in discussions early on as the engineers drafted requirements.

One of the most challenging instruments was the gas chromatograph-mass spectrometer (GCMS), which spent some time on Martin's infamous Top Ten Problems list. A combination of two instruments in one, the GCMS was a crucial instrument for the science the team wanted to achieve with Viking. It would separate, analyze, and identify different molecules from a Mars soil sample; it was cutting-edge science. So cutting-edge, the original GCMS was the size of a room. The Viking scientists and engineers had to shrink it to fit inside a 1-foot cube. They overcame several technical issues that resulted in a GCMS flying on each lander and returning data to Earth successfully.

The innovations that came out of Viking went beyond the creation of complex scientific instruments; they included new solutions in communication, engineering, and mission design made necessary by the complexity of the mission. One of those

Photo Credit: NASA Langley Research Center

Watching for the first images from Viking to come in.

innovations was the Viking Automatic Data System, an early use of computer systems to share and review documents. "This is what we routinely do today, but remember this was 1970," said Gus Guastaferro, the Viking business manager. "They were having a hard time developing it, and I recommended we drop it. Jim [Martin] looked around the room and said, 'Is there anybody else in the room that has an opinion that is also against progress?' And Tom [Young] said, 'Jim, I think it's a great idea and we should pioneer that kind of spillover effect.' And he was right," Guastaferro said. "It was the type of visionary thing that happened in Viking that changed all of us. Jim had an obligation that we had to grow as an organization and introduce new tools and new ways of doing business."

Viking also introduced a revolutionary approach to flight planning when the launch date slipped from 1973 to 1975 due to budgetary reasons. Norm Crabill, part of the mission analysis and design team, recalled that 1973 was a "low energy to Mars year," meaning the journey would take only six months to complete, compared with nine or ten months in 1975. "I had the duty of telling Jim he had to go back to the president and tell him we had to launch in 1973 because you couldn't get there from here in 1975," recalled Crabill. "My education broadened immediately when the answer was, 'You don't understand. You find a way to get there in 1975.'" They put together a team to determine another way to accomplish the journey and discovered what is now called a Type II trajectory, which means flying a spacecraft more than halfway around the sun. "Everyone at NASA got involved because the idea was so radical," said Crabill. "I like to think it broke the mold on interplanetary trajectory design."

Even after the rigorous testing that led to Viking's successful launch in 1975, engineers and scientists worked through scenarios of unexpected events that would require quick brainstorming and solutions to keep the orbiters and landers working. "One of the things we did to prepare for Viking, and is still done today, is put together exercises to simulate what would happen in real time to ensure we didn't forget anything," said Hugh Kieffer, principal investigator for the infrared thermal mapper. One of the exercises covered the first few days of the surface mission, which the scientists found somewhat boring. "We had to go to meetings to plan for data we didn't have," explained Kieffer.

After more than a day of analyzing imaginary but expected data, those leading the effort dreamed up a concept to make it more thrilling and get the team more involved. At the next meeting, they had the water vapor detector report that its instrument seemed to be out of calibration. Then the spectrometer team reported they were receiving strange values. "So the normal process of regularly planning the next day was suddenly getting requests," said Kieffer. "We couldn't follow the plan; we had to change things based on discoveries. We were pushing the flight team out of their comfort zone of regularly planned sequences. By the time the third 'discovery' came up, it was clear we'd stressed the operations team to its limit because Gentry Lee, who was in charge of running daily operations, stood up and pounded his fist on the table, shouting, 'Enough! There will be no more discoveries!'"

Though the team worked hard to anticipate the unexpected, unanticipated problems arose. Ingenuity and foresight helped the team meet those challenges. Jim Cochran, a photographic chemist, recalled one instance where they needed to use a third lander they had kept on Earth for troubleshooting. "We sent a signal for a sampler boom to unhinge on a lander, and it failed," said Cochran. Worried they wouldn't be able to gather an important biological sample, they pointed the lander's camera up at the arm and saw a pin that hadn't fallen out. "They programmed the lander on Earth to twist and wiggle the boom until the pin fell out, then sent the same program to the lander on Mars. They turned the camera back down to the ground until they saw the pin and knew it had dropped. And that's what they did with Viking: they came across problems that had never been solved before and solved them," said Cochran.

THE INNOVATIONS THAT CAME OUT OF VIKING … INCLUDED NEW SOLUTIONS IN COMMUNICATION, ENGINEERING, AND MISSIONS DESIGN MADE NECESSARY BY THE COMPLEXITY OF THE MISSION.

It's About People

In a series of interviews conducted by NASA at Viking's thirtieth anniversary celebration, many of those involved in the program spoke about the extraordinary team that had been gathered to make breakthroughs in planetary exploration to Mars. Martin, for many the most memorable project manager they ever worked for, said, "We probably had the most talented team of engineers you could find."

Viking's success was due to more than having the right people. Everyone worked diligently and collaboratively to find solutions to problems, and they continually learned from previous and on-the-job experience. For example, problems that had arisen on the early lunar Ranger missions were factored into Viking's fabrication. Bob Crabtree, mission operations manager for Viking's cruise phase, said, "Quality assurance then [during Ranger] was unheard of. People were even allowed to smoke in the vehicle assembly building. Now we have techs in white suits, but we didn't know things were that sensitive during Ranger. All the things we learned were factored into Viking, and Viking worked exceptionally well."

And the team never stopped learning during the mission. "We really learned about longevity of engineering," said Steve Wall, a camera engineer for Viking. "To maximize lifetime as we rewired parts of Viking to keep it working is the lesson I'd like carried forward, what I'd like us to be remembered for."

Ed Rinderle, a Viking programmer, attributed some of Viking's success to the working environment: "We were all gathered in one big bullpen, an open area, no cubicles or partitions. You got to know each other on a different level than had we been separated."

The team was also thoroughly dedicated to the success of Viking and maintained an intense focus throughout the mission at all levels. A striking example of this focus occurred during a checkout of a lander's software and computer before it separated from an orbiter. In the middle of this crucial checkout, a red phone connecting directly to the White House rang in Martin's

Photo Credit: NASA

This close-up view shows the mated Viking lander (top) and orbiter in the Kennedy Space Center Spacecraft Assembly and Encapsulation Facility.

JIM INTERRUPTED, 'YOU TELL PRESIDENT FORD, PLEASE, THAT I DO NOT HAVE ANY TIME TO SPEAK TO HIM RIGHT NOW—WE ARE IN THE MIDDLE OF A LANDER CHECKOUT—AND FOR HIM TO CALL BACK IN THREE HOURS.' AND HE HUNG UP ON THE PRESIDENT.

office. "Jim picks up the phone and a voice on the other end says, 'Mr. Martin, this is the White House calling …" recalled John Newcomb, who was involved in the mission design and software. "Jim interrupted, 'You tell President Ford, please, that I do not have any time to speak to him right now—we are in the middle of a lander checkout—and for him to call back in three hours.' And he hung up on the president. In three hours, President Ford called back," said Newcomb. "For those of us who had been working with Jim for eight-plus years, it was a no-brainer. Of course the president was going to call Jim back. Jim told him to!"

Teamwork, dedication, creative problem-solving, and rigorous testing all contributed to Viking's success and the team's feeling of immense accomplishment when the first lander image from Mars arrived line by line. "Viking convinced me that one can take on a major engineering and science challenge and succeed with the right ingredients," said Noel Hinners, then NASA associate administrator for space science. "That includes a great leader and a great team. Don't think anything is so difficult and hard you shouldn't even try it. With the right planning, people, leadership, and budget, you can do a lot and succeed." ●

Interviews were originally conducted by NASA and can be found at http://mars.jpl.nasa.gov/gallery/video/viking30/index.html. For more information regarding the challenges solved on the GCMS, please see the APPEL case study at http://appel.nasa.gov/items/Viking_GCMS_case_07%2025%2006.pdf.

Near the Viking 1 lander on the Chryse Plains of Mars, 'Big Joe' stands a silent vigil. This large, dark rock is about 6.6 ft. long and lies about 26 ft. from the spacecraft—a narrow miss during Viking I's landing.

Photo Credit: NASA Jet Propulsion Laboratory

The April 12 launch at Pad 39A of STS-1, just seconds past 7:00 a.m., carries astronauts John Young and Robert Crippen into an Earth orbital mission scheduled to last for fifty-four hours, ending with an unpowered landing at Edwards Air Force Base in California.

Photo Credit: NASA

LESSONS FROM SHUTTLE DEVELOPMENT

BY JIM ODOM

I was the project manager for the Space Shuttle external tank for eleven years, from the planning days in 1971 through the launch of the sixth shuttle flight in 1983. Work on the shuttle program was widely distributed. The program office was at Johnson Space Center; the engines, solid rockets, and tanks were developed at Marshall; and ground operations were at Kennedy, with major work done by contractors North American Aviation, Lockheed Martin, Morton Thiokol, and Rocketdyne, among others. Although centers and contractors had primary responsibility for different elements of the shuttle system, those elements were tightly interrelated. For instance, avionics and flight control systems were on the orbiter but directly affected the control of the main engines and solid rocket boosters, so success depended on a tremendous amount of coordination and integration. That meant multicenter working groups meeting and communicating frequently, lots of travel, many meetings at Johnson with management and technical people, and daily communication at the program and project level. The frequent budget discussions were held at NASA Headquarters in Washington, D.C.

Design Change and Challenges

Our first proposed booster–orbiter configuration featured a flyback booster and smaller engines on the orbiter than those in the final design. The proposed engines would have had enough power to circularize the shuttle's orbit but not enough to do the heavy lifting to reach orbital velocity. We envisioned ten flights a year. The problem was that design and development of that configuration would cost about $10 billion and Congress was only willing to authorize half as much. We were disappointed, but we had to find a way to live with that budget constraint. It was that or no program at all. We came back quickly with a new $5 billion configuration and program. It was essentially the design that was eventually built: recoverable solid rocket boosters and a disposable external fuel tank that supplied the propellants to the orbiter's three main engines.

Our initially more expensive design would have been more economical in the long run. In almost any space program, the bigger investment you can make up front, the lower the operating costs will be. As a rule, those investments pay off, but political and economic realities often stand in the way of making them.

We knew, too, that the proposed sixty shuttle flights a year in the revised plan were probably not realistic. The number was arrived at by doing the math on how many flights would be needed to meet the financial goals of low pre-launch cost.

From a technical point of view, the structure of the external tank was not especially complicated. It was similar to the second stage of Apollo's Saturn V—a bit smaller in diameter but longer and using similar materials and welding techniques. The real technical challenge came from the fact that the orbiter tiles could be damaged by ice falling off the tank during launch, so the external tank needed enough insulation to keep the outside temperature above 32°F. (The internal temperature was approximately –400°F.) We needed to apply insulating foam to one-third of an acre of tank surface, much of it through automated spraying, but with joint and bracket insulation applied by hand.

The first flight was delayed several weeks because a large section of insulation over the liquid oxygen tank delaminated during the first tanking test at Kennedy Space Center. It turned out that the material bonding the insulation to the tank skin and the foam itself had not been applied properly. That had to be cleaned off and replaced entirely by hand on the launchpad.

Over time, the foam, which had to be both light and aerodynamically resilient, was reformulated eight times when we had to find replacements for chemicals used in its manufacture that were judged to be polluting. A great deal of hard work went into making the foam insulation as safe and effective as possible. The *Columbia* accident showed that we needed to make improvements. Most of the improvements were made in the manual applications and processes.

Another technical challenge was understanding the aerodynamic stresses on the various elements of shuttle system, *This 1972 chart conceptualizes the use of two parallel Solid Rocket Motor Boosters in conjunction with three main engines to launch the proposed Space Shuttle into orbit.*

Photo Credit: NASA

ONE OF THE IMPORTANT LESSONS OF A SUCCESSFUL PROGRAM TRANSITION IS THE VALUE OF MOVING PEOPLE OVER TO THE NEW PROGRAM AND INVOLVING THEM IN THE DESIGN PROCESS AS EARLY AS POSSIBLE.

including, of course, max ascent loads—the point of maximum dynamic pressure. The analysis was extremely complicated and needed to be done from a systems standpoint, rather than separately for parts of the whole. That was another instance when communication and coordination were essential. Emphasizing systems engineering and the interfaces between elements of the program was key.

Program Transitions

The Apollo program was still active when we began working on the shuttle. I worked closely with Apollo program engineers who joined the shuttle program to work on the external tank and brought their very valuable Saturn V knowledge and experience with them. Apollo skills, especially in manufacturing, were directly applicable to the shuttle program.

One of the important lessons of a successful program transition is the value of moving people over to the new program and involving them in the design process as early as possible. That way, you get the full benefit of their expertise and ensure their commitment to the new program.

NASA's challenge today is to make sure the last shuttle flights are carried out safely while we develop the next generation of launch vehicles and spacecraft. The timing appears good to transfer experienced hardware and operations people from the shuttle to Ares 1 and Ares 5 development. If Ares should be delayed more than eighteen months or more, though, NASA will face the problem of not having new work to move experienced people to as the shuttle program winds down. It is important to try to avoid that problem to ensure that the Constellation program will get the benefit of many years of shuttle experience, just as the shuttle program got the benefit of Apollo. ●

JIM ODOM began his career in the launch vehicle business with the Wernher von Braun team as a G.I. developing and launching the army's Redstone and Jupiter rockets. He transitioned with this team to become NASA's Marshall Space Flight Center. He retired from NASA in 1989.

NASA's Inventions and Contributions Board: A Historical Perspective

BY CAROL ANNE DUNN

Outside NASA's scientific community, NASA's Inventions and Contributions Board (ICB) and its Space Act Awards Program are practically unknown, yet its history is a microcosm of NASA's history, and it has been an important factor in NASA's extensive technological achievements. The Board was formed to review waivers of title to inventions by NASA contractors and to award money for scientific and technical contributions that are of significant value in conducting aeronautical and space activities. Created by the original Space Act of 1958, the Board itself was a visionary, innovative, and historical concept that has continually chronicled NASA's challenges and innovations.

The Board's inception was visionary because there was little precedent. A forward-looking Congress recognized that if NASA was to achieve one of its chartered purposes—"the preservation of the role of the United States as a leader in aeronautical and space science and technology"—then incentives must be given to the new agency's scientists, engineers, and technologists to create and invent technologies that would be needed by the fledgling space program. Today, these contributors are honored with awards for innovations that have been reported in *NASA Tech Briefs*, software that has been approved by NASA for release to qualified users, and inventions that have received approval for patent applications by NASA under the Space Act.

NASA epitomizes the spirit of innovation through the imagination of its scientific and engineering communities. In the latest ICB annual report, we highlight the Robot Cable-Compliant Device developed at Goddard Space Flight Center. Goddard featured this invention on its Tech Transfer Web site, stating that it provided customized structural response and mitigated shock and vibration damage. The center also lists a variety of applications in which the technology could be used. One of those applications, developed by Enduro, is a rehabilitative walker that enables patients to stand and move without the aid of a physical therapist. It is currently being used to help soldiers and others at the Walter Reed Medical Center in Washington, D.C.

The device is also being used in the NASA Space Technology 5 (ST5) mission. ST5 consists of three 25 kg satellites orbiting the earth together to measure the magnetosphere and demonstrate miniaturized technology. Each spacecraft has an umbilical separation connector that indicates when the spacecraft is fully released from the rocket. The connector is positioned by a compliant mount, which possesses a high tolerance for misalignment, and allows the spacecraft to separate smoothly. The compliant mount is an alternate embodiment of the Robot Cable-Compliance Device technology. This is one example of how a NASA technology can be developed into many useful applications. The Tech Transfer Office's coordination with ICB helps publicize these inventions, enabling others outside the Agency to help brainstorm the many ways one widget could be used.

Through the years, awards to scientists and engineers have consistently increased in monetary value. The largest award of the sixties was to Francis Regallo of Langley Research Center: $35,000 for a flexible wing (kite). In the seventies it was Richard T. Whitcomb, another Langley employee, who received $25,000 for the Airfoil Shape for Flight. In 2005, Kennedy Space Center employees in conjunction with the University of Florida received $73,000—the largest award for Invention of the Year in the history of the Board—for Zero-Valent Metal Emulsion for Reductive Dehalogenation of DNAPL-Phase Environmental Contaminants, an environmental clean-up technology.

By increasing the awards, the ICB motivates inventors to make their inventions known to a broader audience. NASA technologies that might have otherwise remained behind closed doors are more readily available to industry and other

The NASA Inventions and Contributions board convenes in March 1960 to discuss a petition of Bell Aircraft Corporation for a waiver of patent rights on the invention of the "catalyst bed."

The NASA Inventions and Contributions Board on November 16, 1961.

NASA Centers for future creative applications. This broader dissemination and publication of winning inventions by the ICB helps communicate what's available inside NASA and helps keep innovation between centers and with communities outside the Agency active.

Through the activities of the ICB, each of NASA's ten centers has contributed to NASA's impressive roster of technological achievements. The first Board, convened on December 4, 1958, had 250 cases awaiting review, and during its first year of existence, requests for awards arrived at the rate of 100 per month. On May 9, 1960, T. Keith Glennan, NASA's first administrator, noted, "Directly following lunch we had a briefing by the Inventions and Contributions Board. Those poor devils had to review 2,000 proposals arising out of supposed inventions and contributions." Today's Board comprises twenty-two members and is chaired by the NASA Chief Engineer. The NASA Administrator selects its members, and they serve for a minimum of three years.

In addition to recognizing NASA's innovative scientists, engineers, and technologists, the Board has produced a detailed record of NASA's technological achievements throughout the years. These technologies continue to have a tremendous effect on the U.S. economy. The 2003 ICB annual report estimated that the extraordinary impact of just a few of these inventions on the U.S. economy and world commerce was more than $200 billion, and the aggregate of all 98,000 awards that the Board has granted throughout its fifty-year existence is conservatively estimated to have contributed more than half a trillion dollars in wealth to the economy and enabled technology that will change how we work and live. More importantly, the Board recognizes NASA's finest technical talent, whose expertise covers more than forty fields of science and technology, and makes them more readily available to the public. ●

For a complete list of winning technologies, visit the ICB Web site at http://icb.nasa.gov.

CAROL ANNE DUNN currently works as a project specialist in the Technology Transfer Office at Kennedy Space Center. She is also the awards liaison officer for the Inventions and Contributions Board.

The Knowledge Notebook

Learning from History

BY LAURENCE PRUSAK

NASA's fiftieth anniversary, being observed in a variety of ways this year, including in this special issue of *ASK*, makes me think about the importance of looking back—not just to celebrate but to learn from the past.

I am frequently astonished at just how ahistorical so much of so-called management thinking is—to say nothing of how little history seems to be taught to our students nowadays. From grade school through business school, it is often assumed that the past has little to offer the present or to contribute to preparing for the future. It is really a remarkable reversal of how our grandparents were taught. Their generation considered history a key subject for study if not *the* key subject. History has been highly valued as far back as we have records in ancient China, India, the Near East, and Africa. It's only in the past thirty years or so that schools began to replace the study of the past with understanding the present through various social science subjects such as economics, political science, sociology, and all the stuff lumped under the social science umbrella.

But history counts. The past shapes the present. Organizations, as well as cultures and countries, are what is sometimes called "path dependent." That is, their past experiences and behaviors set the table for present and future actions. And while I am not at all a determinist, it is the rawest folly to pretend that the activities of the near and even far past have no pull or power in the present.

So why do most organizations have so little real and passionate interest in their own past? Well, politics play a role here. While knowledge may sometimes be power, as the saying goes, power is always in a position to dictate what knowledge is taught and what is ignored or denied. It is often difficult to learn anything like the real truth in many organizations because those in power don't care to admit their own imperfections, missed opportunities, outright blunders, and malfeasance (or, for that matter, the valuable contributions of some of their predecessors). Their actions are often covered in clouds of rationalizations and ambiguities, including claims that the right thing to do is focus on the future and not be distracted by "ancient history." This presentism, aptly expressed in the popular saying, "that was then, this is now," tries to pretend that "then" is a useless construct and obstructs current understanding.

But how can we learn to do better if we don't have a real understanding of both the good and the bad in our own past? How can we solve current problems if we choose to ignore their causes? The errors and mistakes we make, at NASA and everywhere else, are often distinct. We need to study them dispassionately to make any progress in doing things more effectively. Without using our own history to teach, we lose the source materials that can best instruct us.

In this anniversary year, NASA is appropriately celebrating its many astonishing accomplishments. It is also, in forums and publications (including this one), hearing about what went into those accomplishments from people who were part of them. It is engaged in discussions about what the triumphs and tragedies of the past tell us about what the space agency needs to do and be to achieve its future goals.

All that is important, but we should also think about how NASA can best learn from the past year in and year out. Here is one way I've seen the past effectively used to inform the present and prepare for the future.

Organizations can write detailed, honest, real-life cases that are then taught with the actors present, taking part in the discussion of what did and didn't work. I have seen this done very successfully at Petrobras, the large Brazilian energy firm. It also works at Harvard Business School by way of their famed case-writing methods, as well as at other organizations, but, alas, rarely at government agencies. Having the actors involved gives the cases far more authenticity—it makes them living history that passes the well-known sniff test and allows for a real discussion to take place, one that gives the participants an opportunity to absorb and socialize the lessons in ways that abstract lectures, sets of rules, or e-learning never allow.

All the training courses available in all the organizations in the world can never have the impact of a true story told in an authoritative voice with the participants present to discuss why they did what they did or didn't do. Of course, this needs to be done in a culture of safety, not one of blame. That would ruin the effort. When done well, though, it is a modestly priced approach that brings history to life, which genuinely promotes learning from the past—a crucial activity humans have relied on for thousands of years. ●

… HOW CAN WE LEARN TO DO BETTER IF WE DON'T HAVE A REAL UNDERSTANDING OF BOTH THE GOOD AND THE BAD IN OUR OWN PAST? HOW CAN WE SOLVE CURRENT PROBLEMS IF WE CHOOSE TO IGNORE THEIR CAUSES?

ASK interactive

NASA Celebrates Fifty Years

Join NASA in celebrating its fiftieth anniversary by reviewing exciting discoveries and images from past missions, watching special lectures from NASA Administrator Michael Griffin and Dr. Stephen Hawking, or visiting interactive Web features that walk you through each decade since the Agency's inception. See how NASA has contributed to inspiration, innovation, and discovery for half a century, what it is accomplishing today, and what it plans for the future. Visit the anniversary Web site at http://www.nasa.gov/50th.

Reminder: PM Challenge 2009

The NASA PM Challenge is the Agency's annual forum for NASA stakeholders to connect and discover current trends in program management, project management, and related disciplines by sharing their knowledge, lessons learned, and new ideas that enhance mission success. PM Challenge 2009, the Agency's sixth annual project management conference, will be held February 24–25, 2009, in Daytona Beach, Florida, near the Kennedy Space Center. Registration opens November 3, 2008. For more information, and to register, visit http://pmchallenge.gsfc.nasa.gov.

Web of Knowledge

Ever wonder about what the Hubble Space Telescope has revealed? Explore a wealth of deep-space images, including far-off galaxies, planets, nebulae, and more at http://hubblesite.org. Also watch video podcasts and short movies about how galaxies interact with each other and even combine to make new galaxies, black holes, other astronomy highlights from Hubble, and celestial events at-home astronomers can witness each month. The site also has resources for children and educators to assist with learning about our cosmos.

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