National Aeronautics and Space Administration

Academy Sharing Knowledge

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Photo Credit: NASA/JPL-Caltech

ON THE COVER

Astronomers used the Galaxy Evolution Explorer (GALEX) telescope to take this deep image in ultraviolet light of the sprawling spiral galaxy M81, hoping to learn where it kept its hot stars. Hot stars emit more ultraviolet than cool stars, and are frequently associated with young, open clusters of stars and energetic star-forming regions. Less than 100 million years old, the young stars are blue and are well separated from the older, yellowish stars of the galactic core. M81, visible through a small telescope, spans about 70,000 light years and lies about 12 million light years away toward the constellation of the Great Bear (Ursa Major).

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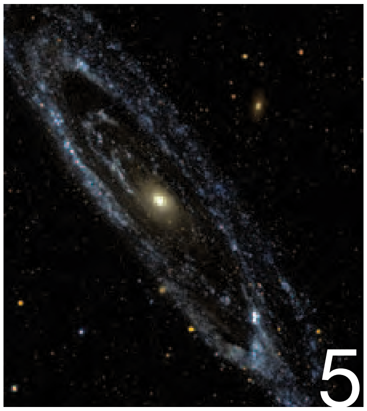

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To Our Subscribers

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ask

Issue No. 46

Staff

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

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

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

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In This Issue

In his "From the Academy Director" column, Ed Hoffman says, "Knowledge is the coin of the realm at NASA," and discusses the challenges of "identifying, capturing, and sharing" the wealth of valuable knowledge the agency possesses. These are the goals of knowledge management, which is about making essential knowledge available and usable where and when it is needed in an organization.

When we consider knowledge and NASA, we probably think first about technical knowledge—the countless insights the agency has gained over the decades into how to engineer spacecraft and launch vehicles, and its wealth of accumulated scientific findings. As Laurence Prusak points out in "The Knowledge Notebook," though, there are many kinds of knowledge. Purely technical knowledge (say the behavior of a particular material in the vacuum of space) is near one end of a spectrum that extends to much less explicit expertise—for instance, knowledge of how to meld disparate groups into a collaborative team. The difficulties of communicating technical knowledge effectively are real but may be ultimately less challenging than teaching the subtler lessons of how to get the work done (among many other skills, how to guide and inspire people, how to recognize problems before it's too late, how to adapt to the unexpected events that are inevitable in complex projects).

Several of the articles in this issue of *ASK* illustrate the critical importance of those so-called "soft" skills (which include, by the way, understanding *when* you need new or better technical knowledge—one source of problems and failures on technical projects is thinking you know everything you need to know). In most of these cases, the most important contribution to solving both technical and organizational difficulties was to gather people in one place to work and talk together. So, for instance, much of the team that built IBM's Watson computer ("Building the Watson Team") spent their days in a single large room without cubicles or closed offices. That proximity supported the exchange of technical information *and* helped create a shared sense of mission.

Similarly, David Young's discussion of planning for an important climate mission ("CLARREO: Bringing Disciplines Together") describes how gathering scientists, engineers, and managers together as early as possible in the process can avoid later wasteful conflicts between what scientists want and what engineers (and budgets) can provide. And in the interview, Lisa May talks about how program execs in the Science Mission Directorate meet to share knowledge from the programs they help manage. And James Fanson offers a negative example of what can happen when you don't bring people together in "GALEX: Managing the Unexpected," telling how leaving an engineer alone to design a key component led to an unusable unit and the need to scramble for a replacement.

The articles here that focus on international collaborations add a further element to the kinds of knowledge needed to carry out projects successfully: cultural knowledge. "An Argentine Partnership with NASA," "Managing Multicultural Teams," and "International Collaboration on BepiColombo" all emphasize the importance of taking time—and spending time together—to learn the values and perspectives of team members from other cultures. The time together and the understanding it helps generate contribute to another essential element of project success: mutual trust.

Don Cohen
Managing Editor

From the Academy Director

NASA's Knowledge Imperative

BY ED HOFFMAN

Like all large, knowledge-intensive organizations, NASA faces continuous challenges identifying, capturing, and sharing what it knows effectively.

Knowledge is the coin of the realm at NASA. Need to understand something about engine cutoff sensors, the physiological impact of extended stays in low-Earth orbit, or how to drive a rover on Mars? That kind of specialized expertise exists at NASA, and often nowhere else.

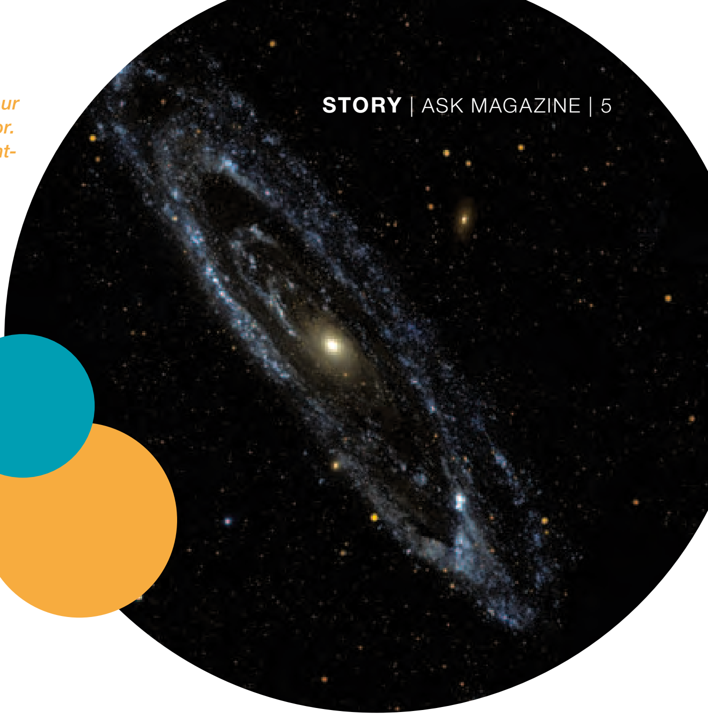
At the same time, (to paraphrase science-fiction writer William Gibson's remark about the future) NASA's knowledge is not evenly distributed. Sometimes the people who know something and the people who need to know it don't connect. And valuable knowledge is at risk of walking out the door as NASA approaches a significant demographic shift: more than half the workforce is eligible for retirement. There's a high likelihood that many senior employees will leave within five years.

The knowledge challenge extends to NASA's failures. Our mishaps, accidents, and anomalies yield critical, hard-won lessons. We use rigorous investigation methodologies such as root-cause analysis to ensure that we discover why we made mistakes. Our track record of learning from these incidents has also been unevenly distributed; we've done better in some instances than others.

Developing more consistent knowledge capability across the agency was part of what motivated the Aerospace Safety Advisory Panel (ASAP), an advisory group established by Congress, to recommend that NASA "establish a single focal point (a Chief Knowledge Officer [CKO]) within the agency to develop the policy and requirements necessary to integrate knowledge capture across programs, projects, and centers." ASAP acknowledged good work in this area at Johnson Space Center and Goddard Space Flight Center, and also recommended that all centers and mission directorates consider establishing CKOs to "ensure standardization."

In response to the recommendation, I was appointed NASA's CKO. In late February, I convened a meeting of the agency's knowledge community, and we took inventory of knowledge services and activities at various centers and mission directorates. Frankly, I had not been fully aware of the quantity or quality of knowledge work going on across the agency before that meeting. In the weeks and months ahead, after our data-collection effort has been fully vetted, I will be writing more about the current state of knowledge services at NASA. It is an impressive story that I look forward to sharing. Both *ASK Magazine* and the online *ASK the Academy*, in a new regular feature called CKO Corner, will also begin highlighting efforts at different NASA centers and mission directorates.

I will remain the director of the Academy of Program/Project and Engineering Leadership as I assume the responsibilities of serving as NASA's first CKO. This is a logical extension of the knowledge services the Academy began providing over a decade ago. I look forward to engaging deeply with the community of dedicated professionals that gathered in February to ensure that our technical workforce has the knowledge it needs to achieve mission success. As always, please feel free to contact me if you would like to share thoughts or ideas. ●



The Andromeda Galaxy, or M31, is our Milky Way's largest galactic neighbor. The entire galaxy spans 260,000 light-years across—a distance so large, it took ten GALEX images stitched together to produce this view of the galaxy next door.

Photo Credit: NASA/JPL-Caltech

GALEX

MANAGING THE UNEXPECTED

BY JAMES FANSON

They say that good things come in small packages, and this has certainly been true for NASA's Explorer Program. Explorers are among the lowest-cost missions flown by NASA, but they can pack a big scientific punch. Such is the case with the Galaxy Evolution Explorer, or GALEX, a mission designed to map the history of star formation over 80 percent of the age of the universe. Since its launch nearly nine years ago, GALEX has transformed our understanding of how and when galaxies formed over time. Along the way, as the team anticipated, several unexpected and intriguing scientific discoveries have been made. What we did not anticipate was the gauntlet of technical and programmatic challenges that had to be overcome to get GALEX into orbit.

IN REALITY, THE DIFFICULTY OF A PROJECT IS MEASURED BY THE RATIO OF AVAILABLE RESOURCES TO THE CHALLENGES BEING FACED.

There's a widely held belief that smaller projects are easier projects. In reality, the difficulty of a project is measured by the ratio of available resources to the challenges being faced. Explorer missions by necessity have small budgets, so it's critically important to assemble the strongest possible team and ruthlessly constrain the magnitude of the challenges. This is easier said than done. Take staffing for example. Smaller missions have fewer team members, so each is more crucial. One needs the sharpest individuals with unusually broad skills. It can be difficult to recruit such people in organizations where importance is measured by the size of the budget managed or the number of direct reports.

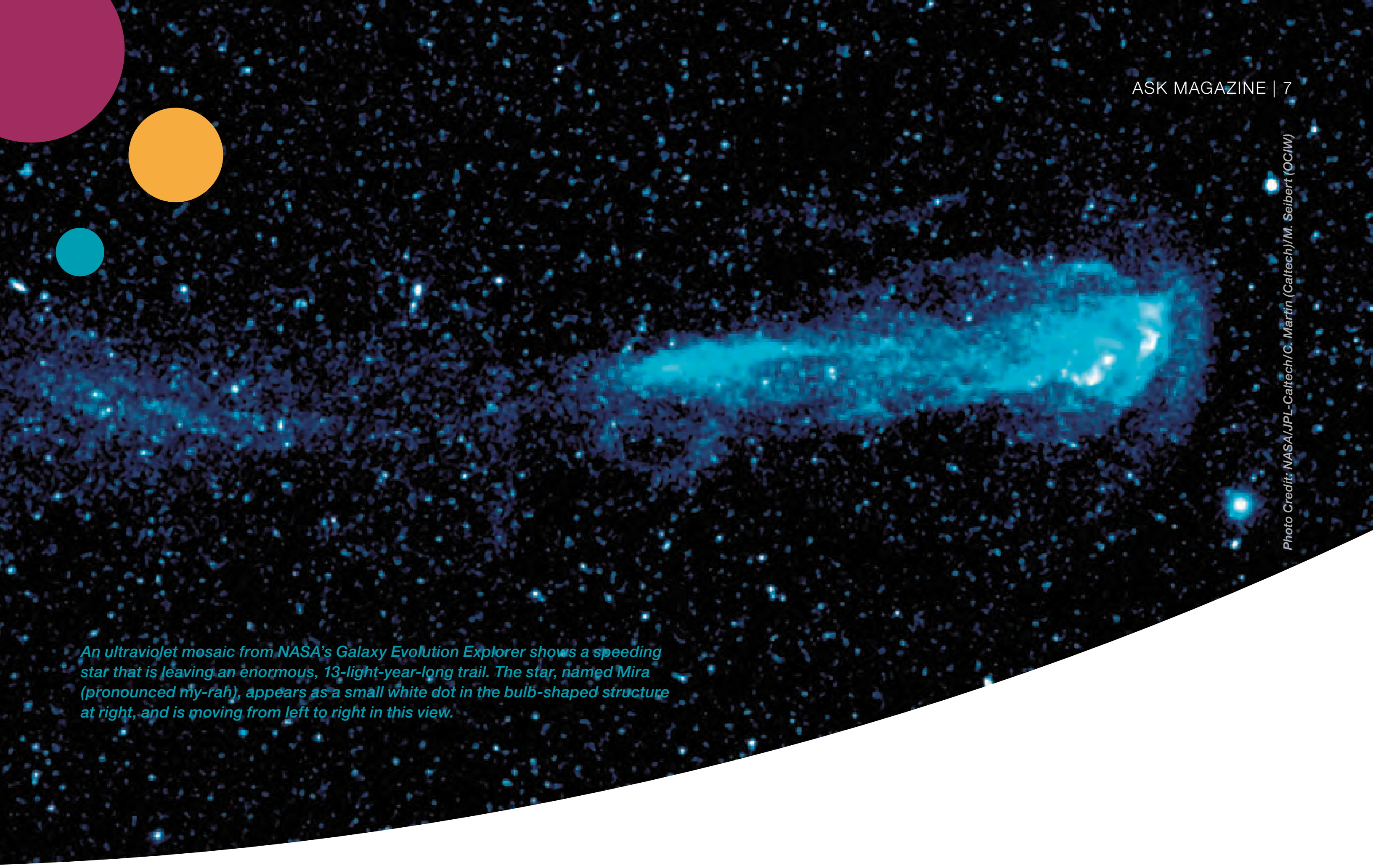
Similarly, smaller missions have fewer instruments and components, but each element therefore tends to be mission critical. GALEX is a single-string, single-instrument design with very limited redundancy. This has two immediate implications: each element must have high reliability, and virtually no component can be eliminated. One of the most important tools available to the manager is the ability to "descope" items in order to contain cost. When each element is mission critical, the descope tool is limited to accepting lower performance from an element rather than eliminating it outright.

Recognizing these facts, GALEX's principal investigator, Chris Martin of Caltech, proposed a mission that was simple in concept and built around a team of experienced individuals and institutions. NASA selected the mission for implementation in late 1997. Thus set sail a hardy band of explorers into what would turn out to be an unusually stormy sea.

Keeping It Simple

The idea for GALEX was to fly a 0.5-meter-aperture telescope with a wide field of view together with two photon-counting detectors, one optimized for the near ultraviolet and one for the far ultraviolet. The detectors would simultaneously image a region of the heavens 1.5° in diameter via a dichroic beam splitter. A filter wheel would enable a grism—a combination of a prism and grating—to be rotated into the beam to produce spectra that could also be imaged on the detectors. The spacecraft would point the telescope at the desired location during the night side of each orbit and orient the solar panels to recharge the battery during the day side. Over a period of twenty-eight months, virtually the entire sky would be imaged. In practice there were some complications, such as not imaging stars bright enough to damage the detectors, but in general the mission design and architecture were quite simple.

We also felt that the mission required no new technology, but we were to learn otherwise. To achieve the required ultraviolet sensitivity, we needed photon-counting microchannel plate detectors. These make use of specially prepared, thin, porous glass plates supported at their edges, stacked and held at



An ultraviolet mosaic from NASA's Galaxy Evolution Explorer shows a speeding star that is leaving an enormous, 13-light-year-long trail. The star, named Mira (pronounced my-rah), appears as a small white dot in the bulb-shaped structure at right, and is moving from left to right in this view.

an electrical potential of several thousand volts. An individual photon of light striking the front surface of the detector produces a shower of electrons at the back. The location of the electron shower is measured by timing the arrival of electrical pulses with an array of very high-speed electrical circuits. While these techniques had been used in earlier detectors, they had not been implemented individually or in combination on detectors of the size required for GALEX.

In the end the detectors proved very difficult to manufacture, even by the group at University of California–Berkeley, considered the best in the business at this type of device. By the time we collectively recognized this fact, it was too late to reduce the size of the detectors, so we persevered and accepted delivery many months behind schedule. We learned an important lesson: scaling technology is sometimes as difficult as maturing the basic technology in the first place.

Paradigm Shift

GALEX began implementation during the height of NASA's faster-better-cheaper era, a period characterized by the desire to find innovative approaches to reduce development cost, even if it meant tolerating and managing increased risk. In keeping with this paradigm, the GALEX implementation plan featured many cost-saving aspects, some of which involved cost and schedule risk. Interestingly, GALEX was confirmed with what today would be considered an absurdly low level of cost reserves: 10 percent, or about $5 million in total.

What we did not see coming was the dramatic change in risk acceptance following the loss of the Mars '98 and other smaller missions around this time. These mission failures sent a shock wave through NASA, which responded by overhauling the underlying implementation processes to be followed by every mission under development. By 2000, the paradigm had firmly shifted from "faster better cheaper" to "mission success first."

Many of the cost-cutting approaches taken by GALEX were no longer considered acceptable. The team came under major scrutiny by outside groups of reviewers trying to reduce mission risk. NASA attempted to compensate the team for the cost of these changes, but it was difficult to estimate what the budget ramifications of the new processes would be. In particular, we knew that buying risk down after the fact would be difficult, as key design decisions and part selection had already been made and implemented. It was an unpleasant transition for all concerned.

Manage What You Can

Since we did not have the resources to oversee the detailed design of every subsystem or component independently, we relied on the expertise of the team members to identify where difficulties required additional attention or assistance. This worked well in most instances, but we dropped the ball in one important

ANOTHER IMPORTANT LESSON WAS LEARNED: WHEN FACED WITH THE DILEMMA OF SHORING UP A FLAGGING EFFORT WITH NEW HELP AT THE EXPENSE OF AN ADDED DELAY TO BRING THAT HELP UP TO SPEED, THE RIGHT ANSWER IS NEARLY ALWAYS TO BITE THE BULLET AND BRING IN THE ADDITIONAL HELP.

area—the detector readout electronics. While the Berkeley team was busy solving how best to build the photon-counting detector assemblies, the detector readout electronics were being designed and prototyped by a single design engineer. There were clear indications that he was overloaded, so the Berkeley team's solution was to isolate him from outside distractions. Being close to Silicon Valley during the dot-com boom, it was difficult for them to hire qualified electronics engineers at university pay scales, and they didn't want to lose their one key designer. Efforts to carry out peer review of his work or bring in outside help were resisted on the grounds that they would slow down the effort. We left the engineer alone. It was a mistake.

Close to the time the flight electronics were due to be delivered, the engineer suddenly resigned and left the university. When we looked at the state of the electronics, we discovered why: an important portion of the readout electronics didn't work and contained serious design flaws. The designer had been misleading us and his management about the status of the development. It took a crash program working with Southwest Research Institute to develop a replacement element. Another important lesson was learned: when faced with the dilemma of shoring up a flagging effort with new help at the expense of an added delay to bring that help up to speed, the right answer is nearly always to bite the bullet and bring in the additional help.

Survive Bolts from the Blue

Every project faces unknown unknowns, things that can't be anticipated. These events call upon the resilience and creativity of the team to overcome. GALEX faced an unusually large number of "bolts from the blue." One event on our mission particularly illustrates how extensive the consequences can be.

Our ITAR-Baby

In order to reduce cost, the spacecraft bus supplier, Orbital Sciences Corporation, selected radio equipment manufactured by a company in Britain. The S-band receivers and transmitter were delivered successfully, but the X-band transmitter was more challenging and took a bit longer to complete. Within weeks of the scheduled delivery, Orbital received a phone call from the company stating that they had declared bankruptcy and were being liquidated. If we wanted the incomplete X-band transmitter, we should show up with a final payment and take delivery at their loading dock.

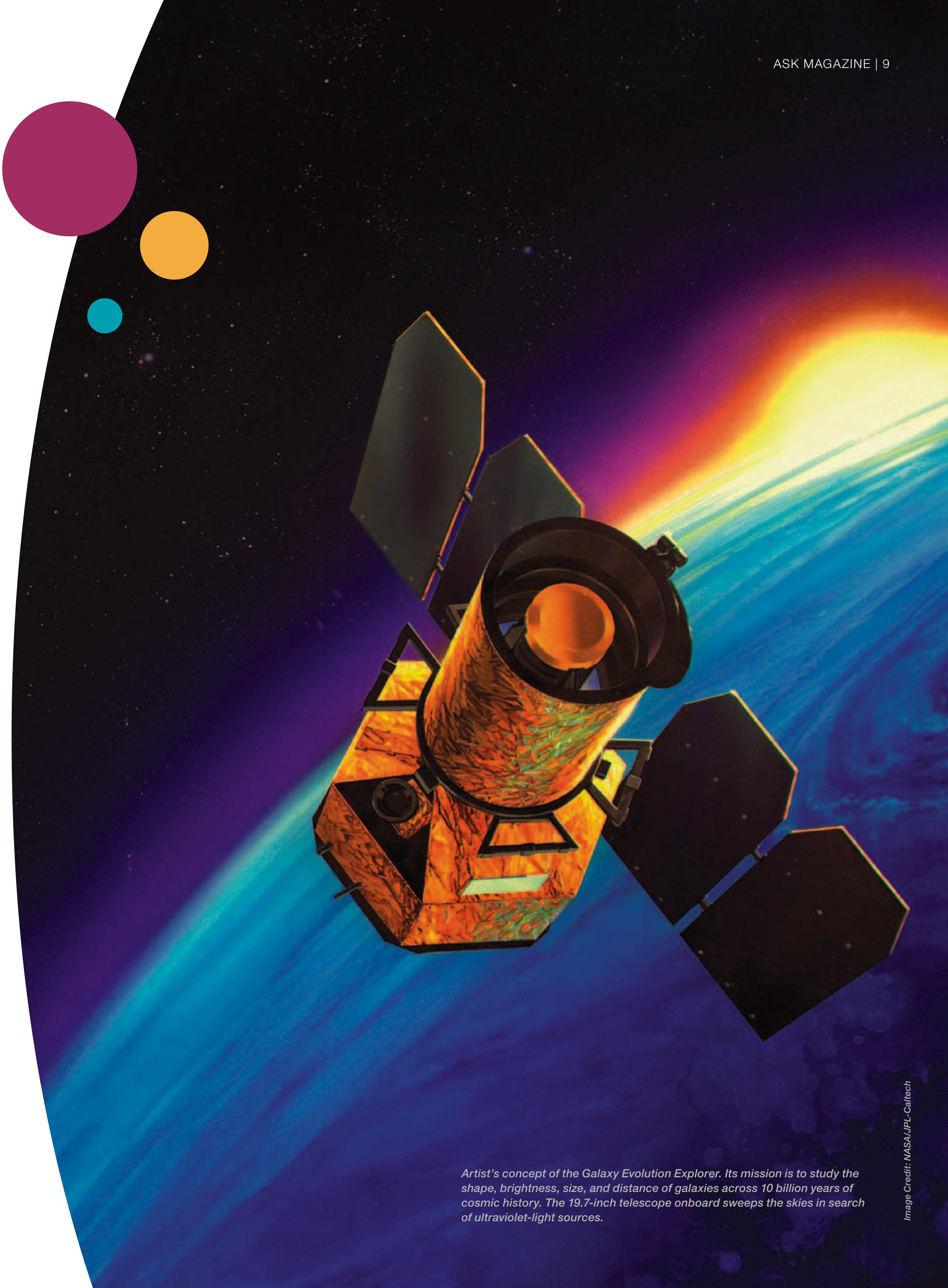
We dispatched a contingent to pick up the hardware and as much design documentation as possible, and returned it to the United States. We approached the radio experts at the Jet Propulsion Laboratory, who explained that what remained to be completed was the staking and tuning of the circuitry, something that could only be done by someone intimately familiar with the design—in other words, they couldn't do it without the engineer who had designed it.

By this time the design engineer was employed with another company in Britain. We explored shipping the unit over to him but discovered that our export license was only for the company that had gone bankrupt; we could bring the radio into the United States, but we couldn't legally ship it back out. The next best thing was to bring the designer to the United States.

This is when we discovered that the designer was a dual British/Iranian citizen. Export-control regulations prohibit providing technical assistance to non-U.S. persons. Orbital explored the possibility of obtaining a Technology Assistance Agreement from the State Department to work with the designer but given his Iranian citizenship, they were encouraged not even to apply.

The last option was to bring the designer to the United States, set him up in an empty lab with a soldering iron and oscilloscope, and let him complete the staking and tuning. At the end of this exercise, we inspected his workmanship and concluded that the unit had been rendered unusable.

Being very short on time to find a replacement X-band transmitter, Orbital identified a potential replacement unit on another NASA spacecraft in their clean room. Several weeks of negotiation produced permission for us to cannibalize



Artist's concept of the Galaxy Evolution Explorer. Its mission is to study the shape, brightness, size, and distance of galaxies across 10 billion years of cosmic history. The 19.7-inch telescope onboard sweeps the skies in search of ultraviolet-light sources.

Image Credit: NASA/JPL-Caltech

Photo Credit: JPL

The GALEX spacecraft before its launch in 2003.

this hardware. The only problem was that it operated at a different frequency than our National Telecommunications and Information Administration license specified, and it used a different modulation scheme. One would think relicensing to another frequency would be straightforward, but it turned out that the new radio transmitted in a part of the X-band spectrum reserved for "downward"-looking vehicles (toward Earth) while GALEX was an "upward"-looking vehicle. We eventually got a special non-interference-based waiver approved. This left only the modulation problem—the way GALEX's data was packaged for transmission—which was solved by a crash program to build new demodulators for the ground stations located in Australia and Hawaii so the data could be "unpackaged" correctly.

Make It Work

The team found creative ways to survive various other bolts from the blue during GALEX: a vacuum-chamber failure that back-streamed diffusion-pump oil and contaminated the spacecraft bus; another mission's in-flight failure of the gyro we had selected, forcing the crash refurbishment of a replacement gyro we found; the sudden loss of liquid-nitrogen supplies on the eve of instrument thermal-vacuum testing because the Enron-driven electricity crisis in California shut down the liquid-air production plant.

Once every development challenge had been successfully overcome, we launched GALEX in April 2003 aboard a Pegasus XL rocket. The scientific return has surpassed our expectations. Looking back on the experience, I appreciate the tremendous training value of the GALEX development; just about every type of problem that could arise did arise. It taught me many lessons I've applied to missions that followed, and gave me a true appreciation that small projects can be just as difficult as the big ones. ●

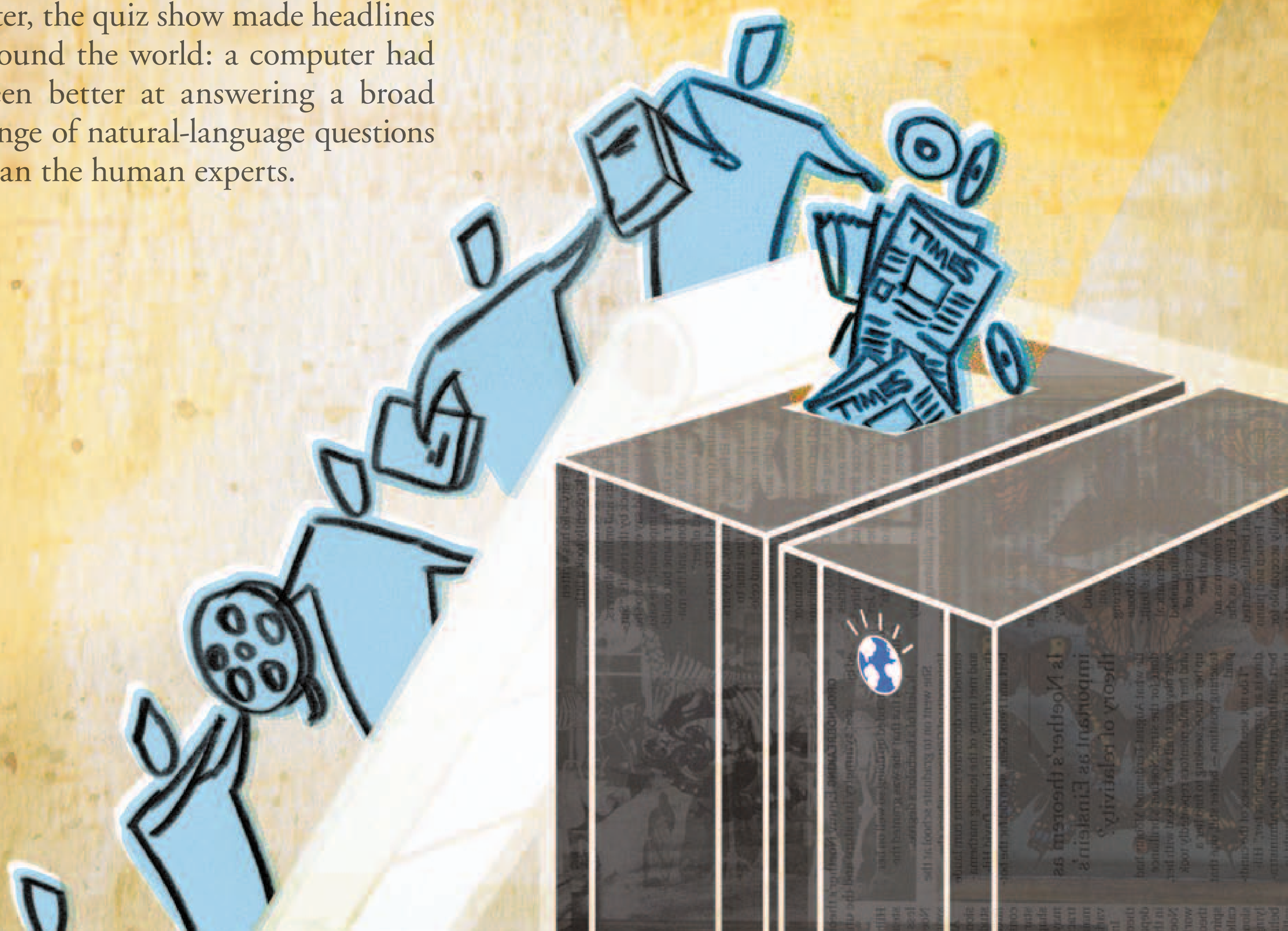
Note: This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

JAMES FANSON's twenty-five-year career at the Jet Propulsion Laboratory has spanned technology development, instrument development, and flight project implementation. He was part of the team that repaired the Hubble Space Telescope; led the team that produced the preliminary design of the Spitzer Space Telescope; and, as project manager, led two telescope missions (GALEX and Kepler) to launch and early science operations.

BUILDING THE Watson team

BY DAVID FERRUCCI

On January 14, 2011, I was in the audience at IBM's Watson Research Lab in Yorktown, New York, along with company executives, major clients, and my project team when our Watson computer soundly defeated two human champions in the third round of their *Jeopardy!* competition. Publicly aired a month later, the quiz show made headlines around the world: a computer had been better at answering a broad range of natural-language questions than the human experts.



The event was the culmination of almost four years of intensive work by my team of artificial-intelligence researchers and engineers. My own qualifications as project leader and principal investigator included a background in artificial intelligence, automated reasoning, and UIMA (unstructured information management architecture), and the experience of working on an open-domain question-and-answer (Q&A) project. But there's also the fact that I was the only one willing to take on the very public challenge of pushing Q&A technology well beyond the current state of the art and putting the result to the test on national television. The risk–reward trade-off was daunting. The project had been shopped around the company by senior executives for several years. Most people didn't think it was possible.

The Challenge

Their skepticism wasn't unreasonable; the difficulties were enormous. Answering *Jeopardy!* questions is not like playing chess, which computers have done at the highest level for years. Unlike that game, with its strict, unambiguous rules and numerous but finite potential moves, *Jeopardy!* questions have no formal logic; many of them are quirky and playful in ways that many humans understand but machines don't. There is no way to map those clues to axioms; they are not regular enough. So we would have to teach Watson to "reason" from unstructured content—that is, large volumes of naturally occurring text.

The computer would also have to acquire knowledge from unstructured sources (for instance, encyclopedias, dictionaries, thesauruses, the works of Shakespeare, the Bible) in a form the system could evaluate and use to answer the questions.

And it would have to do it quickly. Over two years into the project, after we had made a lot of progress developing algorithms that could parse the clues and arrive at reasonable responses, it still took the system about two hours to answer a single question. We had to get that down to a few seconds.

Nevertheless, the feasibility study my group carried out at the end of 2006 concluded that it should be possible to reach the goal in three to five years. We based that assessment on the facts that mechanical reasoning had advanced in recent years, that sufficient computer power for inductive reasoning was now available, and that lots of semi-structured reasoning data existed.

Senior IBM executives gave their approval, but the technical people, who understood the magnitude of the problems, still had doubts. Many of those computer scientists were more comfortable working on their own small projects and publishing papers that announced their modest contributions to the field than devoting a chunk of their careers to a big, risky project.

Building the Team

There is no formula for winning people over and melding them into a team. It was all about personal relationships: meeting with people—often one on one—and repeating the argument that I believed so strongly in my heart. I talked to them about the potential sense of accomplishment of being part of one of the biggest achievements in the history of computer science. I reminded the scientists that they could write and publish five years' worth of papers without answering or even grappling with any of the big questions. The Watson project would give us a chance to be real scientists, to achieve greater certainty about whether this goal could be reached. We would be able to say, "Here's how we did it," or, "Here's why the current state of the art cannot accomplish this task." Even failure would advance the field significantly.

My evangelizing attracted about a dozen scientists; the team eventually grew to twenty-five. Over time, the group developed a strong culture of cooperation and a shared determination to get something done. That practicality was partly inspired by the

engineers on the team. They were I-want-to-make-stuff-work people; they didn't care about publishing papers. They won the respect of the scientists, who adopted some of their can-do attitude.

One of the things that helped make the team cohesive and collaborative was putting the multidisciplinary algorithm group in a single room and doing away with the physical and psychological barriers to working together that exist in traditional offices. We did not even have cubicles in the room, just tables with monitors on them. People were in each other's faces; everyone knew what everyone else was doing. At the beginning, some people had trouble focusing and preferred a private office, but most of them adjusted to the more public space. It became a lively hub of activity. Being away from the lab was a disadvantage—you could quickly lose track of what was happening.

The lab also provided one-stop shopping for other subteams. For example, the infrastructure team was focused on scale-out and reducing latency. They were not involved in algorithm development and were ordinarily not in the lab. But when they found a bottleneck and needed to discuss which algorithms were contributing to the slowdown, they would come to the lab. Everyone who needed to be involved in the discussion was there. The lab made for very efficient one-stop shopping.

The Watson team environment was a big change for scientists who were accustomed to working mainly alone, searching for that one formula or algorithm that can better the last publication. A few people who could not adjust left the team. That is usually part of how new cultures develop: most people adopt the new behaviors and those who can't move on to something else.

Progress

A key was getting an extensible architecture in place that reflected our scientific hypothesis for how a Q&A system effective enough to win at *Jeopardy!* should work. It was a hypothesis based on the decades of collective experience represented by the team, synthesized and laid down in software designs and a framework implementation we called DeepQA. An essential assumption underlying this architecture was that there would be no silver bullet, no single algorithm, no one hero that would solve Q&A; rather, we would have to assemble and combine many algorithms that analyzed the content from different perspectives.

These algorithms could be developed independently by different researchers; the architecture itself would allow for the automatic combination of their results based on statistical machine learning. This approach allowed us to move more rapidly, reducing the requirement to anticipate a perfectly integrated solution and wait for a completely specified top-down design. We had different members of the team work on competing algorithms—that is, algorithms that took different approaches to understanding and answering questions by, for instance, focusing on different parts of speech in the *Jeopardy!* clues. The approaches would simultaneously generate their own reliability scores, and those scores would be weighted statistically to get an overall confidence level. Developing these competing algorithms gave us a big jump in capability.

As we progressed, the size of the incremental improvements got smaller and smaller because the problems remaining were the hardest ones. Consider this clue: "On hearing of the discovery of George Mallory's body, he told reporters he still thinks he was first." This is an example of what we called "missing link" questions. Watson had to discover some unmentioned entity that could lead to the right answer. In this case the missing link was Mount Everest. The answer is "Edmund Hillary."

We did a great deal of rigorous testing using questions randomly selected from past *Jeopardy!* games. (The randomness was important to avoid the unconscious bias we might have introduced by selecting the kinds of questions we believed Watson could answer.) Some of Watson's early answers were ludicrously wrong. Consider this clue: "*NY Times* Headlines: An exclamation point was warranted for the 'end of' this! in 1918."

An early version of Watson answered with "a sentence." The correct answer was "World War I." You might assume Watson had all the headlines of every *New York Times* paper and knew to just look it up. But it was rarely so easy. Among many improvements that resulted from analyzing this error, one was focused on analyzing and weighing temporal information in a clue. A key here was "1918." Watson had to understand that while an exclamation point may end a sentence, the relevant information here had to be unique to a particular point in time.

When one of our scientists got the idea of ordering the test questions chronologically, we discovered that Watson's performance decreased on questions written post 2002. That was when the game was changed to make the categories and questions more entertaining for viewers—that is, perhaps a bit quirkier and funnier. The game was a moving target and we had to keep working to make Watson more flexible.

That we succeeded became clear in early 2011, when Watson became a *Jeopardy!* champion. The system offered a very few ludicrously wrong answers and many astonishingly correct ones and beat its human competitors.

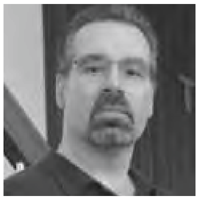
After *Jeopardy!*

Since then, I've worked hard to keep the team together in the face of pressure to chop it up by sending members to other project teams. *Jeopardy!* was only a step on the road to improving analytics and natural-language processing. There is still a lot of work to do.

We are currently working on a machine dedicated to medical diagnosis and treatment evaluation, one that can help make more reliable decisions and explain how it arrives at its recommendations based on analyzing the most current and reliable sources of information. Unlike Watson on *Jeopardy!*, this system will be interactive, cooperating with its human partners. So, for instance, it will be able to say, "I've come up with five possible answers based on the patient data and categorized the evidence based on symptoms, drug interactions, patient history, and demographics. If you can confirm the following, my confidence in the top-most recommendation will increase." The system will also show the documents most relevant to its recommendation to humans who can evaluate their reliability based on their own knowledge and experience and ultimately make a decision.

After that, who knows? We are still at the very beginning of developing capabilities that will astound and serve us in the future. ●

DAVID FERRUCCI is a research staff member and leader of the Semantic Analysis and Integration Department at IBM's T.J. Watson Research Center. His team of twenty-five researchers focuses on developing technologies for discovering knowledge in natural language and leveraging those technologies in a variety of intelligent search, data analytics, and knowledge management solutions.



A FEW PEOPLE WHO COULD NOT ADJUST LEFT THE TEAM. THAT IS USUALLY PART OF HOW NEW CULTURES DEVELOP: MOST PEOPLE ADOPT THE NEW BEHAVIORS AND THOSE WHO CAN'T MOVE ON TO SOMETHING ELSE.

The Million-Mile Rescue

BY THE NASA SAFETY CENTER

The Solar Heliospheric Observatory (SOHO) is a major element of the joint International Solar Terrestrial Program between NASA and the European Space Agency (ESA). Originally a two-year mission to study the sun, from its deep core to the outer corona, and solar winds, the mission was later extended because of its spectacular success. This extension led to software code modifications meant to increase SOHO's operational lifetime. Instead, multiple errors in the new command sequences repeatedly sent the spacecraft into an emergency safe mode. SOHO's attitude progressively destabilized until all communication was lost in the early hours of June 25, 1998.

The mission was designed to maintain an orbit around the First Lagrangian point, the area where the combined and balancing gravity of Earth and the sun would keep SOHO's orbit anchored in the Earth–sun line. Once in this orbit, SOHO's attitude was generally stable and would use spinning reaction wheels controlled by an attitude-control unit (ACU) computer to autonomously adjust for internal or external disturbances. If the wheels reached a spin near their design limit, the ACU would automatically despin the wheels, use thrusters to stabilize attitude, and then reactivate the wheels to resume attitude control. During these maneuvers, the ACU would use one of three gyroscopes (Gyro C) to sense roll.

SOHO's second gyro (Gyro B) was used solely for fault detection—for example, to sense roll rates beyond some predetermined tolerance. If an excessive roll rate was detected, SOHO would enter a safe mode, where it ensured that its solar panels were facing the sun, temporarily suspended the ACU computer, and then awaited the ground commands it needed to restore normal operations. During one such recovery, ground controllers used the third gyro (Gyro A), instead of Gyro C, for roll-rate sensing.

Gyroscope Misconfigurations

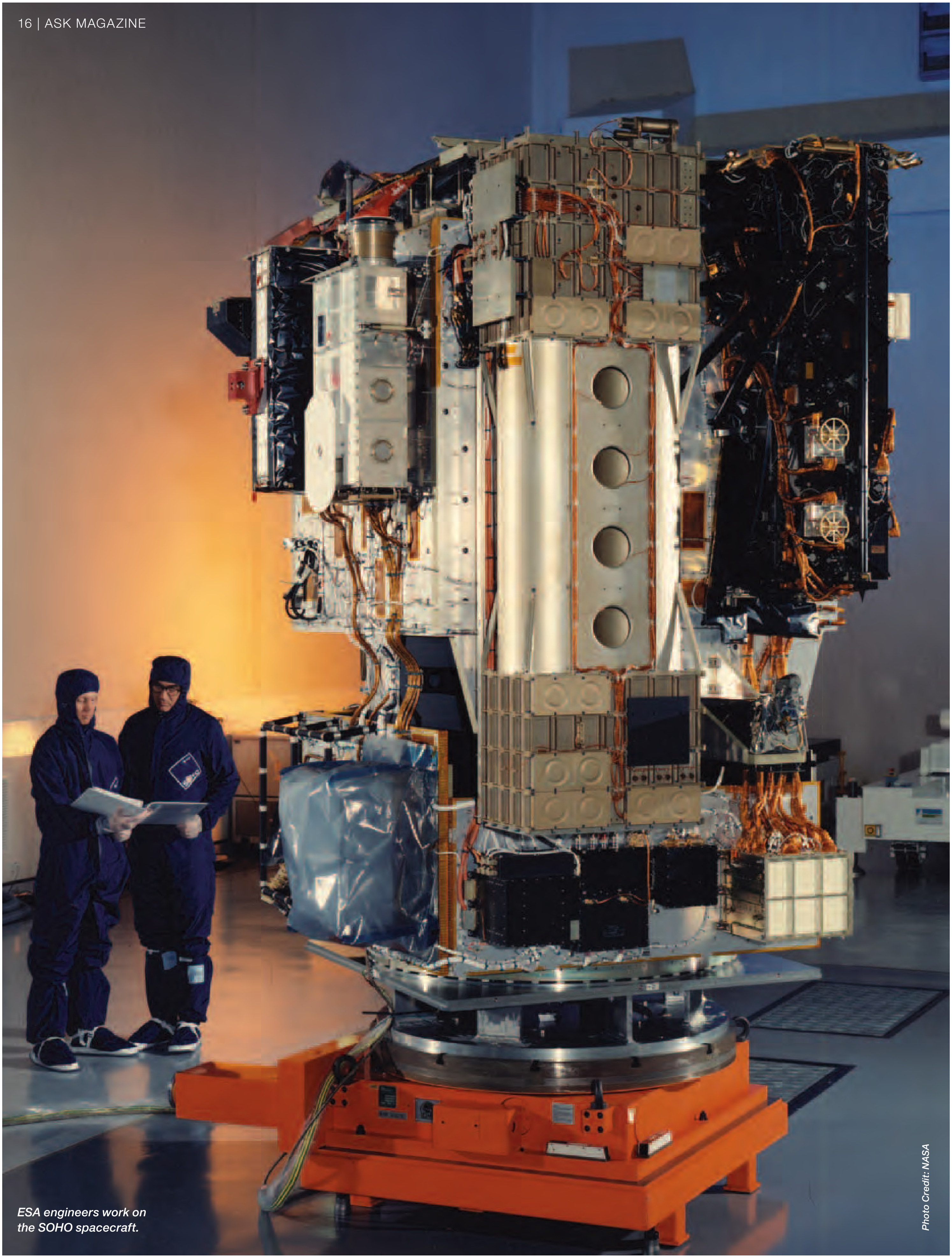
Each gyro onboard SOHO was designed to be used only for its specific independent function. All three require periodic calibrations to account for drift bias, which results from mechanical wear, angular changes, or exposure to extreme temperatures. When drift bias occurs, ground engineers uplink the correct coordinates for each gyro to the spacecraft's onboard computer, allowing the spacecraft's attitude-control functions to operate accurately. The same mechanical and thermal wear that causes drift bias eventually makes the gyros non-operational, which became a concern when the SOHO mission was extended.

In February 1997, the flight operations team modified gyro command sequences in an attempt to address this wear issue. A command was written to deactivate, or spin down, Gyro A when not in use, which is any time other than the safe mode. The code was supposed to include a function to respin Gyro A upon entering safe mode, but this function was erroneously omitted in the new sequence.

The modification had been introduced with a mission operations change request in March 1997 but was not used in gyro calibrations until June 24, 1998. Therefore, even though the SOHO spacecraft had entered safe mode four times prior to June 24, the code modifications were not in use and did not affect successful recoveries by ground crews.

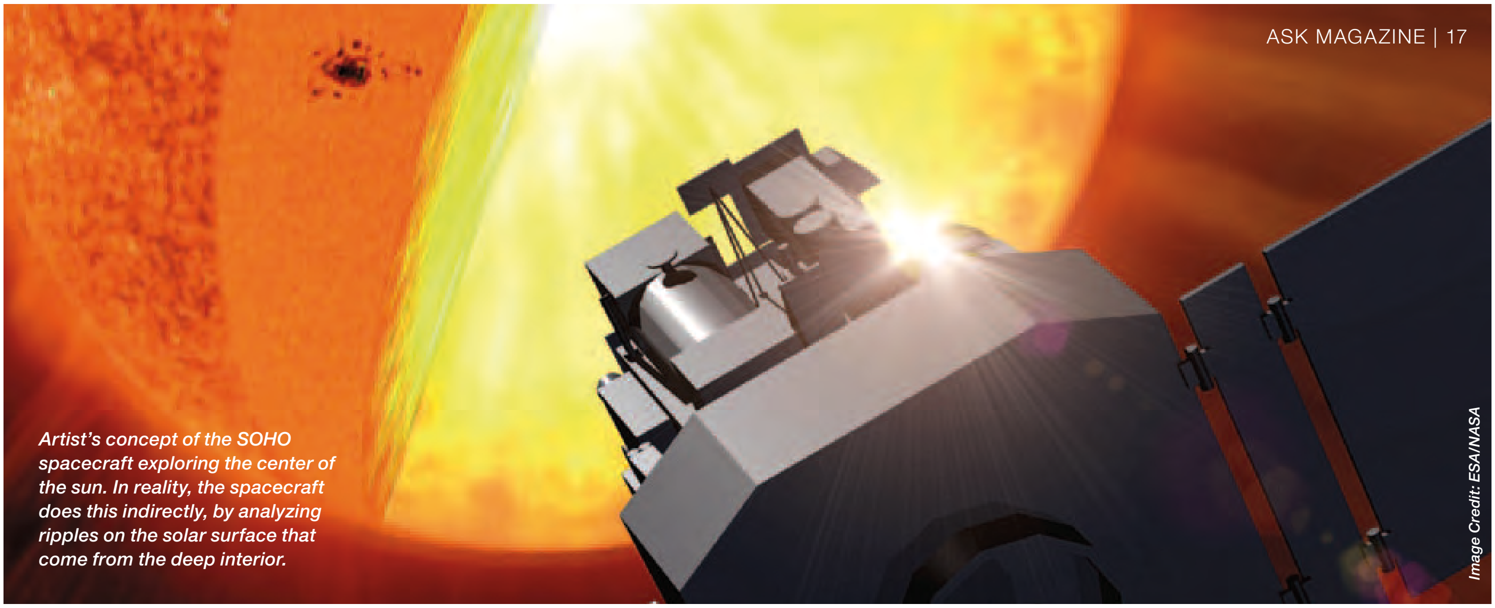
A later review revealed that these modifications were never properly documented, communicated, reviewed, or approved by either ESA or NASA. The change request itself was an internal flight-operations document only distributed within the team. The only testing performed was by a NASA computer-based simulator that verified each change separately, but not all together.

The software modifications contained a second critical error. The fault-detection setting on Gyro B was twenty times



ESA engineers work on the SOHO spacecraft.

Photo Credit: NASA



Artist's concept of the SOHO spacecraft exploring the center of the sun. In reality, the spacecraft does this indirectly, by analyzing ripples on the solar surface that come from the deep interior.

Image Credit: ESA/NASA

more sensitive than it should have been. This error triggered a mishap and sent SOHO into its fifth safe mode at 7:16 p.m. on June 24, 1998.

The recovery effort began immediately but was complicated by the aggressive scientific task schedule planned for June 24–29. The core SOHO team was already working on a compressed timeline without the luxury of additional support or contingency time. Ground controllers quickly discovered and corrected the error in Gyro B but did not notice that Gyro A had not reactivated. Shortly thereafter, as a normal part of the recovery sequence, all three gyros were recalibrated, and the ACU computer was activated to make any necessary adjustments using its thrusters. But when the computer attempted to correct for the drift bias on the spun-down Gyro A, it continuously attempted to correct for a perceived (but non-existent) roll-attitude error until the actual roll rate increased so significantly that Gyro B's fault detection accurately triggered another safe mode at 10:35 p.m. Again, recovery efforts began immediately.

Critical Decision Mistake

The safe mode recovery period was designed to give flight operations and engineering teams sufficient time to understand problematic anomalies before taking action. SOHO was programmed to store telemetry prior to any safe mode so it would be available for examination by ground crews. The operations procedures specifically stated that before attempting a recovery, Gyro A should be confirmed to be spinning and the telemetry should be analyzed. The SOHO operations team did not take advantage of this design feature; instead they chose to initiate recovery sequences almost immediately after each safe mode was triggered without checking either Gyro A's spin status or the telemetry data.

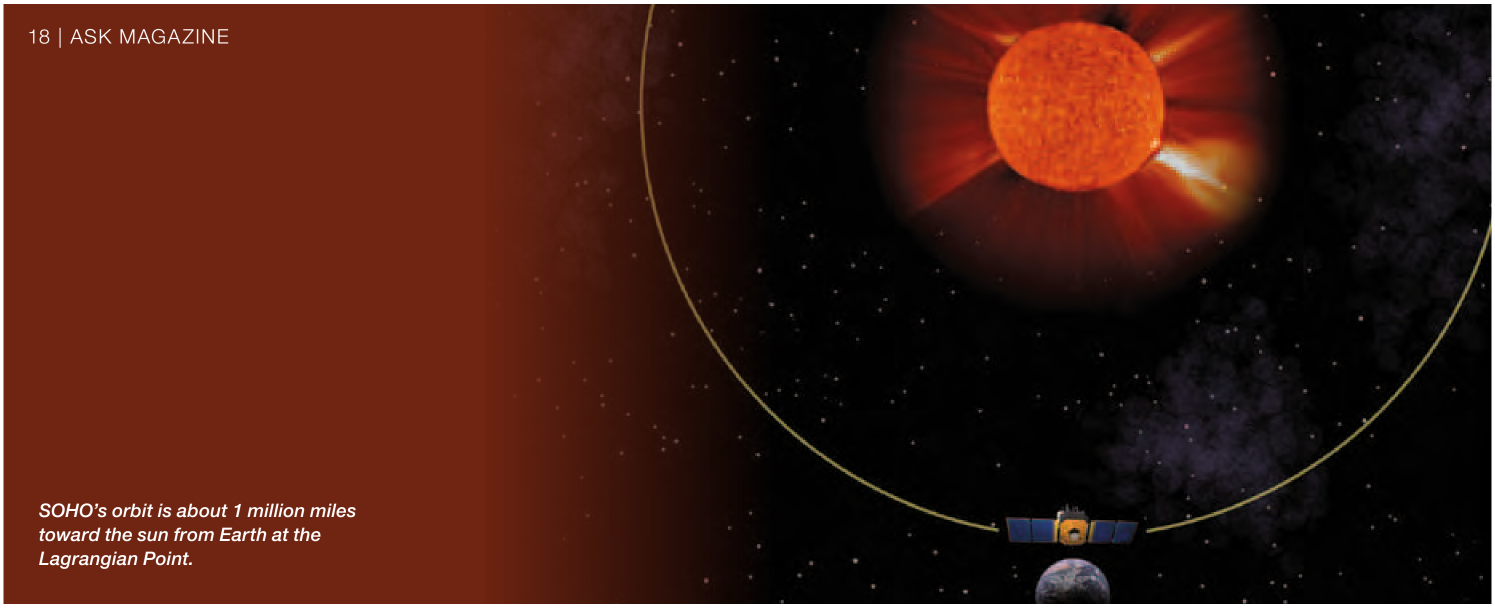
The team observed that Gyro B's readings of an excessive roll rate did not agree with Gyro A's nominal roll-rate reading, but the flight operations crew still failed to notice that Gyro A was not spinning. In a quick decision, the flight operations manager incorrectly concluded that it was Gyro B (and not Gyro A) that was faulty.

Gyro B was shut down, which rendered the fault-detection capability inactive. When control was returned to the onboard computer for the recalibration sequence of recovery, roll thruster firing resumed and sun-pointing errors eventually resulted in pitch and yaw thruster firings. This produced unstable spinning of the spacecraft that exceeded allowed limits and triggered another safe mode at 12:38 a.m. on June 25.

SEVERAL FACTORS CONTRIBUTED TO SOHO'S MISHAP: CHANGE CONTROLS WERE LACKING, PROCEDURES WERE NOT FOLLOWED AS WRITTEN, AGGRESSIVE SCHEDULING OVERTASKED THE TEAM, AND NOT ENOUGH STAFF WAS AVAILABLE TO HANDLE THE PLANNED SCIENCE TASKS AND SUBSEQUENT RECOVERY MODES.

The critical software errors in the modified gyro command sequence meant that SOHO's gyros were configured incorrectly and caused the onboard computer to erroneously fire its thrusters until the spacecraft destabilized. This was exacerbated by the decision to shut down a gyro believed to be malfunctioning in favor of a gyro that was actually inactive.

Within minutes, SOHO's attitude diverged beyond control. Power, communications, and telemetry were all lost. By 12:43 a.m., SOHO was officially lost in space.



SOHO's orbit is about 1 million miles toward the sun from Earth at the Lagrangian Point.

Image Credit: NASA Goddard Space Flight Center

The Million-Mile Rescue

Within hours, investigation teams at both ESA and NASA had been assembled. On June 28 they convened at Goddard Space Flight Center to begin recovery efforts. Based on the last few minutes of telemetry, simulations predicting possible trajectories for SOHO indicated that the spacecraft would diverge and escape into a solar orbit if it was not recovered by mid-November. By a stroke of good fortune, calculations also indicated that, in roughly ninety days, the spin of the spacecraft would naturally align the solar arrays with the sun for about half a spin period, giving the recovery team an opportunity to regain control over SOHO. On July 23, using the Arecibo radio telescope in Puerto Rico in combination with NASA's Deep Space Network in California, the team was able to locate the spacecraft's radar echoes and confirm both its location and spin rate.

The flight operations team uplinked commands to SOHO for twelve hours a day, searching for any signs of return communication. On August 3, contact was established. Over the next two months, SOHO was progressively restored to normal operating mode. On September 25, about ninety days after contact was initially lost, SOHO was fully operational. Remarkably, all twelve scientific instruments remained in complete working condition despite having been subjected to temperatures from -120°C to 100°C during the three-month ordeal.

Lessons Learned for NASA

Several factors contributed to SOHO's mishap: change controls were lacking, procedures were not followed as written, aggressive scheduling overtasked the team, and not enough staff was available to handle the planned science tasks and subsequent recovery modes. As a result, key engineers were preparing for upcoming science tasks rather than assisting with safe-mode recoveries. Recovery efforts were rushed in order to return the spacecraft to its science operations as quickly as possible. Ironically, the prioritization of science over spacecraft safety contributed to the loss of science operations for three months and risked the total loss of SOHO.

It is important that modifications or updates to procedural scripts on future NASA missions have formal approval before implementation, and the entire script (not just the modification) should be revalidated. Operational timelines should also be planned and validated *before* implementation—not in parallel with implementation—with the proper attention and reserve given to contingency planning and safety. There should be sufficient time for coordinating tests and simulations so they do not conflict with management and operations of real-time, on-orbit events.

The health and safety of a spacecraft are critical in achieving any scientific or operational goals. To keep the spacecraft healthy, the team needs to be healthy. Reassess staffing levels periodically, strengthen staff as needed, and provide the capability for the extra support required by contingency operations. This can be difficult in extended operations on missions that have limited budget flexibility, but it is important. In any case, operations teams must be well trained on the systems they will be required to use and should practice responses to emergency situations. ●

This article is adapted from a NASA safety-awareness training document based on information available in the public domain. The findings, proximate causes, and contributing factors identified in this case study do not necessarily represent those of the agency. Sections of this case study were derived from multiple sources listed under References. Any misrepresentation or improper use of source material is unintentional.

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Efficiency Through Document Automation

BY ROBERT DELWOOD

Today's tight budgets and reduced staff mean we need ways to work more efficiently. For office and knowledge workers that should include document automation. Yet organizations overlook a powerful tool they use every day: Microsoft Office. Office automation offers a powerful set of capabilities, both out of the box and with programming, that can transform the way you create and manage documents.

Microsoft Office automation uses built-in features either to place, reconfigure, or format document passages, or to automatically run sequences of commands. The simpler end of the automation continuum includes built-in features such as copy and paste, the "repeat last" command, and document linking (reusing text among different documents), all examples of tasks that can run directly from the Office ribbon. Advanced users may record macros (linking a series of commands) or manage macro libraries to shorten tasks. At the other end of the continuum, programmers create custom applications that manipulate data in specific ways. The intent is the same: to be more efficient by increasing throughput and reducing opportunities for error.

ORBIT®

The advantages are clear, but implementation can be an issue. If it's the job of individual contributors to improve their processes, why doesn't it happen more often? For one thing, automation tools, though often not complex, do require users to change the way they think about their work. There is also often a mismatch of expertise:

- Users understand their own procedures but may not know what can be automated.
- Automation specialists know how to implement Office automation but may not know users' tasks.

The solution is to get the two together. We assign an automation specialist, typically a programmer with Microsoft Office automation experience, to a team to learn users' procedures. Both parties then brainstorm to come up with automation suggestions. We call the process ORBIT, an acronym of five steps:

Observe. Initial observation focuses on the most repetitious procedures to develop a list of candidate processes. In some cases, an automation audit has the team members explain their work step by step, down to the key stroke. The specialist then has the opportunity to ask questions and investigate options. Typically, an audit of no more than thirty minutes can yield several candidate processes for automation. At other times, the observer actually sits with the team and observes their work.

Reengineer. The automation specialist and users work on new procedures, adapting tasks to automation. This may be as simple as recording macros, but sometimes procedures may have to be changed to accommodate automation capabilities. This step also provides an opportunity to eliminate procedures that are no longer needed.

Build. The specialist creates the application or macros to automate the clients' needs. The solutions and user interface must fit their working environment. Builds may also include a prototype or progressive versions of the application to show its proposed look and feel.

Implement and Test. Specialists test the application and interact with the clients. Some features might be reworked

GETTING STARTED WITH AUTOMATION.

You choose your level of involvement with automation. A simple start is the "repeat last" command, or the **F4 key**. This repeats the last command you invoked. For instance, if you need to make lots of text bold, save that operation until last. After bolding the first text, highlight the next instance and **press F4**. You can go through an entire document quite quickly.

If you want to record a macro in Microsoft Word for Windows 2007 or later, start by clicking **View/Tools > Macros > Macros > Record Macro**. Give it a name, **press OK**, then go through all the steps needed to complete your task. Stop the recording by clicking **View/Tools > Macros > Macros > Stop Recording**. To play the macro, click **View/Tools > Macros > Macros**, select the macro's name, and **press Run**.

or redesigned based on feedback. Once the clients' requirements are met, the specialists release the application.

Transfer. We deliver the application to users. Some applications can be modified to accommodate more general requirements for other groups. We place these tools in a public download site and inform potential users and other contractors of their availability.

Sample Cases

Some NASA cases illustrate this approach. At the Johnson Space Center, our DQA (document quality assurance) team, charged with enforcing document quality and style consistency, had unrecognized outdated procedures. One procedure in particular caught the attention of an automation specialist. He noticed that a DQA team member was going through a lengthy printed document page by page. Repetitive actions like that should always be evaluated for automation. The team member was reviewing the manual placement of eighty pages of graphics. The graphics, up to 150 diagrams, were a parts manifest list for the space station in a read-only format. They were routinely and manually inserted into documents. Each diagram had to be printed from its source document, scanned, converted to a TIFF file (tagged image file format), then opened in Adobe Photoshop, where it was cropped and occasionally had text removed. Then it was inserted into the target document and its size possibly adjusted. A single document took twenty to fifty hours.

The process followed clear, repeatable guidelines, which made it ideal for automation. Scripting could print pages from within Word one at a time, create TIFF files by using Microsoft Office's Document Imaging driver, and place them in the target document, resizing them with mathematical precision. We questioned the requirement to remove text and found it to be an old constraint, not needed any more. The resulting solution was a Microsoft Visual Basic 6 standalone Windows application (an executable or .exe file), since it would involve multiple documents, and the code wasn't conducive to being in a document template.

This automation reduced processing time to less than ten minutes with a zero defect rate. Conventional, top-down process improvement would probably have overlooked this task, since it wasn't considered broken. The user who spent so many hours doing the work didn't know it could be automated; it took an experienced automation specialist to identify the opportunity.

Knowing that automation can help with the smallest details, DQA team members began suggesting processes themselves. One was to create tables. New tables have up to fourteen requirements, including multiple font styles, column and row widths, and header formatting. A macro was recorded to create them. The time and quality savings were clear, but that wasn't the real draw of automation here. Of greater concern were existing tables. Having been modified by different authors over time, they were prone to inconsistencies and each had to be manually checked prior to release. This was a good automation candidate since the procedure was manual and repetitive with clear, objective requirements.

We created a macro series to either check each criterion individually, or check all table criteria in the document at one time. The scope later expanded to address user-entry mistakes, replacing line returns with paragraph marks, removing double spaces between words, removing spaces used as line returns,

WHAT MAKES FOR A POOR AUTOMATION PROJECT?

Not all document tasks are good candidates for automation. The following often reduce automation benefits or prevent automation entirely.

- Unclear or changing requirements
- Projects that include too many manual decision points, or interventions
- Subject-matter experts who "just know" what the right action is but who can't or won't explicitly describe the logic behind it
- Projects that have too many rule exceptions
- Inconsistently formatted documents, often the result of many authors modifying the document and/or modification over a long period of time

Finally, some processes just don't convert well to automation steps, either by needing features not available or not supported by Microsoft Office, or because automation isn't practical in a particular environment.

bolding certain words, and removing empty table rows. The greatest benefit was not time savings, although they were significant, but the consistency and assurance that the tiniest of details were fixed.

Our last example is of a complex application, initiated by management to address a specific, long-standing problem: acronyms. Many NASA documents require a list of acronyms and their definitions. In some cases, spelling out the first use of acronyms is required. Acronym management had been a time-consuming and often inaccurate manual process at the agency.

Given the ambiguities and complexities of acronym usage, this became a formal information-technology development project. The key was using Word's automation functions. With a combination of its wildcard find and replace, thesaurus, custom dictionaries, and other features, it was possible to reach nearly 100 percent accuracy. A separate list maintains customized acronym terms. In addition, the application lists words that might be previously unidentified acronyms. Rounding out the application are systems to add or modify terms and definitions, selecting from multiple definitions for the same term, producing and saving terms lists, and generating a new acronym appendix ready to copy and paste into the target document.

The resulting tool had three benefits. The immediate one was that it reduced document processing time for that step from a high of twenty hours to about thirty minutes, along with a dramatically higher accuracy rate. Second, after studying the process in detail, we concluded that authors and editors who supplied documents to DQA could use the tool to catch mistakes earlier and correct those mistakes faster. Lastly, the tool was so effective that we modified it for use by other groups or other contracts and made it available as a free download. It's now used routinely for contract proposals, white papers, and presentations.

With two or three highly visible projects completed, the teams became more confident and started suggesting automation ideas on their own. To date, we have provided more than a dozen tools. Document turnaround time dropped from the required twenty days to just three days. In addition to saving time and money, these tools can reduce stress. Some of our teams found that reviewing document changes in Microsoft Word is awkward and doesn't lend itself well to group meetings. We wrote a tool that cataloged all revisions in a document to a separate list along with user-requested information. One meeting organizer wrote, "This is the coolest tool ever and why everybody doesn't use it is beyond me. I love this thing!" ●

ROBERT DELWOOD is a senior systems analyst for Barrios Technology.

THE NASA DIGITAL ASTRONAUT PROJECT

BY LEALEM MULUGETA AND DEVON GRIFFIN

Conducting human missions beyond low-Earth orbit to destinations such as asteroids and Mars will require substantial work to ensure the well-being of the crew. These new operational conditions, which will include long periods in microgravity, will pose health risks that are currently not well understood and perhaps unanticipated. Developing and applying advanced tools to predict, assess, and mitigate potential hazards to astronaut health is critical. NASA's Digital Astronaut Project (DAP) is working to build well-vetted computational models to help predict and assess spaceflight health and performance risks, and enhance countermeasure development. The DAP aims to accomplish these goals through the following:

- Partnering with subject-matter experts to address human health-risk knowledge gaps and countermeasure development decisions
- Modeling, simulating, and analyzing physiological responses to exposure to reduced gravity and spaceflight-analog environments
- Providing timely information to contribute to mission architecture and operations decisions in areas where clinical data are lacking

To achieve these objectives, the DAP follows a systematic, rigorous process that begins by identifying human health-risk knowledge gaps that are amenable to computational modeling. Subsequently, we work with subject-matter experts within the Human Health Countermeasures element of the NASA Human Research Program to narrow modeling and simulation objectives to inform specific research questions or hypotheses. Then we conduct a thorough field survey to identify state-of-the-art modeling and simulation methodologies that can address the questions and hypotheses effectively. Subsequently, the models are developed, refined, verified, and validated to make them ready for research application.

Once the models have been sufficiently vetted (an effort currently in progress), we work with researchers or provide them models to simulate typical spaceflight-environment scenarios. The results of the simulations can then be interpreted by the subject-matter experts to inform research. Additionally, results from research and flight operations that the DAP informs can be used to further refine and enhance the fidelity of our models for future use. In addition to enhancing countermeasure development, our iterative and collaborative approach offers other benefits:

- Substantiates anecdotal evidence regarding spaceflight health risks
- Reduces cost of flight and ground experiments by running complementary simulations to further substantiate or refine experiments for optimal results
- Provides insight on the effects of long-duration spaceflight scenarios for which data are lacking

To ensure high-quality, repeatable results, the models are rigorously vetted using NASA's Standard for Models and Simulations (NASA-STD-7009). We do everything we can to validate the modeling and simulation against spaceflight or flight-analog data to establish the highest fidelity possible. For example, we are in the process of using on-orbit video data of crewmembers exercising to validate the kinematics of exercise models. We are also gathering muscle and bone data from past spaceflight missions and bed-rest experiments to validate the capability of our musculoskeletal models to predict the impact of exercise countermeasures on musculoskeletal fitness. Given that models and simulations have limitations, we clearly document the validation and application domains of our modeling and simulation to ensure they are not applied beyond their intended use.

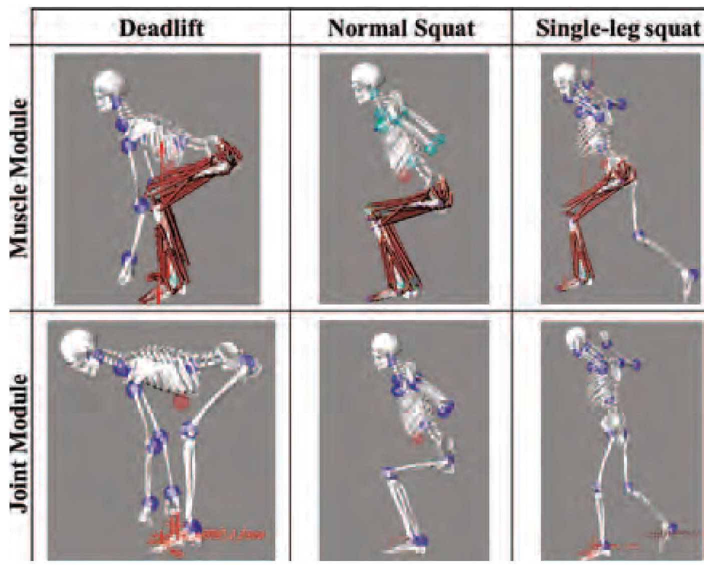


Image Credit: NASA

Three biomechanical exercise modules that include joint and muscle modules.

A Multicenter and Multidisciplinary Collaborative Approach

The DAP is managed out of Glenn Research Center by DeVon Griffin; the science content of the project is directed by Lealem Mulugeta of the Universities Space Research Association (USRA) in Houston at Johnson Space Center. We work collaboratively to lead a tightly knit team of researchers, engineers, and computational modelers located at Glenn and Johnson to execute the project's core mission. We conduct a weekly tag-up teleconference to discuss planned activities for the week and coordinate critical tasks that must be executed to meet milestones. Lealem also meets with the multidisciplinary technical team via a weekly teleconference to conduct highly focused technical discussions regarding the development and implementation of modeling and simulation. DeVon then closes out each week with a programmatic teleconference, during which the team members provide status updates on current activities

BASED ON THE OUTCOMES OF THESE SIMULATIONS, IT MAY BE POSSIBLE FOR CLINICIANS TO GUIDE THE ACTIVITIES OF ASTRONAUTS IN ORDER TO MINIMIZE RISK OF FRACTURE AFTER THEY RETURN FROM A MISSION.

and flag any programmatic risks that need to be addressed or tracked. If required, the team also holds face-to-face meetings to address high-priority issues. Finally, to keep the project and the team focused, we have established project and science management plans to communicate the overarching vision of the DAP and provide a road map that guides the team's efforts.

Applying Models and Simulations for Musculoskeletal Health Research

The DAP is assisting the Exercise Physiology Countermeasures Project (ExPC) at Johnson to model exercise countermeasures that use the Advanced Resistive Exercise Device (ARED) aboard the International Space Station. Given the complementary expertise of DAP and ExPC in computational modeling and exercise physiology, the teams established a cooperative approach to develop and implement three exercise modules of humans and an ARED device module. These model types are currently being integrated to provide data on forces transmitted to various anatomical locations as a result of the exercises.

The ARED exercise models will be integrated with bone and muscle adaptation modules currently being developed. These models use both terrestrial analog data and subject-matter-expert knowledge of musculoskeletal and exercise physiology unique to spaceflight. Once integrated with the exercise models, the bone and muscle models will simulate the response of bone and muscle physiology to exercise countermeasures during spaceflight missions. This will enable researchers to conduct "what-if" analyses to gain insight into questions such as

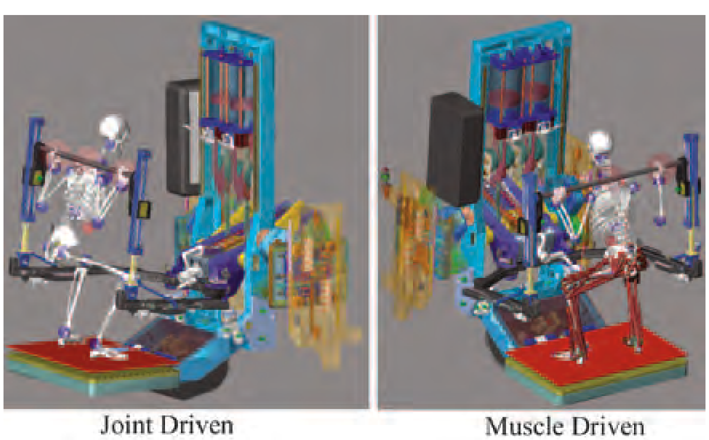
- Is it possible to reduce the amount of exercise time and maintain musculoskeletal performance by increasing exercise intensity or eliminating some exercises?
- Which exercises play the greatest role in maintaining musculoskeletal performance?
- What is the impact of unanticipated failure of exercise equipment on musculoskeletal health, and can the exercise regimen be reformulated to minimize adverse effects?
- Can exercise efficacy be enhanced for individual astronauts based on their unique anthropometrics?

In general, the overarching objective of this collaboration is to develop and implement musculoskeletal modules and modeling capabilities to customize and optimize exercise regimens based on anthropometrics and gender. Another goal is to provide tools capable of answering unforeseen exercise-physiology questions as they arise, as well as scalable and extensible exercise-device modules and modeling capabilities or platforms to evaluate the influence of exercise devices on exercise performance and flight hardware.

Ultimately, these tools will be used to inform ground and flight studies aimed at addressing musculoskeletal-risk knowledge gaps regarding the minimum amount of exercise required to maintain musculoskeletal health and performance, and the minimum set of exercise equipment needed to maintain musculoskeletal health and performance.

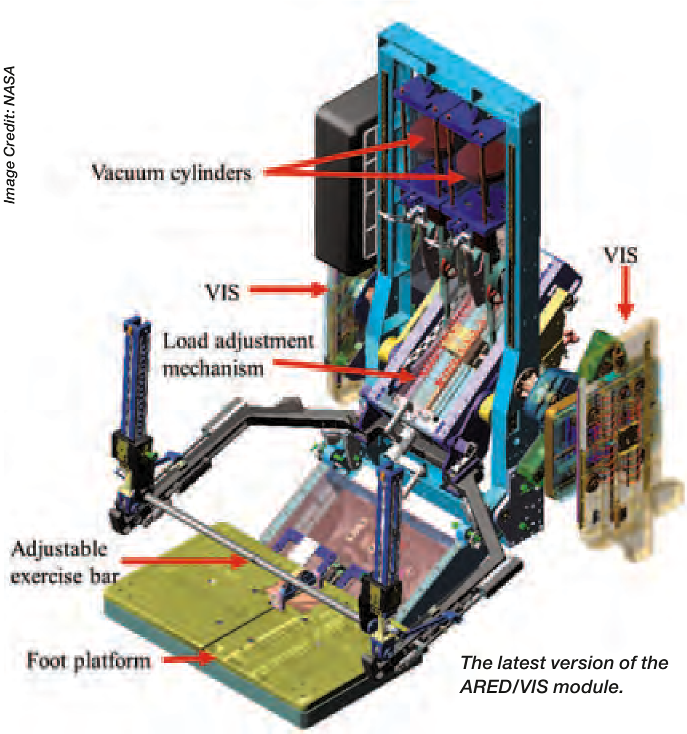
The joint teams developed the ARED model in progressive stages to gradually increase the module fidelity. The first product was a beta version, used as a development and checkout tool for the integration process with the biomechanics exercise modules. The teams maintain the beta release as a development platform throughout the project because it offers a simplified environment for checking and

Image Credit: NASA



Joint- and muscle-driven versions of the squat-exercise biomechanics modules integrated with the ARED/VIS module.

Image Credit: NASA



The latest version of the ARED/VIS module.

troubleshooting the integrated modules. Follow-on versions provide increased fidelity, including accurate characterization of mass, inertial and friction properties of the device, and the vibration isolation system.

Work in Progress

In addition to modeling and simulating exercise countermeasures, DAP is currently collaborating with the NASA Bone Discipline lead within the Human Adaptation and Countermeasures Division to apply modeling and simulation to augment a new bone-strength standard that NASA is currently developing. DAP team members are developing a unique capability that will provide the first simulations of the effects of microgravity on bone turnover. This work focuses on bone-strength changes due to demineralization and architectural changes. It will also be combined with biomechanical modeling to predict the loads experienced at specific bone sites that are at greatest risk for fracture during post-flight activities astronauts might perform, such as jumping. Based on the outcomes of these simulations, it may be possible for clinicians to guide the activities of astronauts in order to minimize risk of fracture after they return from a mission.

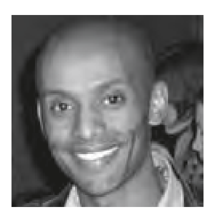
The DAP is working with the Exercise Countermeasures Project Advanced Exercise Concept (AEC) device-development team at Glenn to model advanced-concept devices with the following goals:

- Gaining insight into the efficacy of AEC devices for exercise countermeasures
- Providing timely input for design, development, and refinement of AEC devices
- Reducing the time and cost to develop the exercise devices
- Reducing the time and cost to clinically test new exercise devices

Given that many of the AEC component prototypes will share some common architecture, DAP is developing a generalized modeling toolbox that will make it possible to rapidly benchmark the capabilities of proposed devices for common loading profiles. This builds on DAP's goal to develop scalable, extensible exercise device-simulation modules and capabilities to rapidly and inexpensively evaluate exercise hardware efficacy during exploration missions. As part of that goal, the models will be able to simulate changes in exercise protocol as well, allowing exercise physiologists to conduct what-if analyses of various exercise prescriptions for microgravity conditions.

Finally, DAP is working with the Visual Impairment and Intracranial Pressure project to address recent findings of anatomical changes of the eye and visual performance diminution in many long-duration space station crewmembers. Although these changes have varied in severity, they have occurred at a much higher rate than expected. This project is currently in the field-survey phase to identify modeling and simulation resources that can be extended to answer key questions and test hypotheses in this area. ●

LEALEM MULUGETA works for USRA within the division of Space Life Sciences in Houston. He was appointed as the DAP project scientist in 2011, a key member of the project leadership responsible for all scientific content and direction of the project.



DEVON GRIFFIN has a background in optical instrumentation development for bioscience, microgravity combustion, and microgravity fluid physics. He has been a co-investigator, facility scientist, and project manager for shuttle and station flight projects. He has managed projects for NASA's Human Research Program since 2004.

INTERVIEW WITH

Lisa May

BY DON COHEN

Lisa May is the program executive for MAVEN, the Mars Atmosphere and Volatile EvolutioN mission, in NASA's Science Mission Directorate (SMD). In her spare time, she acts as the female voice of NASA's *ScienceCasts*. Don Cohen spoke with her at NASA Headquarters.

COHEN: How long have you been involved with MAVEN?

MAY: I have been with MAVEN since before there was a MAVEN. I started working on the Mars Scout announcement of opportunity in the fall of 2006, right about the time we downselected to two proposals. MAVEN was selected in September 2008.

COHEN: How does the selection process work?

MAY: It's a formal process that we take very seriously in the Science Mission Directorate. The first step is a broad call for scientific investigations. The principal-investigator-led proposals submitted are reviewed by external peer reviewers for science and for initial technical feasibility. We select the ones that rise to the top in that process to go on to a competitive Phase A, which is the very first step of mission formulation. Out of that, we get a funded concept-study report, which is a substantial document. The proposals have already been selected as having excellent science. We look at science feasibility: Will the instruments and operations proposed in this much more technical document actually support doing the excellent science that we want to select and fly? Step two also includes detailed evaluation of the budget and resources required as well as the management approach.

COHEN: Who makes the final decision?

MAY: In the case of MAVEN, that's an interesting story. Our brand new SMD associate administrator at the time, Dr. Stern, had been the PI [principal investigator] on one of the two proposals selected. There was a lot of discussion with legal about what his role could be. What it came down to was that he could not be involved in anything that had to be approved about the concept-study reports, guidelines, and selection process. Chris Scolese, the agency associate administrator, became the selection official. When Dr. Stern left, Dr. Weiler came back. *He* had been center director at Goddard and had signed the concept-study report for MAVEN, which was proposed from Goddard. So he also had a conflict. For probably the first time, the Science Mission Directorate AA [associate administrator] could not be involved in the decision making. The NASA AA, Chris Scolese, made the selection.

COHEN: So there was an unusual amount of potential conflict of interest to work around.

MAY: There was a different issue of potential conflict of interest having to do with the initial concept-study report. We had to develop an entire new review panel, which took time. So we decided we would slip the mission launch from 2011 to 2013. Mars missions are difficult. They generally have an aggressive development schedule; PI-led missions are cost capped. Adding risk by cutting a good chunk out of their development schedule was just not acceptable. Interestingly, the universe decided to cooperate. The science goal of both missions in the competition was to understand the effects of solar events—winds, ions—on the Mars upper atmosphere. The last solar cycle actually dawdled along and the new solar cycle did not ramp up for almost two years, which is about the length of the delay. The fact that the solar cycle happened to be delayed by almost two years was a fortunate coincidence.

COHEN: What role do you play in MAVEN as program executive?

MAY: The way I frequently describe my job to people is this: When you have a moving vehicle, you've got an engine that drives things and you've got the rubber that meets the road. In the case of space missions, the engine is the administration and Congress. They give us direction and funding. The rubber meets the road at the universities and industry partners and NASA centers that build and deliver the hardware and do the science. In between, you need something to keep the gears from grinding. That's the program executive.

COHEN: So what would be a typical situation where the gears threatened to grind?

MAY: One of the interesting facets of being an agency that builds and delivers things as part of a broader federal government is that oversight, reporting, and data requirements constantly shift as the government expands and contracts, as it looks inward and reports outward. People in various organizations and within NASA want to know more and more about how a project is doing. There is an endless search for tools that enable us to understand and predict how a mission is going to do and where you might need funding later. It's good, responsible management to want to be able to more accurately predict where you want to apply your funding. But saying, "NASA has new tools for figuring out how to do that," is a real hardship for the lean team of a cost-capped and schedule-constrained mission. One of the jobs I do on a semi-regular basis is push back and ask these organizations, "What are you going to do with this tool? How do you use this data? Can I give you the data? Is there existing data you can use?" I try to protect the MAVEN management team from things they had not been asked to plan for. And from requirements creep.

> I **stand up** FOR THE PROJECT AND **find ways** FOR THE PEOPLE WHO NEED INFORMATION TO **get it** WITHOUT DERAILING SOME **significant activity**, AND I TRY TO **maintain the integrity** OF WHAT **we selected** ON BEHALF OF THE TAXPAYERS AND THE SCIENCE INVESTIGATION WE **signed up** TO GET.

I stand up for the project and find ways for the people who need information to get it without derailing some significant activity, and I try to maintain the integrity of what we selected on behalf of the taxpayers and the science investigation we signed up to get.

COHEN: The requests for information come to you?

MAY: In general they do. I try to make sure that either I or the Mars Program Office can handle as many of them as possible. Sometimes organizations want to talk to the project without having a Headquarters filter. That's understandable, though I have a very good relationship with the project and what they'll hear from the project is what they'll hear from me and what they'll hear from the program office. We have a collaborative relationship and a really good flow of information back and forth.

COHEN: I know there's a tremendous amount of documentation associated with a project like this.

MAY: As an example, I'll go back to PDR [preliminary design review], which is followed by something called KDP-C—Key Decision Point C—which is the confirmation review. That is a huge era in a project's life cycle—the run-up to confirmation: the subsystem peer reviews, the flight-system preliminary design review, the mission PDR, and all the paperwork and budget work that has to go into confirmation. There is a raft of documentation that has to be completed and approved in that process: project plans, planetary protection plans, a whole bunch of control plans having to do with everything from parts to safety and mission assurance. There is an enormous list of things that have to be completed and approved. I generated a spreadsheet, which doesn't sound like a huge accomplishment, but it showed everybody who has to approve and everybody who has to concur on the documents and what organizations they're in. What it enabled us to do—me and the program office and the project—is to negotiate which documents would be ready for review when, and when the finals would be ready. The last thing I wanted was to have a bow wave of things that I had to push uphill here at Headquarters a month before confirmation. That is not a strategy for success. Understanding the requirements of review and approval enabled us to have every piece of that done well in advance. We knew that we were going to hit the marks and that the people who had reviewed documents had not just signed them because it was urgent; they signed them because they agreed with them. Headquarters can be a famous bottleneck. Busy, high-level people are not going to sign just because you say so.

COHEN: Do you regularly attend MAVEN project meetings?

MAY: There are regular meetings I attend. Despite our collegial relationship and the fact that I came from Goddard and have known many of these people for a long time, when Headquarters shows up in the room, it affects how a meeting goes. I absolutely understand that they need to do their work, so we pick and choose when and how I get my information. I have tag-ups with their management team weekly; there are quarterly meetings I attend. When they have their monthly meetings at Goddard, I sit down with them and talk about things in their monthly report and things we need for reviews coming up. They are a refreshingly transparent project, but I respect their need to get their work done without Headquarters in the room.

COHEN: So how are things going?

MAY: I've just had two very full days with the MAVEN team, and I'm feeling content with the way things are going. Maybe to an unusual degree, this project team raises problems immediately so everybody can say, "What can we do to help?" It's a different kind of approach to the model that says, "Don't ever take your boss a problem you don't have a solution for." That's a standard supervisory relationship.

COHEN: But not a good strategy, I would say.

MAY: There may be advantages to it, but I'm finding it extremely satisfying to work on a project where people raise problems early. Most times, they are not problems I can solve or have to solve, but they are things I have to know about. My job is to make sure they're being solved. The other part of my job is to report across the Planetary Science Division, because so many of our projects are related; they have a shared pedigree. The spacecraft buses of Mars Reconnaissance Orbiter, GRAIL, Juno, and MAVEN are all from the same family at Lockheed. So if MAVEN comes across something, it's very important to have program execs [PEs] who can stand up in a program review and say to the other PEs, "Hey, did you see this on your bus?" And the instruments are very similar; several of the MAVEN instruments have flown on heliophysics missions. Being able to talk to the helio people and say, "We have a parts issue. How is your mission going?" is valuable. None of these problems are insurmountable, but they are things that you wouldn't want someone else's mission to trip on in case they missed them. It's really helpful to say, "This piece was slow to deliver on the last project; is your project planning around that?"

COHEN: So the communication goes in many directions.

MAY: There are formal reporting systems in NASA for problems, but having our own community here in the Science Mission Directorate helps. And the PEs help each other with process issues, too. As I've said, there is a lot of documentation, paperwork, things that have to be done at a particular point in the life cycle. We sit down with each other and say, "How did you handle this particular requirement?" Then you can go back to the project and say, "This is a successful way for you to approach this" or "This other project that is a little further on in its development handled it this way and I think this is going to work for you. Let's get it sorted out now early so that it doesn't plague you at your major reviews or other milestones."

COHEN: A lot of knowledge sharing.

MAY: We have a Mars Program Office at JPL [Jet Propulsion Laboratory], and my mission manager there is much more involved in day-to-day tag-ups with the project and project details than I am. His JPL expertise—those folks have done Mars mission after Mars mission—helps Goddard with their first Mars mission, helping them as needed to understand specific issues as they crop up.

COHEN: How long have you been at NASA?

MAY: In September, it will be twelve years—ten at Headquarters.

> BEING **able to talk** TO THE **helio people** AND SAY, "WE HAVE **a parts issue**. HOW IS YOUR MISSION GOING?" **is valuable**.

COHEN: **Do you have an engineering or science background?**

MAY: I'm just old enough that people told me I should be a doctor because I was good at math and science. I'm just young enough that they didn't tell me I should be a nurse. But no one said I should be an engineer. I had no idea what an engineer did. I went pre-med, and I hated it. I ended up majoring in communication and working in radio news. I was the only communications major taking calculus and physics and the design of programming languages. I was probably the only speech major who was working the card decks in the basement of Gilmore Hall at UVA [University of Virginia]. I gravitated toward engineering. I ended up being an English grader for the man who became my future advisor. He felt very strongly that engineers needed to know how to communicate. That's how I met him and ended up moving on to engineering graduate school. I have a master's degree in mechanical engineering.

COHEN: **How important is your engineering knowledge in your job?**

MAY: It's absolutely essential. I have not done detailed technical engineering in a long time, but being fluent in it, being able to grasp an issue someone raises about the wrong resistor being on a board or the way they're going to solve a problem, is essential—knowing what they're talking about, whether they have an adequate solution or whether I need to ask more questions. To understand the technical problems being brought to me at a high level, it's important to have the background to understand the low level if I needed to. All program executives are technical. It's a given that you have an engineering or a physics degree.

COHEN: **Did you know when you were studying that you would use your skills in these ways, rather than for hands-on tech work?**

MAY: Not at all. When I went into engineering, it felt like a total break from what I had done in my undergraduate career. Looking back—my thirtieth college reunion will be this summer—I realize that my technical background and my ability to communicate have factored into every job I've had. Those things have all merged into one career. I suspect if you could walk up and down this hall and ask anybody how they ended up here, they would give you a similar story: anything but a straight line or "I always knew I wanted to …." Headquarters requires a broad mix of skills. We do things that are policy- and budget-oriented, technically oriented things driven by the laws of physics, and all of the management and communication tasks and activities that make all those work together. We're not specialists here. People I work with are good communicators, good speakers, interesting people as well as technically competent.

COHEN: **Do the NASA engineers you work with have trouble communicating?**

MAY: There's no way to generalize. There are people who do basic research that doesn't require a lot of writing. There are savvy technical engineers who write proposals, articles, or talks. It's a varied population. The technical competence is consistent. There are people who don't like writing and people who gravitate toward it. People who come to Headquarters on detail who like to focus on one thing at a time tend to self-select to go back to do what they call "real work." This is real work, believe me, but it's not the deeply technical work that some people prefer.

INTERNATIONAL COLLABORATION ON BEPICOLOMBO

BY ELSA MONTAGNON

BepiColombo is a collaborative mission to Mercury between the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA) due to launch in August 2015. The mission is named after Giuseppe (Bepi) Colombo (1920–1984), an Italian scientist who studied Mercury's orbital motion in detail.

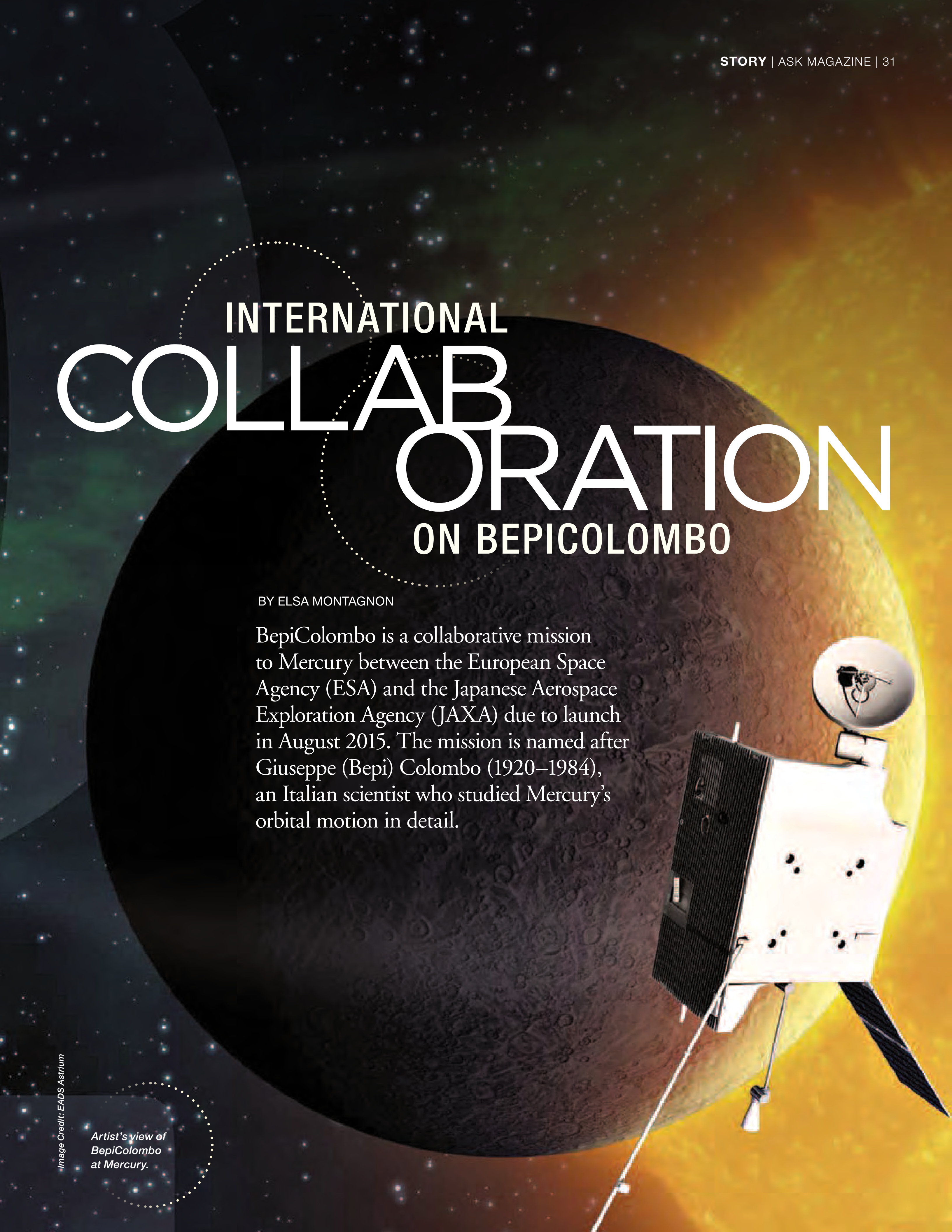
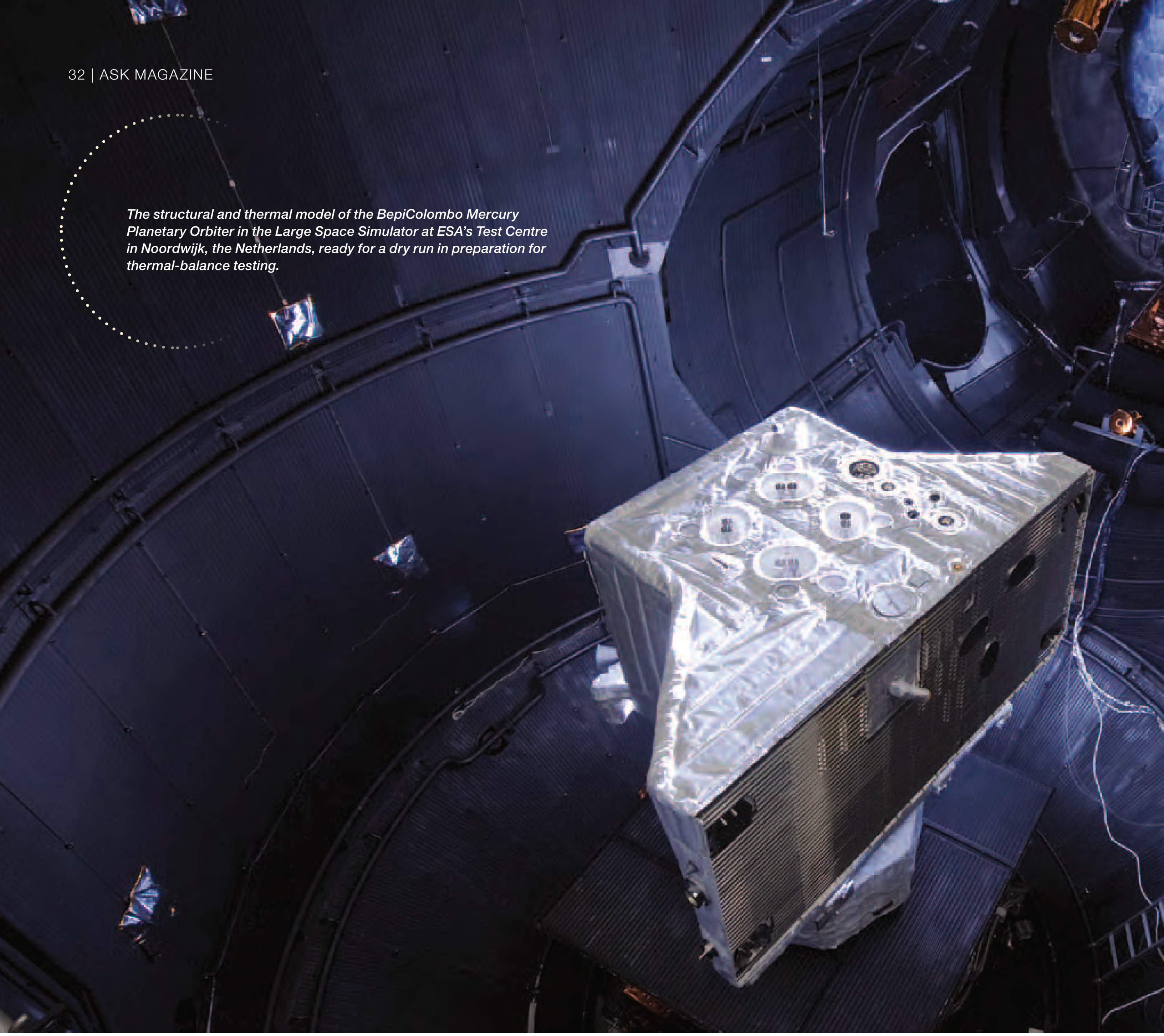


Image Credit: EADS Astrium

Artist's view of BepiColombo at Mercury.



The structural and thermal model of the BepiColombo Mercury Planetary Orbiter in the Large Space Simulator at ESA's Test Centre in Noordwijk, the Netherlands, ready for a dry run in preparation for thermal-balance testing.

Dedicated to the detailed study of Mercury and its magnetosphere, the mission consists of two spacecraft, the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO). Both will be launched as a single composite spacecraft that also includes a dedicated propulsion module and a sunshield for the MMO. ESA is providing the MPO spacecraft, the MMO propulsion module and sunshield, the launch, the operation of the composite spacecraft until delivery of the MMO in its operational orbit around Mercury, and the operations of the MPO around Mercury. JAXA is providing the MMO spacecraft and its operations around Mercury.

This is the first time that ESA and JAXA have collaborated to such a large extent. I will try to address the questions of how the collaboration has been established and how it is working (including the effects and management of cultural differences) from my perspective as the BepiColombo spacecraft operations manager. My team and I are located at ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany. It is from there that we will control the composite spacecraft from its separation from the launcher until the MPO completes its scientific mission at Mercury, about eight years later.

The Mission

The scientific mission objectives of BepiColombo include exploration of Mercury's unknown hemisphere, investigation of the geological evolution of the planet, analysis of the planet's internal structure, investigation on the origin of Mercury's magnetic field and its interaction with solar wind, and characterization of the composition of the planet's surface.

Photo Credit: ESA

To accomplish these and other objectives, the MPO has a payload of eleven instrument packages, and the MMO payload complement includes five instrument packages designed to study fields, waves, and particles.

Launch is planned for August 2015 by an Ariane 5 from Kourou, French Guiana. The long cruise phase will include a combination of electric propulsion and gravity-assist maneuvers (once by Earth, twice by Venus, and four times by Mercury). Arrival at Mercury is currently planned for January 2022. After delivery of the MMO to its operational orbit and jettisoning of its sunshield, the MPO will finally reach its target orbit and start its scientific mission, which will last one Earth year, and may be extended by another Earth year.

My team and I are responsible for conducting composite spacecraft operations from the BepiColombo Mission Operations Centre (BMOC), located at ESOC. For communications with the spacecraft, we will use the ESA network of Deep Space Antennas and JAXA's Usuda and Uchinoura ground stations. After delivery of the two scientific spacecraft to their final orbits, we will remain responsible for operations of the MPO. In Japan, an operations team located at Sagamihara will be responsible for MMO operations. This team will interface with us until separation of the MMO from the composite spacecraft. Science ground segments in Europe and Japan will support the operations centers in the planning of scientific operations and archiving of scientific data. Finally, instrument operations will be supported by teams typically located at an instrument's home institution.

Defining the Collaboration

The collaborative mission was selected by ESA in 2000. Like all missions selected as part of ESA's mandatory science program, it underwent studies, first within ESA, then supported by the two main industrial prime contractors in Europe. Finally, at the beginning of 2007, a contract was placed with Astrium Germany to implement the European space-segment contribution.

The collaboration with JAXA on this mission was formalized in a memorandum of understanding signed in April 2007 by the ESA director general and the JAXA president. A slim document of fourteen pages, it establishes the framework of this collaboration in terms of responsibilities, management, handling of reviews, transfer of goods and data, access to scientific data, intellectual property rights, and release of public information. It was complemented shortly after by a program plan working out the principles outlined in the memorandum in more detail.

The First Meeting

Our first meeting with JAXA took place in October 2006 at ESOC. As the popular saying goes, "You never get two chances to make a good first impression." This meeting was therefore very important, as it would set the tone for the entire collaboration.

At ESA, we are used to handling international collaboration. We interact with colleagues from our nineteen member states as part of our daily work; our contractors may come from additional countries outside the member states. We work daily with industrial representatives and scientists from member states, as well as from long-standing partners such as the United States or Russia. These culturally challenging interactions are facilitated by an important though easily forgotten fact: most of these partners are familiar with the ESA environment. They normally know how we are organized, who does what, and what stands behind the job titles. When we met with our JAXA colleagues for the first time, all this was new to most of them, as their ways were to us.

WE DID NOT TALK ABOUT HOW WE WOULD LATER WORK TOGETHER, BUT FOCUSED ON TRYING TO UNDERSTAND EACH OTHER'S WAYS OF DOING BUSINESS.

We therefore took care when defining the meeting agenda to dedicate time to background information on our centers and organizations. On the ESOC side, the meeting was chaired by my boss, the BepiColombo ground segment manager. At the beginning of the meeting, his boss, the head of the Mission Operations Department, which is responsible for spacecraft and ground-station operations at ESOC, joined to introduce himself personally to our Japanese colleagues and present the ESA organization, top-down, as well as a comprehensive overview of the missions being operated at ESOC.

We then spent some time explaining our operations concepts to each other. We did not talk about how we would later work together, but focused on trying to understand each other's ways of doing business. Then we took them on a tour of ESOC's mission operations facilities.

The rest of the meeting was dedicated to discussing in detail all aspects of our interactions.

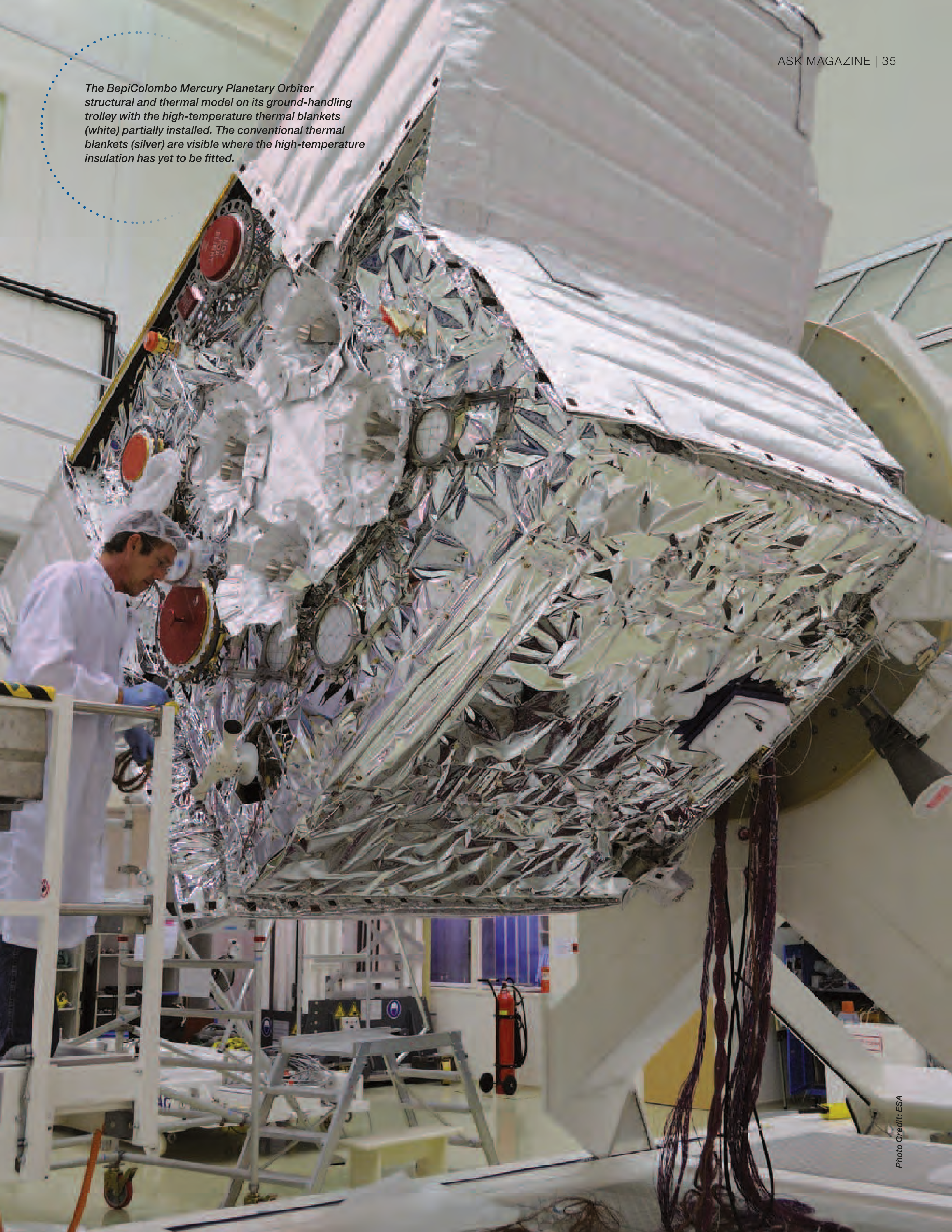
For this first meeting, we felt strongly that it was important to make responsibilities clear. While during meetings among European colleagues we do not normally evaluate statements by who is delivering them, we felt it would be very important to have topics explicitly covered by the person in charge of them in this first meeting with JAXA. We were also aware that our meetings occasionally become quite lively, with participants bringing up their views or opinions spontaneously on the subjects being discussed, sometimes even interrupting the speakers. We realized that this could blur the picture we were trying to establish, and therefore agreed that we would try to avoid that in the meeting.

The meeting took two full days. We had about ten ESA participants and eight from JAXA. On the evening of the first day, we arranged to have dinner together at a nearby restaurant.

One of the cultural differences manifested in meetings with our JAXA colleagues is their approach to internal communications. The MMO project manager or the ground segment manager normally handles all interactions with other MMO team members, communicating with their team in Japanese and with us in English. This pattern remains the same whether the team is physically located with us, as was the case for the first meeting, or connected by phone or videoconference, as is now mostly the case. This has certainly contributed to removing the language barrier almost completely, since our interlocutors are fluent in English. On our side, there are now more spontaneous interventions from the team than in the first meeting, but JAXA's way of communicating helps keep discipline on our side.

Setting Up the Interfaces

We have been holding yearly operations interface meetings since 2008. The initial meetings were aimed mainly at clarifying the



The BepiColombo Mercury Planetary Orbiter structural and thermal model on its ground-handling trolley with the high-temperature thermal blankets (white) partially installed. The conventional thermal blankets (silver) are visible where the high-temperature insulation has yet to be fitted.

Photo Credit: ESA

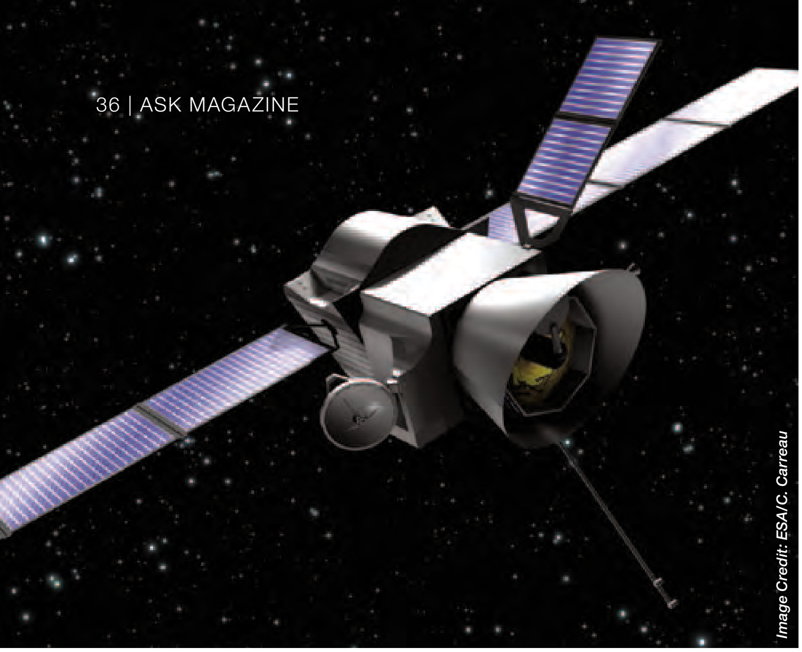


Image Credit: ESA/C. Carreau

This artist's view shows the two BepiColombo orbiters mounted on top of their transfer module, forming a single composite spacecraft.

requirements each agency placed on the other, in preparation for the ground-segment requirements review, which took place in November 2009. Our Japanese colleagues adopted very easily the ground segment interfaces that we proposed, based on our experience with other external agencies. But cross-support requirements needed to be consolidated in more detail. We have worked with JAXA to produce an implementation agreement, working out the responsibilities and services outlined in the program plan in detail, and as many interface-control documents defining the technical details of the relevant interfaces as necessary. Some of these documents—for instance, regarding ground station cross-support—are specific to the JAXA interface; others are shared across all external partners.

Some of the interface work has required considerable discussion, flexibility, and creativity. For instance, the MPO–MMO onboard interface is such that we are blind to what JAXA is uplinking to the MMO. This raises a concern on the difficulty for the two centers to support near-real-time interactive MMO operations, as is typically the case during near-Earth commissioning. We raised this point in the very first meetings with JAXA, and JAXA came back with their own concerns on the matter in 2010. After analysis of the MMO database structure, we came up with some ideas on how to improve the visibility by extra nonstandard processing of the data blocks by our systems. Requirements have been placed and are being implemented.

Another specific aspect of this collaboration is the availability of technical documentation. JAXA only produces a subset of their documentation in English. We specified and justified very early on in the project the information to be shared with ESA. It is being provided either in a document in English, or translated in English within a document in Japanese. Instead of full documents, there have been cases—for instance, for joint reviews—where JAXA has summarized the review-relevant information in the form of viewgraphs. Though the amount of information we get access to is limited compared with what is normally available on a space program, it has until now been compatible with our needs.

Outlook

We are now moving into the ground segment implementation and operations preparation phase. A lot remains to be done, but we are benefiting from having established personal and formal interfaces with our JAXA colleagues early. Thanks to the preparatory work, the scope of the activities lying ahead of us is well-defined.

Any joint decisions with JAXA take a long time to prepare. Our Japanese colleagues do not normally make decisions during the interface meetings. The meetings are used to collect information, discuss issues, and endorse prepared decisions. So far, this has not been a problem, but it requires careful attention in the preparation and timing of the meetings.

I have taken Japanese lessons regularly between 2004 and 2011, and have been to Japan twice, in 2005 and 2009. Neither trip was related to BepiColombo. When I started learning Japanese, I was mostly interested in getting exposure to a non-Western culture. At that time, BepiColombo was very much in the background and did not enter into my decision to study the language. I will never speak nor read Japanese fluently—I study too little for that—but I have developed a keen sensibility for the Japanese culture. This experience has changed me, and certainly influences the way I handle the interaction with our JAXA colleagues.

The collaboration with JAXA is an aspect of the mission that I enjoy a lot. It is undoubtedly one of the challenges of the BepiColombo mission: we carry the huge responsibility of delivering the MMO spacecraft safely into its orbit. We have managed to establish a relationship based on mutual trust and respect. Though not sufficient, it is a necessary condition to overcome the difficulties expected on the way. ●

Since 2007, **ELSA MONTAGNON** has been leading the flight control team for BepiColombo, the ESA–JAXA cornerstone mission to Mercury. Her responsibilities include the specification, acceptance, and validation of the ground segment preparation; validation of flight operations plans and procedures; and build-up and training of the flight control team.

Managing Multicultural Teams

BY CONRADO MORLAN

Having the opportunity to work for a company that operates in more than two hundred countries and territories and is a global leader in logistics has given me the opportunity to lead large global and regional information-technology projects. While technology made the work complex, the element of culture, both national and organizational, amplified the complexity.

A Global Project

The objectives of my first assignment were to lead the convergence of existing invoicing applications hosted and managed by country IT teams to a centrally managed single platform hosted in one of the regional data centers, and to standardize operations and processes. The new invoicing platform would be used by all countries in the Americas region; changes would follow a formal change-request process.

Although the existing invoicing applications shared core functionality, IT departments in individual companies had customized them by adding nonstandard functions that often did not comply with regional guidelines. This uncontrolled behavior led to new functions and processes that disrupted the standard operations at country and regional levels.

The technical team supporting the countries was challenged by reported incidents that often related to the customized functions, not core functionality. This was a source of conflict between the country IT teams and the technical support team, which many times was unable to address the issue. Business users did not produce invoices on time and their level of satisfaction was low. All this affected country and regional cash flow.

The Americas management board sponsored the project and mandated that all countries stop using any feature or function not aligned with the regional invoicing standards.

The Project Team

The project team consisted of stakeholders, the deployment team, and a technical support team. Stakeholders were the permanent regional management board and rotating country officials, including general manager, finance officer, and IT officer, who joined when the new platform was deployed in their particular country. The core deployment team was the same from project inception through completion and consisted of a project manager, technical-support team lead, and subject-matter experts in technology and invoicing. The rotating team members included country resources, both technical and end users. The technical support team, remotely located in Asia, supported day-to-day operation during the Americas business hours.

During team formation, team management became complex as some stakeholders and members of the deployment team changed when a new deployment started. New members came on board and others departed as the deployment in their countries was completed. I had to understand how to integrate new members into the team smoothly, convincing them to accept change and promptly collaborate with the project.

I learned that I needed to develop cultural competencies to manage the project team effectively and establish connections with team members when they came on board. A kick-off meeting to explain the purpose and benefits of the project helped establish the bond between new team members and the project. The most important part of connecting was stressing the importance of their roles and how their local experience would enrich the project, as this created a sense of belonging that translated into engagement. But the connection was strengthened by understanding and respecting the different communication styles and preferences of the national cultures involved.

There are many books about national cultures, but few resources explain how to deal with national cultures in project teams. While attending project management congresses, I was able to connect with other project management professionals who had faced similar challenges and learn from their experiences. I also learned from my own mistakes. During my first visit to Asia, I met with the technical-support team lead and his team and inadvertently broke the local meeting protocol when I started asking direct questions of team members. After catching the nonverbal cues of team members that showed they were asking the team lead for permission to answer, I switched to directing questions to the lead. He then selected the person to answer the question. At the end of the meeting, I apologized to the team lead and team members for my oversight and made it clear that my intention was not to make them uncomfortable or violate local meeting standards. I quickly shared what I learned with the rest of the deployment team.

Speaking foreign languages is a must in a global project environment, but language skill alone does not make a cross-cultural expert. It is necessary to understand other cultures' values, beliefs, and communication preferences. Knowing how they manage and resolve conflict is essential, for obvious reasons.

DURING MY FIRST VISIT TO ASIA, I MET WITH THE TECHNICAL-SUPPORT TEAM LEAD AND HIS TEAM AND INADVERTENTLY BROKE THE LOCAL MEETING PROTOCOL WHEN I STARTED ASKING DIRECT QUESTIONS OF TEAM MEMBERS.

It is also important to understand your own culture's norms and behaviors. That knowledge helps guard against interpreting other cultures' behaviors in terms of your own unexamined expectations. Reflecting on your own culture helps you understand and interpret why people from other cultures act the way they do.

With those recommendations in mind, I looked for ways to improve my cultural awareness in order to better understand my team members. As the project progressed and my cultural awareness improved, my connection with international team members became closer and more robust. When I had to spend more than two weeks in a country, I usually spent my weekends visiting popular spots where locals met: restaurants, farmers' markets, coffee shops, and occasional sporting events where I observed people's customs, traditions, and behaviors. My observations in those settings helped answer my questions about culture. When in doubt, I asked questions either of the locals or my colleagues.

Intracompany Networking

I often met with country management boards during the course of the project; these meetings offered good opportunities to establish long-lasting business relationships. I learned the importance of doing "my homework," gathering all the relevant information prior to any meeting and knowing the audience in advance. Having established strong relationships in the initial phase of the project helped me get insight into country officials from people who had already dealt with them. Knowing the preferences and sometimes the opinions of a country's management board about the project helped me to build the right deployment strategy and know what to expect from meetings.

In every meeting with country management boards, my team and I wore business attire and arrived on time. Board members arrived gradually and the general manager usually arrived late, demonstrating his status. The meeting started with preliminary discussions that helped build rapport. Deployment discussions occurred only after rapport was established. Usually, the first meeting exceeded the original allotted time and a second meeting was required to make the final decisions.

In this kind of project, it is important to have a well-defined circle of people who can influence the outcome. It can be like having "invisible" team members who support important functions and contribute to project performance.

Relationships should span all levels of the organization and not be limited to the higher ranks. Establishing a good relationship with users gives you feedback regarding the operation of the application and how it can be enhanced. For instance, Costa Rican users helped solve a common problem: end-of-day activities that involved several steps that required constant attention and, often, work after regular business hours. They suggested assessing the feasibility of automating these tasks. The assessment was positive and the tasks were automated, enabling Costa Rica and the other countries to avoid overtime payment.

A New Project Manager's Role

In an environment where organizations depend on global projects for benefits that contribute to strategic objectives, the project management professional needs to explore new ways to lead, execute, and deliver projects supported by dispersed and diverse teams. Technical expertise is not enough. Project managers must adopt a business-oriented approach and cultural awareness and other soft skills. The most important knowledge and skills include the following:

- ***Strategic Management.*** Understanding an organization's strategy will provide the backdrop for future assignments and an understanding of project selection criteria. Only projects that help the organization fulfill its intended purpose should be selected.
- ***Mindful Communication.*** Communication is crucial to project success. Communication needs to be customized to the specific cultures involved in a diverse project team. Good communication influences and inspires project teams and helps build strong relationships across the organization.
- ***Adaptability.*** New leadership styles that fit the global project are required when working with diverse and dispersed teams located across time zones.
- ***Resilience.*** Realigning or repairing projects facing unexpected hardship because of miscommunication and problematic behaviors as well as cross-cultural issues and conflicts will be a regular part of the project manager's task.
- ***Transparency.*** Adherence to an organization's values and culture as well as professional codes of ethics is mandatory in global projects. The state of the global project needs to be shared promptly with relevant parties whether the project is in good shape or facing hardships.

In this new role, the project manager will turn into a perennial learner striving toward excellence, a great communicator, and a business partner who ensures that projects will produce the benefits the organization is seeking.

Key Questions

If you manage or are thinking of managing a global project, here are some basic questions you should ask yourself:

- As a global project manager, how do you deal with cultural issues in your project team?
- What is your strategy to deal with conflict in a cross-cultural team?
- Do you enjoy the challenge of being a global project manager? ●

CONRADO MORLAN has more than twenty years of experience as a project and program management practitioner, leading complex projects in North America, Latin America, and Europe and managing complex negotiations and influencing organizations across functions and levels. He routinely shares his knowledge and experiences through events sponsored by PMI and PMI Chapters in the United States and Latin America. He can be reached at conrado@thesmartpms.com or on Twitter, @thesmartpms.

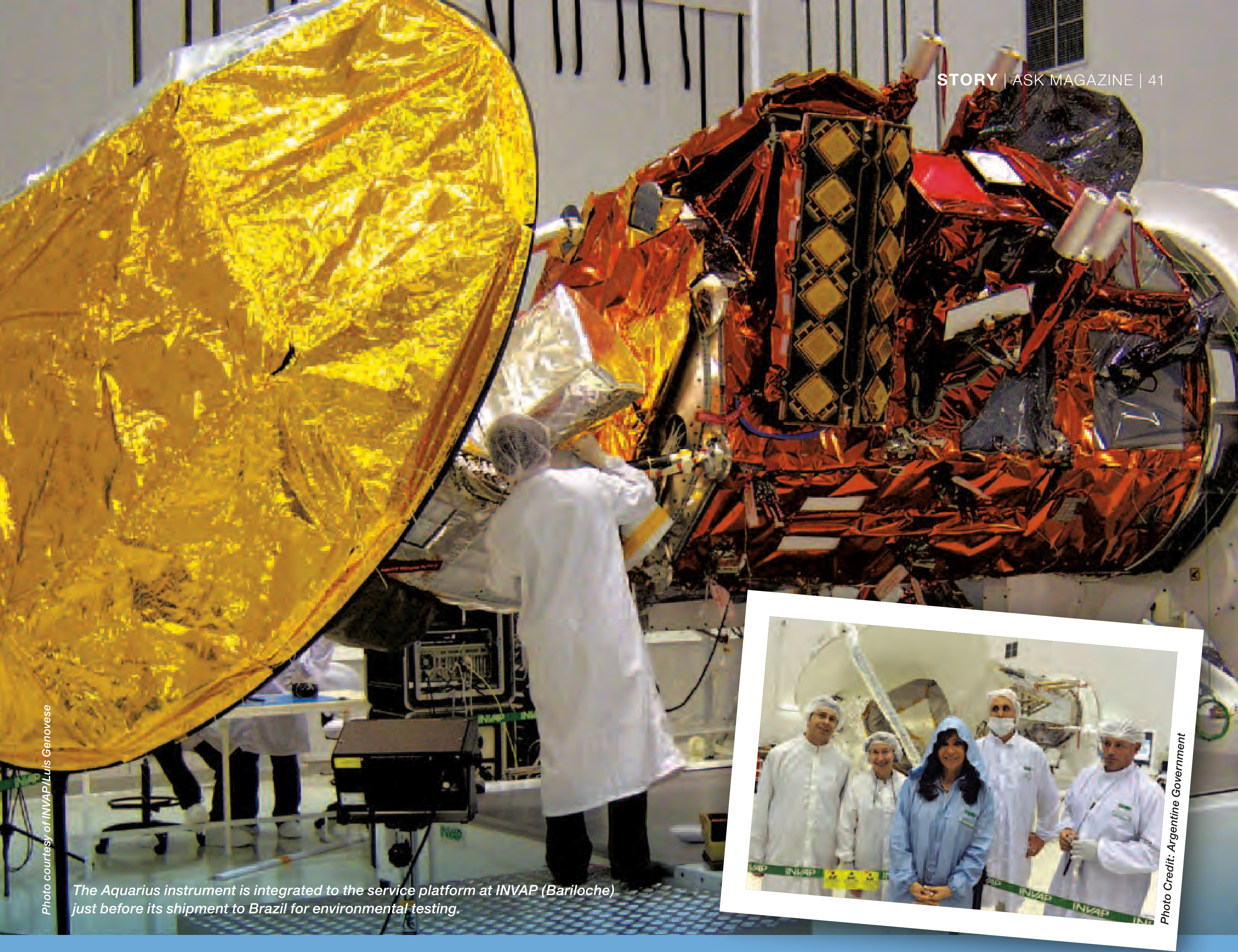


Photo courtesy of INVAP/Luis Genovese

The Aquarius instrument is integrated to the service platform at INVAP (Bariloche) just before its shipment to Brazil for environmental testing.

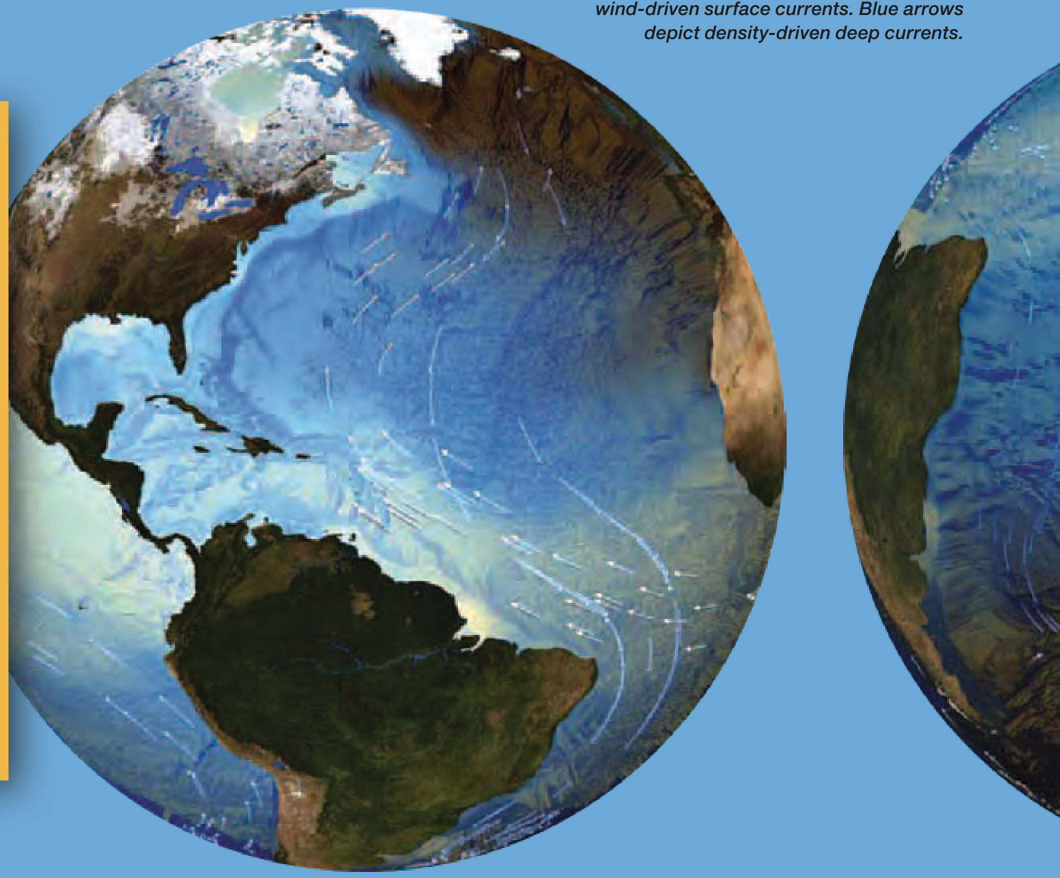
Photo Credit: Argentine Government

Argentine President Cristina Fernandez de Kirchner (center in blue) was briefed on Aquraius January 20, 2010. From left, Aquarius instrument manager Simon Collins, JPL; Aquarius instrument systems engineer Dalia McWatters, JPL; President Kirchner; Alejandro Ibanez, INVAP; and Juan Carlos Miazzi, INVAP.

AN ARGENTINE PARTNERSHIP WITH NASA

BY MATTHEW KOHUT

When the Aquarius mission launched from Vandenberg Air Force Base in June 2011, few Americans outside the Earth-science and space communities probably knew that the satellite itself came from Argentina.



Schematic visualizations of circulation in the North Atlantic, South Atlantic, and Indian Ocean basins. White arrows depict wind-driven surface currents. Blue arrows depict density-driven deep currents.

EYE ON THE OCEANS

Aquarius will allow scientists to see how freshwater moves between the ocean and the atmosphere as a result of rainfall, evaporation, ice melt, and river runoff, and will supply new insights on ocean circulation and climate. Aquarius's measurements of sea-surface salinity will provide a new perspective on the ocean and its links to climate, greatly expanding upon extremely limited past measurements. During its first few months in space, the mission will acquire as many measurements of sea-surface salinity as had been collected from ships and buoys during the previous 125 years.

The Aquarius/SAC-D mission (SAC is the acronym for Satélite de Aplicaciones Científicas—Scientific Applications Satellite) is the fourth in a series of satellites developed by the Comisión Nacional de Actividades Espaciales (CONAE), Argentina's space agency, in collaboration with NASA. CONAE's industry partner, INVAP, was responsible for building the spacecraft and conducting all integration and testing activities.

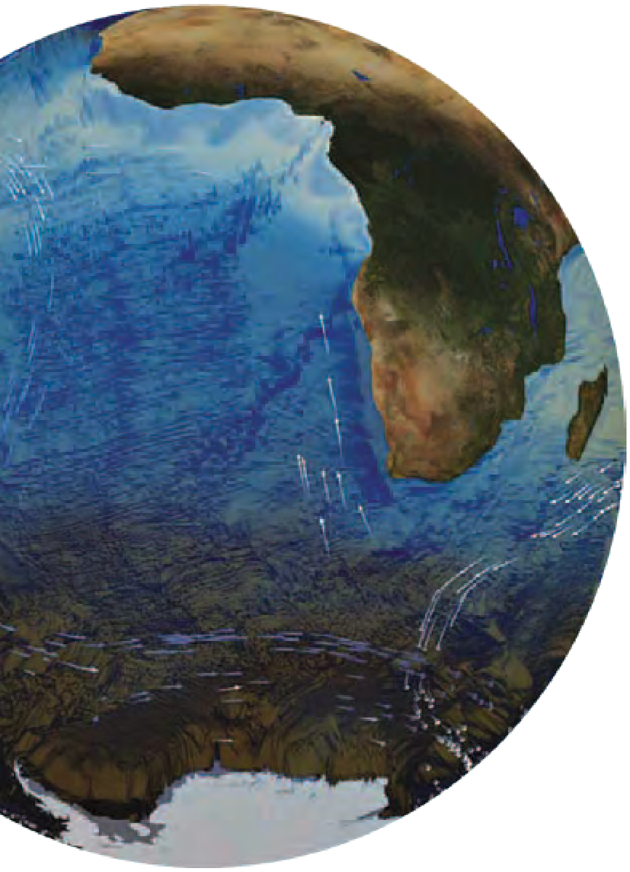
For Luis Genovese, INVAP's project manager for the Aquarius/SAC-D observatory, this project reflected the maturation of a collaborative relationship with NASA that began in the early 1990s. By the time of the Aquarius proposal in 2002, he had worked with his partners at the Jet Propulsion Laboratory (JPL) for years. "This was the first time we were participating in a project where the mission itself was a NASA mission," he said, noting that Aquarius was selected by NASA through a competitive process.

Since NASA's Aquarius instrument would be flying on a CONAE–INVAP spacecraft bus, NASA implemented a rigorous insight program to ensure alignment with the agency's standards and requirements. "We provided a high level of visibility into the methodology and the processes that we follow in our space missions, and this went very well, as many of the processes were already qualified from the previous SAC projects," said Genovese, citing electronics manufacturing and software engineering as competencies that already met NASA standards or certification requirements.

Genovese also had other stakeholders to manage. In addition to the Aquarius instrument, the spacecraft carried seven other instruments—five developed in Argentina, one from France's Centre National d'Etudes Spatiales, and one from the Italian Space Agency. "Everyone had configuration requirements that required the right implementation, and at the same time we had to ensure full system compatibility," he said. With such diverse partners, the challenge extended beyond technical compatibility. "Our cultures are different so it was kind of a challenge for many, many people being able to communicate to different NASA centers with different ways of operations."

As with any spaceflight project, Genovese and his team encountered unanticipated hurdles along the way. The original mission design called for using a nickel-hydrogen battery from a U.S. vendor to power the spacecraft. As the design progressed and requirements changed, the cost of the original battery technology became prohibitive. After assembling a tiger team that included experts from Goddard Space Flight Center, CONAE and

Image Credit: NASA/Scientific Visualization Studio



NASA approved a decision to switch to a lithium-ion battery, which would offer greater efficiency and performance. The new battery technology had never been subjected to as many cycles as Aquarius demanded, so significant work had to be done once a vendor was selected to ensure the new battery would meet the mission's requirements.

Another problem emerged relatively late in the spacecraft integration process. A test of the propulsion subsystem revealed a leakage problem with the thrusters. At this point, a worst-case scenario might have been a delay of a year or more. Fortunately, INVAP's partners at JPL were able to procure a qualified replacement thruster from a U.S. vendor with minimum trouble. "Working as a team with JPL, CONAE, and the vendor, and having the luck to have all the expertise, we had to be sure that everything was implemented correctly because our technicians had to reconnect the thrusters and test the overall system from mechanical, electrical, and propulsion points of view," said Genovese. Much of the repair work was performed in Brazil, where the observatory environmental testing took place, adding another level of complexity in terms of project management.

SAC-D also posed an infrastructure challenge to INVAP: at the time the project was awarded, the spacecraft's dimensions were significantly larger than their existing facilities could accommodate for integration and testing. The company made a strategic decision to invest in a new 60,000-square-foot facility in Bariloche, Argentina, to meet the needs of the project. "When we started to assemble the service platform, it was the first time we used this new assembly and integration facility," Genovese said. "We were very proud of having the Aquarius instrument being delivered to Bariloche for system-level integration and testing at our own facilities."

Reflecting on how Aquarius demanded a deeper level of international collaboration than the earlier SAC projects, Genovese emphasized the role of trust and constant communication. "We especially took care to provide a high level of visibility of our work to NASA. We worked really as a team, and we were not hiding anything in any aspect," he said. "This project took eight years of work here. More than two hundred people were involved, and more than 650,000 engineering hours were devoted to this project, so I would say that trust and communications were the most important considerations." ●

HMA's NASA-enhanced, ultra-high-pressure fire-suppression systems can extinguish a range of fire situations in significantly less time and using less suppressant than traditional low-pressure, high-volume systems.

SPACE-PROPULSION TECHNOLOGY HELPS SUPPRESS FIRES FASTER

BY BO SCHWERIN

Photo courtesy of NASA's Spinoff

Much deserved attention is given to the feats of innovation that allow humans to live in space and robotic explorers to beam never-before-seen images back to Earth. In the background of these accomplishments is a technology that makes it all possible—the rockets that propel NASA's space-exploration efforts skyward.

Marshall Space Flight Center has been at the heart of the agency's rocketry and spacecraft-propulsion efforts since its founding in 1960. Located at the Redstone Arsenal near Huntsville, Alabama, the center has a legacy of success stretching back to the Saturn rockets that carried the Apollo astronauts into space. Even before Marshall was established, Redstone was the site of significant advances in American rocketry under the guidance of famous rocket engineer Wernher von Braun; these included the Juno I rocket that successfully carried the United States' first satellite, Explorer 1, into orbit in 1958. And from the first orbital test flight of the Space Shuttle *Columbia* through the final flights of the shuttle program last year, these vehicles have been enabled by the solid rocket boosters, external tank, and orbiter main engines created at Marshall.

Today, Marshall continues to host innovation in rocket and spacecraft propulsion at state-of-the-art facilities such as the Propulsion Research Laboratory. Like many of its past successes, some of the center's current advancements are being made with the help of private industry partners. The efforts have led not only to new propulsion technologies but to terrestrial benefits in a seemingly unrelated field—in this case, firefighting.

Partnership

Orbital Technologies Corporation (ORBITEC) of Madison, Wisconsin, has been a longtime NASA partner, working with the agency on numerous projects—many through the Small Business Innovation Research (SBIR) program—on a range of space-exploration needs, from growing crops in space (*Spinoff* 2010) to advancing rocket engines.

Through the SBIR program, ORBITEC has collaborated with several NASA centers, including Marshall, to develop products such as a cool-wall vortex combustion chamber that represents a new way in rocket engine design. By feeding a liquid or gas oxidizer into the combustion chamber in a manner that generates a swirling vortex flow, the design confines the mixing and burning of the propellant to the core of the chamber, keeping the walls free from volatile thermal stresses. This process increases the durability and lifespan of the engine while allowing for smaller, cost-effective, and even reusable engine designs. Through further SBIR contracts with Marshall, ORBITEC applied this innovation to an advanced vortex hybrid rocket engine that combines solid and liquid fuel to power a low-cost, highly reliable, and versatile propulsion option.

Rory Groonwald, chief engineer for ORBITEC subsidiary HMA Fire, saw potential in much of ORBITEC's propulsion technologies beyond space exploration. Through extensive work with the U.S. Air Force Fire Rescue Research Group to develop means for more effectively extinguishing hydrocarbon-based fuel fires, HMA developed fire-suppression systems that used ultra-high pressure (UHP) for firefighting. Groonwald was exploring ways to improve the efficiency of fire-suppression systems by reducing the time and amount of water needed to extinguish a fire.

"We were trying to make something more effective and safer for firefighters to use," Groonwald said.

The idea of management of high-pressure flows, as ORBITEC does with rocket engine design, repeatedly came to mind. Working with its partners, HMA incorporated elements derived from ORBITEC's propulsion work into its design for fire suppression, and the improvements significantly enhanced the performance of HMA's UHP systems. For example, the company studied how to better manage the flow of a liquid to create an energetic blanket of fine water droplets. Through iterative design and testing, they optimized a method for providing a continuous and effective stream that uses much less suppressant.

Benefits

HMA's propulsion-inspired design is only one of the benefits the company's UHP suppression systems provide to firefighters. The systems introduce an approach to fire suppression that is complementary to—and in a number of cases superior to—traditional firefighting methods.

"The fire industry still has a mentality of 'surround and drown'—the more water you put around a fire, the faster the fire will go out," Groonwald said. "But that is not necessarily true."

One series of tests using empty houses at Vandenberg Air Force Base compared an HMA system with a 20-gallon-per-minute, 1,400-pound-per-square-inch (psi) discharge capability (at the pump) versus a standard 100-gallon-per-minute, 125-psi standard hand line—the kind that typically takes a few firemen to control. The standard line extinguished a set fire in a living room in 1 minute and 45 seconds using 220 gallons of water. The

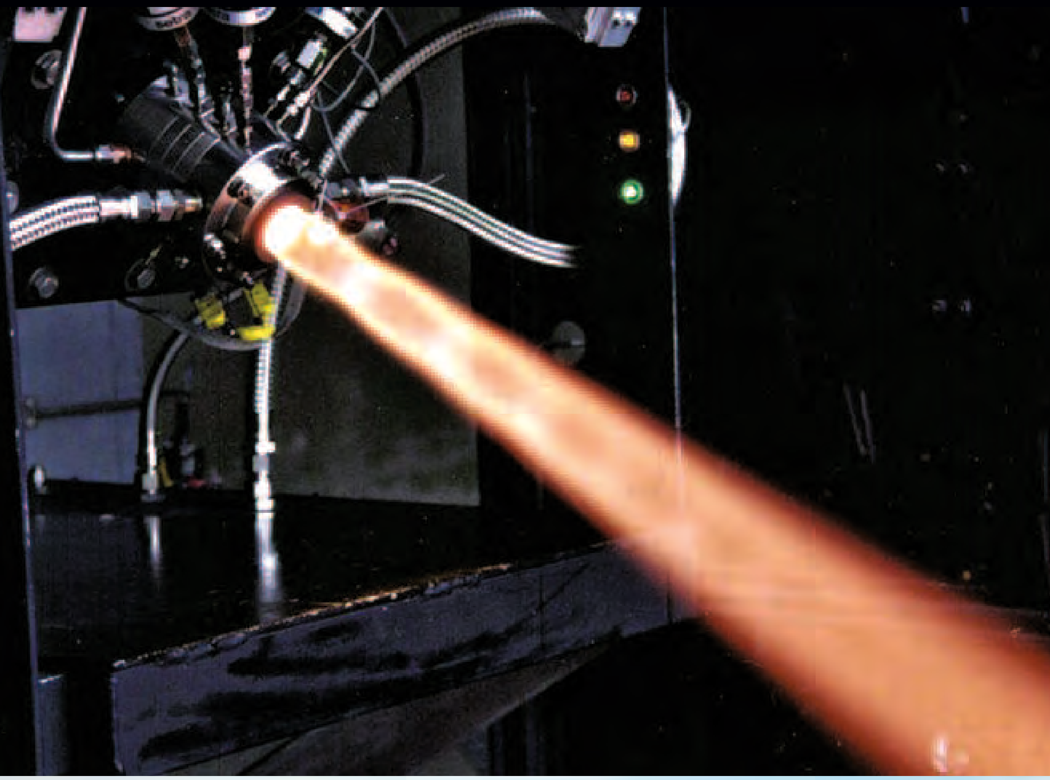


Photo courtesy of NASA's Spinoff

Through NASA's Small Business Innovation Research program, ORBITEC developed vortex combustion technology, representing a new approach to rocket engine design. ORBITEC's NASA work led to advancements in fire-suppression systems by the company's subsidiary, HMA Fire.

Photo courtesy of NASA's Spinoff

HMA's fire-suppression technology is ideal for a host of firefighting applications, including combating wildfires in areas unreachable by standard fire trucks. Here, HMA's L3 (light, lean, and lethal) vehicle demonstrates these capabilities.

THE STANDARD LINE EXTINGUISHED A SET FIRE IN A LIVING ROOM IN 1 MINUTE AND 45 SECONDS USING 220 GALLONS OF WATER. THE HMA SYSTEM EXTINGUISHED AN IDENTICAL FIRE IN 17.3 SECONDS USING 13.6 GALLONS—WITH A HOSE REQUIRING ONLY ONE PERSON TO MANAGE.

HMA system extinguished an identical fire in 17.3 seconds using 13.6 gallons—with a hose requiring only one person to manage.

"[The HMA system] sucked the life out of the fire and did it faster than anything I've ever seen before," said Devin Misiewicz, captain of the Vandenberg Air Force Base Fire Department.

The key to the HMA system is the pressure of its discharge, which results in smaller droplets dispersed on the fire. The smaller droplets create a greater total surface area contacting the flames—four times the total surface area of the larger droplets from standard, low-pressure systems. In addition to helping rapidly extinguish a fire, HMA's UHP approach also quickly reduces the temperature around a blaze—in the case of the Vandenberg test from 1,400°F to below 250°F within 60 seconds, about 2 minutes and 30 seconds faster than the standard equipment—and results in less smoke.

"What this does is create a safer environment for the firefighters to conduct an offensive suppression attack on the fire," says Groonwald. Using less water also reduces one of the major sources of damage from a fire situation: the water itself.

HMA's Hydrus systems are commercially available in a range of platforms. The T4 and T6 First Responder Emergency Systems incorporate the system into easily maneuverable, all-terrain vehicles. Along with the company's Proteus Series Brush Trucks and skid-mounted mobile units that can be loaded onto any number of vehicles, HMA's systems provide a quick-response firefighting tool for a range of fire situations. Carrying their own water sources, these systems are ideal for fighting wildfires in areas unreachable by standard fire trucks. The systems' high-pressure discharge can also penetrate 7 inches into the ground if desired, cooling lingering embers and heat sources that can reignite a wildland-type fire. The UHP systems are also highly effective against hydrocarbon fuel–based car fires and have been repeatedly proven to extinguish fully engulfed cars in 9 seconds.

While Groonwald says that HMA's systems are not intended to replace standard firefighting technology in all cases, they can be installed on fire trucks as a first-attack tool complementing traditional low-pressure, high-volume systems.

"Our systems become a force multiplier," said Groonwald. "You can do more safely with the same amount of people."

Government partnerships like those between HMA and ORBITEC, NASA, and the air force have supported the research and development leading to the creation of these game-changing firefighting tools, said Marty Gustafson, ORBITEC engineer and applications research manager.

"This is where the government–industry partnerships make a difference," she said. "They allow you to prove out a technology in a way that gives you instant credibility."

The experts are buying in: the U.S. military employs four UHP units at the forward operating base near Kabul in Afghanistan to help combat fuel fires and firebomb attacks. The navy uses the systems in the Middle East, and twelve air force bases in the United States employ the technology. Alaska is also examining the systems for remote towns, where they can be used by operators without firefighting training, and the Mojave Air and Space Port in California features the technology on a specially designed rapid-response rescue truck. Plus, municipal fire departments are interested in the technology's NASA-enhanced capabilities, meaning cities and towns nationwide could soon benefit from another example of space-exploration technology improving daily life. ●

Hydrus™, T4™, T6™, and Proteus™ are trademarks of Orbital Technologies Corporation.

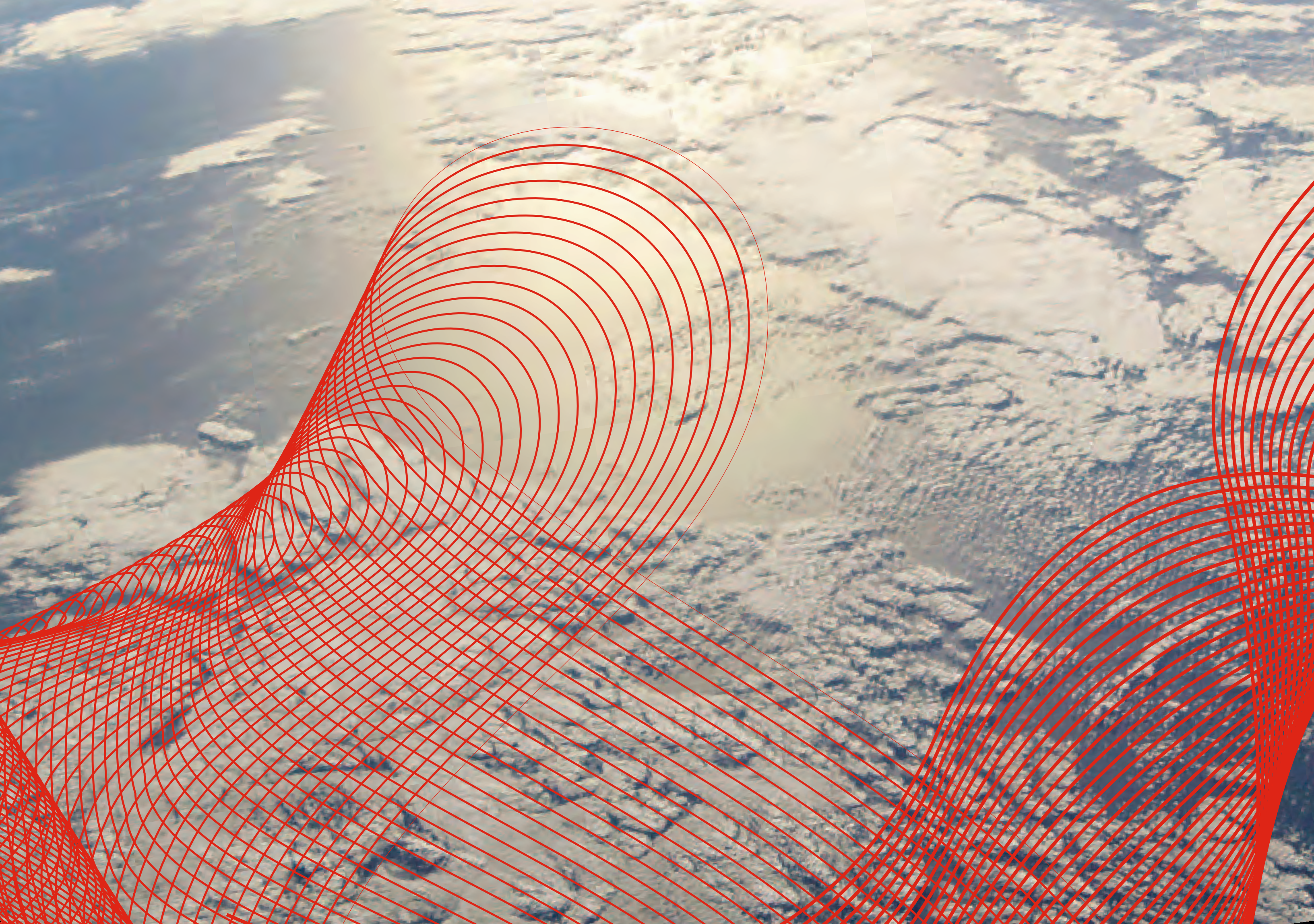
This article was originally published in NASA's Spinoff *2011.*

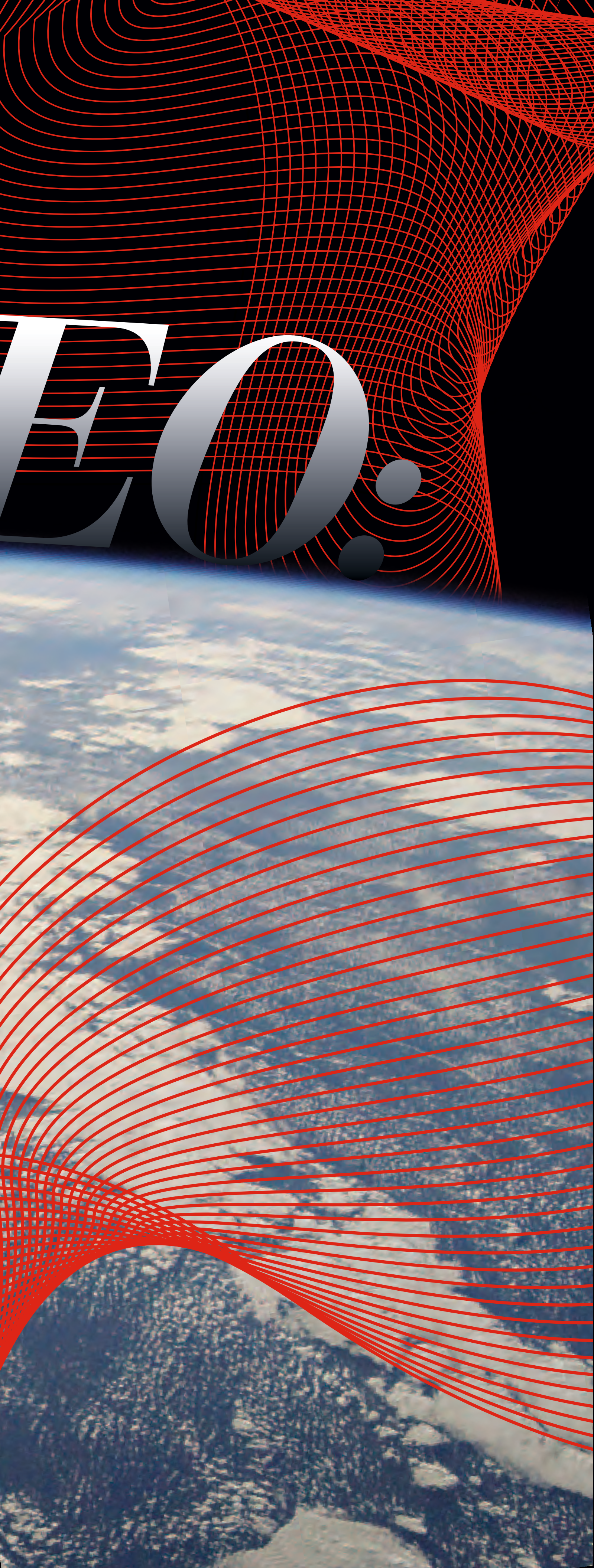
BO SCHWERIN is an award-winning writer and editor-in-chief of NASA's annual *Spinoff* publication, which features the year's best examples of NASA technology transfer and innovative partnerships benefitting life on Earth.

CLARR

BRINGING DISCIPLINES TOGETHER

BY DAVID YOUNG



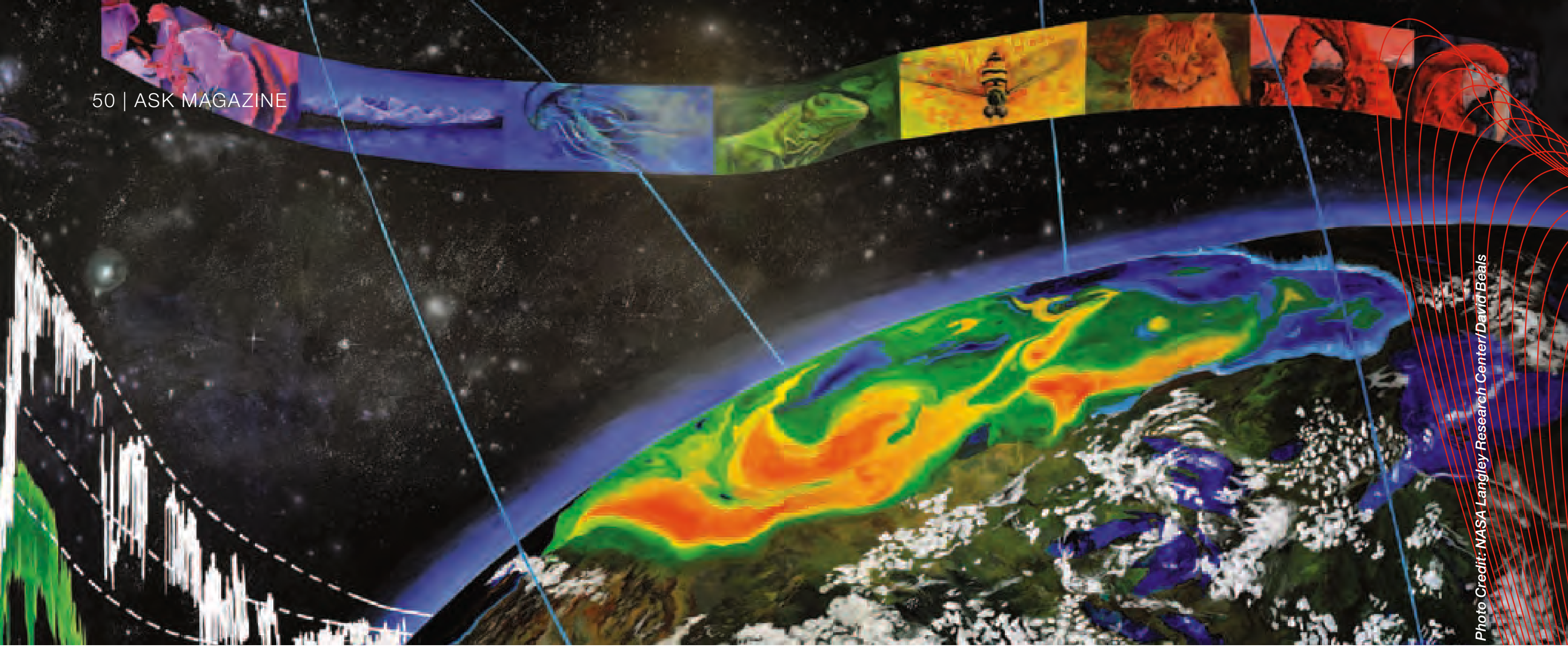


CLARREO, the Climate Absolute Radiance and Refractivity Observatory, is an Earth-science satellite mission in pre-Phase A (conceptual study) that is being designed to capture critical climate-change data much more precisely than has been possible with existing instruments. Its spectrometers, sensitive to the full range of infrared and visible radiation, will improve the accuracy of measurements of all the radiation leaving Earth by a factor of two to ten. That accuracy and the mission's ability to measure trends over a decade or more could help scientists know whether climate change will be less or more severe than expected as much as two decades earlier than current data allow. This could be a key determinant for decisions concerning our nation's response to changes in climate.

So it's not surprising that the 2007 decadal survey of "Earth Science and Applications from Space" considered CLARREO one of four high-priority Earth-science missions. In response to the survey, a small team of scientists was formed at Langley Research Center to define the mission. In early 2009, we gathered a full-fledged preformulation team including scientists, systems analysts, discipline engineers, and business analysts at Langley along with smaller teams at Goddard Space Flight Center and the Jet Propulsion Laboratory and about ten external organizations with the goal of developing a feasible concept for CLARREO.

Bringing the Team Together

Having worked on other NASA science missions, including CERES (Clouds and the Earth's Radiant Energy System) and CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations), mission scientist Bruce Wielicki, mission formulation manager Steve Sandford, and I were well aware of a familiar pitfall—that the CLARREO scientists would want only the best possible data regardless of the practical difficulties involved in getting it. That would lead to time-consuming and potentially acrimonious trade talks when scientific desires came up against engineering and budget realities. To avoid that kind of problem, we were determined to bring the team together



A mural painted by summer student Amanda Cichoracki to represent CLARREO's mission.

early and make the science and engineering decisions part of one discussion, not two. From the outset, the management team had a vision of forming a truly interdisciplinary team that involved systems thinking at all levels.

We began by holding a two-day off-site retreat, facilitated by 4-D team-assessment experts. The 4-D Systems approach focuses on critical "soft skills" for scientists, engineers, and project leaders. The retreat included some typical team-building activities, such as people talking about their backgrounds to get to know one another, but most of the team building came from doing actual project work: establishing a clear shared vision of the mission, defining roles and responsibilities, and dealing with bottlenecks that had already become evident by diffusing authority that was concentrated in one overworked individual. The 4-D facilitators also provided the team with training that helped us appreciate the benefits of continual engagement across the diverse skills of the team.

Back at Langley, the entire team was collocated in an open area that had once been a cafeteria. There were no closed offices, only cubicles and multiple meeting areas, so everyone was aware of what his or her colleagues were doing. The project leaders worked in cubicles, too, and were always accessible. We had not only an open-door policy, we had a no-door policy. This resulted in a dynamic, collaborative environment that furthered the bonding process that started at the retreat.

Although at times noisy and a bit chaotic, this arrangement made it easy to join in conversations and address issues as they arose. On multiple occasions, I was able to quickly provide clarification of technical aspects of the science in response to conversations in our break room. We encouraged systems thinking by including science and engineering representatives at almost every technical meeting. Communication was further enhanced through daily, early-morning, stand-up meetings to share late-breaking news and set daily priorities.

Our integration initiatives went beyond the Langley team. Internal and external science team members participated in weekly telecons in the first year as scientific goals and priorities were clarified. We also worked actively to bridge the common gap between scientist-observationalists, who focused on how to gather data, and the data users, who wanted the best possible data and didn't give much thought to issues related to the instruments that would gather it. We brought several teams of global climate modelers who would be the primary CLARREO data users into our requirements planning from day one. That has led to the development and use of innovative climate-observing system-simulation experiments that have not only demonstrated the utility of CLARREO data for improving climate predictions, but have been essential in setting rigorous accuracy requirements for the measurements.

The Science-Value Matrix

The most significant result of our integrated approach has been the development of the science-value matrix (SVM). This tool has helped clarify our trade discussions and weigh scientific value against cost, risk, and reliability as fully and objectively as possible. Like other work on CLARREO, developing the science-value matrix was a cooperative team effort.

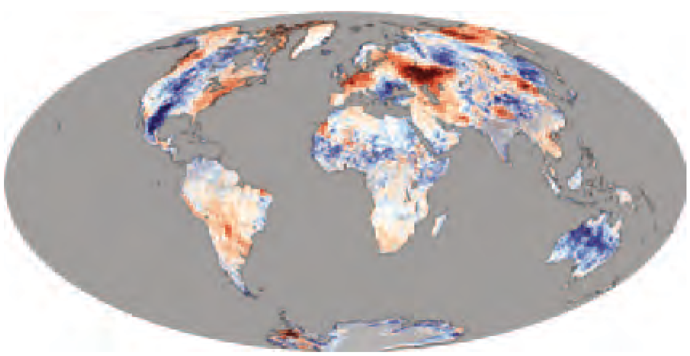
The relative merits of competing goals are difficult to quantify for a complex mission with multiple science objectives. This is particularly true for a mission like CLARREO, where the measurements are applicable to a wide range of climate objectives. Without an objective means of calculating science benefit, our team could not effectively evaluate the relative costs and benefits of multiple engineering approaches. We met this challenge by developing the SVM: an innovative approach to quantitatively defining science value for key aspects of the mission, including measurement accuracy, orbit type, and record length. Benefits were measured based on the specific advances that CLARREO would provide in reducing uncertainties in the climate observations as defined by the Intergovernmental Panel for Climate Change. By rigorously defining relative science value across the broad climate objectives of CLARREO, the team

WE HAD NOT ONLY AN OPEN-DOOR POLICY, WE HAD A NO-DOOR POLICY. THIS RESULTED IN A DYNAMIC, COLLABORATIVE ENVIRONMENT THAT FURTHERED THE BONDING PROCESS THAT STARTED AT THE RETREAT.

provided a mechanism for optimizing science value relative to cost for a broad range of potential mission architectures.

The SVM was also designed to be a management tool to be used over the project's life cycle. The matrix grounded and shaped discussions in objective fact and helped avoid what could otherwise easily have become formless, inconclusive debates. It definitely helped us guard against mission creep—the temptation to add just one more capability that could quickly lead to losing control of budget and schedule.

For instance, members of our external science team advocated the addition of a polarimeter that would use the polarization of light to analyze aerosols (particles suspended in the atmosphere) to CLARREO's instruments. They wrote a peer-reviewed paper arguing for the instrument. In fact, it would have been a potentially great addition, since aerosols influence the amounts of absorbed and reflected radiation. The question was, how would that added value compare to the added cost? The SVM allowed us to determine that a polarimeter would give us 30 percent added value but would raise the cost by 30 percent as well. Headquarters agreed that the instrument was a great idea but decided it was a great idea we couldn't afford within the CLARREO project.



This global map shows temperature anomalies for July 4–11, 2010, compared with temperatures for the same dates from 2000 to 2008. CLARREO's ability to measure trends over a decade or more could help scientists know whether climate change will be less or more severe than expected as much as two decades earlier than current data allow.

Image Credit: Jesse Allen, based on MODIS land-surface temperature data available through the NASA Earth Observations web site

The Future of CLARREO

The CLARREO team successfully passed its mission concept review in November 2010. The effectiveness of team integration was confirmed by the review panel's board chair, who cited the exceptional working relationship among science, project management, and engineering as a major strength of the project, leading to a mission concept that was extremely mature for that project stage. Due to budget considerations, CLARREO remains in an extended pre-Phase A.

NASA continues to fund efforts to refine the mission design and to look for cost-effective alternative ways to carry it out. For instance, we are examining the possibility of putting the instruments on the International Space Station instead of on their own satellite observatories. We have also been working on a study with a group in the United Kingdom, exploring possibilities for international partnering. And we are using the science-value matrix to search for a less expensive way to achieve the mission's science goals, perhaps with less capable but still adequate instruments.

The budget constraints are challenging, but we remain committed to this critical climate mission. This team experience has been one of the most rewarding of my career, and I believe that the trust and cooperative spirit the CLARREO team has developed in our years together will help us succeed despite these challenges. ●

DAVID YOUNG is the project scientist for CLARREO at Langley Research Center, where he has been working for more than thirty years to help understand Earth's climate. He currently serves as the deputy for programs in the Langley Engineering Directorate.

ASK Bookshelf

Here are descriptions of some books that we believe will interest ASK *readers.*

An Engineer's Alphabet, by Henry Petroski (Cambridge University Press, 2011)

Author of *The Evolution of Useful Things* and *The Pencil: A History of Design and Circumstance* among other books, Henry Petroski has long been an astute and eloquent explainer of how engineering works and why it matters. His *An Engineer's Alphabet* is an entertaining and thought-provoking collection of anecdotes, facts, quotations, and brief essays on subjects ranging from abbreviations and acronyms in engineering to *Zen and the Art of Motorcycle Maintenance*. Along the way, Petroski writes about calculators, peer reviews, pocket protectors, skunk works, the Tacoma Narrows Bridge disaster, useless things, and hundreds of other topics of interest to engineers.

The many entries represent, as Petroski says, "the distillation of decades of writing, talking, and thinking about engineers and engineering." There is trivia here—for instance, a list of universities whose sports teams are nicknamed "engineers"—but also serious food for thought. Under "Hubris in engineering," Petroski writes:

> It took Galileo, who opened his treatise on two new sciences with stories of well-considered things that did not work, to explain how physical considerations that may be ignored on a small scale can dominate the behavior of a larger but geometrically similar design. Unfortunately, what Galileo knew in the Renaissance was not always remembered in subsequent centuries.

Discussing the commercial failure of supersonic airliners later in the same little essay, he offers this wisdom: "The designs of engineers must be more than just strong enough and fast enough; they must also be compatible with the existing physical, social, and political infrastructure."

And what engineer would disagree with this, from "Scientists vs. engineers":

> It is a common lament among engineers that all too often in the news media successful technological endeavors and achievements are attributed to science and scientists, whereas technological problems and failures are blamed on engineering and engineers. Thus, landing astronauts on the moon was hailed as a scientific achievement, but when a test rocket exploded on the launch pad it was described as an engineering failure.

Mastering the Leadership Role in Project Management, by Alexander Laufer (FT Press, 2012)

The former editor-in-chief of *ASK Magazine* argues persuasively that sound management skills—mainly the ability to plan, control, and measure risks and results—are not enough to ensure the success of challenging projects. Those projects require leadership: that is, the capacity to inspire others, willingness to challenge the status quo when necessary, and, above all, the ability to analyze and adapt to the changing circumstances that are inevitable in today's complex and uncertain world of work. Routine tasks can be managed but ambitious, one-of-a-kind projects—like most of what is done at NASA—need to be led.

To demonstrate his points, Alexander Laufer tells the stories of eight demanding projects in aerospace, construction, and the military. He depends on the power of stories to suggest the human as well as the technical complexity of the projects and their contexts and to show rather than tell what project leaders think and do, and the effects of their actions on team members. Stories (like leaders) have the power to inspire as well as instruct. Laufer hopes these stories will help readers not only learn how to be better project leaders, but also unlearn some outdated and more mechanical ideas about project management. He does not suggest that management, in the traditional sense, has no role to play in complex projects, but it

functions effectively in the context of leadership dealing with issues that are literally unmanageable.

These stories provide examples of project leaders challenging the status quo with courage and creativity. The U.S. Air Force project leader who changed the government's relationship with contractors from adversarial oversight to trusting partnership and the manager of a large construction project who motivated procrastinating designers by beginning construction before their plans were complete faced strong opposition and incurred a lot of personal risk, but they believed that radical action was the only way to succeed. They were very much rebels with a cause: Laufer emphasizes the importance of fighting the status quo only when and where it is necessary.

Many of the stories—the air force story mentioned above is one—are partly about culture change: developing new ways of working and new ways of thinking about work. Although the exact nature of that change varies from story to story, in all cases its foundation is trust. And trust is developed by working together—by demonstrating trustworthiness—and through constant, honest communication. The fact that leadership and project success depends on good communication in all available forms (and especially traditional person-to-person conversation) is an underlying theme of all these stories.

Note: Ed Hoffman, Larry Prusak, and Don Cohen (all of us currently associated with ASK*) have contributed in various ways to this book, but it is very much Laufer's accomplishment.*

The View from Here: Optimize Your Engineering Career from the Start, by Reece Lumsden (Illumina Publishing, 2011)

Reece Lumsden, an experienced aerospace engineer, has written a book primarily for young engineers and students considering a career in engineering. The topics he covers range from the qualities that make a good engineer to the value of co-op programs and mentoring to the importance of systems thinking and good communication skills. He also offers some sound advice on job hunting and what to expect—and how to succeed—once you find an engineering job.

The View from Here offers engineering students some of the benefits of mentorship, providing down-to-earth advice from an older, experienced professional about many of the possibilities and pitfalls of their chosen profession. Managers of young engineers will find value in the book, too, as a guide to their role in helping those new hires develop and flourish. ●

The Knowledge Notebook

The Greeks Had Many Words for It

BY LAURENCE PRUSAK

At the end of February, the Office of the Chief Engineer at NASA convened a meeting at Kennedy Space Center to discuss a variety of practices and policy issues regarding knowledge management at the agency. The meeting included representatives from NASA centers and some guests who talked about knowledge management work being done at the FBI and the World Bank. For two and a half days, we shared experiences and thoughts about how best to share and use knowledge at NASA.

One aspect of the meeting stood out for me, however. While we were all there to talk about knowledge, the word itself clearly had diverse meanings for the assembled practitioners. In fact, if we had gone around the room asking people what knowledge is, there would be far less overlap in meanings than anyone would have guessed going into the meeting.

That fundamental disparity has been my experience in many such meetings for the past two decades or so. Unlike our shared understanding of almost any other term used in organizations—technology, systems, information, data, markets, processes—we seem to lack a common idea of what knowledge is. This makes working with knowledge quite problematic.

Whenever I mention that I study and consult on the subject of knowledge, this absence of shared understanding of the meaning of the word "knowledge" is conveyed to me in starkest terms. Some people ask me if I can help them fix their PC (absolutely not); others want to know if I can help their kids write a philosophy term paper (I probably could, but I'm not a philosopher); one person asked me to explain the Myers-Briggs personality test (my explanation would be no better than most people's). When a large, diverse organization undertakes to develop some innovative knowledge practices, think of the semantic confusion that is likely to ensue—and get in the way of effective cooperative work.

Part of the problem is a linguistic issue. We really have just one word—knowledge—for what is in fact a very broad set of meanings or understandings. Many other languages have at least two words for knowledge; some Asian languages have three. The classical Greeks had at least seven words they used to describe different varieties or aspects of what we are forced to call "knowledge."

Let me give you an example of how wide are the parameters of what we think of as knowledge. On one end of a continuum of meanings of "knowledge," we might have the example of the Pythagorean theorem beloved (or hated) by high-school geometry students. It can easily be considered as a "piece" of knowledge. It surely is a part of the whole we call geometrical knowledge. The Pythagorean theorem is complete in itself. It needs no context or further documentation to make its meaning clear. It can be readily and fully explained by a geometry teacher and understood by her students.

Now let's move to the other end of the spectrum of meanings of "knowledge." A few months ago, I gave a talk to a group of Irish executives visiting Boston. When I was discussing knowledge and knowledge management, one of them told us that his brother was a well-known horse trainer in rural Ireland. The brother was famous for his skills but practically inarticulate when it came to describing how he does what he does. Even though a clear explanation of his work might bring him added business or repute, he can't describe it except in the most banal and meaningless way. And this is a person in a country where people are known for their expressive skills! But his knowledge is almost all tacit—subtle, contextual, and very hard to represent or make understandable except, perhaps, by *showing* rather than *telling*. Yet we would likely use the same English word to describe the Pythagorean theorem and the expertise of the horse trainer. How can one devise acceptable practices and policies for knowledge when the word can mean such different things?

Well, some organizations do it. How they do it is by devising a consensus definition that meets the needs of the organization and is clear to everyone in the organization. It's that simple. No language police are called for, no attacking others' meanings and pet ideas—just a negotiated truce that makes clear what we are talking about when we talk about knowledge. ●

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NASA in the News

Focusing on a space program that is built to last, NASA's FY2013 budget details plans for the agency's endeavors in Earth and planetary science, astrophysics, heliophysics, aeronautics, technology, and exploration. NASA Administrator Charles Bolden remarked that the budget "moves the agency forward strongly on a path that will maintain America's preeminence in space exploration. … embarking upon an ambitious exploration program that will build on new technologies as well as proven capabilities as we expand our reach out into the solar system." The proposed budget seeks $17.7 billion for NASA to continue implementing its major elements and advance developing technologies. Read about the budgetary plan in detail at www.nasa.gov/news/budget/index.html.

Future of Human Spaceflight

NASA is embarking on a new era of space exploration in which humans will travel deeper into the solar system than ever before. The International Space Station will be the centerpiece for exploration and will serve as a test bed for research and new technologies, and as a stepping-stone to future destinations. While partnering with commercial industry to transport cargo and eventually crew to the space station, NASA will continue to focus on developing advanced exploration systems. To learn more about where NASA is going, explore the agency's latest interactive feature at www.nasa.gov/externalflash/human_space.

NASA TV in HD

Want to know what life looks like in space? Watch live video from the International Space Station in high definition on UStream at www.nasa.gov/multimedia/nasatv/iss_ustream.html. When the crew is scheduled for onboard tasks, look for internal views of the station. The rest of the time, expect to see stunning views of Earth. Since the station orbits Earth once every 90 minutes, it experiences a sunrise or a sunset about every 45 minutes. When the station is in darkness, the external camera video may appear black but can sometimes provide spectacular views of lightning or city lights below.

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