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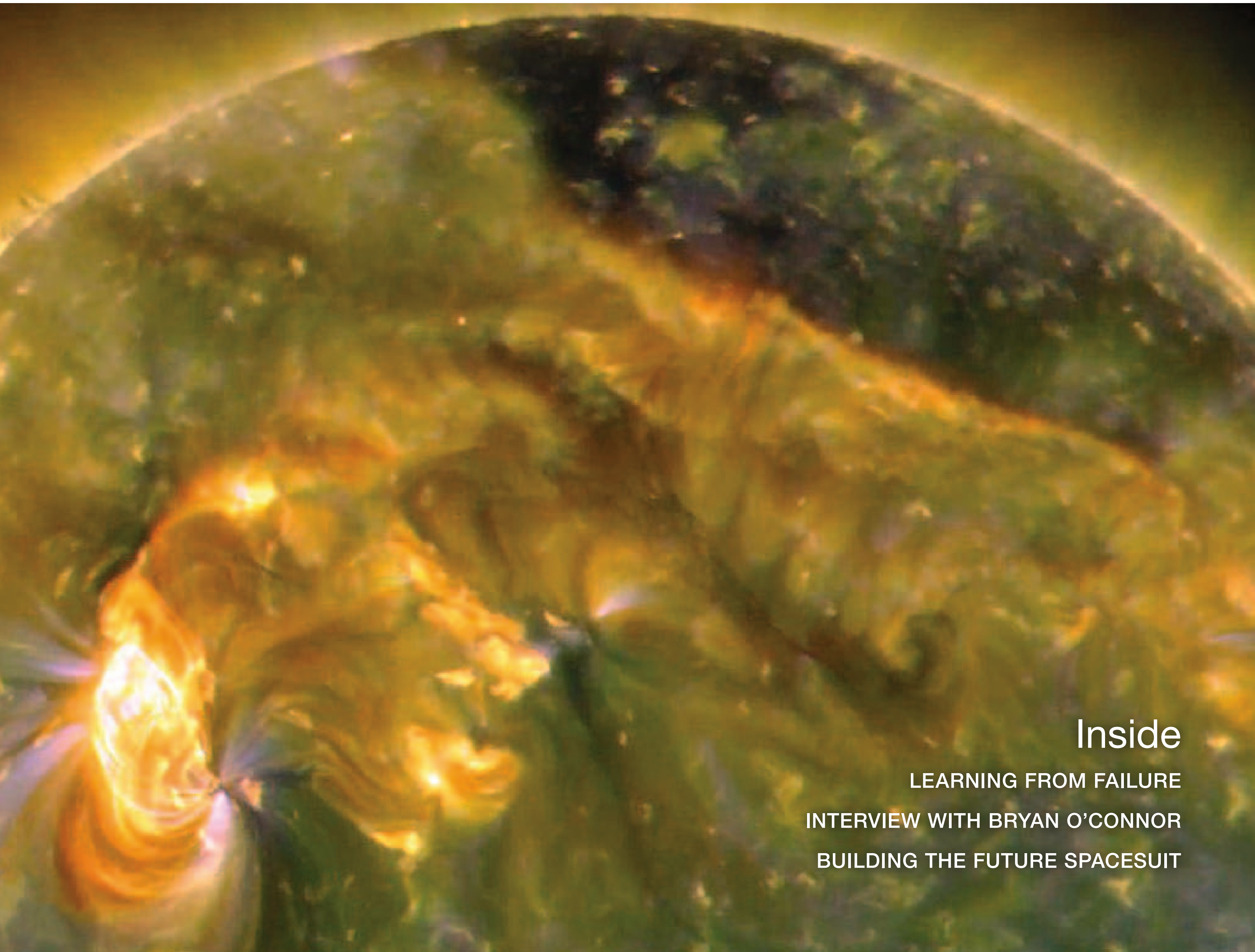

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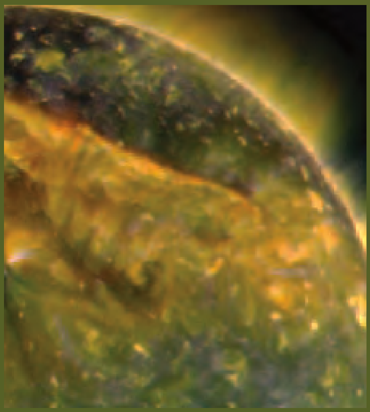

Photo Credit: NASA/SDO

ON THE COVER

On August 1, 2010, almost the entire Earth-facing side of the sun erupted in activity from a C3-class solar flare, a solar tsunami, large-scale shaking of the solar corona, radio bursts, a coronal mass ejection, and more. This extreme ultraviolet snapshot from the Solar Dynamics Observatory (SDO) shows the sun's northern hemisphere in mid-eruption. Different colors in the image represent different gas temperatures ranging from about 1 million to 2 million kelvin.

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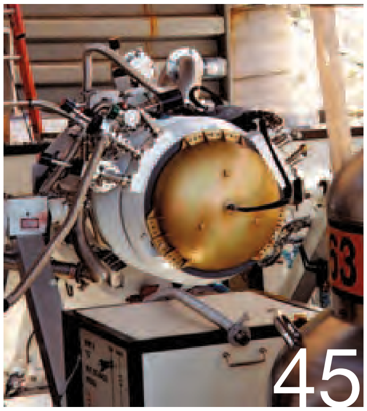

ask

Issue No. 45

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.

For inquiries about Academy Knowledge Sharing programs and products, please contact Yvonne Massaquoi, InuTeq LLC, 6303 Ivy Lane, Suite 130, Greenbelt, MD 20770; yvonne.massaquoi@inuteqllc.com; 301-837-9127.

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In This Issue

In their frank analysis of the failure of the Wide-field Infrared Explorer's primary mission ("WIRE: Learning from Failure"), Bryan Fafaul and Kerry Ellis explain that this project based on "insight, not oversight" didn't have enough of either. Poor communication meant that essential testing was inadequately done. Reflecting on his experience as mission manager for WIRE, Fafaul says, "I remind everybody constantly that we are *all* systems engineers." In other words, everyone on a project should understand the wider context of the work—not only how the technical pieces fit together, but the influence of managerial and organizational issues on how work gets done.

The importance of that wider context is a central theme in this issue of *ASK*. Karl Saad's story of Canada's contribution to the James Webb Space Telescope details some technical challenges, including developing a new instrument at a late date when the one originally planned ran into problems. But he especially emphasizes the importance of understanding and communicating the big picture, including political pressures on program funding and how his Canadian Space Agency team connects to the much larger NASA team. Alessandro Ercolani ("The Importance of Human Factors") talks about the value of avoiding overspecialization on the European Space Agency projects he has managed. Team members with a range of skills can help one another when problems arise. (He also notes the importance of keeping other projects informed about how these changes will affect them.)

Roger Forsgren's recounting of the story of how Abraham Lincoln managed a cabinet crisis provides another example of focusing on the broader context—in this case, the need to win a war and preserve the Union. Lincoln did not let personal animosities or the problems caused by "difficult" people stand in the way of forming the talented team he needed to succeed.

A corollary of the big-picture approach is that bringing together people with different expertise helps projects. Their shared work and shared conversations counter the dangers of too narrow a focus and are likely to uncover problems at system interfaces that can doom missions. So Bryan O'Connor, in the interview, talks about the value of having skilled safety personnel involved in the earliest stages of design and development. And Dava Newman describes the benefits of involving engineers, astronauts, scuba-diving experts, and designers of motorcycle-racing outfits in the creation of a new, more flexible spacesuit.

There are other extraordinary scientific and technical feats described in this issue of *ASK*: advances in solar science; the Juno mission on its way to study the structure and origin of Jupiter; the development of a car expected to reach speeds above 1,000 mph. We enjoy celebrating those wonders in the magazine. But we continue to pay more attention to the human and managerial context of these efforts than to their technical dimensions.

Why? Because no amount of technical skill will make up for problems in those areas. And because, as Fafaul tells us, "management anomalies" are more difficult to address than technical ones—harder to recognize and understand, and harder to fix.

Don Cohen
Managing Editor

From the Academy Director

The Appeal of Space

BY ED HOFFMAN

The first International Astronautical Congress (IAC) held on the African continent was a potent reminder that nations seek the benefits of spaceflight for many different reasons.

At an event commemorating the fortieth anniversary of Apollo 8, former mission commander Frank Borman said, "The reason we went to the moon on Apollo 8 was to beat the Russians."

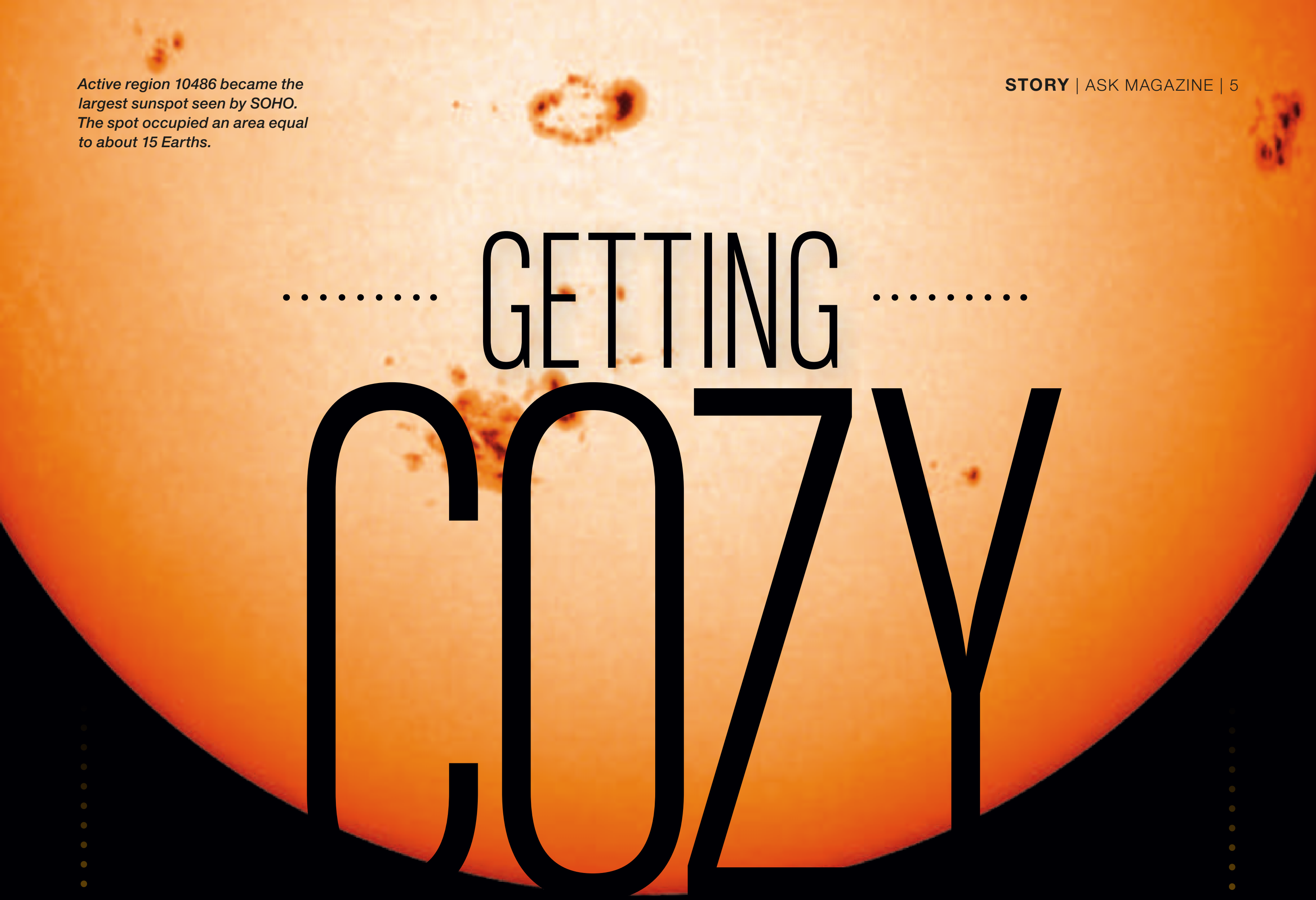
I was reminded of Borman's words while speaking with Dr. Peter Martinez of South Africa and Dr. Adigun (Ade) Abiodun of Nigeria during a special Masters with Masters event at the IAC. Both had to blaze their own career paths in aerospace because there were no well-trod paths to follow in their respective countries; neither country had the capability to put a rocket into orbit. The odds were against them, but each persevered.

They were initially drawn to space by different motivations. Peter said he considered himself "one of the products of Apollo"—he was inspired by our lunar program and astronauts like Borman. Ade was an engineer with expertise in hydrology whose interest stemmed from the potential of space applications to provide critically useful information—he was interested in learning what role satellites could play in understanding water resources in Nigeria. Both went on to work extensively with the United Nations Committee on the Peaceful Uses of Outer Space, with Ade even serving as its chairman for a time.

The aspirations they have for their countries in space are rooted in their appreciation of its practical benefits. In the United States, on the other hand, we periodically engage in public debate about the merits of space exploration as a national priority. Since we're no longer trying to beat the Russians (to use Borman's phrase), some ask if space exploration is still worth the cost when there are many competing priorities for public expenditures. But Peter and Ade did not talk about space exploration as an abstract concept or an expensive frill. Each wants his people to reap the benefits—including essential knowledge about the earth and advanced technological expertise—that more mature space-faring nations take for granted.

A common theme at IAC among individuals I met from emerging space-faring nations was the need to build local capability in space. Many said they do not want to continue relying on existing space powers; they want their own engineers and their own facilities. They understand that the skills developed and aspirations stimulated by a healthy space program help build an educated workforce that has the capability to improve society in a broad range of ways.

In a time of transition and uncertainty at NASA, it's easy to lose sight of the big picture. Peter and Ade reminded me that space's power to inspire goes hand in hand with its power to improve the lives of millions in ways that many of us take for granted at this point. We can learn from them. ●



Active region 10486 became the largest sunspot seen by SOHO. The spot occupied an area equal to about 15 Earths.

GETTING COZY WITH OUR CLOSEST STAR

BY HOLLY R. GILBERT

Photo Credit: NASA/SOHO (ESA and NASA)

We inhabitants of Earth have an intimate and complex relationship with the sun. As we learn more about the underlying physics driving the magnetic ball of plasma that is essential for our very existence, the complexity of that relationship becomes increasingly apparent. The field of solar physics has made incredible strides over the past fifty years. Even so, we find ourselves in a vulnerable period of time due to our increasing dependence on technology. What does the sun have to do with technology? The sun has a dark side, so to speak—a moody shift in behavior that generates space weather with the potential to threaten satellites, power grids, and astronauts. To understand the origins and implications of space weather, we must get up close and personal with the sun.

The enigmatic sun provides scientists with plenty of puzzles to solve, including the coronal heating problem, why the eleven-year activity cycle occurs, and why structures on the solar surface become unstable and release enormous amounts of energy. Through sophisticated observations and models, solar physicists are delving further into these fundamental questions and surfacing with some intriguing results.

New Observations, New Understanding

NASA's contribution to the progress made in solar physics is invaluable, both historically and during the past five years. The Solar Dynamics Observatory (SDO), launched in February 2010, is producing full-disk imaging of the sun in ten white-light, ultraviolet, and extreme ultraviolet band passes, taking one high-resolution image every second and allowing scientists to study the details of the origins of space-weather events. The Solar Terrestrial Relations Observatory (STEREO), two nearly identical spacecraft that in effect slowly drift in opposite directions away from Earth by about 22 degrees per year—one ahead of Earth in its orbit, the other trailing behind—has provided us with images of the sun from two additional vantage points since 2006, allowing 3-D measurements to study the nature of coronal mass ejections. For the very first time, we are able to see an entire 360 degrees around the sun, ensuring we don't miss a thing.

Not only does NASA have its eye on the entire sun all the time through its SDO, STEREO, and Solar and Heliospheric Observatory (SOHO) missions, it has a fleet of missions dedicated to understanding how the variable sun affects us in the near-space environment of Earth, as well as its effects on other planets and the edge of the solar system.

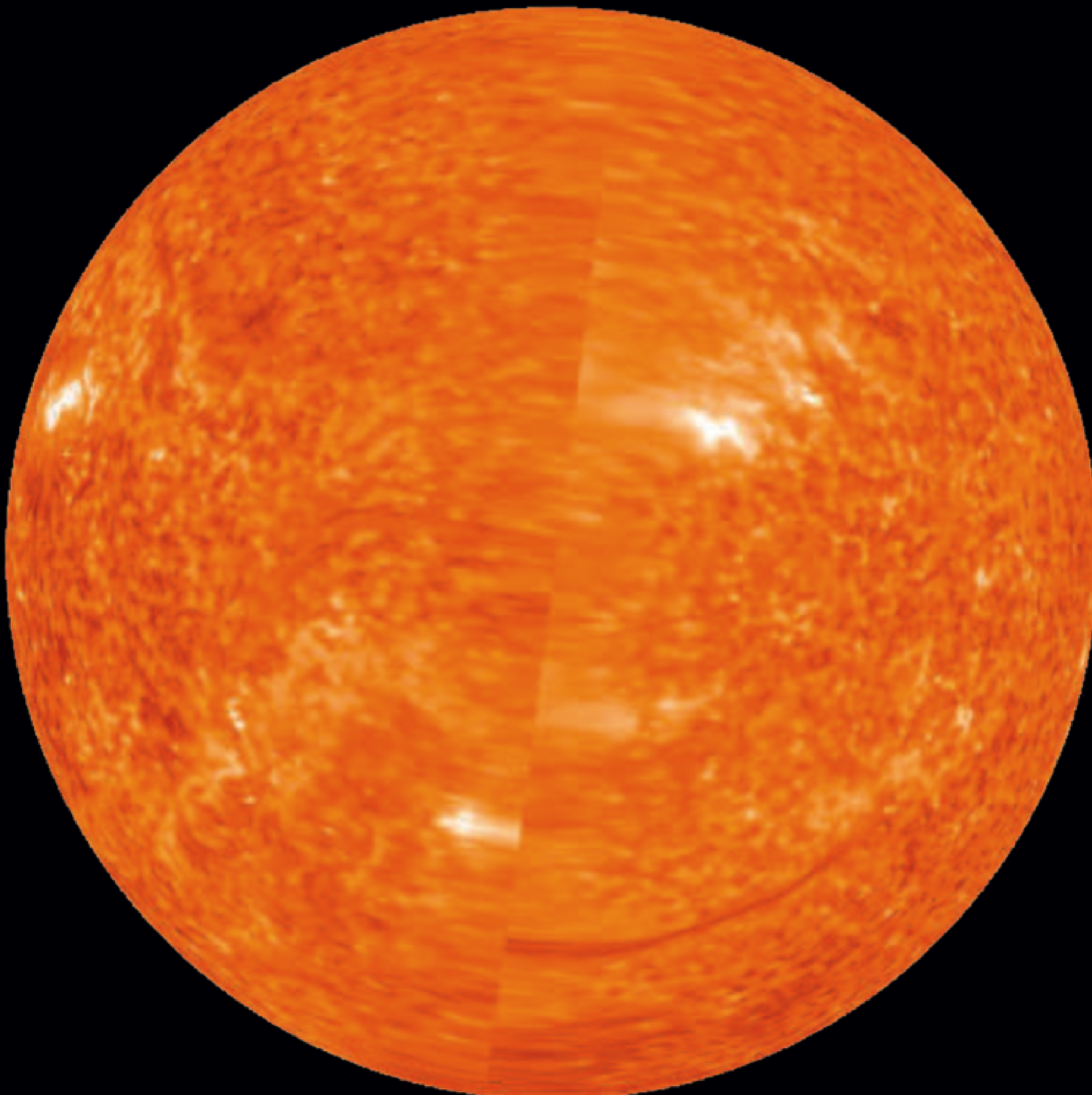
These new and better observations are helping us unravel some of the sun's most baffling puzzles.

One of them is why the outermost layer of the solar atmosphere, the corona, is heated to much higher temperatures (millions of degrees) than the underlying layers, even though it is further from the core, the source of all solar energy. This counterintuitive fact has bothered scientists for decades. Energy is deposited in the corona by some not-yet-established mechanism referred to as coronal heating. Recent progress toward understanding this enigma offers new and exciting possibilities.

Many theories have been suggested through the years, but a couple of provocative recent studies have grabbed the spotlight. A group of scientists from Lockheed Martin, NCAR (National Center for Atmospheric Research), and the University of Oslo suggest that the chromosphere (the cooler, middle layer of the atmosphere) provides the corona with a mass supply via small, ubiquitous cool jets of material called spicules that are constantly shot up into the corona. Although spicules have been observed for decades, this newly identified spicule, referred to as "type II," is shorter-lived (by about 100 seconds) and more dynamic (by about 50 to 100 km/second) than its classical counterpart. The discovery was enabled by observations from SDO and Hinode, a Japanese-led international mission to study solar magnetic fields. This recent work emphasizes the importance of the chromosphere, a region that has typically been neglected in understanding the heating of the solar atmosphere.

Another theory addressing the coronal heating problem deals with small-scale flares, or "nanoflares," which occur millions of times every second across the sun. As noted in papers in 2010 and 2011, researchers at Goddard Space Flight Center present observational and theoretical evidence that suggests much of the corona is heated by small bursts of energy, or impulsive heating, that occurs within a magnetic flux strand. Turbulent motions at the solar surface "stir" the coronal magnetic field, causing it to get tangled and stressed until it breaks, releasing a small burst of energy called a nanoflare. Unlike larger solar flares, which can be viewed by satellites and ground-based telescopes and can disrupt electronics and communications networks on Earth, nanoflares are so

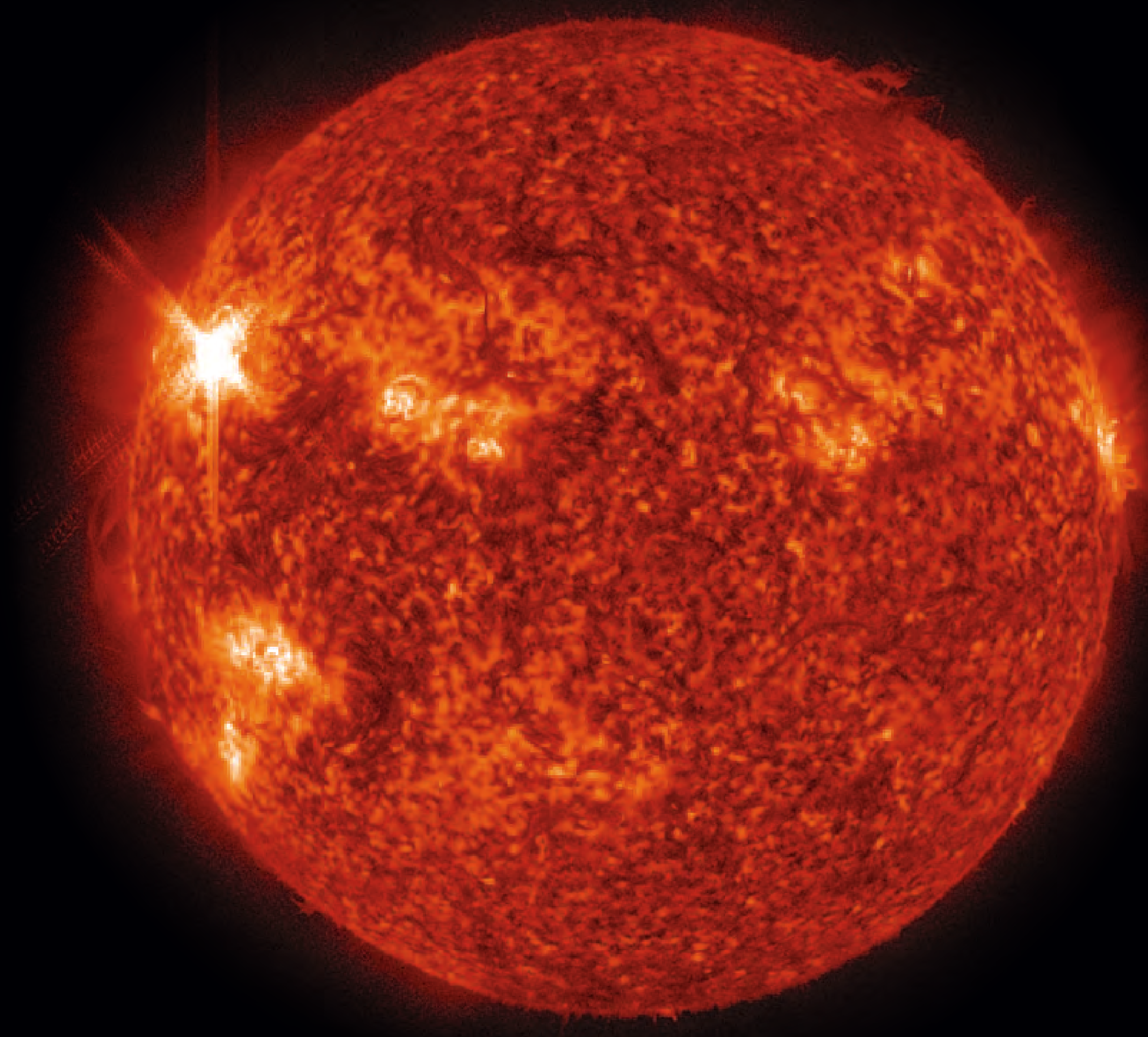
First complete image of the far side of the sun taken on June 1, 2011.



FOR THE VERY FIRST TIME, WE ARE ABLE TO SEE AN ENTIRE 360 DEGREES AROUND THE SUN, ENSURING WE DON'T MISS A THING.

Photo Credit: NASA/STEREO

RECENT DISCOVERIES BY A TEAM LED OUT OF THE UNIVERSITY OF COLORADO HAVE SHOWN THAT THE ENERGY IN A LATE-PHASE FLARE (APPROXIMATELY ONE IN SEVEN FLARES EXPERIENCES AN AFTERSHOCK ABOUT NINETY MINUTES AFTER THE FLARE DIES DOWN, CALLED THE LATE PHASE) CAN EXCEED THE ENERGY OF THE PRIMARY FLARE BY AS MUCH AS A FACTOR OF FOUR.



SDO captured this image of an X 1.9–class flare that burst out from an active region on the sun on November 3, 2011.

Photo Credit: NASA/SDO

small that they cannot be resolved individually, so no direct evidence of nanoflares was seen until recently. The ultra-hot plasma cools very quickly, which explains why it is so faint and difficult to detect. Modeling of nanoflares and type II spicules and the subsequent comparison of simulations to observations is ongoing. Scientists hope to discover which mechanism dominates, bringing us one step closer to solving the coronal heating puzzle.

The much larger, energetic cousins of nanoflares are the flares we're all used to hearing about—the phenomena that produce the most powerful explosions in the solar system. Recent discoveries by a team led out of the University of Colorado have shown that the energy in a late-phase flare (approximately one in seven flares experiences an aftershock about ninety minutes after the flare dies down, called the late phase) can exceed the energy of the primary flare by as much as a factor of four. That's quite a punch for what is already the most energetic phenomenon in the solar system!

Sunspots are often the birthplace of solar flares, and although they are historically the longest-observed solar phenomena, they are not excluded from recent discoveries. Helioseismology, the science of studying wave oscillations in the sun using an approach similar to that used in earthquake detection, allows a glimpse into the solar interior where sunspots are waiting to emerge. Helioseismologists learn what is under the surface by studying acoustic waves traveling throughout the sun's interior. Submerged magnetic fields (like those found in sunspots) affect the sun's inner acoustics, allowing detection prior to their breaking through the surface. This has Stanford researchers excited about the implications for predicting where sunspots will appear on the solar surface.

One of the surprises the sun has thrown at solar scientists recently is the deep, extended solar minimum that we just emerged from, a period of time during which the sun had very few sunspots, flares, and big eruptions (or coronal mass ejections). In 2008, no sunspots were observed on 266 of the year's 366 days (73 percent of the time). The last time a year had more spotless days was 1913, which produced 311 days of a blank sun. Solar minima (and subsequent maxima) are expected to occur about every eleven years on average. The switch from a perfectly "normal" series of activity cycles to an extended solar minimum is keeping many scientists busy trying to explain why the last cycle was twelve and a half years long, while the one before it was ten and a half years long. Out of the twenty-four numbered solar cycles, only four have started more slowly than this one. Now that the new cycle has finally begun, solar scientists are still being surprised by the sun's behavior.

By studying different aspects of the solar interior, the surface, and the corona, some scientists from the National Solar Observatory and the Air Force Research Laboratory have found evidence that the next solar cycle (number 25) may be very different from what we're used to. A missing solar jet stream, slower activity near the poles of the sun, and a weakening magnetic field (leading to fading sunspots) are raising eyebrows. The start of Cycle 25 may be delayed, with an ultra-extreme minimum. Or not—as we've experienced in the recent past, the sun may also show its unpredictable side and surprise us all during the next cycle.

More to Come

Future missions, like Solar Orbiter and Solar Probe Plus, will take us closer to the sun than ever before. Solar Orbiter, a mission led by the European Space Agency with strong NASA participation, will launch in 2017, making it possible to study the sun with a full suite of *in-situ* instruments (to detect particles and conditions near the spacecraft) and remote-sensing instruments (to observe the sun itself) for the first time from as close as 0.28 Astronomical Units, or about 23,000,000 miles, and will provide imaging and spectral observations of the sun's polar regions from out of the ecliptic—the plane of Earth's orbit around the sun. Solar Probe Plus will fly into the corona, gathering data on the processes that heat this layer of the atmosphere and accelerate the solar wind.

Solar and space-weather missions aside, NASA is also home to advanced data centers and the Community Coordinated Modeling Center (CCMC). The CCMC provides a mechanism to validate, test, and improve research models for eventual use in space-weather forecasting.

The sun continues to keep solar physicists very busy. The questions we are still struggling to answer are many. For instance, in the not-too-distant future, we hope to uncover the source of the solar activity cycle; how magnetic energy is created, stored, and released from the sun; and how solar wind is accelerated, to name just a few. Our capacity to observe the sun more and more closely should help us find the answers. ●

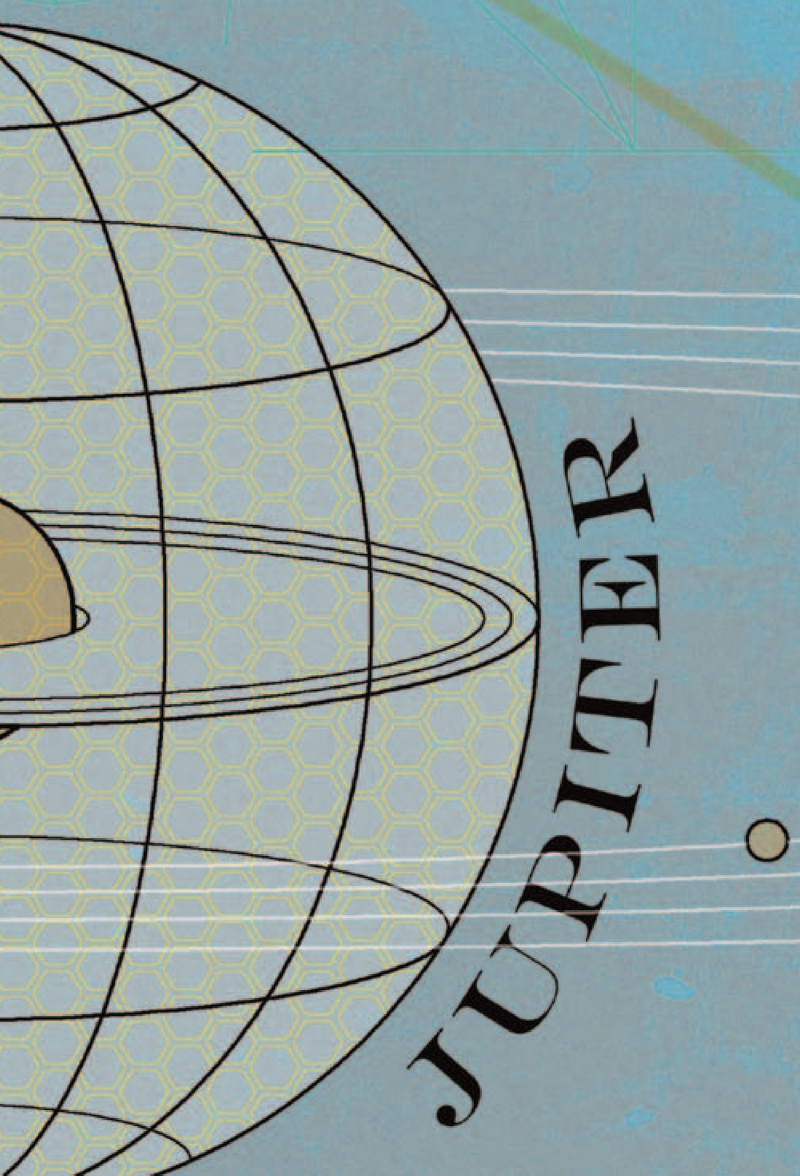
HOLLY R. GILBERT is chief of the Solar Physics Laboratory at Goddard Space Flight Center. She has more than fourteen years of experience in solar physics research, with an emphasis on the physics of the solar corona and chromosphere, including prominences and other phenomena associated with coronal mass ejections.

JUNO:

A Look Back at Successful Development

Juno's flawless launch on the first day of its launch period marked one more success for the mission after completing its development on budget and on schedule. The spacecraft will arrive at Jupiter in July 2016 for its yearlong study of the gravity, magnetic field, and atmosphere around our solar system's largest planet.

BY JAN CHODAS



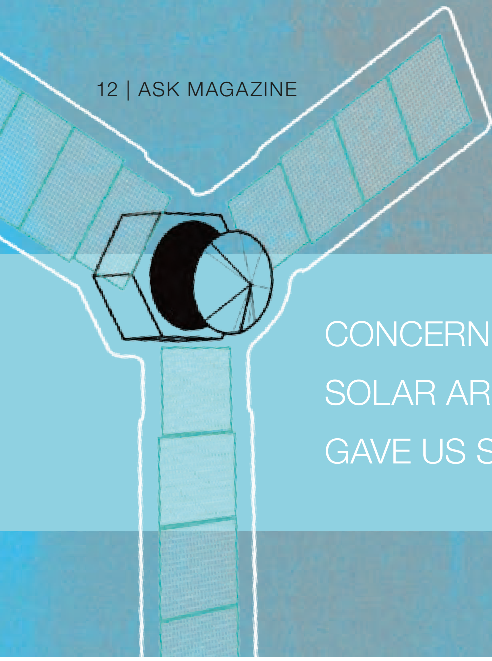
Dr. Scott Bolton, Juno's principal investigator from the Southwest Research Institute, and the Juno team had been working toward this milestone for several years. A mission of this length and complexity required careful planning and testing to increase its chances of success. Everyone felt a great sense of accomplishment when, shortly after separating from the Centaur upper stage, the spacecraft deployed its large solar arrays as planned and began its journey to Jupiter.

The second mission in NASA's New Frontiers Program, Juno experienced an unusually long definition and planning phase—described by Juno's first project manager, Rick Grammier, in *ASK Magazine*'s Spring 2008 issue—that gave us several advantages, including "more time to talk." This proved beneficial for a distributed team that included members from the Jet Propulsion Laboratory (JPL), Lockheed Martin, Goddard Space Flight Center, Southwest Research Institute, the Applied Physics Laboratory, University of Iowa, Malin Space Science Systems, the Italian Space Agency (ASI), and others. We were able to establish strong working relationships and excellent communication by having regular status telecons, workshops, and frequent in-person meetings.

These relationships helped tremendously during our risk-mitigation planning efforts, which included integrating instruments early on; working through issues such as the impact the L'Aquila, Italy, earthquake had on the Ka-band translator development; developing fallback options for Juno's system-level environmental tests; and using an innovative tool to track our schedule margin.

Integrating Instruments Early

Early in the implementation phase, the Juno team performed interface tests at the Lockheed Martin facility between the engineering models (early versions of hardware) of each instrument's electronics and the spacecraft's flight-like hardware. These early integrations helped find and fix hardware and software bugs in the interfaces, increasing the



CONCERNED ABOUT POSSIBLE LATE DELIVERIES OF THE AVIONICS AND SOLAR ARRAYS, WE ALSO PREPARED A SET OF FALLBACK OPTIONS THAT GAVE US SOME FLEXIBILITY FOR COMPLETING THE TESTS SUCCESSFULLY.

likelihood that flight-instrument integrations would proceed more smoothly.

The first set of tests in spring 2009 between the instruments' engineering models and the Data, Telemetry, and Command Interface (DTCI) Engineering Development Unit (EDU) board focused on confirming the compatibility of the commanding, engineering telemetry, low-speed science data, and high-speed science data hardware interfaces. These tests uncovered some issues early—such as the clock polarity coming out of the DTCI being inverted—and gave us confidence to move forward with the spacecraft and instrument flight builds. A side benefit was the establishment of an excellent working relationship between the instrument teams and the Lockheed Martin software, simulation, and instrument-integration team members, which was helpful throughout the implementation phase.

During the first part of 2010, instrument engineering models were sent to the Lockheed Martin facility's System Test Lab for a second round of tests that focused on confirming higher-level functionality in the flight-software interface. Greg Bollendonk, the flight software lead, accelerated the development of the instrument-interface portions of the spacecraft flight software in order to deliver beta versions for these tests. Another goal was to flow data to each instrument's ground-support equipment—as would be done during the assembly, test, and launch operations (ATLO) phase—to enable the instrument teams to become familiar with the data formats and ATLO processes. At the time, the spacecraft field-programmable gate arrays that controlled the instrument interfaces were not yet mature, so they benefited from this early testing as well.

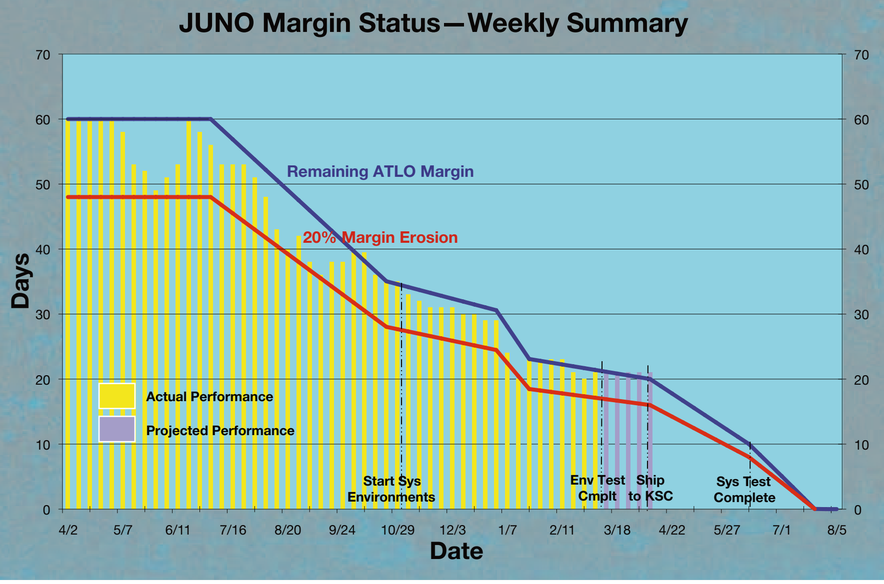
More issues were uncovered and corrected, including significant ones in the high-speed data interface that required several months to resolve. One issue in this interface involved the spacecraft's memory-management software. This spacecraft flight software wasn't saving the highest-quality data for the ultraviolet spectrograph (UVS) instrument. The flight software team took advantage of the UVS engineering model in the System Test Lab to iterate code changes with remote support from the instrument team (located at Southwest Research Institute) until the problem was resolved. All in all, this risk-mitigation program paid off in smoother flight-instrument integrations during ATLO.

Recovering from a Natural Disaster

ASI contributed two instruments to Juno's payload: the Jovian infrared auroral mapper (JIRAM) and the Ka-band translator for the gravity science investigation. These contributions, added during the definition and planning phase, were not part of the original mission proposal. The ASI contribution gave us an alternate supplier for the Ka-band translator in the original proposal while the JIRAM instrument was completely new. One key feature of this arrangement was that neither of these contributions were required in order for Juno to satisfy its mission success criteria.

This decoupling helped when a magnitude 5.8 earthquake in L'Aquila, Italy, in April 2009 severely damaged the Thales Alenia Space plant where the Ka-band translator's engineering model was being built. This natural disaster threw its development into disarray. Initially, the team had no idea what the impact would be on the model's delivery, scheduled to happen by June 2009, or on the flight unit's delivery scheduled for December 2009.

Rick Nybakken, Juno's deputy project manager and the prime project interface with ASI, led the development of a recovery plan that upgraded the engineering model to a flight-quality unit (called the flyable engineering model, or FEM), enabling one unit to meet both delivery requirements. This higher-risk approach was acceptable because full performance from the Ka-band translator was not required for Juno to meet its success criteria. A flight unit would still be built and tested, and if it became available soon enough, we would consider it for flight. The FEM was delivered and installed in April 2010. When the flight unit became available in August 2010,



we replaced the FEM with the flight unit due to its higher reliability and because we could still accommodate a swap at that late date.

Working through this difficult situation was helped by the excellent rapport that Scott, Rick, Dorothy Lewis (Ka-band translator cognizant engineer), and the project team had with ASI and Thales Alenia Space. Quarterly meetings helped foster this relationship. Rick had seen this model used successfully on the Cassini mission and set up a rotation of a core set of Juno personnel, both management and technical, that would travel to Italy every three months for management and technical discussions. The ASI/Thales Alenia team traveled to JPL occasionally for the same purpose.

The relationships established proved to be very useful when we worked with ASI and Thales Alenia to recover from the earthquake. The team worked closely with Roberto Formaro, ASI program manager for Juno, to align the project and ASI strategies for revised delivery requirements and tactical interactions with Thales Alenia. All Thales Alenia customers who had been affected by the earthquake were claiming priority in the recovery planning, but Juno's only option to receive a flyable Ka-band translator in time for launch was to develop and implement a coordinated strategy among Juno, ASI, and Thales Alenia. Establishing a successful path forward might not have been possible without the meetings and resulting relationships established during the early part of development.

Having Preapproved Fallback Options

The system-level environmental test suite is a major test activity every spacecraft experiences during the ATLO phase. Its purpose is to subject the spacecraft to the environments it will experience during its mission. These environments include the vibration of launch (simulated by an acoustic test), the shock of separation from the launch vehicle, the spacecraft's electromagnetic self-compatibility at launch and during science-data gathering, and the temperature in the vacuum of deep space that the spacecraft will experience on its trajectory to Jupiter. The Juno team planned a traditional set of tests involving the flight hardware and flight software and presented that baseline at the environmental test readiness review (ETRR).

Concerned about possible late deliveries of the avionics and solar arrays, we also prepared a set of fallback options that gave us some flexibility for completing the tests successfully. These options outlined the minimum set of hardware required for each test, including the required pedigree (flight or non-flight). For example, flight-like engineering models could be used for the self-compatibility tests if the flight avionics were not available, and the solar-array qualification model could be used for the shock test if the solar arrays had not yet been delivered. We also outlined specific vibration-level and thermal-cycle tests that would need to be executed to ensure the complete environmental qualification of the spacecraft if a flight-hardware component had to be reworked post-test. Preparing these fallback options ahead of time helped clarify and align our thinking for these anomalous situations.

These options were also presented at the ETRR and discussed openly with the review board. This up-front review minimized the management coordination the project needed later on when some of the options had to be implemented to complete the environmental tests within schedule.

"Stay in the Corridor"

Tim Halbrook, the Lockheed Martin ATLO manager, used typical schedule tools to track Juno's progress: a sixteen-month ATLO flow updated monthly, a thirty-day Gantt chart updated weekly, and a seven-day Gantt chart updated daily. To plan and track the use of Juno's sixty days of ATLO schedule margin, however, Tim also developed a Corridor plot (see figure at top of page). On the Corridor plot, the curve of schedule margin burndown—the rate at which margin is used up—corresponded with the margin days sprinkled strategically throughout the ATLO flow. Tim also included a second curve on the plot that

NEW FRONTIERS PROGRAM OFFICE INSIGHT AND PARTICIPATION

By Brian Key

Juno benefited greatly from an extended definition and planning phase that gave the project team “more time to talk. This additional time also allowed the New Frontiers Program Office to become more familiar with the mission definition and to independently assess the project s planning activities. Understanding schedule and technical risks prior to confirmation also allowed the program office to develop a representative cost risk that could be carried as an unallocated future expense (UFE) by the Science Mission Directorate (SMD), and could be included in the overall life cycle cost for the project at confirmation. This cost risk was established not only through understanding risks but also by examining previous mission performance histories to determine the soundness of the mission cost and schedule profiles.

Upon confirmation, NASA established a principal investigator cost cap and an overall project cost cap. Throughout implementation, the principal investigator (PI) and project manager managed to the tighter PI cost cap. Allocations from the SMD held UFE were controlled through a process established by the program office, which required the project to formally request a UFE allocation and provide a rationale for the request. The program office would evaluate this request and provide the Planetary Science Division (PSD) New Frontiers program executive with an assessment and recommendation.

Essential to this process was the well established communication among the project, program office, and PSD. Open and candid communication and information flow between the project and program office mission manager gave all levels of NASA management a good understanding of the project s status. This communication and information came in many forms, from monthly status meetings to weekly tag ups to daily test status e mails, intertwined with frequent, impromptu teleconferences.

As the project developed and implemented early risk mitigations, worked around impacts from natural disasters, and developed and executed alternate test flows and configurations due to component, instrument, or subsystem delays, these developments were communicated effectively and efficiently to the program office mission manager and PSD New Frontiers program executive.

was offset by 20 percent below the nominal curve. Juno’s actual schedule margin use was plotted weekly on the same figure.

If our actual margin burndown remained between these two curves, we did not need to take action. But if it dropped below the 20 percent margin erosion curve, Tim would schedule second shifts and/or weekend shifts to bring the actual burndown back within the corridor. Shortly after ATLO started, unplanned troubleshooting and rework with both the avionics and telecom hardware dropped the schedule margin close to the 20 percent margin erosion curve. We recovered schedule margin by using additional shifts once the issues had been worked through successfully.

This graphic became a handy visual tool for the whole team to monitor the schedule margin and to make decisions regarding resource control. It also enabled Juno managers and external managers to tell at a glance how ATLO was progressing.

An Excellent Beginning

Throughout Juno’s implementation phase, management teams at all levels looked for ways to help development proceed more smoothly and with lower risk, and the team as a whole worked through many challenges successfully. This was possible due to our strong working relationships and excellent communication, enhanced by the close communicative style of our project leaders. The result meant completing Juno on time and on budget, and its excellent flight performance so far shows the benefits of our efforts. ●

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.

JAN CHODAS is currently the project manager for the Juno mission in the New Frontiers Program. Prior to this position, she served at the Jet Propulsion Laboratory in numerous roles, including manager of the Systems and Software Division, assistant flight system manager for the Mars Exploration Rover project, flight system manager for the Space Interferometry Mission, project element manager for the Cassini attitude and articulation control subsystem, and technical manager for the Galileo attitude and articulation control subsystem.

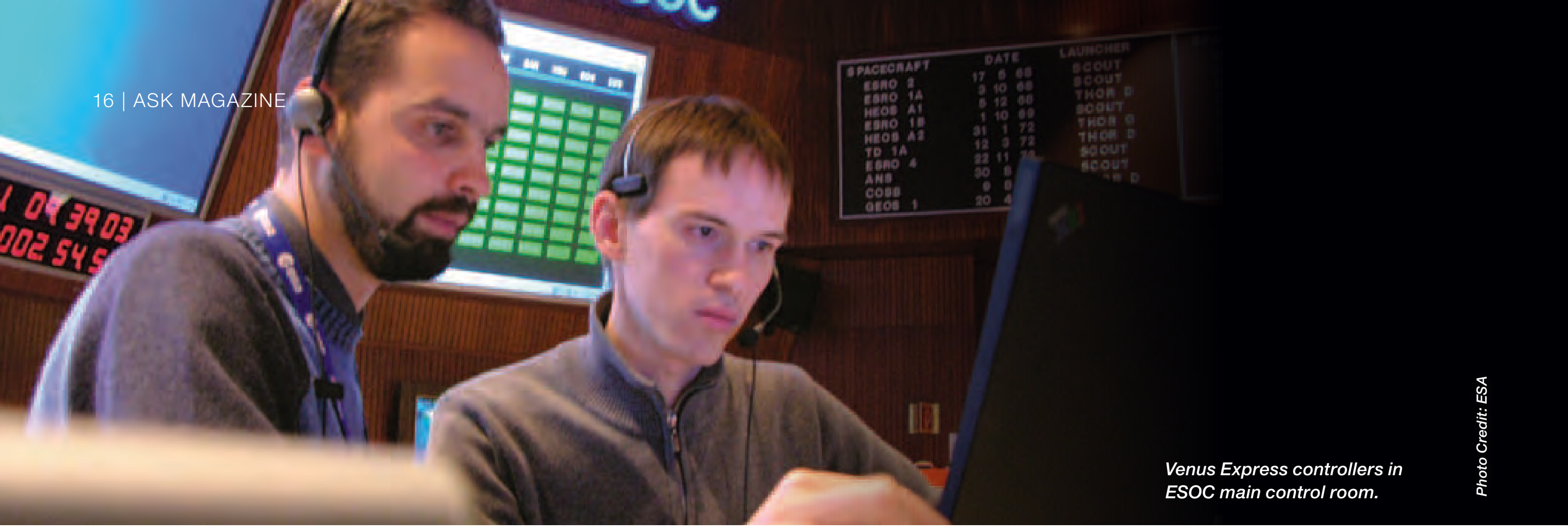
The Importance of Human Factors

BY ALESSANDRO ERCOLANI

Since joining the European Space Agency, ESA, in 2000, I have developed my whole career at the Department of Ground Segment Engineering. The main task of my section (HSO-GDS) is to provide mission data systems software—mission control systems, simulators, mission planning systems—to the ESA science (astronomy, interplanetary, and solar) missions controlled from ESOC, the European Space Operations Centre in Darmstadt, Germany.

The HSO-GDS team.

Photo courtesy of Alessandro Ercolani



Venus Express controllers in ESOC main control room.

Photo Credit: ESA

My initial assignment was the mission control system to operate the Rosetta spacecraft, an ambitious ESA mission to catch a comet in 2014. For three intense years, I participated as software coordinator in the launches of three successful ESA missions: Mars Express (2003), Rosetta (2004), and Venus Express (2005). After later working on the Galileo and Gaia missions, I was awarded the post of head of HSO-GDS in 2009, and life changed quite a bit.

From Technical Officer to People Coordinator

Suddenly the focus of my daily job diverged from classical technical matters to a whole new set of tasks. After a while I realized that I had to change my attitude in order to avoid frustration and be a good support for the people in my section. I had to accept the fact that my direct involvement in development of technical systems was gone forever (no more launches as software coordinator from the main control room, sigh!). And I had to start to thinking about what was needed to allow every section member to work in the best way.

After two years in the post, I'm still learning, but there is one thing I have no doubts about: having technical skills available in the team is no guarantee of success; the quality of the working environment is at least as important.

The Working Environment

We spend a considerable part of our life at work; we see our colleagues for more hours a day than our partners at home. The conditions we experience at work have a fundamental influence on the quality of our lives, so one of a manager's most important goals is to ensure that people come to work with a good attitude and spend their day in a pleasant environment.

Sounds obvious, right? But it's easy to lose sight of that fact when technical challenges and deadlines clamor for attention.

What do I mean by a "good working environment?" First and most important for me is to realize that colleagues in the section are trusted and trusting, open, supportive, and friendly people. We are a team of people who work together and try to help each other, rather than a collection of individuals who just ensure that their own projects are successful. Everyone is aware of the others' tasks: the successes of one project are successes for the whole section. If a project has issues, everyone else feels that they need to give a hand and solve the problem.

The "Space Musketeers"

You may be thinking, "Too good to be true." Time for a real-life example. At the end of last year, the situation became difficult for Phil, a new team member, who found himself under pressure during his handover period because of multiple demanding tasks.

He had joined the section a few months earlier and was working as the prime data systems manager on the mission control systems (MCS) of Rosetta, Mars Express, and Venus Express. A former member of the software support team for Venus Express at the time of launch, he already had all the technical background needed for the job. Suddenly, one of our core contractors resigned to accept a staff position at the European Meteorological Satellite Organization, and I found myself in the unenviable position of losing a key person involved in the maintenance of MCS for four flying missions: Integral, X-ray Multi-Mirror (XMM), Herschel, and Planck.

I asked Phil to become "the man in the middle" and work with the departing person in order to later transfer the knowledge to the newcomer. The rationale for this decision was that the MCS of Integral and XMM are all based on the same infrastructure version as those of Rosetta, Mars Express, and Venus Express, and he was the best choice from a technical point of view. He also got Herschel/Planck because I wanted to avoid having too many people involved in the handover, and the other members of the section were all under pressure, too.

The causes of the problem were that I assigned too many tasks to him, and some unexpected problems consumed more effort than foreseen.

Luckily, Phil understood the philosophy of the section, so rather than keeping the problems to himself and struggling until the final disaster, he came to me. In case of overload, there is always someone else who can help complete some work, while it can take dramatically long to recover from a burnout. I called an emergency section meeting, explained the situation, and asked for support from the rest of the team. I gave some indications of possible work redistribution, but invited everyone to suggest alternatives and propose ways in which everyone could help with any of the tasks.

IN CASE OF OVERLOAD, THERE IS ALWAYS SOMEONE ELSE WHO CAN HELP COMPLETE SOME WORK, WHILE IT CAN TAKE DRAMATICALLY LONG TO RECOVER FROM A BURNOUT.

The Herschel telescope.

Photo Credit: ESA

Considering that each person is typically following many projects in parallel, I was particularly pleased by the outcome. Most people were already overloaded, but each nevertheless found a way to lend a hand.

One colleague offered to take over all the administrative and managerial tasks on Herschel/Planck (she was the backup data systems manager for Herschel/Planck and essentially switched to a full prime role). Since this would have created problems in the testing schedule for a recent delivery of the Lisa Pathfinder MCS, another colleague offered to give a hand with that, sacrificing a bit of the work on the Gaia MCS, which was in a less critical phase. All people involved in this extra effort identified a few work items that could be postponed to a later date to make room for the new tasks.

It was important to explain to the various missions the phase we were in. I made sure they understood that we had an emergency situation; I explained the details of the handover and clarified that some tasks would have been delayed and some others would have been "degraded" for the next few months. I believe that transparency and honesty helped to gain their support.

When the new core contractor joined our section, the second handover period started quite smoothly and, thanks to the technical skills and good relations among the persons involved, we completed this phase smoothly. Open and frank discussion helped us find the best combination of tasks, and after a few months we were back to a normal situation. One for all and all for one!

I was more or less aware of the steps needed to make things work, but most of the useful hints came directly from the staff during our open discussion. More importantly, I didn't have to impose my thoughts by telling people, "You now do this, you do that," because they identified who could help where. If they had not volunteered, I would have had to make a decision myself, of course, but that didn't happen.

Never Feel Alone

The way work is structured in the section helps this kind of mutual assistance. Everyone has, in principle, the same range of skills and performs similar activities, although on different missions. This allows one person to quickly become proficient in a different mission's environment once the specific tasks are identified. At least two people (prime and backup) are assigned to each project in the section, so there is no dependency on a single person for any activity. Having all the knowledge on a subject in the head of a single person is obviously a danger. Everyone should be a valuable asset, but nobody should be indispensable. Having the organization to ensure division of tasks and responsibilities is a complex exercise that results in more effort for people but has obvious benefits.

Anyone can go on leave without putting all their work on hold. The availability of a responsible backup is very important also in case of sickness or job change. Even more important for me is the case of maternity leave. Luckily, ESA staff rules and regulations guarantee exceptionally good conditions for women becoming mothers, and I try to ensure that this event is seen as a fantastic experience and not as a threat to a woman's career.

Holidays

There is an open goal in the section: everyone should try to use all leave days available in the year. I trust that when someone requests a period of leave he or she has checked that it would not cause problems with the mission, and I approve without questions or further checks on my side. This has worked smoothly so far, has saved me a lot of time, and has increased the sense of responsibility and independence of the individuals. I try to be a good example and typically run short of annual leave before the Christmas holidays.

I stress the importance of *balance* between work and private life, and balance means that there can be periods where it becomes impossible to use all available leave days. For me, working overtime, including weekends, was the norm between 2002 and 2005. I have supported four launch campaigns in three years, and in that period I accumulated seventy-five days of compensatory leave! In the following years I have used these additional leave days. Overall, our workload follows the phases of the missions we support, so there is a time for sweat, blood, and tears, and a time for snow, sand, and sea.

The International Background

ESA is international by definition, so cultural differences are constantly part of the game. In my section, we have two Brits, two Portuguese, one German/French, and two Italians; two women and five men in total. We are of course different from each other, and we try to understand and appreciate our different views. Sometimes when you set up an appointment, you have to specify whether it is "Spanish time" or "German time." The first means that you are expected to show up at least half an hour after the time of the appointment.

In some cultures, like the Italian one, it is quite normal to have heated discussions. Voices may be raised and movement of the hands and body language may be a bit extreme, but what to outsiders could seem like the beginning of a physical confrontation is probably just a "lively" conversation.

As long as people are aware of these known characteristics of cultural groups, there is no problem. The moment you have a German waiting half an hour for a Spaniard or an Italian shouting at a Brit, the differences are not fun anymore.

We have an excellent tradition, which started spontaneously, of organizing "cultural evenings" at someone's place, with food and drinks of the country of origin and very often board games as well. We have, in fact, a board-games tournament spanning the whole

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year, with an overall classification that determines who holds the "GDS gamer of the year" trophy for the next twelve months.

People First

I believe we live in a kind of small family in our section. Whenever there is some change in the composition of the section, I always try to think about how to preserve this environment. A new candidate is selected not just for technical skills, but also for the capability to integrate in the peculiar environment we have created. I have always been supported by my line management in this approach. I'm convinced that the spirit of the current group can continue for years, even with changes in the team. One of my global goals is to ensure that current values and habits become an integral part of the section's DNA, and I'm sure that it will not be so difficult to convince newcomers (even a new head of section) to adopt them.

Time will tell whether or not this is a sustainable model. So far our customers are happy with our support. I'm convinced that the quality of our technical output is related to the positive environment we work in. I am aware, naturally, that this situation is in large part due to the combination of a number of lucky factors (size of the section, character, attitude, age of individuals, and type of work) and that there is no single "recipe for happiness" that applies to all situations.

An obvious enabler for our nice working environment is the favorable conditions offered by ESA. The introduction of flex time, part time, and telework have all facilitated the increase in balance between work and family life. Moreover, the support for sport and social clubs gives people a chance to know each other in various external contexts, and then have a better relationship on the job. I believe we have good foundations for building a socially satisfying and stimulating work environment. ●

ALESSANDRO ERCOLANI began his career at the European Space Agency (ESA) in 2000 as a software engineer in the department of Ground Segment Engineering in Darmstadt, Germany. He is currently leading the Science Mission Data Systems section, whose task is to provide mission control system and operational simulator software to ESA interplanetary and astronomy missions. E-mail: alessandro.ercolani@esa.int

XMM preparation.

Photo Credit: ESA/D. Parker

INTERVIEW WITH

Bryan O'Connor

BY MATTHEW KOHUT

Bryan O'Connor retired as chief of Safety and Mission Assurance on August 31, 2011, after serving nearly a decade as NASA's top safety and mission assurance official. O'Connor is a former U.S. Marine Corps test pilot and aeronautical engineer, with more than five thousand hours of flying time in over forty types of aircraft. He joined the NASA astronaut program in 1980 and flew two Space Shuttle missions, serving as pilot on STS-61B in 1985 and commander of STS-40 in 1991. *ASK the Academy's* Matthew Kohut spoke with him on his last day in the office.

KOHUT: You were a test pilot and a shuttle astronaut before becoming chief of Safety and Mission Assurance, and your successor, Terry Wilcutt, followed a similar career trajectory. Can you talk about how being a test pilot is good preparation for leading in safety and mission assurance?

O'CONNOR: As you mentioned, both of us have test-pilot backgrounds, for about the same amount of time and from the same place. Different airplanes, but we came from Patuxent River Naval Air Test Center backgrounds. We learned there that you have to have a great deal of respect for the potential and kinetic energy of these things we strap on to ourselves. We spent an awful lot of time planning for the flights we did.

There's an obvious safety piece that was a little different than what we had as operational pilots. We learned the difference between hard rules that you just cannot violate and rules that are the kind you challenge. An operational pilot knows that you're supposed to stay within the flight envelope of the aircraft: don't go faster or higher than the aircraft is cleared for. But we were creating the envelope as test pilots, so we gained a great deal of respect for the idea of expanding an envelope, and all the test preparation and understanding of the aerodynamics and the engineering and the systems stuff that we had to know in order to rewrite, challenge, or change things that in the past had been inviolable rules. I think it was that learning that helped us appreciate the safety aspects of what we were doing when we came to NASA.

KOHUT: What changes have you seen in the safety culture during your time at NASA?

O'CONNOR: Before the *Challenger* accident, the safety and mission assurance community and the safety culture in human spaceflight were what we'd inherited from the Apollo days. There was a substantial operational flavor to it. For those of us in the crew office, I remember one of the first lectures we heard as brand-newbies down there in Houston was the Apollo 13 story. Gene Kranz himself gathered us all around and spent about three hours talking about that flight, and what it meant to the human spaceflight community to have experienced the failure of the hardware and bringing back the crew alive, and how Apollo 13 was considered by folks in the mission operations world as right up there almost at the same level of success as Apollo 11 itself.

Later, I read about the British explorer Ernest Shackleton, who failed in his mission to explore the South Pole and Antarctica, but got all twenty-seven of his people back. He spent two years down there after his ship got stuck in the ice and then was crushed and sunk, and his men were standing on ice floes for all that time before they could finally get them back to England. It's the fact that he saved everybody that makes that story very compelling and unusual, and it has a special place in the hearts and minds of British people when they talk about their heroes. The Apollo 13 story has the same flavor. It suggested that we like doing high-risk things, but we really like bringing the crew back alive afterward. So that was what I was introduced to in Houston.

The developmental aspects of systems safety engineering were there, but they were not very well founded. They weren't accepted too much by the engineering community; even though there were safety, reliability, and quality engineers involved in the design, development, and test flying, it was almost as if they were checks in the box: "Did somebody remember to call them?"

It was the learning from both the *Challenger* and *Columbia* accidents that helped solidify the need for a capable and credible SR&QA [safety, reliability, and quality assurance] workforce to help from day one in the development of a new system. I hope that's the legacy of those mishaps, because there were strong words in both of those mishap reports about the safety organization. Where is it? What is it doing? Is it relevant? Do the things that the safety people do mean anything to the developers? I think today that as a [SR&QA] community, we're much more appreciated. They're [engineers and designers] actually asking us to show up for their meetings because they don't want to start them without us. That's been a big change.

KOHUT: A couple of years ago at an event at Goddard on organizational silence, you said that there has to be an institutional system in place that ensures that people speak up and bring relevant information forward. Do you think NASA has arrived at that point today?

O'CONNOR: There has been a lot of work done since the *Columbia* accident

WHEN TERRY [WILCUTT] AND I WERE AT PAX [PATUXENT] RIVER, WE spent A HECK OF A LOT more time planning and participating IN THE DEVELOPMENT OF THE next aircraft OR THE next major mod TO AN AIRCRAFT WITH THE DESIGNERS AND THE DEVELOPERS THAN WE DID in the cockpit.

investigation. There was a need to improve the standing of both the engineering and the SR&QA organization in decision making when there's residual risk. So, we explicitly wrote into our policy the requirement that all these people have a seat at the table, that they have mandatory votes where their authority calls for it. We've also instituted and put in writing for the first time the role of the risk taker when we're talking about residual risk, and that's been very important.

I think of it as the four-legged stool: the technical authority owns the requirements, the safety and mission assurance authority decides whether the risk is acceptable or not, the risk taker must volunteer to take the risk, and then and only then, when those three things have been done, can the program or project manager accept that risk. Those four roles have been stated in the highest documents for governance in the agency. It's flowing down—and in some places it was already there—for the decision making for the high-risk work that we do, especially when there's safety involved.

Having said that, I keep telling my people and the center directors around the agency that instituting that governance model in a set of words does not make it work. The only way it works is if you have good, credible, respected people populate the various legs of that stool. You shouldn't just hire enough crewmembers to fly the space station missions and no more. You must have experienced crewmembers who are not currently flying available to the next development activity as part of the development team, so that you can get the crew's look at residual risk areas, and have them in tune and involved enough so they understand what the risks are and can represent "the crew volunteers to take the risk" model that I talked about. I say this because there are people questioning how many crewmembers NASA needs, and why you need more than what you're flying. This is an R&D activity; it's not just about flying.

When Terry [Wilcutt] and I were at Pax [Patuxent] River, we spent a heck of a lot more time planning and participating in the development of the next aircraft or the next major mod to an aircraft with the designers and the developers than we did in the cockpit. We spent a tremendous amount of time in simulators and design sessions, and looking over hazard analysis reports, and giving the crew's input to the development. That same thing applies here at NASA. Sometimes people forget that.

In the past we sometimes were criticized for not having capable people in our workforce. Folks might show up at a meeting and not be prepared or not understand the issue. Maybe we'd send a propulsion person from the safety organization when the subject was aerodynamics. They weren't much help, and they didn't bother to ask for help because staffing was very low in the home office. These are all problems that cannot be fixed by simply saying, "You have to have the safety office represented in the meeting." You have to have good, capable, credible people in those organizations with responsive home offices to back them up. This is the job of the center directors, by and large, and I credit them for putting really good people in our safety and mission assurance [SMA] organizations over the years. In my opinion, NASA SMA is populated today with the best group that we've ever had at NASA.

KOHUT: What do you think is the most memorable contribution you've made in your time?

O'CONNOR: I don't know that I've personally made any contributions, because I tend to steal from other (smarter) people. [Laughs.] I am not very good at inventing things or coming out of nowhere with creative ideas, but I know a good one when I see it, and I'll steal it and benchmark it and ask my guys to do something like it if we think it makes sense. Coaching and prodding is the mode that I've been using. The real work that's been done is by the folks in the trenches.

The requirements work that it takes to do this job at Headquarters is continuous. We often are criticized for having too many "shall" statements, and then the very next day we're criticized by others for not being standardized enough across the agency, which begs for more "shall" statements. Trying to drive that mission-support function that we own in SR&QA down the middle of that road is tricky. We're not a bunch of Chicken Littles waving red flags every five minutes, and yet we're credible enough that when we do speak up, people will listen because they trust us. That's the car I've been trying to drive, but I'm just steering. The folks who are in our divisions here and at the Safety Center and at the IV&V [Independent Verification and Validation] facility, and the safety and mission assurance directors at the centers with their people, are the ones who get the credit for these changes over time.

KOHUT: What do you see as the biggest challenge on the horizon for safety and mission assurance?

O'CONNOR: Fighting complacency. I commonly tell our folks that there are two modes of mishap prevention. One mode is reacting to the last big accident, and the other mode is fighting complacency. Just about everything we do in the SR&QA world can fit into one of those two buckets. For example, the Launch Services Program has seen a couple of failures with the commercial Taurus XL rockets that they buy. They're reeling right now and trying to figure out how to prevent that in the future. Complacency is not anywhere to be seen in that community. Reacting to the last mishap and trying to understand what happened and put things in place that will prevent similar failures in the future basically defines their entire workday. In the human spaceflight world, we haven't had any failures in quite a while. Right now we've got a logistics issue with Russian rocket problems, but by and large since the *Columbia* accident there hasn't been a real human-safety failure to speak of.

There's a tendency—not necessarily of the people in the trenches—but we Washingtonians sometimes tend to forget the lessons because we haven't thought about them in a while. We sometimes forget the tremendous amounts of energy involved and the challenges posed by the environment and the human elements to our designs. Those things become a little bit past history, and unfortunately that sometimes feeds complacency. It shows up at all levels, including our stakeholders outside the agency. If it's been a while since our last failure, people who are looking to us to do great things sometimes forget how hard this work is to do. We start talking more about affordability than safety, and about getting the NASA oversight and insight down to very low levels because it's so expensive, without mentioning in the same sentence how important oversight and insight are to preventing mishaps. We even hear our astronauts being referred to as simply

IF IT'S been a while SINCE OUR last failure, PEOPLE WHO ARE looking to us TO DO GREAT THINGS sometimes forget HOW HARD THIS WORK IS TO DO.

"biological cargo" by people who should know better. These are signs that we look for that we're in complacency mode, and of course it's natural for that environment to creep up on us. It's a real challenge for our community to fight that.

KOHUT: What are your thoughts about the safety and mission assurance challenge ahead regarding the transition to commercial crew?

O'CONNOR: The SMA challenge for commercial crew is trying to figure out where we fit in best, how to support the program in ensuring that, when we do finally decide to put our people on top of these rockets, we're not taking unnecessary risk. These are not NASA developments, per se. The concept designs are coming from the commercial people. We're experimenting with new ways to oversee that work with as few people as we can manage in order to meet the affordability goals. It's a big management experiment for us, and our folks are not comfortable with it, just as nobody is comfortable when they're getting into unknown territory. I think the big challenge that I hand off to Terry is, "Make sure that we're not doing something inappropriate here in pulling back or not having the visibility we need, or by not setting the table properly for our decision makers to accept risk and to put our people on these rockets when they're relatively new and haven't been tested yet."

KOHUT: What advice do you have for young professionals entering the aerospace profession fresh out of college?

O'CONNOR: When we hire a fresh-out, we do it because we like their technical potential, their education, and their energy, and we want them to help us go to the next levels in the agency. Because of that, when they see something they don't understand or that doesn't pass a sanity check, it's okay for them to raise their hand and say something about it. This goes back to that concept of organizational silence. Sometimes our new people are intimidated a little bit and don't speak up, even when something doesn't smell right. We should encourage them to go ahead. You don't want to overdo it, of course, and have people being disruptive or educating themselves at the expense of everyone else who's trying to get something done. I know that can be overdone. But when I first showed up at the Johnson Space Center, they had a plaque over the wall in the mission ops control room that said something to the effect of, "In God We Trust—All Others Bring Data." That was quite intimidating to a new person, because between the lines it suggested that, "We're not interested in your opinion on things. If you have data, we'll listen, but your opinion is not requested here."

A lot of us came to NASA after years of flight testing and R&D work and so on. After the *Challenger* accident, I really beat myself up for being too silent in the first few years that I was there, and I said to myself, "This agency isn't as smart as it thinks it is," to quote Tommy Holloway. ●

Ball Aerospace optical technician Scott Murray inspects the first gold primary mirror segment, a critical element of NASA's James Webb Space Telescope, prior to cryogenic testing.

Photo Credit: NASA/Marshall Space Flight Center/David Higginbotham

MANAGING CANADA'S CONTRIBUTION TO THE JAMES WEBB SPACE TELESCOPE

BY KARL SAAD

Along with a half dozen NASA centers, the European Space Agency (ESA), and a variety of academic and industry partners, the Canadian Space Agency has been working on its contribution to the James Webb Space Telescope. JWST, as it is commonly known, is a large infrared telescope that will make observations from almost a million miles from Earth after its launch near the end of the decade. With a light-collecting area about seven times that of the Hubble telescope and its sensitivity to infrared wavelengths, JWST will be able to see the most distant (and earliest) galaxies in the universe. It should also provide new insight into the birth of stars and the nature of planets outside our solar system.

I BELIEVE IT IS IMPORTANT FOR PEOPLE TO UNDERSTAND THE CONTEXT OF THEIR WORK AT THE PROGRAMMATIC LEVEL.

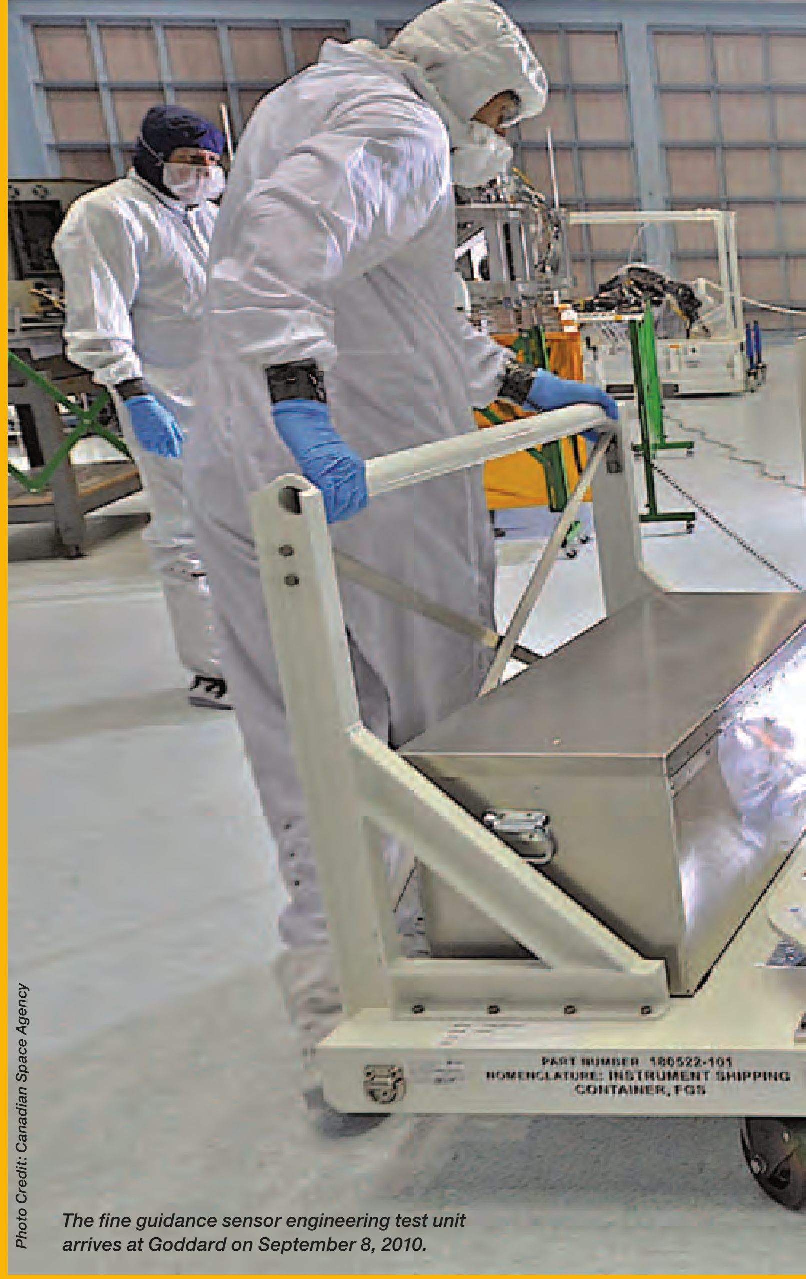


Photo Credit: Canadian Space Agency

The fine guidance sensor engineering test unit arrives at Goddard on September 8, 2010.

Canada is providing two essential instruments. The fine-guidance sensor (or FGS) helps JWST point precisely at its targets and maintain that orientation over the time needed to gather enough light for high-quality images. The near-infrared imager and slitless spectrograph (NIRISS) has several important science objectives: detecting “first light” (the light of the first stars formed in the universe) and finding and characterizing exoplanets.

The Challenges

We have faced plenty of technical challenges designing and building these new instruments. The most challenging aspect of the FGS is the need to achieve the required pointing accuracy while surviving cryogenic temperatures (around -240ºC). The FGS will measure the position of guide stars with an accuracy of one millionth of a degree (3.5 milli-arcseconds). The harshness of the environment requires precise considerations of the thermal effects on materials to ensure proper alignment of all optical elements from ambient to cryogenic temperatures. NIRISS replaces what was originally called the tunable filter imager (TFI), because unsolved technical difficulties with a TFI subcomponent threatened the project’s capability to meet its scheduled delivery to NASA.

As is often true of complex projects, the organizational challenges of communication and cooperation are at least as daunting and important as the technical ones. For instance, the decision to replace the TFI with NIRISS during Phase D of the program—the development phase—was necessarily the product of close collaboration among the interested parties. It could not have happened without the mutual trust and understanding of good working relationships.

Joining the Program

I became project manager for these instruments when the project was already well under way. Phase B preliminary design work had been completed, and we were well into Phase C design, preparing for our critical design review. So a lot was set, but there were still many issues to deal with.

I had previously worked on Herschel, the ESA infrared space telescope launched in 2009. For the Herschel mission, the Canadian Space Agency (CSA) partnered with the Netherlands Institute for Space Research (SRON) for our contribution to the heterodyne instrument in the far infrared (HIFI), one of three science instruments on board Herschel. Working on this project, I gained some experience with issues and technologies relevant to JWST and was exposed to all the facets and challenges of managing a project in an international context. Prior to being assigned to JWST, I had some high-level knowledge of the project from monthly project reviews. But I knew that my first task would be to learn from the team, to keep my eyes and ears open and absorb what was going on rather than try to impose my own ideas on the project. You have to respect and depend on the team.

I was fortunate to have a deputy project manager, Luminita Ilinca Ignat, who had been on the project for several years. She

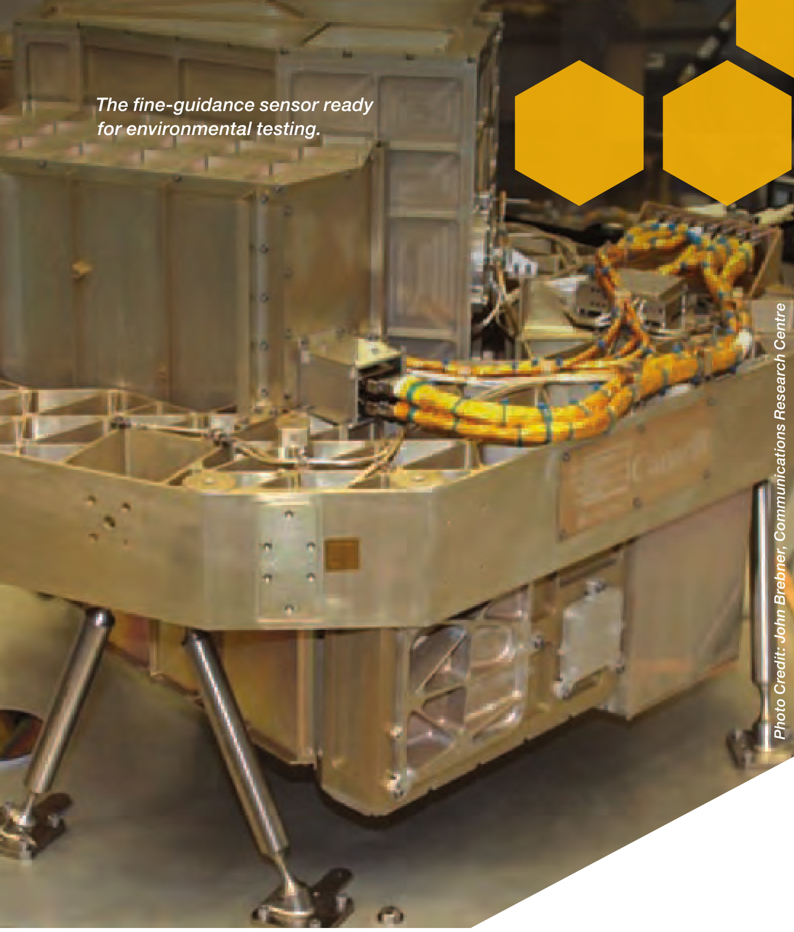
ensured a good transition from the old project manager. Along with providing valuable project knowledge, Luminita helped me focus on priorities while giving me time to understand the project and its challenges. Without her as my right-hand person, taking on such a complex project would have been a hair-raising experience, with a real risk of my dropping the ball on important issues.

Deputy project managers work outside the spotlight and most often do not get the praise they deserve for their vital contribution to complex projects. The deputy project manager and project manager form a team within the project team. The relationship between them is critical for creating team cohesion and project success. The challenges of working with a deputy project manager cannot be overlooked either. They are likely to have similar interests and needs with respect to their responsibilities and growth, so it is important to establish clear roles and responsibilities agreed to by both. Most importantly, one must assess when the role of deputy project manager is no longer required on a project and to allow this person to continue to grow professionally and apply the experience and knowledge gained to another project as a project manager. It is all too easy to lose sight of this while managing a complex project.

Our aim is to produce technology, but a project manager deals with people, not machines. You have to get to know them and learn their points of view. You have to let them know that you trust and respect them and believe they have important contributions to make. The project manager needs to bring the team together to work like a well-trained orchestra.

So good communication is essential. We have regular weekly team meetings that include engineers, scientists, and principal investigators—typically a dozen people in the room and another eight or ten calling in. These meetings are very much two-way or multidirectional conversations, with participants hearing from each other.

I believe it is important for people to understand the context of their work at the programmatic level. The JWST project has been in the news recently as a result of the discussions associated with the U.S. government's appropriation process. This process is not easy



The fine-guidance sensor ready for environmental testing.

Photo Credit: John Brebner, Communications Research Centre

A technician prepares the Canadian-built fine-guidance sensor's engineering test unit for cryogenic testing at the Canadian Space Agency's David Florida Lab in Ottawa.

Photo Credit: Canadian Space Agency

for foreigners to follow, and the uncertainty of the project's future reported by the media, in light of concerns about cost increase and schedule slip, had the potential to affect our team's focus on the task at hand. The weekly meeting in this case helped the overall team understand the situation. Team members were kept up to date on developments on this front and assured that our project and its tasks were not directly affected. This was good for morale. This was happening at the same time as we were embarking on NIRISS. It was important for the team not to be distracted by events in the United States over which we had no control.

The replacement of the troubled TFI with the NIRISS was another case when close communication was absolutely necessary. The decision to make that change was taken in the final months of the development and testing phase of the project. Among other things, it meant a change from a fixed-price contract to a cost-reimbursement contract with the prime contractor for this portion of the work. To successfully make the shift to a new instrument, we brought the scientists, the prime contractor, CSA, and NASA together for several one- to two-day workshops. The parties hashed out the new specs together.

Because NIRISS needed to be implemented quickly, rapid decisions were required. To ensure an efficient decision process with our prime contractor, we needed everyone to clearly understand the objectives, the concept for NIRISS, and the scope of work. It was vital to clearly communicate our principal investigator's vision, concept, and objectives to the entire team: scientists, engineers, and project managers. It was also important to involve all necessary engineering and science disciplines in the concept phase.

The workshops were instrumental in getting everyone in one room and capitalizing on the synergy of their participation in the discussions. This process enabled us to develop initial science and systems engineering requirements in June 2011 and hold the NIRISS critical design review by October. In addition to the workshops, we continue to hold weekly NIRISS status reviews with our scientists, engineers, and project managers to provide a clear overview of NIRISS development and keep a handle on potential problems. The final result, we believe, is an instrument that will most likely support world-class science.

Working with NASA

Before my first visit to the Goddard Space Flight Center, I did not fully understand where we fit in the large, complex JWST program. I needed to know what technical and interface issues still needed to be resolved. And I felt somewhat daunted, a bit like a little kid with his big brother. I worried, too, about the possibility that our relatively small CSA team could be flooded and distracted by constant queries from the much larger contingent of NASA engineers.

That first visit—for a technical interchange meeting—was reassuring. People at Goddard welcomed me as a colleague, not a junior partner. NASA instrument systems engineer Jim Abell and instrument systems manager Scott Lambros, who served as the primary NASA–CSA contacts, functioned as access control points for information from JWST to the Canadian team and vice versa, making sure that the Canadian team would not be overwhelmed by NASA while keeping us fully informed on the development of technical interfaces, and enabling prompt coordination of


Photo Credit: Canadian Space Agency

The international James Webb Space Telescope team in front of the Parliament of Canada building in Ottawa. The photo was taken when all partners met in May 2009 for a technical and scientific workshop.

I WORRIED, TOO, ABOUT THE POSSIBILITY THAT OUR RELATIVELY SMALL CSA TEAM COULD BE FLOODED AND DISTRACTED BY CONSTANT QUERIES FROM THE MUCH LARGER CONTINGENT OF NASA ENGINEERS.

resources to address technical issues efficiently. They came to Canada for quarterly reviews and attended technical meetings. Jim and Scott helped us make the contacts necessary to do our work, telling us which NASA people we needed to work with and helping to get them together with the appropriate CSA and prime contractor team members. More importantly, they were always able to put the technical issues being flowed down to the FGS project in perspective. We were able to understand the dynamics of JWST issues in relation to the FGS and were therefore able to communicate our concerns with specific issues and potential solutions back to the NASA team.

Scott and Jim have been critical to ensuring good and timely communication between the FGS team and NASA's team. They have shown how important the "soft" interfaces are to international collaboration. Creating the personal bonds that go beyond "business" has been critical for us to see our instruments evolve successfully within the complex system of JWST. Scott and Jim's soft approach and dedication to the JWST project and to our instruments has made them an integral part of the Canadian team, not perceived as outsiders with the sole task of overseeing us.

Communication between CSA and NASA has included a weekly one-hour teleconference to deal with management issues (plus three or four one-on-one phone calls), a weekly systems engineering telecon, and a weekly flight software telecon. On a biweekly basis, we hold reviews of action items raised at our various meetings and reviews. We attended a JWST project workshop held twice a year until recently and have one or two technical interchange meetings in Canada or at Goddard per year. At the management level, the JWST project manager has held monthly management council meetings involving all partners and industry prime contractors. This level of communication is critical to maintain the interface, to adjust to the dynamics of this interface, and to maintain an overview of the program in such a complex project.

As I write this, our challenge is to get the instrument together, tested, and ready for delivery to NASA. We are scheduled to deliver our protoflight instruments in the late summer of 2012. If all goes well, our success will be due to the technical skills of the team and to the openness, transparency, and constant communication that have characterized our work. ●


KARL SAAD has been at the Canadian Space Agency since 2001 working as a project manager. He has worked on projects involving the Netherlands, European Space Agency, and Jet Propulsion Laboratory. Since 2007, he has been the project manager for Canada's contribution to NASA's James Webb Space Telescope.

Exploring Science with NASA

BY PAUL HERTZ

NASA's Science Mission Directorate (SMD) provides opportunities for scientists outside the agency to determine what science NASA should pursue in future missions. Several different programs, such as Discovery and Explorer, publish announcements of opportunity so ideas can be proposed, vetted, selected, and flown in the pursuit of groundbreaking scientific discovery. And as much as SMD loves the missions we choose for further consideration and would like to do all of them, we can only do as many as we can afford. To give those missions as high a chance of success as possible, NASA provides guidance and processes along the way.

The NASA science program looks at the big questions: how and why are Earth's environment and climate changing, how and why does the sun vary and affect Earth, how do planets and life originate, how does the universe work? Just a tiny question, that last one: how does the universe work? NASA science questions can be clearly articulated. We talk to the public about what we're doing. We can excite them because we have exciting science to do. And that's what makes it so much fun to be part of the NASA science program.

Within SMD, we have sixty operational missions and twenty-seven more in development. We fund more than 10,000 U.S. scientists. We're partnering with a dozen federal agencies and sixty other nations. NASA has a huge impact on how people think about Earth and the universe.

How do we do business at SMD? We believe in ruthless competition. We can only pick a few of the missions submitted in response to each announcement of opportunity, and those that make the cut duke it out and then go through peer review to assess which are most viable. Scientific merit via peer review, that's the ruthless competition.

The community is an active participant in directing what science we do: advisory committees, decadal surveys, peer reviews, science working groups, the whole gamut. None of us at NASA Headquarters think we make the decisions about science priorities; it all comes from the community. The science community is vital to NASA's science mission.

Broad education outreach and public communication are also important. During Phase A of any selection process, downselected missions—those that are chosen for further consideration—must demonstrate to us how they can use their mission and their science to further the nation's education objectives. These missions also support scientific exploration around the world, as the data collected is given to the entire international science community.

But just being able to do great science isn't enough. NASA promises the government and the American public to spend only what it's given. So that great science has do be done within budget and within a specific time—as schedule also plays into budget.

There's a lot of attention inside Washington on all federal programs to determine whether they are delivering the benefits for the costs that were promised to Congress, to the administration, to the American people. We at NASA think these are perfectly reasonable expectations to be held to—once we agree with Congress on what the cost is. We don't mind being held to high standards.

So how do you become a successful NASA science mission?

Any leader of a science mission needs to establish the team's working relationships and coordination, a management control board, and whatever processes the team needs for implementation. When NASA reviews these missions to determine if they have reasonable technical, management, and cost proposals, we also look to see if the leaders of those missions are capable of doing all the hard work, making the hard decisions, and pulling together the prickly personalities in order to get the missions done successfully.

A leader who disengages is not going to be successful. Leaders have to be the glue that holds the team together. Being fully engaged means great communication within the team, using the formal and informal lines of communication that it takes to be successful.

A LEADER WHO DISENGAGES IS NOT GOING TO BE SUCCESSFUL. LEADERS HAVE TO BE THE GLUE THAT HOLDS THE TEAM TOGETHER. BEING FULLY ENGAGED MEANS GREAT COMMUNICATION WITHIN THE TEAM, USING THE FORMAL AND INFORMAL LINES OF COMMUNICATION THAT IT TAKES TO BE SUCCESSFUL.

NASA has learned through failures about the importance of minority points of view—the importance of being able to raise your hand and say you're uncomfortable with the way something is going. Every project needs to ensure it has learned that lesson so that the qualified and capable people within any team have the authority to speak up when they think something is going south, to have their concern brought up and considered. The longer a problem festers, the more unsolvable it gets. Being able to listen and ask questions is just as important as being able to give direction.

The scientists who lead many of these missions are called principal investigators. They're in charge, but they're responsible to NASA. If something goes wrong, NASA takes the hit. That's why we want to work closely with these science missions and their principal investigators—to ensure they are successful. And to make sure we fulfill the promises that we, together as a team, have made to the American people and to Congress. In effect, these principal investigators are asking to be put in charge of missions that cost from the tens of millions to hundreds of millions of dollars. That's a privilege, not a right, and it comes with responsibilities. ●

PAUL HERTZ is chief scientist for the Science Mission Directorate (SMD). He manages Directorate-level science activities, including the solicitation, evaluation, and selection process for SMD; the SMD Science Management Council; and SMD's research policies and procedures. He is the Directorate lead for agencywide science activities, including grants activities, peer-review services, and postdoctoral and graduate student fellowship programs.

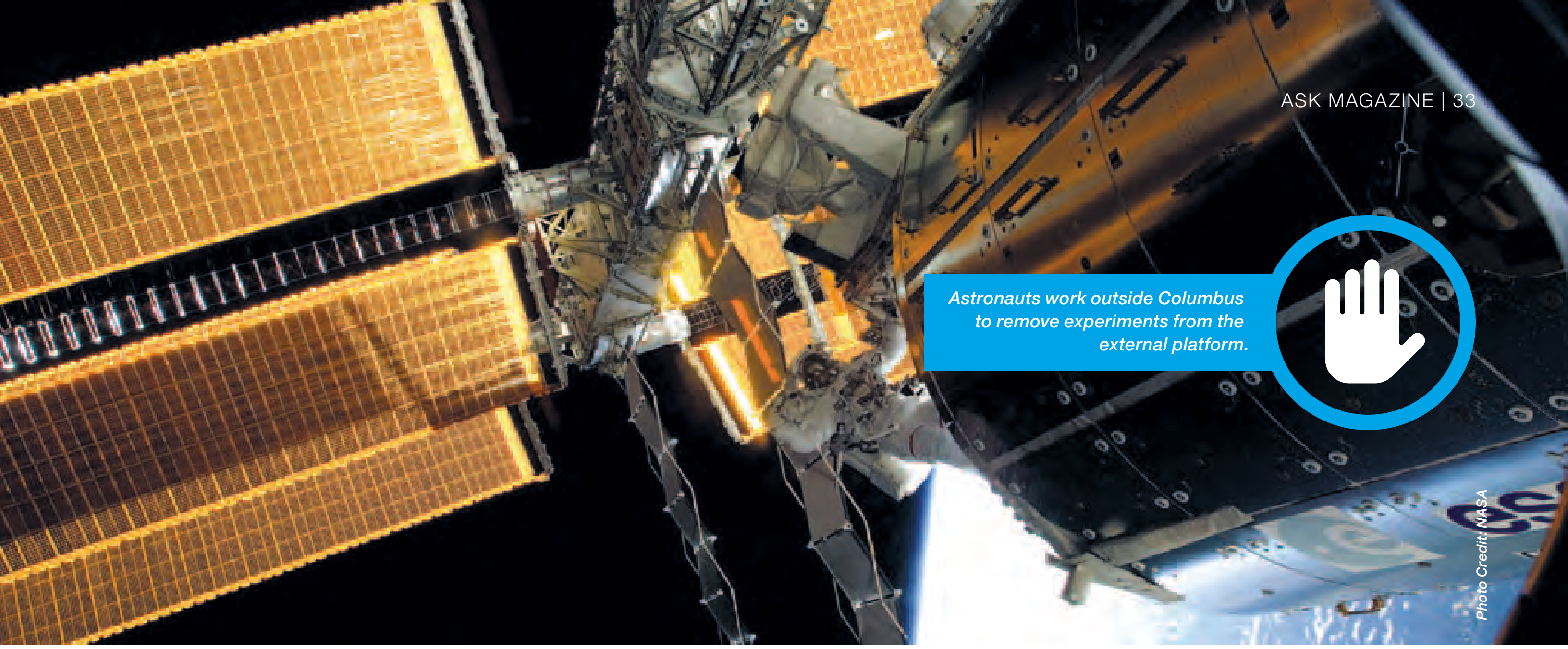
Hands-On vs. Hands-Off Project Management at ESA

BY BOB CHESSON

Most European Space Agency (ESA) projects are contracted to European industry on a firm fixed-price (FFP) basis. These FFP contracts and their statements of work transfer most of the project risks to the prime contractor, who then transfers as much risk as he can to subcontractors and equipment suppliers.

Fisheye view inside the European Columbus laboratory.

Photo Credit: NASA



Astronauts work outside Columbus to remove experiments from the external platform.

The prime contractor has a high probability of completing the project successfully within cost and schedule, provided the ESA project manager does not change the requirements, and provided that the industrial organization is sound, with a competent and experienced prime contractor who has good oversight and direction of his subcontractors and suppliers. This outcome also presupposes that the lower-level contractors are competent and will provide early indications to the prime when things start to go wrong. In practice, requirements will probably change due largely to external influences beyond the ESA project manager's control, and he will have set aside a realistic risk reserve to cope with the changes.

Even if these conditions are not met, the ESA project manager should not in theory be liable for the effects of poor performance in the industrial camp. Theory and practice are often different, though.

A weak prime contractor with little oversight and control of his subcontractors and suppliers may not detect a problem in, for example, an equipment supplier's design or development program. The supplier may choose to keep quiet, especially if he is aware of the possibility of future customer- or prime-contractor-imposed changes to his area, which he can use to financially cover additional work needed to fix the problem. So basic problems can remain undetected until relatively late in the integration and test phase, when their impact is sometimes so enormous that the prime is unable to cover the costs within the FFP contract. In those cases, ESA is left with the options of financing the overruns or terminating the project.

To avoid this, many project managers, especially when they have reservations about the competence of the prime or important subcontractors, use a "hands-on" approach to managing the industrial contract, closely monitoring the areas of major risk at all levels. Provisions are made in the contract for oversight, which allows the ESA project manager to get an early warning of potential problems and to alert the prime to take action before the consequences are too serious.

Although the hands-on approach is popular in some ESA directorates, it is by no means universally applied. Some ESA project managers, who have a well-defined set of requirements and plans at the systems requirement review, a well-understood risk register with sufficient provisions for risk mitigation, and a competent and trusted industrial organization, are comfortable with a "hands-off" approach. In such cases, the project is managed via regular (for example, quarterly) progress meetings, ESA independent reviews, joint management boards, and contract change boards. In addition, ESA technical specialists and product assurance managers are called in to participate in management review boards and ad hoc working groups to help solve major problems.

Two very different projects within the Human Spaceflight Directorate show how ESA has applied these different management styles. The Columbus Laboratory is an example of hands-off project management that was delivered within budget despite a number of launch delays. The Automated Transfer Vehicle (ATV) started life as a hands-off project under FFP contract, became very much hands-on under cost-reimbursement conditions, and eventually reverted back to an FFP contract with hands-on project management.

The Columbus Laboratory

The Columbus Laboratory was the only surviving element of the Columbus program started in response to the 1984 U.S. invitation to join the International Space Station (ISS) program. It was derived from the Spacelab module first launched in 1983; the work was largely distributed among the same contractors that designed and built Spacelab with ERNO, later to become DASA (Daimler Chrysler), and finally Astrium, as the prime contractor. Columbus went through ten years of Phase A and B studies, the unusual length of time due to the *Challenger* accident in 1986 and then the space station redesign in 1993.

ESA's ISS program, including both Columbus and the ATV, was approved at the ESA Council at Ministerial Level in

HANDS-OFF FIXED-PRICE CONTRACTS ARE USUALLY ONLY SUCCESSFUL IF THERE IS A STRONG, COMPETENT, AND EXPERIENCED PRIME CONTRACTOR.

1995. Before approval could take place, however, the price for Columbus had to be reduced from €1.3 billion to €650 million.

The savings were achieved by a "design-to-cost" approach by Astrium that reduced the module from four to two segments and arranged for the structure to be provided by the Italian Space Agency (ASI) in return for an environmental control and life-support system supplied by the Columbus program for the ASI multipurpose logistics models. The size reduction allowed the module outfitted with systems and payload facilities to be launched in one Space Shuttle flight.

Astrium also insisted that the only way the company could deliver Columbus for the reduced price was to conduct the program in a strictly hands-off FFP mode, with minimal interference from ESA. This was the opposite approach to that taken for the Spacelab development, but ESA program management felt confident with a hands-off approach to Columbus because of the following:

1. Competent and experienced prime contractor and major subcontractors. The industrial consortium had learned a lot from NASA and U.S. industry during the Spacelab program.
2. Competent and experienced customer. The core of ESA's Columbus project management team had been key players in the Spacelab program; the relationship with the industrial team was excellent.
3. Little new technology development. Only the condensing heat exchanger and the fan designs involved new technology.
4. Mature specifications. Ten years of Phase A and B ensured that the system requirements document and external interface specifications were at an excellent state of definition.
5. The price included adequate margins to cover risks.

Not everyone in the small ESA Columbus team of fewer than twenty people was happy with the lack of visibility provided by the contractor, who did not allow ESA any interference with subcontractors. The quarterly progress meetings were conducted at a fairly superficial level, and it was difficult for the ESA subsystem specialists to get information from subcontractors. This lack of visibility did prevent some issues from being identified at an early stage, notably problems in the data management software design.

Astrium did ask for an ESA specialist to help solve technical problems and for the technology developments. ESA also approved the system specification and some system-support specifications that answered requirements in the software requirements definition. Furthermore, the ESA team had a major role in the qualification and acceptance process, approving all test procedures related to verification of system requirements and witnessing the entire test program.

In the end, Columbus was delivered on time and within cost despite various delays in the shuttle and ISS programs. Furthermore, an external platform, not foreseen in the original design, was provided within the €650 million price.

The Automated Transfer Vehicle

The ATV project was a different story.

ATV was introduced at the time of station redesign as a way of paying for ESA's ISS common costs. A high-level agreement was negotiated with NASA limiting ESA's common system operations cost obligation to fewer than six ATVs for ten years of Columbus operations.

The definition of ATV up to the end of Phase B1 was done by Astrium Bremen (then DASA). Then, in order to provide French interest in the ISS program and to ensure an adequate return to French industry, prime contractorship for phases B2/C/D was transferred to Astrium Les Mureaux (formerly Aerospatiale). This was a difficult transition, aggravated by German–French rivalry within EADS, and resulted in significant demotivation of staff in Astrium Bremen.

The cost target at that stage was set at around €400 million, which was unrealistic for such a complex vehicle. Hard

The International Space Station docked with Europe's ATV Johannes Kepler *and Space Shuttle* Endeavour *as seen by Expedition 27 crewmember Paolo Nespoli from the Soyuz TMA-20.*

Photo Credit: ESA/NASA

negotiations with participating member states and industrial companies followed to achieve a viable industrial setup.

The requirements baseline at system requirement review was sketchy to say the least, particularly in the requirements for the ISS interface. This applied especially to the Russian segment to which the ATV would dock. At that time, the Russians were not very cooperative, as they saw ATV as a competitor to Progress. Also, NASA requirements on visiting vehicles to the ISS were in their early stages of development.

Nevertheless, a fixed-price contract based on the requirements baseline from the system requirement review was placed with Astrium Les Mureaux in 1998. It would be continuously updated due to maturing requirements on the U.S. and Russian segments.

The fixed-price contract implied a hands-off approach and Astrium Les Mureaux provided minimal visibility to the ESA ATV team in the early stages of the project. Furthermore, the ATV prime contractor was weak and had little experience as a system prime since Astrium Les Mureaux was accustomed to having CNES, the French space agency, in such a role, particularly for launcher developments. Consequently, problems emerged in configuration management, management of subcontractors, and the design process itself.

The complexity of a vehicle that was required to automatically and safely rendezvous and dock to the ISS began to emerge, and the preliminary design review showed that the contractor was far from mastering several issues.

In 2000, the preliminary design review demonstrated that the current design of the ATV could not satisfy many requirements, particularly in the domain of rendezvous and docking. The review was declared unsuccessful, the ESA project manager was replaced, and a new preliminary design review was scheduled for six months later.

During this time, the overall concept of guidance and navigation was rethought, some specifications were rewritten, and some hardware changes were made—for instance, videometer optical sensors for rendezvous and docking were introduced.

The subsequent preliminary design review was a success and detailed design began, but costs of the project were clearly getting out of control as a result of a considerable number of Class A changes. Furthermore, given the inexperience of the prime contractor management team, the new ESA project manager was concerned about the prime's ability to implement the complex ATV design across the consortium without hands-on guidance from ESA.

ESA therefore decided to change the overall approach by doing the following:

- Suspending the fixed-price contract.
- Introducing a cost-reimbursement scheme with ceiling, cost sharing, and incentives.
- Collocating the ESA project team with the Aerospatiale team in Les Mureaux and instigating hands-on management by ESA.

Following their relocation to Les Mureaux, ESA's ATV project team had complete access to all design decisions and, in many cases, directed the design process. They also had access to subcontractors and could verify the compatibility of the design at system, subsystem, and equipment levels.

Despite problems in the propulsion system and the software, the technical side of the ATV project was back on track by the time of the critical design review. Financially, though, the project was spiralling out of control in the cost-reimbursement environment. Something had to be done to regain control.

After critical design review, negotiations were started with the ATV prime with a view to re-establishing a fixed-price contract for the remaining work. Agreement was eventually reached on a price and the new contract was put in place. Despite being back in the fixed-price contractual realm, ESA retained a hands-on approach throughout the qualification and acceptance phase.

THE HANDS-ON COST-REIMBURSEMENT APPROACH IS EFFECTIVE FOR SOLVING COMPLEX TECHNICAL/TECHNOLOGY PROBLEMS AND SHOULD BE CONSIDERED FOR SOME PHASES OF A COMPLEX PROJECT.

Photo Credit: ESA/CNES/Arianespace/Photo Optique du CSG/S. Martin

ATV-3 case integration.

Due to a variety of problems in the latter stages, costs continued to grow to a final total of around €1.2 billion, about three times the original target price.

Some Lessons

What can be learned from these two very different experiences of large-project management?

- First, it is essential to perform a thorough definition phase before entering into a fixed-price design and development contract.
  - A stable, mature set of requirements must be established during Phase B1 and verified at system requirement review.
  - Based on requirements, a realistic cost must be established for use as a cost target for the fixed-price offer.
- Hands-off fixed-price contracts are usually only successful if
  - There is a strong, competent, and experienced prime contractor.
  - The customer team is strong, competent, and has experience working with the prime.
  - The requirements baseline is sound, stable, and complete.
  - There are no major technology developments required.
  - There is adequate funding to cover the project costs and credible risks.
- Fixed-price contracts are not a universal panacea.
  - If Class B losses are too heavy, primes may find it more expedient to terminate the project and pay penalties than to finish it with massive losses.
  - Customer project management must prevent the prime from taking on risks that it cannot cover.
- The hands-on cost-reimbursement approach is effective for solving complex technical/technology problems and should be considered for some phases of a complex project. Costs are difficult to control in this regime, though, and the customer project manager should work toward establishing a fixed-price regime as soon as appropriate. ●

BOB CHESSON has worked in the European Space Agency's (ESA) human spaceflight program since 1976 and was program manager for ESA's International Space Station operations program from 2000 until 2006. From 2006 to 2011, he was head of human spaceflight operations and is presently senior advisor to ESA's director of human spaceflight.

BUILDING THE FUTURE SPACESUIT

BY DAVA NEWMAN

For the past dozen years, I have been working with colleagues and students here at the Massachusetts Institute of Technology (MIT) and with collaborators in various disciplines from around the world to develop a new kind of spacesuit. My hope is that the astronauts who some day walk on the surface of Mars will be protected by a future version of what we are calling the "BioSuit™."

The BioSuit is a "second skin" spacesuit that would allow for greater degrees of freedom in movement.

Photo Credit: Professor Dava Newman, MIT: Inventor, Science and Engineering; Guillermo Trotti, A.I.A., Trotti and Associates, Inc. (Cambridge, MA): Design; Dainese (Vincenca, Italy): Fabrication; Douglas Sonders: Photography

Beyond the Balloon

The suits that kept NASA astronauts alive on the moon and those worn by Space Shuttle and International Space Station crewmembers for extravehicular activities (EVAs), including the Hubble repair missions, are technological marvels; in effect, they are miniature spacecraft that provide the pressure, oxygen, and thermal control that humans need to survive in the vacuum of space.

The greatest problem with these suits is their rigidity. The air that supplies the necessary pressure to the bodies of wearers turns them into stiff balloons that make movement difficult and tiring. These suits are officially known as EMUs—extravehicular mobility units—but they allow only limited mobility. Astronauts who perform repair work in space find the stiffness of spacesuit gloves especially challenging: imagine manipulating tools and small parts for hours wearing gas-filled gloves that fight against the flexing of your fingers.

The suppleness of these gloves is improving. Aerospace engineer Peter Homer has won two NASA Centennial Challenge competitions with designs that add an X-shaped bit of fabric to finger joints, creating a kind of hinge that increases dexterity. But that improvement, though significant, has been made within the context of the fundamental limitations of a glove that remains a gas-filled bladder.

Future space exploration will be expensive. If we send humans to Mars, we will want to maximize the work effort and science return. One contributor to that efficiency will need to be a new kind of spacesuit that allows our explorer-astronauts to move freely and quickly on the Martian surface. That could be the BioSuit.

MIT student Kristen Bethke works on the BioSuit knee joint.

Photo Credit: Professor Dava Newman, MIT: Inventor, Science and Engineering; Guillermo Trotti, A.I.A., Trotti and Associates, Inc. (Cambridge, MA): Design; Dainese (Vincenca, Italy): Fabrication

A New (and Old) Approach

The BioSuit is based on the idea that there is another way to apply the necessary pressure to an astronaut's body. In theory at least, a form-fitting suit that presses directly on the skin can accomplish the job. What is needed is an elastic fabric and a structure that can provide about one-third of sea-level atmospheric pressure, or 4.3 psi (approximately the pressure at the top of Mt. Everest). The skintight suit would allow for a degree of mobility impossible in a gas-filled suit. It also would be potentially safer. While an abrasion or micrometeor puncture in a traditional suit would threaten sudden decompression—puncturing the balloon and causing a major emergency and immediate termination of the EVA—a small breach in the BioSuit could be readily repaired with a kind of high-tech Ace bandage to cover a small tear.

The mechanical counter-pressure spacesuit is not a new idea. Physiologist Dr. Paul Webb introduced the concept in the late sixties and developed a prototype in the early seventies. It was a great idea that came before its time, in my opinion; advanced materials that could exert the necessary pressure on the skin were not available then. In addition, the wearer needed help getting Webb's prototype suit on and off (as do astronauts donning and doffing existing spacesuits), which results in expensive downtime for astronauts. A really practical BioSuit would be one the wearer could don and doff herself in, say, less than ten minutes.

In the late nineties, colleagues and I revived Webb's innovation and began work on second-skin spacesuit designs. Our hypothesis was that new developments in materials (for instance, Spandex and its more sophisticated polymer descendants) plus supportive patterning of the material could make a successful counter-pressure suit feasible.

Learning Together

Thanks to some funding from the NASA Institute for Advanced Concepts, we were able to gather a team to begin the practical work that would test our hypothesis. Students have been part of the core team from the beginning. Like most research at MIT, the spacesuit work is about teaching as well as practical results. MIT engineers and biomedical engineers are part of the team, as is Jeff Hoffman, a professor who has flown on five shuttle missions, including a Hubble repair. As someone who has worn and worked in current operational spacesuits, he can use his experience to tell us where we may be going wrong in our design.

Collaborators outside the MIT community include Trotti and Associates, an architectural and industrial design firm in Cambridge, Mass.; engineers from Draper Laboratories; and Dainese, an Italian manufacturer of motorcycle racing "leathers"—leather and carbon-fiber suits designed to protect racers traveling at up to 200 mph.

Bringing together designers from Trotti and Associates and students from the Rhode Island School of Design and my MIT engineering students has greatly influenced the way our groups work. In our early sessions together to realize a second-skin spacesuit, my engineering students spent much of their time hunched over their laptops, calculating and analyzing the governing equations, while the designers—visual thinkers—took out sketchbooks and immediately started drawing to attack the problem. After working together for weeks, the engineers got more comfortable with the idea of sketching solutions and some of the designers added Matlab and its more analytical approach to their repertoires. We all ended up better off.

Photo Credit: Professor Dava Newman, MIT: Inventor, Science and Engineering; Guillermo Trotti, A.I.A., Trotti and Associates, Inc. (Cambridge, MA): Design; Dainese (Vincenca, Italy): Fabrication; Douglas Sonders: Photography

Dava models the BioSuit.

We have "collaborated" with researchers from earlier eras, too. Not only Paul Webb (still active, he is an advisor to our team), but also Dr. Arthur Iberall, a physicist who did important work on mobile spacesuits. He died in 2002, but his daughters—happy to see his work continued—gave me access to his papers. We have expanded his great idea of a pattern of three-dimensional lines on the body that do not extend by deriving the mathematical representation and visualization of what I call a soft exoskeleton and structure for the BioSuit. There is also Dr. Karl Langer, the nineteenth-century Austrian anatomist who experimentally studied and mapped the tension lines in human skin.

Iberall's and Langer's work informed our thinking about possible patterning designs for our suit, and we've patented our innovations. Elastic fabrics alone cannot provide the essential combination of sufficient pressure and flexibility we need, especially at knees, elbows, and finger joints. (The flexible parts of the body are the biggest challenge, of course.) Laminating our mathematically derived web of less-flexible lines, or the soft exoskeleton pattern, to our elastic compression suit has gotten us closer to the necessary pressure production goals, and we've exceeded our mobility and flexibility performance goals.

Tremendous challenges remain before we can vacuum test a complete BioSuit, and that will be only one step on the road to an operational system that astronauts could wear in space. So far, we have been testing leg prototypes in a vacuum chamber at MIT. We are within striking distance of our pressure goal. Adding wearable sensors to the suit is another challenge that we are working on currently, and we've designed a new gas-pressured helmet, one that is closer fitting than current globe-shaped helmets. We would like to give astronauts the ability to turn their heads and look over their shoulders, which means designing a new kind of airtight joint between the helmet and the rest of the BioSuit.

There is also the question of how to package life support for the suit. The large backpack that supplies oxygen, thermal control, and other necessities to current spacesuits tends to unbalance astronauts working in partial-gravity environments. We have tapped into the professional diving community for help designing a new life-support system for the BioSuit, perhaps a modular one to allow astronauts to carry only what they need and provide quick bottle changes for their extreme exploration assignments.

Given a full core team of about a dozen people (which we do not have presently because of lack of funding), I think we could have a complete suit ready for testing within three years. But, as with any research and development project, it is important to keep an open mind in this process. We even need to be willing to accept evidence that our idea won't work. (So far, fortunately, we haven't found any deal breakers; our results suggest that the BioSuit is technically feasible and could become a practical reality.) And we have to consider alternatives that may prove more practical than our original concept, though not as elegant—for instance, a hybrid suit that combines mechanical counter-pressure arms and legs with a gas-pressurized trunk.

The Potential

We started this work with a vision of bio-suited explorers on the surface of Mars. That is still our goal, but for the past five years we have received National Science Foundation funding for applications on Earth that are also exciting.

We have been working with colleagues at Children's Hospital in Boston, Harvard's Wyss Institute, Boston University, and Draper Laboratory to see if we can use our technology and engineering designs to help infants with brain damage that affects motor skills, children with cerebral palsy, and stroke victims, who typically lose motor skills on one side of their bodies. The idea is first to use BioSuit "sleeves" with built-in sensors on the legs to measure movements—to understand, for instance, how much motion and kicking by infants is typical and compare that with the limited kicking and motions of children with cerebral palsy. The next step—a big one—is to add actuators that can enhance and direct movement. In the case of cerebral palsy and stroke victims, that would be a way of giving back some of the lost motion. People with cerebral palsy expend a lot of energy moving and have stiffened muscles; our BioSuit technology and know-how could guide movement and enhance mobility to make it more efficient. And because the brains of newborns are still so plastic, enhancing the natural kicking of infants with potential motor problems from brain damage might actually reshape the motor programs and partly "heal" their brains.

Like an operational bio-spacesuit, the biomedical applications are in the future, but we are making encouraging progress. In the process, we are learning about materials science and biomechanics; creating diverse cooperative communities of engineers, designers, scientists, and artists; and training a new generation of creative engineers. The possibilities are endless. How about putting actuators on a skintight spacesuit to give astronauts more-than-normal speed and agility? No one knows how far we can go. Stay tuned. ●

DAVA NEWMAN is professor of aeronautics and astronautics and engineering systems at the Massachusetts Institute of Technology (MIT). She is also the director of the Technology and Policy Program and a Margaret MacVicar faculty fellow. Her expertise is in multidisciplinary research that combines aerospace biomedical engineering, human-in-the-loop modeling, biomechanics, human-interface technology, life sciences, systems analysis, design, and policy.

"WHAT WORKS" LUNCHEON

BY MAUREEN MADDEN

I love to learn about all the cool things we work on here at NASA, but I don't have time to read all the press releases or go to all the workshops and conferences. So in 2005, I started my public service activity of taking coworkers out to lunch. I am a senior systems engineer who has worked on everything from particle detectors that study the sun to ground systems that will capture data from weather satellites. When I am working on a project, I see the same group of coworkers, and we talk about our project. I feel that I am missing out on what other projects are doing. The lunches help me catch up with old colleagues and get energized by their passion for their projects.

Listening to colleagues' success stories is a great way to learn from and build on what worked for them. Why reinvent a solution to a problem when you can improve or adapt what someone else has already discovered? No one at NASA knows all there is to know about everything.

I am one of the rare extroverts at Goddard Space Flight Center, and I have no problem inviting scientists, engineers, technicians, attorneys, managers, and directors out of the office for a friendly lunch. What I like about the lunches is that I learn something new at every event, as does the person I invite. They also appreciate my effort to get them out of their routines and their offices. It is like giving them a gift. Over the past six years I have taken hundreds of coworkers to lunch—Dutch treat, of course. This year I decided to step up my lunches by bringing my network of friends from around Goddard together to share their success stories with others who may need their knowledge, or who might hear about a solution to a problem that can be adapted to another challenge in another part of the organization to make improvements.

It is not hard to locate an open conference room and send out an e-mail to my friends inviting them to talk about what is working here at Goddard. I hold the lunches monthly and rotate the days of the week so that no one will be left out because they have a standing meeting at lunchtime on a particular day. Then I collect the RSVPs and see who is free to meet this month. The turnouts have been a diverse group of about ten to twenty people from most of the organizations on center.

When firsthand knowledge and experiences are exchanged in story form, we connect to that expertise on an emotional level. Also, we can immediately ask questions to get a better understanding of the situations and actions taken. And we connect with the storytellers, building relationships that expand our network of subject-matter experts.

Everyone needs a break to improve his or her productivity. These monthly lunches offer a break from routine, from the back-to-back meetings, endless e-mail, and quick lunches in the office. Everyone is welcome, whether or not they have a story to tell. Sometimes people just want to listen and learn from others; sometimes they don't have a new success story they are ready to share. That's okay. Just by coming, people see a positive outcome and have new energy to take back to their offices.

Stories have included a variety of topics: How did you find the funding for that needed test? How did you promote your employee? Why are your meetings so productive? How

> I HOLD THE LUNCHES MONTHLY AND ROTATE THE DAYS OF THE WEEK SO THAT NO ONE WILL BE LEFT OUT BECAUSE THEY HAVE A STANDING MEETING AT LUNCHTIME ON A PARTICULAR DAY.

did you solve that high-priority issue? How did your team solve that anomaly? How did you develop trust with Headquarters or your contractor? How did you solve that technical challenge or develop that new technology? How did you move that plan to implementation? How did you move the funding around so fast? How did you win that proposal or secure that contract? How did you save the project money? How did you support a colleague's success? How do you get through all your e-mail?

Participants have offered stories on turning a "no" into a "yes," solving an "impossible" problem, turning an almost cancellation into a success story, and having a successful promotion. There are also stories about how two diverse proposal teams affected morale and motivation, creative and collaborative ways to present at a project monthly review, and how the Information Technology (IT) and Communications Directorate can help in ways we didn't know about.

The successful promotion story was about getting the facts right and resolving misunderstandings. A couple of listeners were also advocating for a promotion but didn't understand the process or requirements. This story helped answer some of their questions and encouraged them to have conversations with their supervisors to get to an understanding about their particular requirements.

Eric Newman, from the Management Operation Directorate, shared a story about fixing an "impossible" problem. In procurement, where Eric works, everyone uses the same web site to research past procurement precedents before they develop new procurement documents. Over time, the procurement policy page had grown larger and larger; there was never really a "master plan" for its layout and development. The result was a page that was inefficient and not user friendly. The user had to know where things were or had to look through long lists of information, often in multiple places. This process was extremely inefficient and caused important guidance to be overlooked because it was so hard to sift through all the information to find what was relevant. Everyone knew this was a major problem, but no one had the time or knowledge needed to redesign such a complicated search tool.

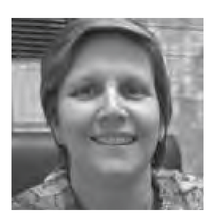
Eric stepped up and started to gather a team of friends and coworkers who he thought understood the details of the problem, had ideas to make improvements, and were motivated to get to a solution.

It took a lot of effort just to get everyone to meetings but, once they saw that success was possible, people became committed to the project. He also used his network to find an IT person who could work on the web site. He found out that procurement fell within the center's overhead budget and specific funds would not need to be found to cover the cost of the Information Technology and Communications Directorate to provide a web designer.

The response to the new web site has been overwhelmingly positive. Since it went live, Eric has received numerous phone calls from coworkers who were excited about how quickly and easily they were able to find what they needed. The web-site redesign team recently won an award for innovation. The award write-up said, "The results of this work benefit an entire operational community who use this information daily to award and administer contract instruments. We couldn't be more excited about the new look and feel. It is user friendly and will save contract specialists time and energy in finding the information that they need." So, thanks to leadership, persistence, and networking, this team developed an efficient new user-friendly tool that benefits the whole office and entire center. A lunch participant who heard Eric's story also needed a new web site but did not have the funds. His story moved her to contact the Information Technology and Communications Directorate to see if they could help.

You don't know what you don't know, and you never know what may be useful. At the lunches, people hear about creative new ways of solving old problems. We learn from and support each other at no cost for the knowledge transfer. That is why I have named the lunch group the "Collaborative Collective." The group is stimulating innovation by creating a culture more open to change and willing to leave behind old habits that no longer serve us, like eating in our offices instead of talking to each other over lunch.

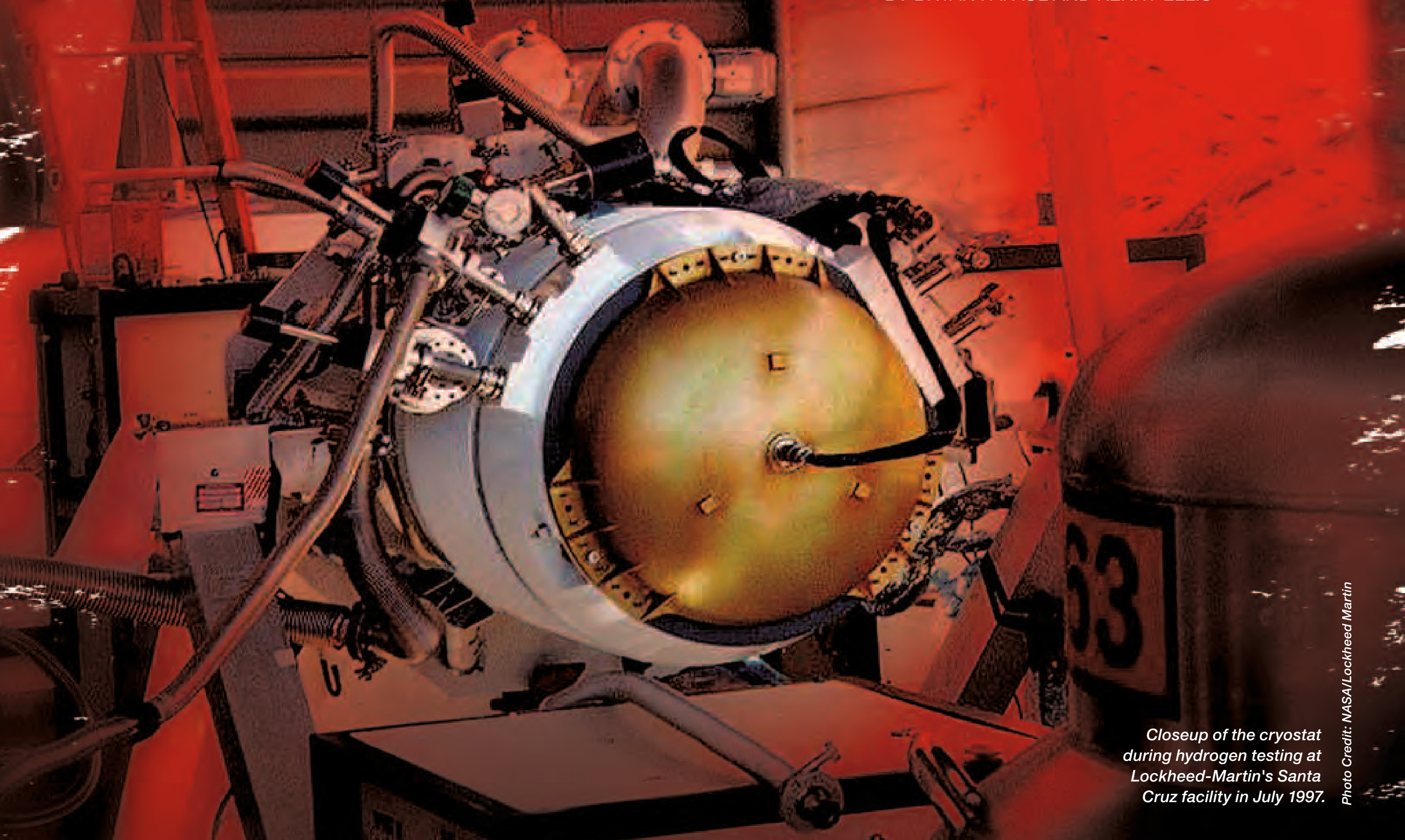
Even this article is an example of how the Collaborative Collective works. Steve Scott, the Goddard chief engineer, suggested at one of our lunches that I write it. Now maybe reading it has given you ideas about a new way to share your knowledge. What success story do you have? Who can benefit from hearing it and help move NASA forward?



MAUREEN MADDEN began her career at Goddard Space Flight Center in 1990 in the High Energy Astrophysics Lab as the solid-state detector lead. In 2001 she served as the Small Explorers mission director and is currently a senior systems engineer supporting the Joint Polar Satellite System Ground Segment project.

WIRE: LEARNING FROM FAILURE

BY BRYAN FAFAUL AND KERRY ELLIS



Closeup of the cryostat during hydrogen testing at Lockheed-Martin's Santa Cruz facility in July 1997.

Photo Credit: NASA/Lockheed Martin

In 1999, the Wide-field Infrared Explorer (WIRE) lost its primary mission thirty-six hours after launch. Those who worked on WIRE, which was the fifth of the Explorer Program's Small Explorer–class missions, thought they had done what they needed to achieve success. But a mishap investigation and a 2002 Government Accountability Office report on NASA's lessons learned highlighted poor communication and incomplete testing as contributors to this and other NASA failures. The team's informal motto, "insight, not oversight," also helped WIRE's issues stay hidden.

The motto was meant to respect the professionalism and expertise of each organization involved in the mission. WIRE had a complex organizational structure, with mission management at Goddard Space Flight Center, instrument development at the Jet Propulsion Laboratory (JPL), and instrument implementation at a contractor's location with supervision by JPL. This arrangement was meant to capitalize on the strengths of each organization. By guiding team interactions with "insight, not oversight," the goal was to avoid perceptions of distrust or micromanagement and facilitate a smooth working arrangement that could proceed without the hang-ups of too much oversight. This approach, however, had unintended consequences.

WIRE's sensitive infrared telescope was the most visibly affected by the limited oversight. Meant to study how galaxies formed and evolved, the telescope's infrared detectors required an extremely cold, 7 kelvin environment in order to operate with precision and without interference from the heat of the telescope itself. To achieve this, the telescope was protected inside a frozen-hydrogen-filled dewar, or cryostat. The plan was to keep the telescope safely covered inside the cryostat until WIRE made it into the deep cold of space. Then the cryostat cover would be ejected and the telescope would begin operations.

"We spent three years ensuring that cover would come off, and probably only a handful of hours making sure that it would stay on," said Bryan Fafaul, who was the mission manager for WIRE.

Soon after launch—too soon—the cover ejected.

Communication Breakdown

During development, delivery of the pyro box that would eject the cover had been delayed. As a result, the box wasn't adequately included in a scheduled peer review of WIRE's electronics. A change of management, and the failure to communicate to the new management that the peer review was inadequate, resulted in no additional review of the design.

"We as engineers and scientists do a very good job addressing technical anomalies. We do a great job diagnosing the problem, making the appropriate corrections, and performing the necessary regression testing to ensure success," said Fafaul. "Management anomalies are just as important but are more difficult to address. They take a long time to recognize, aftereffects are unclear, and regression testing is difficult. For WIRE, we had an issue: we weren't communicating anymore. Ultimately, we had some personnel change out, and that made a significant difference in our communication. But the thing we didn't know how to do was analyze what damage had been done as a result. We made a change, but we didn't know how to go back and verify [regression test] what we caught and what we missed. We just didn't know how to do that."

The result was a chain reaction of miscommunication that led to a lack of insight.

Jim Watzin, who was the Small Explorer project manager at the time, described the communication difficulties as a matter of misconceived ownership and distrust of outside opinions. "These folks feared oversight and criticism and hid behind the organizational boundaries in order to ensure their privacy," he wrote in response to a case study on the mission. "They lost the opportunity for thorough peer review (the first opportunity to catch the design defect) and in doing so they lost the entire mission."

"Everyone was being told to back off and let the implementing organization do its thing with only minimal interference," added Bill Townsend, who was Goddard's deputy director at the time, in his own response. "… This guidance was sometimes interpreted in a way that ignored many of the tenets of good management. Sometimes the interpretation of this was to do nothing …. Secondly, WIRE had two NASA centers working on it, one [JPL] reporting to the other [Goddard]. Given that either center could have adequately done any of the jobs, professional courtesy dictated neither get in the way of the other. While this was a noble gesture, it did create considerable confusion as to who was in charge of what."

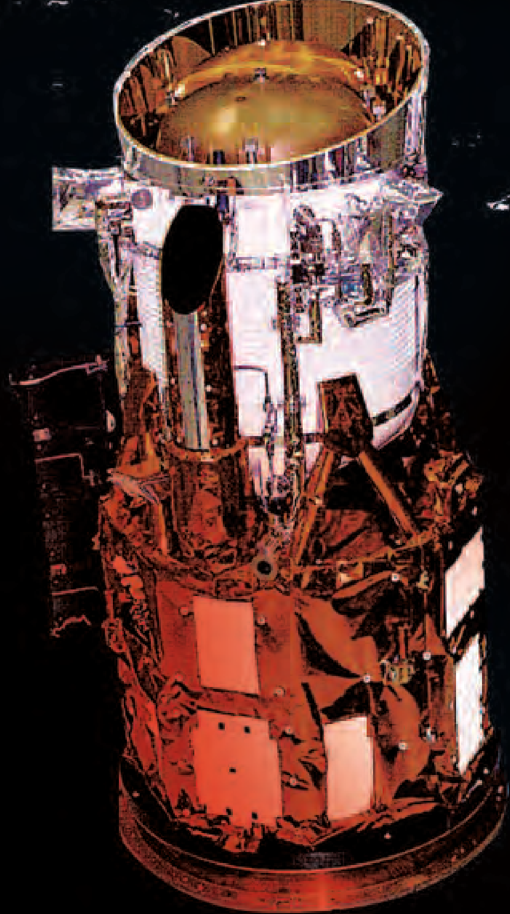
As a result, the contractor was able to proceed with the pyro box development without the peer review oversight needed to ensure success. Crucial details about the box design were not complete, others had little documentation, some were included in notes but left off data sheets. No one had a complete view of all the circuitry involved in the pyro box, and an indication that something might be amiss wasn't fully analyzed during integration testing.

Test as You Fly, Fly as You Test

One of the undocumented pieces of information was the startup characteristics of the pyro box—namely how long the instrument took to power up and the effects other current signals would have on the box's field-programmable gate array (FPGA) during its startup. This detail was overlooked due to delays in the box's design delivery that prevented it from being included in subsystem peer review and the mission system design review.

Testing of the pyro box was challenging because of the cryostat. "It was a hydrogen dewar. You can't just load it up with hydrogen and take it into any building and test it," explained Fafaul. "So we had to adapt and make provisions to do things a little bit differently."

Since the cryostat itself could not be tested with the actual pyro box while filled with frozen hydrogen—otherwise known as being in its nominal, or ideal, state—the team used a pyrotechnic test unit to simulate the pyro event. The test unit had been successfully used in testing for previous Small Explorer–class missions, and was well known for being a bit



WIDE-FIELD INFRARED EXPLORER

The Wide-field Infrared Explorer.

Photo Credit: NASA

Photo Credit: NASA

The WIRE telescope inside the cryostat assembly.

WITHOUT THE CRYOSTAT'S PROTECTION, THE INFRARED DETECTORS WOULD MISINTERPRET THE TELESCOPE'S OWN HEAT AS SIGNAL NOISE, WHICH EFFECTIVELY ENDED WIRE'S PRIMARY MISSION.

finicky about false triggers. This knowledge, and a contractor's documented explanation of a similar event, would be the foundation for dismissing a valid early-trigger event that made itself evident during spacecraft testing.

Before WIRE launched, the pyro box on the cryostat had been powered off for nearly two weeks, allowing any residual charge in the circuitry to bleed off. Residual charge turned out to be the key to maintaining a valid test configuration for the pyro box during spacecraft testing, which was occurring almost daily. When the team sent a signal to power up the system after launch, the pyro box powered on in an indeterminate state and the spacecraft immediately fired all pyro devices. The cryostat cover blew off, exposing the frozen hydrogen to the heat of the sun. It boiled off violently, sending the spacecraft into a 60-rpm spin. Without the cryostat's protection, the infrared detectors would misinterpret the telescope's own heat as signal noise, which effectively ended WIRE's primary mission.

Taking Tough Lessons to Heart

"For every shortcoming we had on WIRE, you'll find nearly an identical shortcoming in every successful mission. Like it or not, you're close to failure all the time," said Fafaul.

"I've had seven or eight different offices since my WIRE days, and directly across from my desk you will always find my picture of WIRE," he continued. "There are important lessons there that I want to be reminded of every day as I move through life."

Among the tough lessons learned during WIRE, Fafaul took six especially to heart:

- Test and re-test to ensure proper application of FPGAs.
- Peer reviews are a vital part of mission design and development.
- Effective closed-loop tracking of actions helps keep everyone informed of progress or delays.
- Managing across organizational boundaries is always challenging. Don't let respect for partnering institutions prevent insight.
- Extra vigilance is required when deviating from full-system, end-to-end testing.
- System design must consider both nominal and off-nominal scenarios—and must take the time to understand and communicate anything that doesn't look right.

"I remind everybody constantly that we are *all* systems engineers," explained Fafaul. "I expect everybody, down to the administrative staff, to say something if they see or hear anything that doesn't seem right. Remember, you need to be *a* team to be an A team."

Despite the loss of its primary mission, the team managed to recover WIRE from its high-speed spin and a scientist developed a very successful secondary mission using the spacecraft's star tracker. WIRE began to study the oscillations in stars, releasing data that led to new scientific discoveries. WIRE continued to operate until the summer of 2011, when it returned to Earth. ●

BRYAN FAFAUL has worked at the Goddard Space Flight Center since 1986 in a variety of technical and management positions. He has served as the mission manager for the Wide-field Infrared Explorer; instrument systems manager for Hubble Space Telescope Servicing Missions 3A, 3B, and 4; deputy project manager for the National Polar-orbiting Operational Environmental Satellite System preparatory project; and project manager for Glory prior to his current position as the project manager for the Joint Polar Satellite System flight project.

Lessons from Lincoln

BY ROGER FORSGREN

Like most people, project managers and engineers may have an interest in history without realizing that understanding the past can help them better understand and manage the present. Studying the past can be an opportunity to see how leaders overcame daunting obstacles to achieve their goals.

We use recent history to guide our work. A doctor relies on a patient's history to chart future care, a lawyer reviews precedent to make a solid case, and an engineer studies a failure report or participates in a mishap review to improve a design.

Although economic, political, and cultural landscapes evolve over time, human nature remains the same. So history can shed light on how people act and react, how they win and lose, and how they lead others to do great things. As Niccolo Machiavelli noted, "Whoever wishes to foresee the future must consult the past; for human events ever resemble those of preceding times. This arises from the fact that they are produced by men who ever have been, and ever shall be, animated by the same passions, and thus they necessarily have the same results."

Even though he lived one hundred and fifty years ago, we can still learn from the actions of an extraordinary leader: Abraham Lincoln.

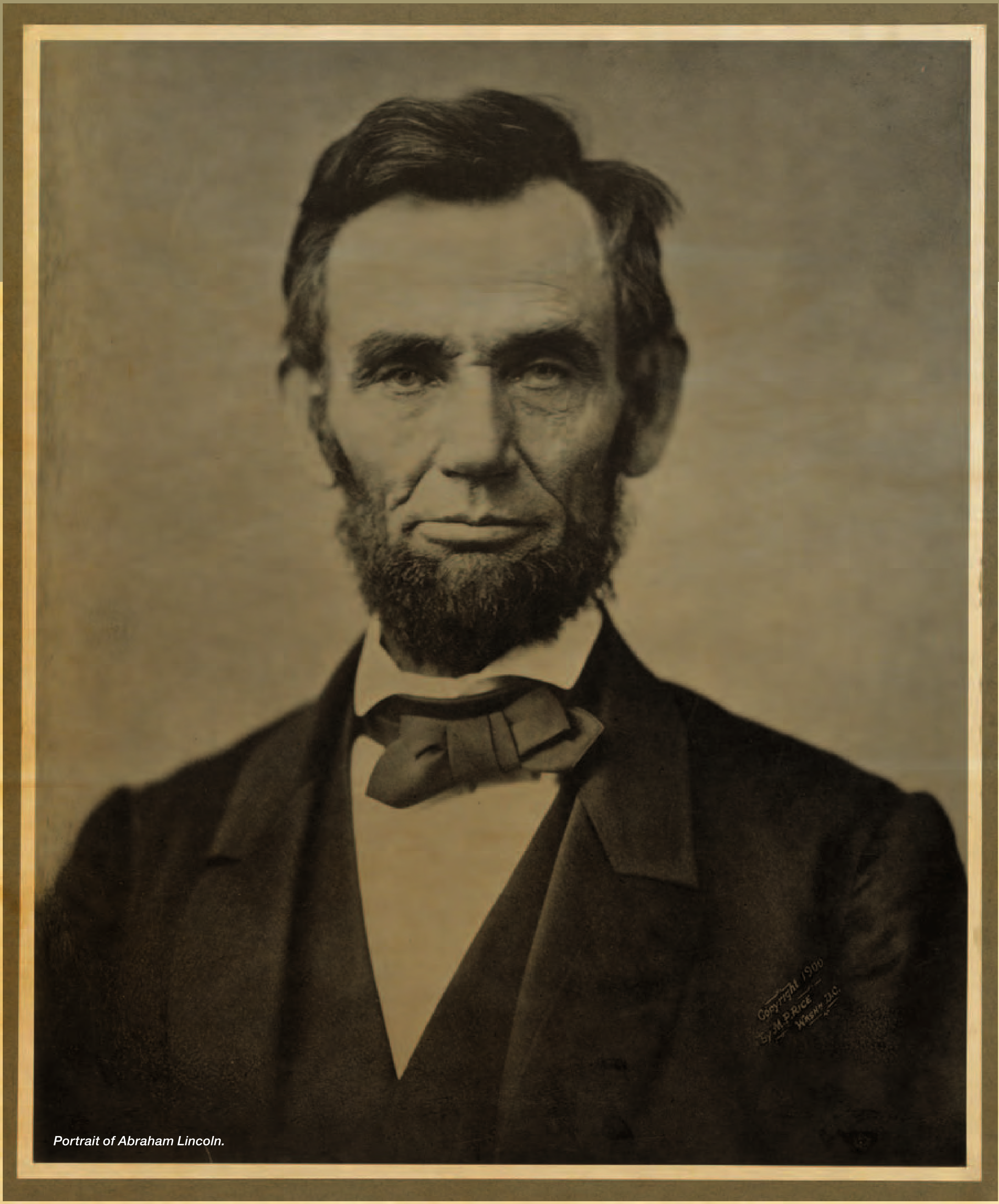
Lincoln lived in a fragile new nation that struggled with the dichotomy of its revolutionary pronouncement that "all men are created equal" while millions of men and women remained in bondage. He fought to sustain the democratic dream by preserving the Union and eventually freeing the slaves. His actions completed the American Revolution and finally fulfilled the promise of the Founding Fathers.

Lincoln had little political experience before becoming president, serving only one term as a congressman from Illinois, then losing the race for the U.S. Senate seat from Illinois to Stephen Douglas. His remarkable performance in debates with Douglas brought him national attention and paved the way to his nomination for the presidency from the newly formed Republican Party. Lincoln wasn't even on the ballot in nine of the southern states and won the presidency in 1860 with barely 40 percent of the popular vote. Before he was inaugurated, seven southern states seceded from the Union.

To the political professionals of both the Democratic and Republican parties, Lincoln appeared to be a country bumpkin woefully unprepared to tackle the question of slavery. He found himself dealing with the essential question inherent in the idea of a republic: can democracy survive partisanship and regional interests? The rebellion of the southern states seemed to confirm what the repressive monarchies of Europe had thought all along: that America's democratic experiment was naïve and destined for failure. Human nature was meant to be contained and controlled, not set free.

Lincoln understood human nature better than the career politicians who were dismissing him before he made the train journey to Washington for his inauguration. He knew he had to form a unified government to deal with the national crisis and selected cabinet members who would not only represent the interests of various states whose support he considered essential, but who were also in his opinion the most qualified to help him succeed. In doing so, he reached out to several former political opponents that had run against him for the Republican nomination.

William Henry Seward, the eminent senator from New York, had been considered the front-runner for the nomination but couldn't gather sufficient support from the most radical wing of the Republican Party to gain the nomination. Seward was the career politician who understood how Washington worked. He considered the new president inexperienced and ill prepared for the job that confronted him; furthermore, he assumed his appointment as secretary of state meant that



Portrait of Abraham Lincoln.

Photo Credit: Alexander Gardner/Library of Congress Prints and Photographs Division

BY USING A STRAIGHTFORWARD AND HONEST APPROACH, LINCOLN REPULSED AN ATTACK UPON HIS CONSTITUTIONAL POWERS BY THE RADICAL REPUBLICANS WITHOUT ANTAGONIZING HIS ACCUSERS AND WITHOUT FURTHER FRAGMENTING HIS DELICATE POLITICAL POSITION AS PRESIDENT.

Lincoln would cede presidential authority to him. A few months into the new administration, Seward realized he was mistaken. He learned to enjoy the president's down-home, straightforward style and admired the president's keen mind. In February of 1862, Seward watched his president and now friend remain steadfast to the cause and his work even as his son, Willie, died of tuberculosis in the White House. Rather than feeling animosity toward Lincoln for winning the nomination, he felt a kinship to this man who suffered so much in order to keep the Union together.

Salmon P. Chase had served as governor of Ohio and had recently been elected to the Senate. Lincoln needed the support of Ohio and also knew that Chase had a brilliant mind and was an accomplished administrator. Lincoln appointed Chase his secretary of the Treasury. The politically ambitious Chase was dumbfounded that he had lost to the backwater candidate from Illinois. Chase disdained Lincoln's unrefined and unpretentious style and never fully respected Lincoln's leadership.

By December 1862, the Civil War had dragged on for nearly two bloody years. The Union Army took a crushing blow from Robert E. Lee's Army of Northern Virginia at the Battle of Fredericksburg. As the endless procession of Union casualties were being carried back to Washington, Lincoln said, "If there is a place worse than hell, I am in it."

Not only was the Union split, but the North itself was fracturing into two irreconcilable camps: the Democratic Copperheads, who wanted to make peace with the South and allow them to secede, and the Radical Republicans, who wanted immediate emancipation of the slaves and were in open revolt against what they saw as Lincoln's mismanagement of the war effort. As the Copperheads began demanding an end to the killing, the Radical Republicans, furious over the Union defeat at Fredericksburg, began congressional hearings over the conduct of the war.

A lifelong abolitionist, Chase held close ties to the Radical Republicans and had been telling them for months that the North's misfortune was due to Seward's influence over

Image Credit: Published by Currier & Ives/Library of Congress Prints and Photographs Division

President Lincoln and his cabinet in council, September 22, 1862, adopting the Emancipation Proclamation.

Lincoln. He reinforced the idea that Lincoln was in over his head. Seward, he claimed, was not only leading the Union to defeat but was also responsible for Lincoln's protracted inaction in freeing the slaves.

The Radical Republicans began to demand Seward's resignation. In reality, Lincoln's primary concern was saving the democratic ideals of the nation by preserving the Union. To achieve that end, he was even willing to allow slavery to remain in the South as long as the southern states stayed in the Union and agreed not to let slavery spread. Lincoln hated slavery but believed it would naturally decline as economic forces made it unprofitable. He also found himself walking a political tightrope over the issue of emancipation because many of his own northern troops enlisted not to free the slaves but to keep the Union intact. Furthermore, Lincoln had to consider the crucial role played by the border states of Kentucky and Maryland. Either state might easily side with the South if they concluded that Lincoln was waging a war only to free the slaves.

Had Maryland sided with the South, Washington, D.C., would have been surrounded by hostile territory.

With Chase's scheming and intrigue egging them on, a majority of Republican senators demanded Seward's removal and a reorganization of Lincoln's cabinet. Rumors soon swept the capital that the cabinet was going to resign and that the president himself had decided to resign. Lincoln understood that the Radical Republicans were attempting to usurp his executive powers and were determined to take control of the war effort away from the duly elected commander in chief. He also knew that the political intrigue aimed at him was fostered by his own Treasury secretary.

The president, who had faced turmoil and derision since his election and had watched helplessly as his generals, through incompetence or refusing his orders, allowed the northern armies to be humiliated by smaller rebel forces, now faced the biggest test of his political power. As he revealed to a friend, "What do these men want? They wish to get rid of me, and I am sometimes half disposed to gratify them." Lincoln continued, "Since I heard last night of the proceedings of the caucus, I have been more distressed than by any event in my life … We are now on the brink of destruction. It appears to me that the Almighty is against us, and I can hardly see any ray of hope."

Seward offered Lincoln his resignation, hoping that might defuse the situation.

When a group of Republican senators arrived at the White House, Lincoln heard their complaints against Seward and their insistence that the war was being lost because of the secretary's influence on the president's decisions. Lincoln listened politely and then told the senators that he would take their advice under consideration. He invited them back to the White House for a second meeting the next day.

When they arrived the following day, they were surprised to be ushered into the room where the entire cabinet was seated. The cabinet members, including both Seward and Chase, were shocked to see the senators enter the room. Lincoln asked the senators to state their grievances in front of his cabinet. They

Photo Credit: Alexander Gardner/Library of Congress Prints and Photographs Division

Abraham Lincoln on the battlefield at Antietam, Maryland, October 3, 1862.

boldly repeated that the war was being mismanaged because Lincoln had failed to listen to the advice of his entire cabinet and was being manipulated and controlled by Seward.

Lincoln responded to the charges by stating that he listened to and thought carefully about any recommendation given to him by his cabinet ministers and, although he relied on their opinions, it was he alone who made the final decision. Lincoln then turned to his cabinet and asked each one of them to state publicly if they agreed with his statement. All eyes were fixed on Chase. The secretary of the Treasury squirmed in his chair before admitting that he agreed with the president's statement but added, in a feeble attempt to save face, that he wished major decisions could be more thoroughly discussed in the cabinet. The senators angrily left the White House, thoroughly disgusted with Chase's inability to stand up in public to those he accused in private.

The next morning a humiliated and chagrined Chase arrived at the White House with his letter of resignation. He told the president that the previous day's meeting had been a "total surprise" to him and that he "had been painfully affected by the meeting." Lincoln anxiously grabbed the document from Chase, who seemed surprised at the president's apparent eagerness to accept it.

The following day Lincoln informed both Seward and Chase that he would not accept their resignations. Lincoln never had any intention of accepting Seward's resignation. As for Chase, Lincoln hoped his lesson in humility would chasten his secretary of the Treasury because the president recognized Chase's ability and skill to keep the war effort funded. Lincoln wrote in his response to Chase that it was in the "public interest" that he remain at his post at Treasury and that he would not accept his resignation.

By using a straightforward and honest approach, Lincoln repulsed an attack upon his constitutional powers by the Radical Republicans without antagonizing his accusers and without further fragmenting his delicate political position as president.

Trying to lead in such desperate times meant that Lincoln had to gain the support and help of factions that he may not have agreed with. Lincoln *needed* the support of the Radical Republicans in Congress and also *needed* the expertise of his scheming secretary of the Treasury to hold the Union together. He was willing to take abuse and criticism as long as he controlled the situation and could move people and events toward a successful conclusion of the war and the preservation of the Union.

Lincoln's pragmatic approach to an insubordinate cabinet minister and the Radical Republicans managed to defuse a potential constitutional crisis concerning presidential authority, which would have subordinated his powers as president and commander in chief to a congressional caucus. Lincoln certainly faced bigger and more trying circumstances in his presidency, but this episode shows his brilliance in manipulating a dangerous situation to his advantage.

What lessons does this story offer to today's leaders and project managers? Here are a few of the important ones:

- Keep your eye on the ultimate goal and make decisions that will help you achieve it. Don't let your personal feelings or those of your team stand in the way.
- Favor open communication. Openness about what has been happening behind the scenes is a powerful tool.
- Don't be in a hurry to eliminate talented but difficult people. There may be ways to win their cooperation.

Note: The story of Lincoln's cabinet crisis comes from Doris Kearns Goodwin's excellent book, Team of Rivals.

ROGER FORSGREN is the deputy director of the NASA Academy of Program/Project and Engineering Leadership. He is responsible for the contractual and financial management of the entire Academy program, and has recently been responsible for developing new engineering courses that focus on foundational learning of NASA-specific engineering and space sciences; creative thinking and innovative engineering methodologies; and leveraging of invaluable knowledge from historical NASA lessons learned.

Something to Shout About

Bloodhound Supersonic Car

BY HALEY STEPHENSON

Photo Credit: Nick Haselwood

The full-size, full-length Bloodhound SSC show car unveiled at Farnborough in July 2010.

The Bloodhound Supersonic Car aims to set a new land-speed record and a new standard for openness in projects.

Project Director Richard Noble and his team are building a car that will go from 0 to 1,050 mph in 40 seconds. Named after Britain's 1950s Bloodhound Missile Project, the Bloodhound Supersonic Car (SSC) car is 12.8 meters long, weighs 6.4 tons, and cruises on high-grade aluminum wheels, which will experience radial stresses of up to 50,000 times the force of gravity at full speed.

The project is risky, dangerous, and unprecedented. Focused on building the safest car possible, Noble's Bloodhound team intends to overthrow the current FIA World Land-Speed Record by 30 percent. "It's such a huge leap, of course we're going to get into trouble," said Noble. "We're going to learn an awful lot as we develop it."

World records aside, the team wants to capture the attention of students and inspire a new generation of engineers.

Genesis

In 1898, French driver Gaston de Chasseloup-Laubat set the world land-speed record at 39 mph. Fast-forward to 1970 when, after decades of battle between the Americans and British, an American-built car called Blue Flame set a new record of 630 mph. "We in Britain were very keen to get it back again," said Noble. "Or, at least, I was," he laughed.

Noble assembled a team to build a new car, Thrust2. With Noble literally in the driver's seat, Thrust2 set a new record of 634 mph in 1983, sparking a race for the sound barrier.

Building and modeling cars intended to travel upward of 600 mph was difficult, dangerous, and nearly impossible. Noble had pushed the limits with Thrust2. "The [aerodynamic] data was varied and not reliable," said Noble. What designers needed was a transonic wind tunnel with a sort of car treadmill capable of speeds up to 900 mph, he explained. It didn't exist.

With competitors already at work, Noble decided to throw his hat into the Mach 1 race with Thrust SSC. This time around, Chief Aerodynamicist Ron Ayers insisted on modeling the car. Software programs in the early 1990s facilitated new ways of using computational fluid dynamics (CFD) to model Thrust SSC, but Ayers wanted to confirm their results. The team went to a long rocket test track, normally used for accelerating warheads up to Mach 3 and slamming them into slabs of concrete, and used a modified rocket sled to test their CFD data. They ran thirteen tests of their car. "Amazingly, we found there was just a 4 percent variation in the data," said Noble. This proved that the car was safe and viable.

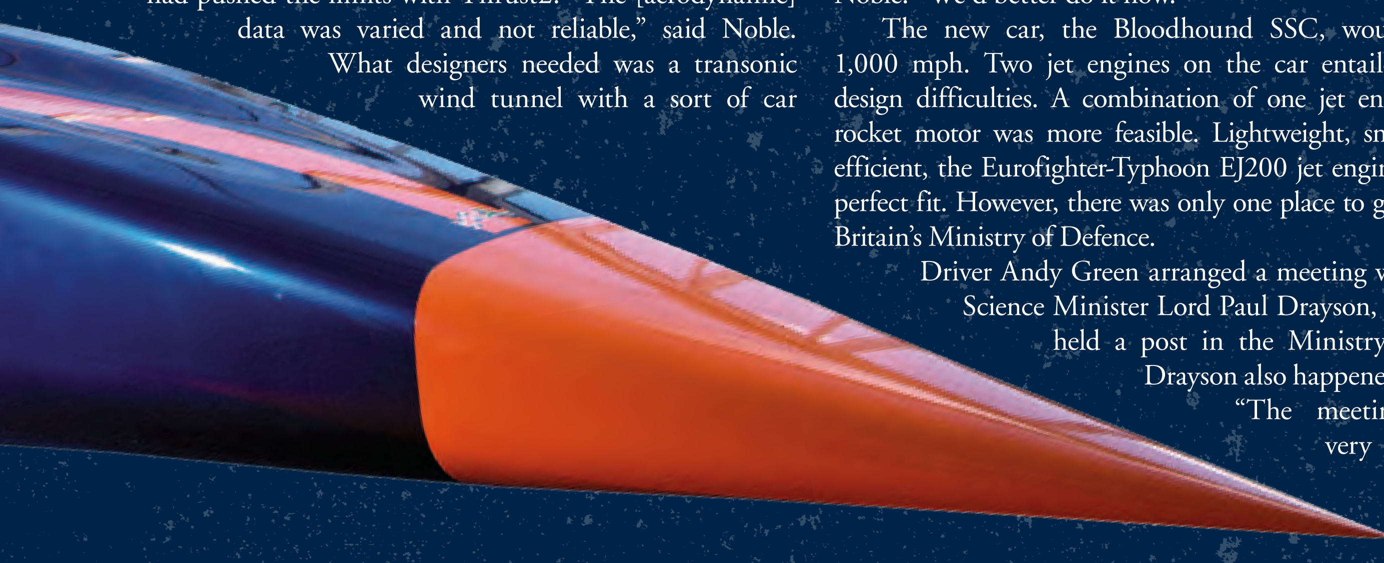
In 1997, Thrust SSC went supersonic five times in the Black Rock Desert of Nevada. Fifteen miles away in the town of Gerlach, the sonic boom knocked the covers off a classroom sprinkler system. "We all said that we would never, ever do this again," said Noble. Little did they know they weren't done—with building supersonic cars or rattling educational establishments.

Meeting with the Minister

After Thrust SSC's run, the late Steve Fossett, a world-renowned aviator and sailor, expressed an interest in overtaking the new speed record. If they waited, Noble and his team would spend five years studying how Fossett bested them, and then another six years building a defender. "We all looked at each other, got slightly grey-haired, and decided eleven years was too long," said Noble. "We'd better do it now."

The new car, the Bloodhound SSC, would shoot for 1,000 mph. Two jet engines on the car entailed too many design difficulties. A combination of one jet engine and one rocket motor was more feasible. Lightweight, small, and fuel efficient, the Eurofighter-Typhoon EJ200 jet engine would be a perfect fit. However, there was only one place to get the engine: Britain's Ministry of Defence.

Driver Andy Green arranged a meeting with then-UK Science Minister Lord Paul Drayson, who formerly held a post in the Ministry of Defence. Drayson also happened to race cars. "The meeting remained very friendly until



DURING THE 1960s, THERE HAD BEEN A NEW AIRPLANE EVERY YEAR, WHICH GOT KIDS EXCITED AND MOTIVATED THEM TO BECOME ENGINEERS. DRAYSON TOLD NOBLE AND GREEN THAT WAS THE GOAL: THEY COULD HAVE THEIR ENGINE IF THEY AGREED TO START AN EDUCATION PROGRAM WITH THEIR PROJECT.

I asked him for the jet engine," Noble chuckled. Sensing they had failed dismally, they started to retreat from the room.

"Then Drayson said something that changed all of our lives," said Noble. "He said, 'Look, there's something you could do for us.' I said, 'Of course, Minister, what can we do for you?'" Drayson explained that the Ministry of Defence was having a problem recruiting engineers. There didn't seem to be any in Britain anymore. During the 1960s, there had been a new airplane every year, which got kids excited and motivated them to become engineers. Drayson told Noble and Green that was the goal: they could have their engine if they agreed to start an education program with their project.

Noble agreed and shook Drayson's hand. "We walked out of his office intent on setting up an enormous education program, which we knew nothing about," Noble said.

Engineering: A Dead Subject?

Noble's team went to work researching the state of education in Britain. "We found all sorts of terrible things were happening," he said. Britain's skilled workforce was on the decline, its students were sliding in international rankings, and the country's information technology sector was dismal. They needed to create an Apollo effect—to inspire people to change their lives because of this project.

With their posters and a model of the car, the Bloodhound team attended education exhibitions across the country, talking to as many STEM (science, technology, engineering, and mathematics) teachers as they could. Their conversations went something like this:

> "What's it like teaching STEM?"
>
> "Absolutely awful. It's an absolute nightmare. The kids aren't interested. They are very arrogant. All they think they need to know how to do is add, subtract, and work percentages."
>
> "Sounds pretty bad."
>
> "It's like teaching ancient Latin or Greek. You know, dead subjects."

Their conversations proved enlightening. "We needed to do something exciting," said Noble, "but above all, we had to be able to share the information." If they were going to educate Britain, teachers needed to be able to understand the charts, models, and drawings so they could make new lesson plans and explain it to their students. Every aspect of the project had to be accessible.

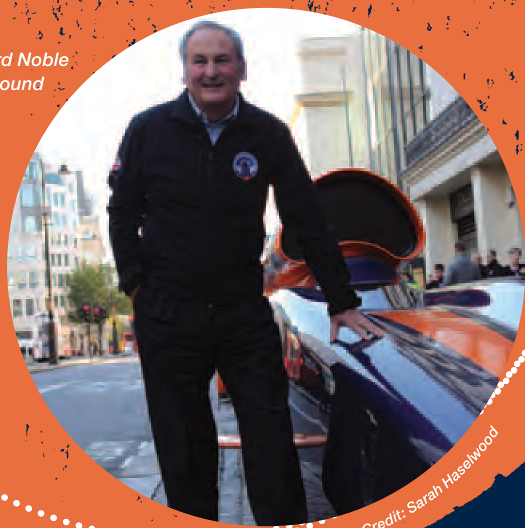
This lack of secrecy initially worried the Bloodhound team. Then they realized that their fears were unnecessary. The only rules for the land-speed record are that the car must have at least four wheels and be controlled by the driver. "All of the cars and all of the challengers are completely different," said Noble. "The technology simply won't transfer from one competitor to another. We realized that we could make all of the data available. Absolutely everything."

Nitrous Oxide: Not So Funny

The Bloodhound team is blazing a new trail. They still have many challenges to overcome but have learned a great deal so far. One particular lesson came from choosing the oxidizer for their hybrid rocket motor. The team thought it had an easy answer: nitrous oxide (N_2O). Safe, reliable, and easily accessible, N_2O seemed a sensible choice. Not so, warned one of Noble's peers—N_2O is not to be trifled with.

Noble investigated the claim. After scouring the web, his team found a paper from 1936 that explained how pressurizing N_2O beyond 13 bar (or about 190 psi) could cause an explosion. "Whole plants had been taken out by nitrous oxide explosions," explained Noble. Nitrous was also the culprit in a 2007 Scaled Composites explosion that killed three people. The Bloodhound team was shocked.

They selected high-test peroxide (HTP) as an alternative that is less likely to set off an explosion. Testing with smaller rockets has been successful, with the rocket motor running



Project Director Richard Noble stands with the Bloodhound SSC show car outside Coutts Bank in The Strand, London.

Photo Credit: Sarah Haselwood

Photo Credit: Flow Images

The Bloodhound SSC show car at the Bloodhound Technical Center.

at 98 percent catalyst efficiency. The team is currently doing testing on the full-scale motor.

The Team: Grey to Green

Chief Rocket Engineer Daniel Jubb worked the N_2O problem. He joined the Bloodhound team in 2005 when he got a call from Noble for a meeting. Highly recommended by several seasoned rocket engineers, Noble drove out to Manchester to meet Jubb. "I discovered that I was face to face with a guy who was twenty-three," said Noble.

From Jubb to Ayers (who is in his eighties), Noble respects the importance of having a generationally diverse team. Typically, young engineers only see one part of a project. Rarely do they see the whole life cycle. "Getting the overview perspective is very, very important," said Noble. The project is demanding but offers young engineers (the youngest is eighteen) the opportunity to gain tremendous experience and acts as a stepping stone to a future career.

"It's very important from our point of view to use as many young people as we possibly can," said Noble. He finds the younger generation's rapport with technology enormously useful. "But, of course, they've got to be able to contribute to the project," he said. The flat structure of the Bloodhound organization facilitates this. Everyone has his or her own set of responsibilities and authorizations, and everyone in the organization is empowered. "Anyone can go fail the project if they wanted to," said Noble. "One would think this is some sort of undisciplined rabble, but it's certainly not.

"You end up with a very, very fast-moving, highly motivated organization and, therefore, can do [great things] on very small sums of money," he continued. (Thrust SSC was completed for £2.4 million, 12 percent of what their competitors budgeted.)

Something Incredibly Wonderful Will Happen

Partway through the project, Noble and his team realized there was a flaw in their openness plan. "If we were going to put up all of the operational data after each run on the web, we'd have to be very clever about the way we actually presented it," said Noble. "Unless people were given the appropriate education, they wouldn't understand the data. It would just be numbers to them, and they wouldn't really be able to take part in the program."

Taking the lead from the highly successful Khan Academy, Noble partnered with Southampton University to develop educational tools the public will need to engage with the Bloodhound SSC data flow. Today there are 4,600 schools in Britain and 207 countries worldwide participating in the Bloodhound engineering adventure, as the team preps for their 2013 run in South Africa. Via the Bloodhound SSC web site, anyone can be a part of the project through games, videos, pictures, explanations of the car elements, drawings, and blog posts from Noble. Just months ago, the team posted a suite of forty computer-aided design drawings online to help people understand how the car was designed and built. There have been approximately 2,500 downloads of the drawings.

"It might well be that someone makes a [copy], which would be brilliant," chuckled Noble. "We could race!" ●

Richard Noble and Andy Green with a model of Bloodhound SSC.

Photo Credit: Bloodhound SSC

The Knowledge Notebook

Networks and Success

BY LAURENCE PRUSAK

Every once in a while, some U.S. or other government agency or a nongovernmental organization issues a report that is actually very useful and—dare I say it—even startling in its implications.

This happened recently with the release of *Networks for Prosperity*, a report by UNIDO, the United Nations Industrial Development Organization, which is a division of the United Nations that focuses on more commercial issues than the larger organization. This report is far more interesting and important than the usual sort of statistical or analytical presentations that emerge from the consensus-style development discussions that are usually the norm for such organizations.

For one thing, it actually ranks countries by the degree of their connectedness through knowledge networks. Using three indices of international, interorganizational, and intraorganizational networks, the report aggregates these numbers to produce a general index that ranks Switzerland as the most highly connected country. Sweden and Holland are next. The United States comes in fourth. These top four are followed by the "usual suspects" of Europe and Asia. African and Central Asian countries are the laggards. These rankings are then correlated with the general economic success of the nations as shown by per-capita gross domestic product. Not surprisingly, the results are highly correlated. Prosperity and connectedness go together.

The report is not just a collection of measures and graphs but has many stories and short cases demonstrating just how this network–wealth equation works in practice. Real-life examples like these are also rare in such reports and add to the value of this one. They help make the point that purposeful connections actually contribute to (and don't just accompany) prosperity.

If this is true for nations, it is just as true, as I see it, for organizations and individuals.

I would like to stress the word "purposeful" here. Just being connected to anyone for any reason (or no particular reason) has little value beyond feeding narcissism. The huge focus on social media, and especially on the quantity of connections (the hundreds or thousands of "friends" one has, the number of views of a video or blog), is far less important than subtler questions of what is being shared with whom, and to what end. As the UNIDO report states, "Successful knowledge sharing depends less on specific IT [information technology] platforms and more on interests and incentives." I would have added the word "identity" to that sentence, but its meaning is still pretty apparent. It's not the technology but the "what" and "why" and "who" of connections that matter.

Imagine for a moment such a report about particular government agencies and corporations. How do you think your organization would rank? Do many government workers seek to join or build knowledge networks in their spheres of interest? Do executives in commercial organizations spend a lot of time and effort creating networks of peers and advisors?

And if not, why not?

I believe that far less of this sort of thing happens than should because, for all our talk of teamwork and knowledge sharing, many of us—at least in the Anglo-American culture—still adhere to an individualistic form of knowledge development. We tend to think of ourselves as self-sufficient knowledge engines who can reach our goals without much help from anyone and with no more additional information and knowledge than what we can find through Google. There has long been a sort of intellectual "machismo" to going it alone. The Westinghouse Corporation had this idea embedded in their culture. They rarely asked consultants or professors to bring them new ideas because they thought they knew all they needed to know. They had a very early lead in many technologies, but they ran out of steam because they never went outside to "refuel" with external knowledge. General Electric, founded the same year, has always looked for new theories, thoughts, models, and patents wherever they could find them. General Electric is of course still sitting high atop the Fortune 500 list.

In our own time, because of the astounding ubiquity and cheapness of information technologies, networks clearly have become the most important source of new ideas for countries, organizations, and individuals. To be isolated from the networks in one's own interest area is a self-defeating strategy. And these networks are not only sources of new knowledge. As the UNIDO report so well puts it, "Knowledge networking is about building trust, dialogue, and collaboration across sectors and borders." In other words, these networks provide valuable help and support of many kinds.

So spend some time, effort, money, and energy building, joining, and taking part in networks that are sustaining and valuable to you. There is no better way for you to thrive in our new, vastly interconnected world. ●

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ASK interactive

NASA in the News

NASA's Kepler mission has confirmed its first discovery of a planet in the "habitable zone," the region where liquid water could exist on a planet's surface. The newly confirmed planet, Kepler-22b, is located 600 light-years away and, at about 2.4 times Earth's radius, is the smallest yet found to orbit in the habitable zone of a star similar to our sun. Scientists don't yet know if Kepler-22b has a predominantly rocky, gaseous, or liquid composition, but its discovery is a step closer to finding Earth-like planets. Learn more about this discovery and Kepler's mission at www.nasa.gov/mission_pages/kepler.

NASA Radio

NASA's new custom-produced Internet radio station, Third Rock – America's Space Station, seeks to reach tech-savvy young adults. "NASA constantly is looking for new and innovative ways to engage the public and inspire the next generation of scientists and engineers," said David Weaver, associate administrator for the Office of Communications at NASA Headquarters. Third Rock will also help partner companies fill job openings in the engineering, science, and information technology fields. In addition to the NASA web site, the station will be available in the future at the radio tab of Apple's iTunes and on other sites as well as through NASA iPhone and Droid mobile apps. Listen now at www.rfcmedia.com/thirdrockradio.

Next-Generation Spacesuits

PBS's *NOVA scienceNOW* investigates what it takes to make spacesuits less bulky for future space travel. Featuring an introduction by Neil deGrasse Tyson and interviews with NASA astronaut Mike Massimino and Dava Newman from the Massachusetts Institute of Technology, the episode explores what today's spacesuits are like and how they could evolve to make space exploration more manageable. Watch the episode online at video.pbs.org/video/1741682176.

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