National Aeronautics and Space Administration

Academy Sharing Knowledge

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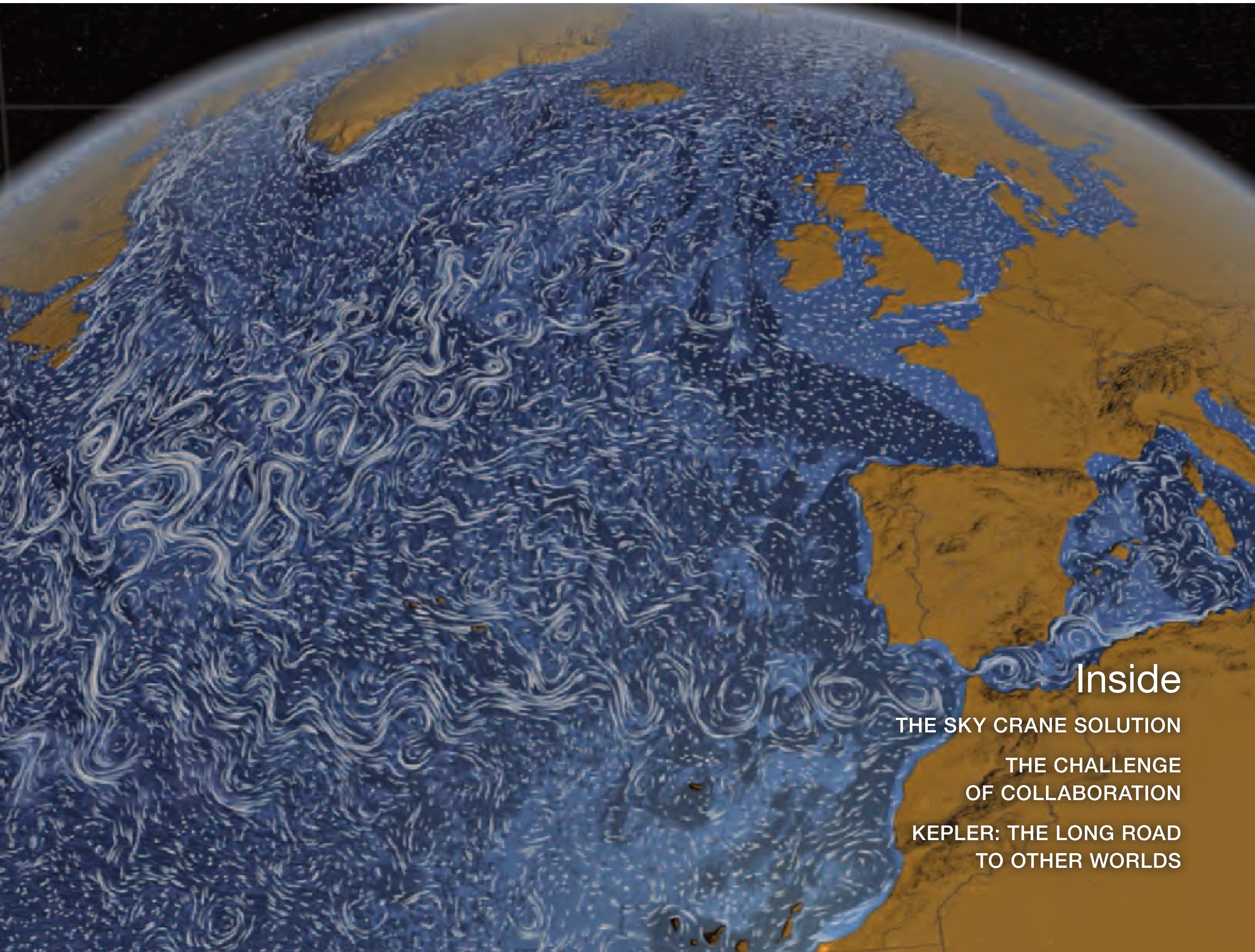
SUMMER | 2012



Inside


Photo Credit: NASA/Goddard Space Flight Center
Scientific Visualization Studio

ON THE COVER

This visualization shows ocean surface currents around the world during the period from June 2005 through December 2007, produced using model output from the joint Massachusetts Institute of Technology (MIT)/Jet Propulsion Laboratory project: Estimating the Circulation and Climate of the Ocean, Phase II, or ECCO2. ECCO2 uses the MIT general circulation model to synthesize satellite and *in-situ* data of the global ocean and sea-ice at resolutions that begin to resolve ocean eddies and other narrow current systems, which transport heat and carbon in the oceans. ECCO2 provides ocean flows at all depths, but only surface flows are used in this visualization.

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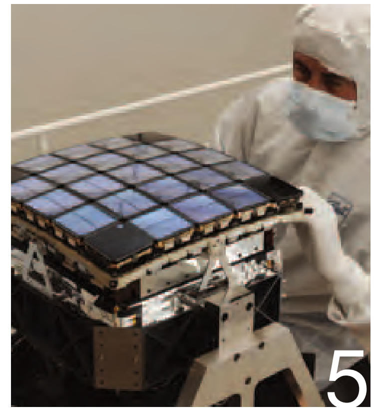

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ask

Issue No. 47

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

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

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

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In This Issue

In his “From the Academy Director” column, Ed Hoffman argues that political and social skills are essential to carrying out ambitious projects. “Politics” often has a negative connotation; “playing politics” suggests doing or saying anything for personal or party advantage while pretending to act on principle. But Otto von Bismarck called politics “the art of the possible,” and Hoffman would agree. Political skill involves understanding where power and influence reside and knowing how to gain the support of those powerful and influential individuals and groups. Those abilities can be used for unworthy purposes, of course, but they are also necessary to achieve valuable goals, like launching a new telescope that will help us understand the origins of the universe.

Or cooperatively building a space station used for technological and scientific research by the space agencies of the United States, Europe, Japan, Canada, and Russia. In “The Challenge of Cooperation,” Lyn Wigbels recalls the long negotiations that turned a distant possibility into an international project. Understanding and respecting the varied needs and concerns of all the governments and agencies involved required significant political skill. Keith Woodman and Paul Krasa’s “Is Your Project Viable?” is also partly a story about political skill, since it identifies understanding and adapting to changes in the environment outside the project as essential to project survival. Political *awareness* (for instance, recognizing the limits of financial support) is important.

The social skills Hoffman discusses have a political dimension—connecting with people to gain their support—but social skills are also needed to acquire the technical and procedural knowledge that difficult projects demand. ”Knowledge Topics: A Vital Project Resource” considers the role of social capital in project success. The personal networks of trusted colleagues that team members go to for help and advice—their social capital—give them access to expertise that cannot be readily acquired in any other way. Knowledge, especially subtle, experiential knowledge, can be most effectively shared by people who have a relationship characterized by trust and mutual understanding. That is why this article is the first in a series of “Knowledge Topics” we will feature in *ASK*: articles that focus specifically on how knowledge is developed and shared.

In “The People Behind the NASA Engineering Network,” Manson Yew illustrates this social-capital principle, showing how the agency’s online engineering communities thrive when their members connect in a variety of ways, including in face-to-face meetings that build relationships that make effective electronic exchanges possible.

Virtually every NASA story is at least in part a story of trust-based collaboration. Helen-Nicole Kostis describes how colleagues help one another in the open environment of the Scientific Visualization Studio in “Scientific Visualization: Where Art Meets Science and Technology.” And “The Sky Crane Solution” tells the story of the massive collaboration necessary to solve the problem of landing the Mars Science Laboratory. In Rob Manning’s opinion, “Only Apollo and shuttle have brought NASA together to this extent.”

“Kepler: The Long Road to Other Worlds” shows the knowledge, social and political skill, and persistence sometimes needed to carry out a mission successfully. Scientists literally spent decades developing technologies, overcoming rejection, and winning the support of skeptics to build and launch the telescope now discovering planets orbiting distant stars.

Don Cohen
Managing Editor

From the Academy Director

Projects Built Around People and Networks

BY ED HOFFMAN

What is the most likely culprit in failures to meet grand societal challenges? How do we understand and address the increasing complexity of missions? To rephrase those questions in more general terms: What poses the greatest risk to projects?

A lot of observation and reading seems to suggest that project risk exists within the boundaries of technology, cost, and time. Certainly this is how professional project managers are schooled. The project management profession equips its practitioners with the competence to rationally manage technical, schedule, and cost risks. Project management literature and training focus extensively on those areas.

Yet it seems increasingly obvious that the most likely cause of project death is the social dimension.

Look at the complexities that projects encounter. Technical innovation and the interdependencies among technologies lead to technical complexity that can influence budget and schedule. But project teams have a relatively sophisticated set of tools and training to deal with technical issues. Organizational complexity stems from the interactions of the larger project team, including partners and suppliers. Strategic complexity resides in the project's sociopolitical context, and primarily concerns stakeholders and funding. Projects today experience the dramatic and constant pressure of social and political demands—compromised cost estimates resulting from the need to win support, complicated partnerships, challenges from external budgetary and political stakeholders, and changes in popular support.

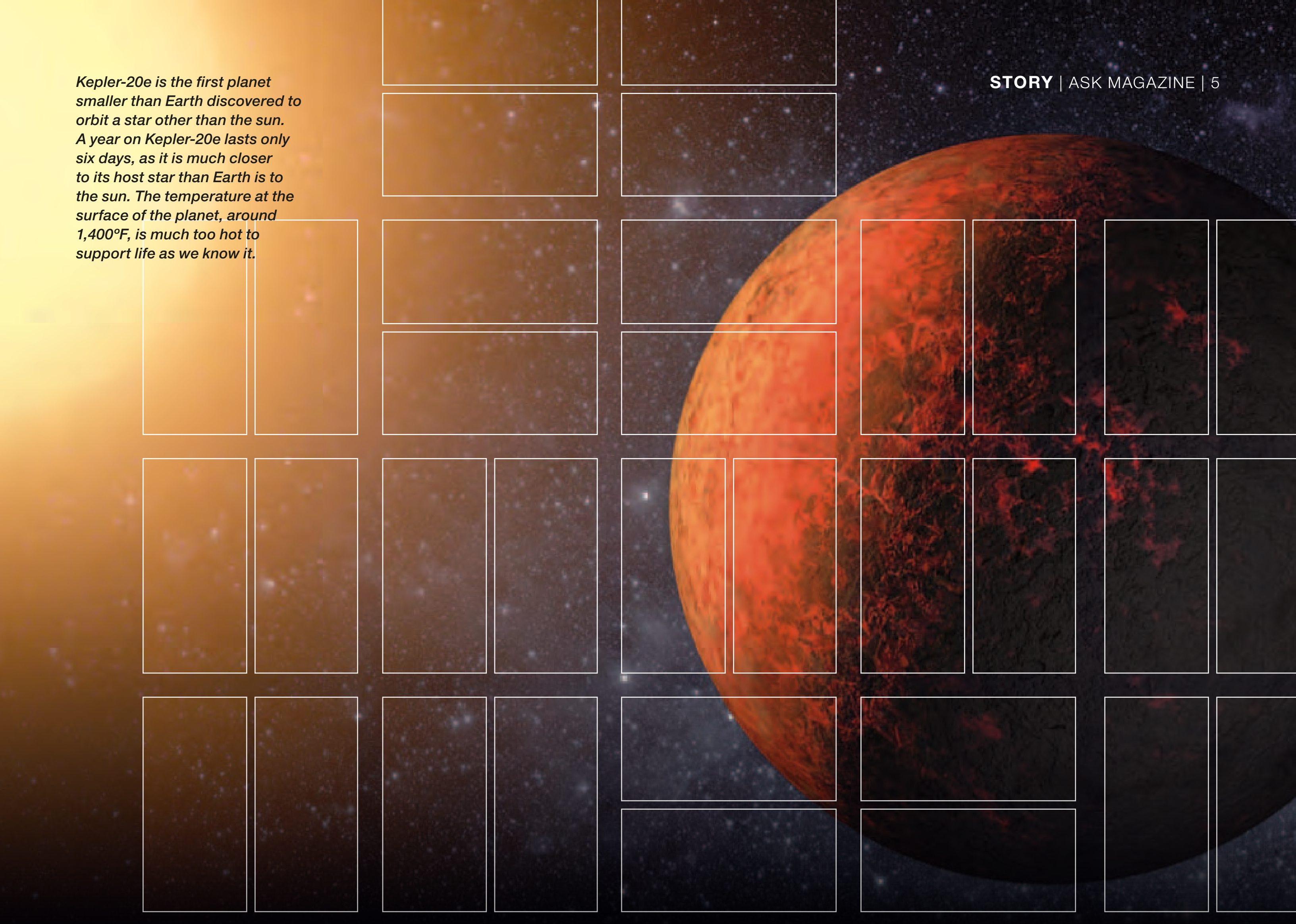
There are many people in many positions who determine whether a program lives or dies, but the field of project management largely ignores all but the technical and cost factors.

In a May 10, 2012, *New York Review of Books* article, Steven Weinberg warns of the demise of big science projects largely because of these factors. He points to increasing challenges to large programs such as the (canceled) Superconducting Super Collider, the James Webb Space Telescope, and the International Space Station and concludes that "big science" is entering a period of crisis. The same challenges affect every large project that relies on continuing public and political support.

We have entered a world that demands social, strategic, and political sophistication. It is not enough to sell a project once and assume it will survive, and not enough to address only technical, cost, and schedule issues.

Instead, projects—whether in science, exploration, construction, or the Olympic Games—need to have a strong social network of people committed to their conception, design, development, implementation, and conclusion. Organizations, leaders, and teams in the business of creating and delivering large-scale projects will need to recognize that social risk has become the biggest project risk, and that a critical part of their job is generating and maintaining a large community of people who follow and support their missions.

Social skills are needed to gather multidisciplinary knowledge and expertise that is distributed around the world. Necessary social skills also include effective communication to inform and educate a diverse stakeholder community. Overcoming the social risks projects face calls for widespread efforts to transform projects from circumscribed communities to networks of advocates involving both internal team members and a broader audience of external stakeholders. ●



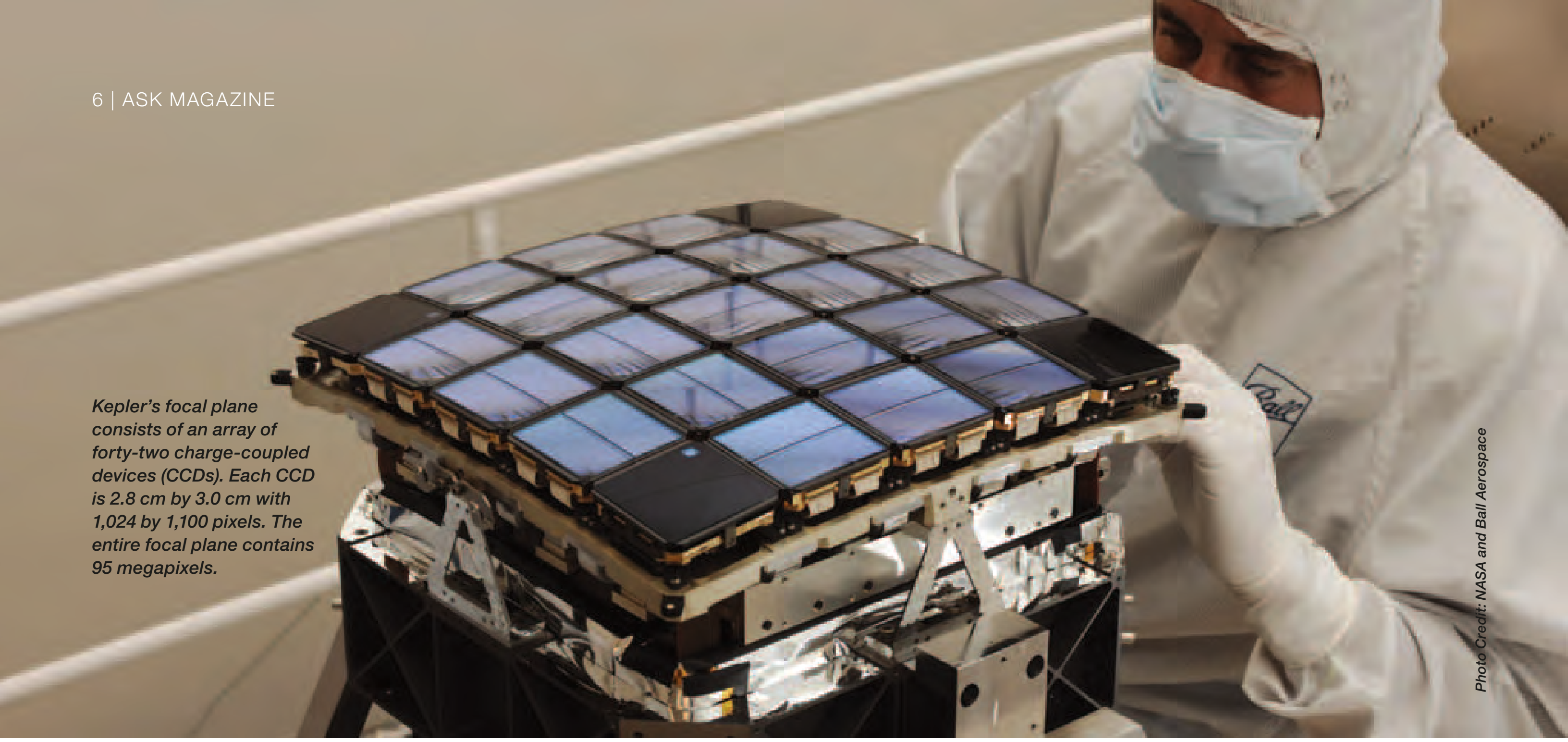
Kepler-20e is the first planet smaller than Earth discovered to orbit a star other than the sun. A year on Kepler-20e lasts only six days, as it is much closer to its host star than Earth is to the sun. The temperature at the surface of the planet, around 1,400°F, is much too hot to support life as we know it.

Image Credit: NASA/Ames/JPL-Caltech

KEPLER: THE LONG ROAD TO OTHER WORLDS

BY KERRY ELLIS

Navigating to alien planets similar to our own is a universal theme of science fiction. But how do our space heroes know where to find those planets? And how do they know they won't suffocate as soon as they beam down to the surface? Discovering these Earth-like planets has taken a step out of the science fiction realm with NASA's Kepler mission, which seeks to find planets within the Goldilocks zone of other stars: not too close (and hot), not too far (and freezing), but just right for potentially supporting life. While Kepler is only the first step on a long road of future missions that will tell us more about these extrasolar planets, or exoplanets, its own journey to launch took more than twenty years and lots of perseverance.



Kepler's focal plane consists of an array of forty-two charge-coupled devices (CCDs). Each CCD is 2.8 cm by 3.0 cm with 1,024 by 1,100 pixels. The entire focal plane contains 95 megapixels.

Looking for planets hundreds of light-years away is tricky. The stars are very big and bright, the planets very small and faint. Locating them requires staring at stars for a long time in hopes of everything aligning just right so we can witness a planet's transit—that is, its passage in front of its star, which obscures a tiny fraction of the star's light. Measuring that dip in light is how the Kepler mission determines a planet's size.

The idea of using transits to detect extrasolar planets was first published in 1971 by computer scientist Frank Rosenblatt. Kepler's principal investigator, William Borucki, expanded on that idea in 1984 with Audrey Summers, proposing that transits could be detected using high-precision photometry. The next sixteen years were spent proving to others—and to NASA—that this idea could work.

Proving Space Science on the Ground

To understand how precise "high-precision" needed to be for Kepler, think of Earth-size planets transiting stars similar to our sun, but light-years away. Such a transit would cause a dip in the star's visible light by only 84 parts per million (ppm). In other words, Kepler's detectors would have to reliably measure changes of 0.01 percent.

Borucki and his team discussed the development of a high-precision photometer during a workshop in 1987, sponsored by Ames Research Center and the National Institute of Standards and Technology, and then built and tested several prototypes.

When NASA created the Discovery Program in 1992, the team proposed their concept as FRESIP, the Frequency of Earth-Size Inner Planets. While the science was highly rated, the proposal was rejected because the technology needed to achieve it wasn't believed to exist. When the first Discovery announcement of opportunity arose in 1994, the team again proposed FRESIP, this time as a full mission in a Lagrange orbit.

This particular orbit between Earth and the sun is relatively stable due to the balancing gravitational pulls of Earth and the sun. Since it isn't perfectly stable, though, missions in this orbit require rocket engines and fuel to make slight adjustments—both of which can get expensive. Reviewers again rejected the proposal, this time because they estimated the mission cost to exceed the Discovery cost cap.

The team proposed again in 1996. "To reduce costs, the project manager changed the orbit to heliocentric to eliminate the rocket motors and fuel, and then cost out the design using three different methods. This time the reviewers didn't dispute the estimate," Borucki explained. "Also at this time, team members like Carl Sagan, Jill Tarter, and Dave Koch strong-armed me into changing the name from FRESIP to Kepler," he recalled with a laugh.

The previous year, the team tested charge-coupled device (CCD) detectors at Lick Observatory, and Borucki and his colleagues published results in 1995 that confirmed CCDs—combined with a mathematical correction of systematic errors—had the 10-ppm precision needed to detect Earth-size planets.

But Kepler was rejected again because no one believed that high-precision photometry could be automated for thousands of stars. "People did photometry one star at a time. The data analysis wasn't done in automated fashion, either. You did it by hand," explained Borucki. "The reviewers rejected it and said, 'Go build an observatory and show us it can be done.' So we did."

They built an automated photometer at Lick Observatory and radio linked the data back to Ames, where computer programs handled the analysis. The team published their results and prepared for the next Discovery announcement of opportunity in 1998.

"This time they accepted our science, detector capability, and automated photometry, but rejected the proposal because

THE SCIENCE MERIT FUNCTION THAT BILL DEVELOPED WAS A BRIDGE BETWEEN THE SCIENCE AND ENGINEERING THAT WE USED IN DOING THESE KIND OF TRADE STUDIES …

we did not prove we could get the required precision in the presence of on-orbit noise, such as pointing jitter and stellar variability. We had to prove in a lab that we could detect Earth-size transits in the presence of the expected noise," said Borucki.

The team couldn't prove it using ground-based telescope observations of stars because the atmosphere itself introduces too much noise. Instead, they developed a test facility to simulate stars and transits in the presence of pointing jitter. A thin metal plate with holes representing stars was illuminated from below, and a prototype photometer viewed the light from the artificial stars while it was vibrated to simulate spacecraft jitter.

The plate had many laser-drilled holes with a range of sizes to simulate the appropriate range of brightness in stars. To study the effects of saturation (very bright stars) and close-together stars, some holes were drilled large enough to cause pixel saturation and some close enough to nearly overlap the images.

"To prove we could reliably detect a brightness change of 84 ppm, we needed a method to reduce the light by that amount. If a piece of glass is slid over a hole, the glass will reduce the flux by 8 percent—about one thousand times too much," Borucki explained. "Adding antireflection coatings helped by a factor of sixteen, but the reduction was still sixty times too large. How do you make the light change by 0.01 percent?

"There really wasn't anything that could do the job for us, so we had to invent something," said Borucki. "Dave Koch realized that if you put a fine wire across an aperture—one of the drilled holes—it would block a small amount of light. When a tiny current is run through the wire, it expands and blocks slightly more light. Very clever. But it didn't work."

With a current, the wire not only expanded, it also curved. As it curved, it moved away from the center of a hole, thereby allowing more light to come through, not less.

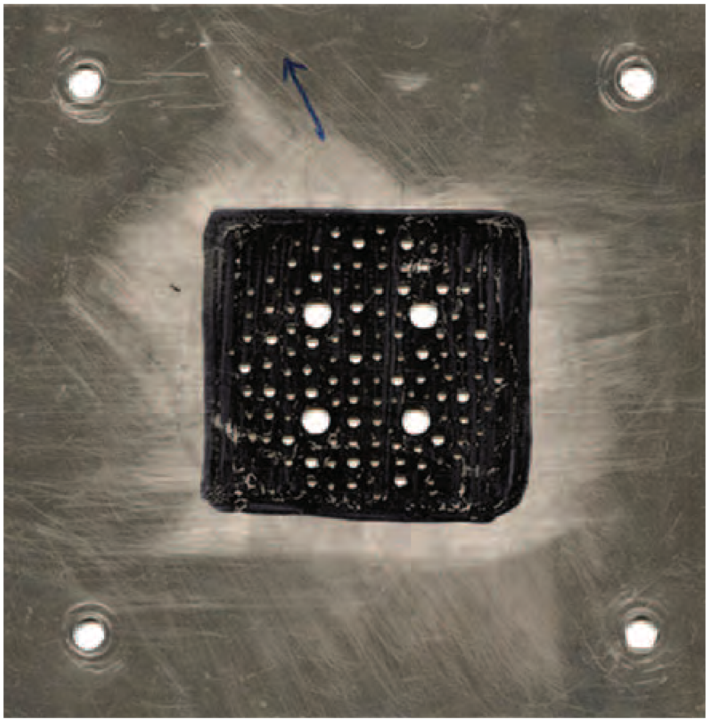
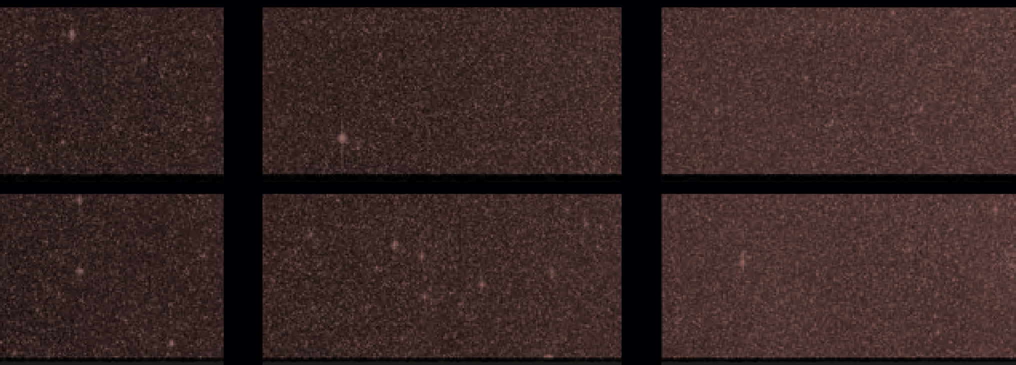


Photo Credit: NASA/Kepler Team

This star plate is an important Kepler relic. It was used in the first laboratory experiments to determine whether charge-coupled devices could produce very precise differential photometry.



A single Kepler science module with two CCDs and a single field-flattening lens mounted onto an Invar carrier. Each of the twenty-one CCD science modules are covered with lenses of sapphire. The lenses flatten the field of view to a flat plane for best focus.

Photo Credit: NASA/Kepler Mission

"So Dave had square holes drilled," said Borucki. "With a square hole, when the wire moves off center, it doesn't change the amount of light. To keep the wire from bending, we flattened it." The results demonstrated that transits could be detected at the precision needed even in the presence of on-orbit noise.

After revising, testing, publishing, and proposing for nearly twenty years, Kepler was finally approved as a Discovery mission in 2001.

Engineering Challenges

After Kepler officially became a NASA mission, Riley Duren from the Jet Propulsion Laboratory joined the team as project systems engineer, and later became chief engineer. To help ensure a smooth progression, Duren and Borucki set out to create a common understanding of the scientific and engineering trade-offs.

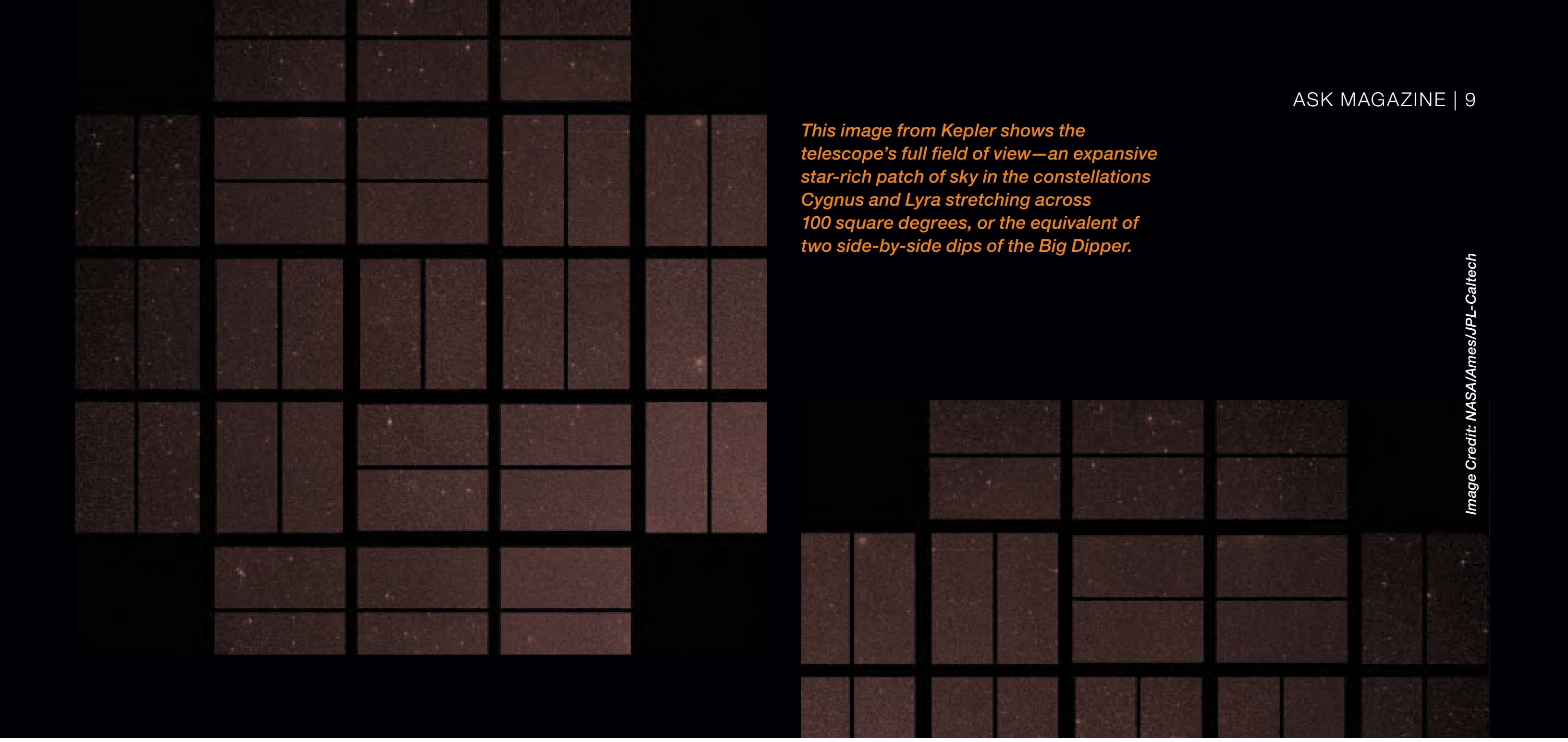
"One of the things I started early with Bill and continued throughout the project was to make sure that I was in sync with him every step of the way, because, after all, the reason we're building the mission is to meet the objectives of the science team," said Duren. "It was important to develop an appreciation for the science given the many complex factors affecting Kepler mission performance, so early on I made a point of going to every science team meeting that Bill organized so I could hear and learn from the science team."

The result was something they called the science merit function: a model of the science sensitivity of mission features—the effects on the science of various capabilities and choices. Science sensitivities for Kepler included mission duration, how many stars would be observed, the precision of the photometer's light measurements, and how many breaks for data downlinks could be afforded. "Bill created a model that allowed us to communicate very quickly the sensitivity of the science to the mission," explained Duren, "and this became a key tool for us in the years that followed."

The science merit function helped the team determine the best course of action when making design trade-offs or descope decisions. One trade-off involved the telecommunications systems. Kepler's orbit is necessary to provide the stability needed to stare continuously at the same patch of sky, but it puts the observatory far enough away from Earth that its telecommunications systems need to be very robust. The original plan included a high-gain antenna that would deploy on a boom and point toward Earth, transmitting data without interrupting observations. When costs needed to be cut later on, descoping the antenna offered a way to save millions. But this would mean turning the entire spacecraft to downlink data, interrupting observations.

"Because we're looking for transits that could happen any time, it wasn't feasible to rotate the spacecraft to downlink every day. It would have had a huge impact on the science," Duren explained. So the team had to determine how frequently it could be done, how much science observation time could be lost, and how long it would take to put Kepler back into its correct orientation. "We concluded we could afford to do that about once a month," said Duren. Since the data would be held on the spacecraft longer, the recorder that stored the data had to be improved, which would increase its cost even as the mission decreased cost by eliminating the high-gain antenna.

"The science merit function that Bill developed was a bridge between the science and engineering that we used in doing these kind of trade studies," said Duren. "In my opinion, the Kepler mission was pretty unique in having such a thing. And that's a lesson learned that I've tried to apply to other missions in recent years."



This image from Kepler shows the telescope's full field of view—an expansive star-rich patch of sky in the constellations Cygnus and Lyra stretching across 100 square degrees, or the equivalent of two side-by-side dips of the Big Dipper.

Image Credit: NASA/Ames/JPL-Caltech

The tool came in handy as Kepler navigated through other engineering challenges, ensuring the mission could look at enough stars simultaneously for long periods of time, all the while accommodating the natural noise that comes from long exposures, spacecraft jitter in orbit, and instrumentation. This meant Kepler had to have a wide enough field of view, low-noise detectors, a large aperture to gather enough light, and very stable pointing. Each presented its own challenges.

Kepler's field of view is nearly 35,000 times larger than Hubble's. It's like a very large wide-angle lens on a camera and requires a large number of detectors to see all the stars in that field of view.

Ball Aerospace built an instrument that could accommodate about 95 million pixels—essentially a 95-megapixel camera. "It's quite a bit bigger than any camera you'd want to carry around under your arm," Duren said. "The focal plane and electronics for this camera were custom built to meet Kepler's unique science objectives. The entire camera assembly resides inside the Kepler telescope, so a major factor was managing the power and heat generated by the electronics to keep the CCD detectors and optics cold."

What might be surprising is that for all that precision, Kepler's star images are not sharp. "Most telescopes are designed to provide the sharpest possible focus for crisp images, but doing that for Kepler would have made it very sensitive to pointing jitter and to pixel saturation," explained Duren. "That would be a problem even with our precision pointing control. But of course there's a trade-off: if you make the star images too large [less sharp], each star image would cover such a large area of the sky that light from other stars would be mixed into the target star signal, which could cause confusion and additional noise. It was a careful balancing act."

And it's been working beautifully.

Extended Mission

Kepler launched successfully in 2009. After taking several images with its "lens cap" on to calculate the exact noise in the system, the observatory began its long stare at the Cygnus-Lyra region of the Milky Way. By June 2012, it had confirmed the existence of seventy-four planets and identified more than two thousand planet candidates for further observation. And earlier in the year, NASA approved it for an extended mission—to 2016.

"The Kepler science results are essentially a galactic census of the Milky Way. And it represents the first family portrait, if you will, of what solar systems look like," said Duren.

Kepler's results will be important in guiding the next generation of exoplanet missions. Borucki explained, "We all know this mission will tell us the frequency of Earth-size planets in the habitable zone, but what we want to know is the atmospheres of these planets. Kepler is providing the information needed to design those future missions." ●

SINKING THE

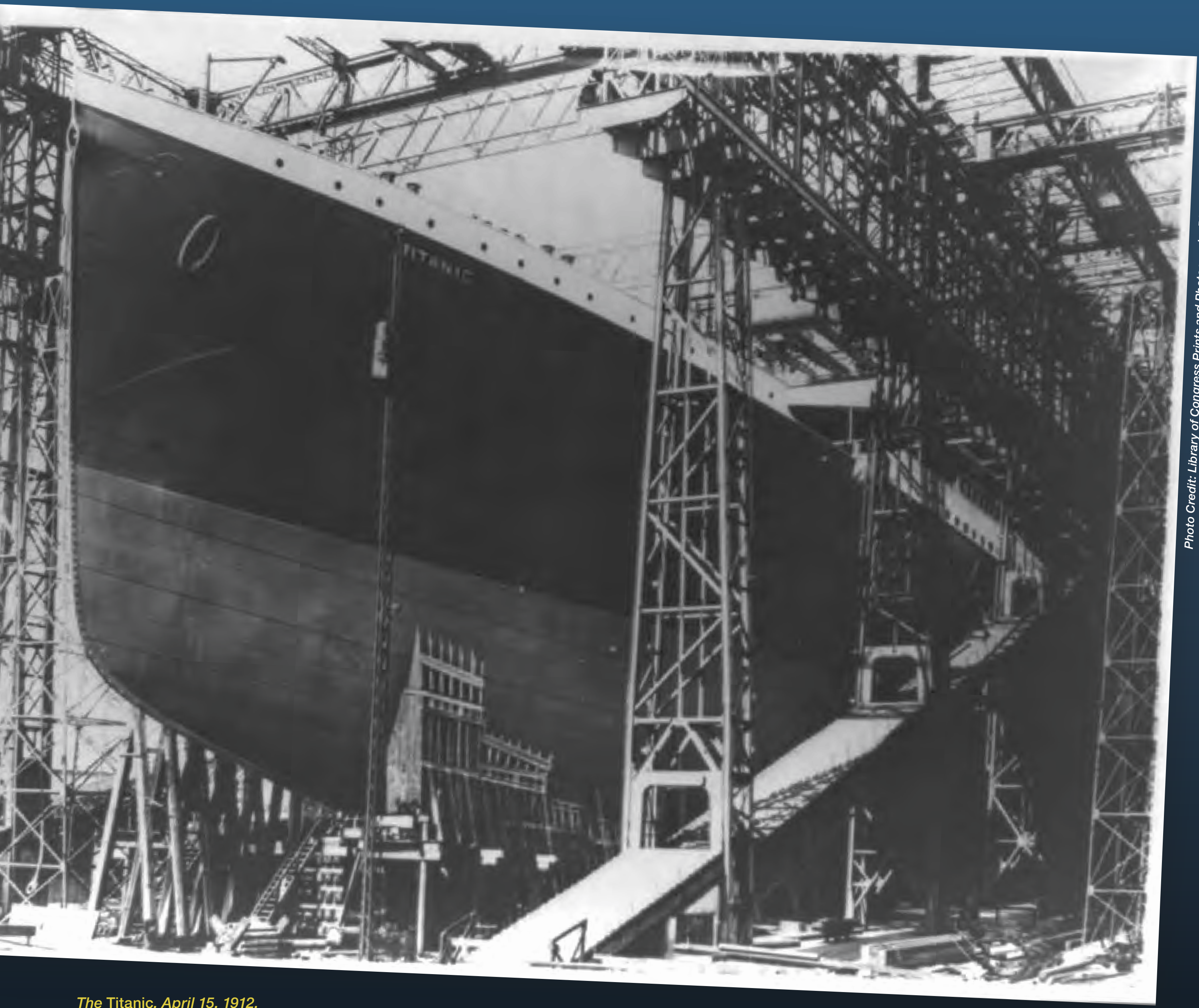


Photo Credit: Library of Congress Prints and Photographs Division, Washington, D.C.

The Titanic*, April 15, 1912.*

"… my purpose is to ascertain what lessons this disaster teaches us …"
—Senator I. Raynor, May 28, 1912, during the U.S. Senate Inquiry on Titanic *Disaster*

UNSINKABLE: LESSONS FOR LEADERSHIP

BY PEDRO C. RIBEIRO

On April 15, 1912, the "unsinkable" RMS *Titanic* sank during its maiden voyage only 2 hours and 40 minutes after hitting an iceberg. Investigations and inquiries led by the U.S. Senate and the British Wreck Commission indicated that a combination of overconfidence, ignored warnings, lack of communication, and lack of leadership resulted in one of the greatest disasters in maritime history.

On April 10, 1912, when she steamed out of the harbor at Southampton, England, on her maiden voyage, the *Titanic* was the largest moving object ever built by man. The product of five years of planning and construction, *Titanic* was compared to the greatest monuments of the world. Proclaimed by a leading naval engineering journal as "practically unsinkable," she sank during her maiden voyage, taking with her the lives of 1,517 people.

What happened? The *Titanic* disaster hearings and related sources offer some lessons to today's project leaders and teams.

Compliance Is Necessary but Not Sufficient

Titanic's original project plan included a configuration of forty-eight lifeboats, sufficient to accommodate all her passengers and crew. The original plans, however, were not approved by J. Bruce Ismay, chairman of White Star Line. Ismay's arguments were based on the fact that *Titanic* could be in full compliance with the British Board of Trade rules with just twenty lifeboats, enough for 1,176 passengers. He reasoned that the ship was designed to be practically unsinkable, a lifeboat in itself. Additional lifeboats would unnecessarily clutter the boat deck that could be used as a promenade area.

Titanic sailed on her maiden voyage in full compliance with legislation, with 2,223 passengers and crew on board, but with a total lifeboat capacity for just 1,176 passengers.

Sometimes Leaders Have to Rock the Boat

Titanic's original lifeboat plans were conceived by Alexander Carlisle, managing director of shipbuilder Harland & Wolff. He believed that new giant ocean liners needed a larger number of lifeboats than the number required by rules set by the British Board of Trade. He presented his plans during meetings held with White Star Line but did not press his views after the client refused to accept his plans, considering this to be a client decision.

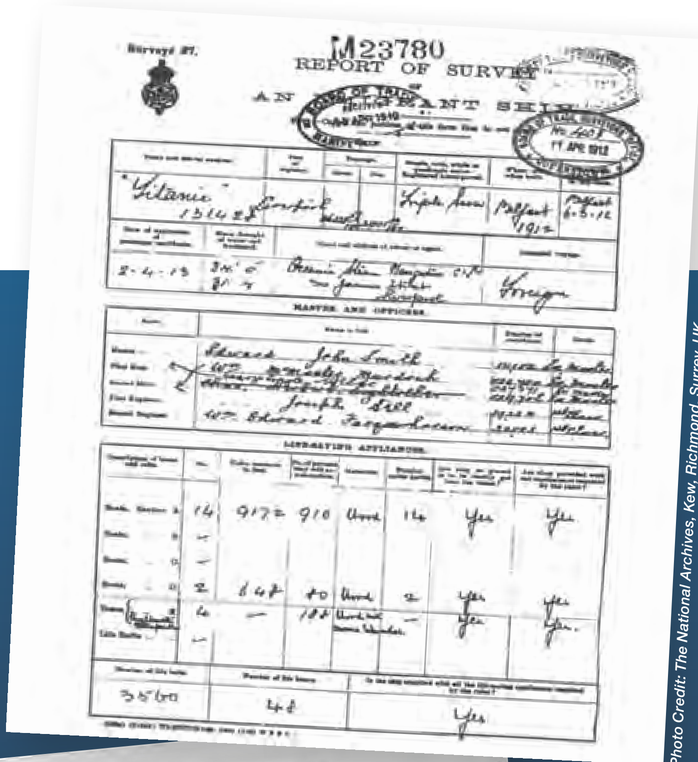
Later, during the British Wreck Commission's inquiry, he said he regretted not being forceful enough with his client and peers in defense of his call for more lifeboats.

Near Misses and Mishaps Are Learning Opportunities

A trail of mishaps and near misses pointed to the challenges of controlling the hydrodynamic forces of the new class of ocean liners:

- **June 21, 1911:** *Olympic*, *Titanic*'s sister ship, nearly sank the tug *Hollenbeck* by suction when it was caught in the ship's backwash in New York.
- **September 20, 1911:** Due to the suction effect, *Olympic* was involved in a serious collision with Royal Navy cruiser *Hawke* in Southampton, and was left with a large hole punched in her side. The *Hawke* suffered major damage to her bow.
- **February 24, 1912:** The *Olympic* collided with the Grand Banks off Newfoundland, Canada, and lost a propeller blade.
- **April 10, 1912:** Departing from Southampton on her maiden voyage, *Titanic* caused a suction effect on the SS *New York*. Collision was avoided by a few meters.

Near misses and mishaps are opportunities to learn and to take steps to make sure that similar problems will not happen in the future. However, instead of increasing awareness, they contributed to augmenting the level of confidence in the new class of ships in terms of maneuverability and endurance to collisions. According to author Leo Marriott, the fact that *Olympic* endured collisions with a warship and stayed afloat,



Surveys 27.

M23780
REPORT OF SURVEY
OF AN EMIGRANT SHIP

"Titanic" 131428

Belfast 1912

Edward John Smith

Wm. Murdoch

Joseph Bell

LIFE-SAVING APPLIANCES.

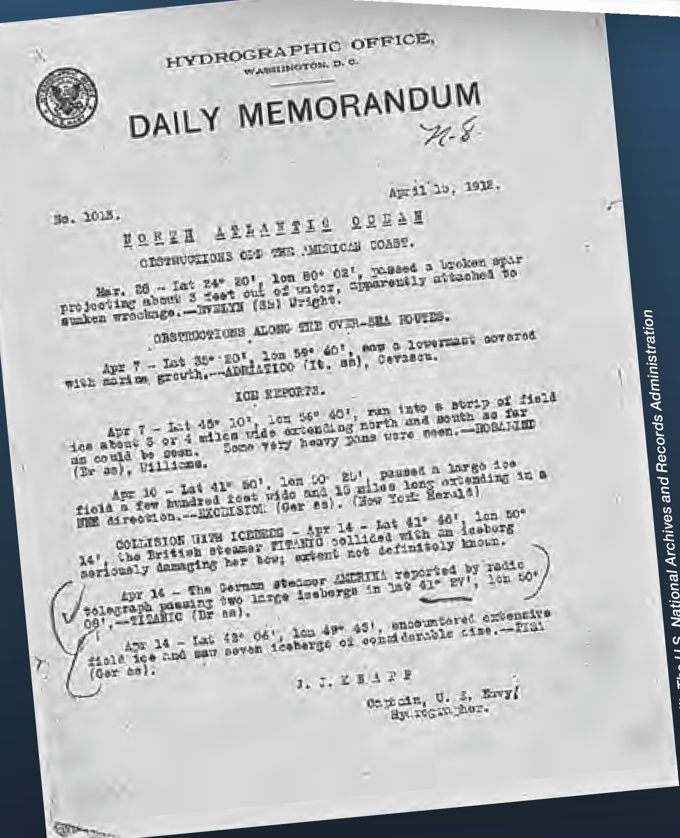
14	9172	910	Wood	14	Yes	Yes
2	848	80	Wood	2	Yes	Yes
4	—	188		—	Yes	Yes

3560 — 48 — Yes

Photo Credit: The National Archives, Kew, Richmond, Surrey, UK

Report of Survey of an Emigrant Ship 04/11/1912.

The Board of Trade Survey Report shows Titanic *in compliance with twenty lifeboats on her maiden voyage.*



HYDROGRAPHIC OFFICE,
WASHINGTON, D. C.

DAILY MEMORANDUM

H-8

April 15, 1912.

No. 1018.

NORTH ATLANTIC OCEAN

OBSTRUCTIONS OFF THE AMERICAN COAST.

Mar. 28 – Lat 24° 20', lon 80° 02', passed a broken spar projecting about 3 feet out of water, apparently attached to sunken wreckage.—EVELYN (SS) Wright.

OBSTRUCTIONS ALONG THE OVER-SEA ROUTES.

Apr 7 – Lat 35° 20', lon 59° 40', saw a lowermast covered with marine growth.—ADRIATICO (It. ss), Cerasco.

ICE REPORTS.

Apr 7 – Lat 45° 10', lon 56° 40', ran into a strip of field ice about 3 or 4 miles wide extending north and south as far as could be seen. Some very heavy pans were seen.—ROSALIND (Br ss), Williams.

Apr 10 – Lat 41° 50', lon 50° 25', passed a large ice field a few hundred feet wide and 15 miles long extending in a NNE direction.—EXCELSIOR (Ger ss). (New York Herald)

COLLISION WITH ICEBERG – Apr 14 – Lat 41° 46', lon 50° 14', the British steamer TITANIC collided with an iceberg seriously damaging her bow; extent not definitely known.

Apr 14 – The German steamer AMERIKA reported by radio telegraph passing two large icebergs in lat 41° 27', lon 50° 08'.—TITANIC (Br ss).

Apr 14 – Lat 42° 06', lon 49° 43', encountered extensive field ice and saw seven icebergs of considerable size.—PISA (Ger ss).

J. J. KNAPP

Captain, U. S. Navy,
Hydrographer.

Photo Credit: The U.S. National Archives and Records Administration

Daily Memorandum from the Hydrographic Office Reporting Titanic *Disaster, 04/15/1912.*

The Hydrographic Office memorandum that registered on April 14 Titanic's *transmission of an iceberg message from* SS Amerika *reporting two large icebergs, and* Titanic's *collision with an iceberg in the same area she reported.*

with no casualties, despite serious flooding, appeared to vindicate the design of the Olympic-class liners and reinforcing their "unsinkable" reputation.

Confidence Is Important; Overconfidence Is Dangerous

Confidence is a leadership virtue, but the border between confidence and overconfidence is easily crossed.

Captain Edward Smith, commander of *Titanic*, was the most experienced captain of White Star Line. Talking about his experience during a press interview in 1907, he declared: "… I have never been in an accident of any sort worth speaking about … nor was I ever in any predicament that threatened to end in disaster of any sort … I cannot imagine any condition which would cause a ship to founder …. Modern shipbuilding has gone beyond that."

It is important to note that according to White Star Line logs, Captain Smith's experience prior to 1911 was based on ships no larger than 24,000 tons. *Titanic* and her sister *Olympic*, the largest ships ever constructed, were 45,000-ton ships.

Captain Smith's assumption, based on his past successful experience, was that *Titanic* could establish visual contact with any iceberg in front of the ship in sufficient time to maneuver and avoid it. The report of the disaster hearings would find, among other conclusions:

> … *Titanic* rushed onward on her true course, one recognized as appropriate … yet dangerous at this season of the year, when the Labrador current may be bearing vast masses of ice across the track of ships …. Ice positions so definitely reported to the *Titanic* just preceding the accident located ice on both sides of the track or lane which the *Titanic* was following. … No general discussion took place among the officers; no conference was called to consider these warnings; no heed was given to them. The speed was not relaxed, the lookout was not increased, … [Smith's] indifference to danger when other

Titanic Disaster Hearings held at the Waldorf Astoria New York, April 19, 1912.

and less pretentious vessels doubled their lookout or stopped their engines … was one of the direct and contributing causes of this unnecessary tragedy. … Overconfidence seems to have dulled faculties usually so alert.

Watch Out for Organizational Silos

Organizational silos—bureaucratic or cultural barriers between departments or groups—decrease incentives to collaborate, share information, or team up to pursue common objectives.

The winter of 1912 was the mildest winter in thirty years, resulting in the creation of an enormously large crop of icebergs from the Greenland glaciers. Unusual winds blew these bergs far southward, crossing established ship routes. Accordingly, on January 16, 1912, the Hydrographic Office in Washington, D.C., sent a circular letter to shipmasters, requesting them to make use of the United States naval radio stations for the purpose of reporting to the Hydrographic Office ice or other dangers to navigation, using the telegraph as a navigational aid in addition to traditional lookouts.

White Star Line had a partnership with Marconi Wireless Telegraph Company, but Marconi telegraph operators were not considered part of the crew; they were employed by the Marconi Company, not by White Star Line. They had their own clear goals and priorities, namely to send and receive commercial paid messages for passengers. There was little established coordination or procedure, and no incentives for the radio room and the bridge to handle ice warnings cooperatively.

On April 14, 1912, the day of the disaster, *Titanic* received seven iceberg warnings. One of these messages was transmitted from the SS *Amerika* via the *Titanic* to the Hydrographic Office in Washington, D.C. The message reported ice along *Titanic*'s route. *Titanic* radio operators retransmitted the message to the Hydrographic Office but not to *Titanic*'s bridge. Later, the Hydrographic Office would mention in its annual report the irony that *Titanic* hit an iceberg she herself had reported: "It is a lamentable fact and a remarkable coincidence that the sinking of the *Titanic* was caused by an iceberg the report of which she had transmitted …. Had she but heeded the one warning that she transmitted she would probably have saved herself."

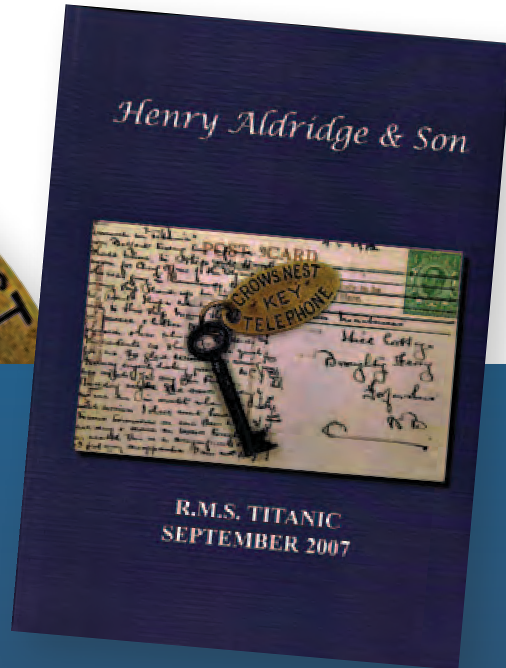
The disaster hearings also discovered that an important ice-warning message was received approximately one hour before the accident. The SS *Californian*, on the same route of the *Titanic*, stopped due to ice and tried to warn *Titanic*. To this the operator of the *Titanic* replied, "Shut up. I am busy. I am working Cape Race." He was focused on his work, that is, sending and receiving passengers' paid messages.

Ineffective coordination, procedures, and communication between organizations that should have worked together were contributing factors in blocking essential information that could help to prevent the disaster.

Listen to All Levels of the Organization

No job in an organization is too small to help break the sequence of events that create a crisis. Research indicates that 90 percent of employees can perceive far in advance when projects are doomed; 71 percent say that they try to speak up about their concerns to key decision makers but do not feel they are heard; and 19 percent don't even attempt to speak.

In the case of the *Titanic*, the disaster hearings reports and other sources indicate that lookouts who could have prevented the disaster did not have the tools or status needed to ensure their concerns would be acted on. According to the *Boston Sunday Globe* of April 21, 1912, and researcher George Behe, past vice-president of the *Titanic* Historical Society, lookout Frederick Fleet tried to warn the bridge about the apparent presence of icebergs before the fatal iceberg hit the ship. He was not heard because, due to weather conditions, he was unsure and could not confirm his sighting as an iceberg. The bridge did not take appropriate action because they needed confirmed iceberg sightings to change course or reduce speed. The lookouts had no binoculars, however, which made confirmation difficult. The binoculars in the crow's nest were locked; nobody knew



Source: Author's collection

Titanic *crow's nest key, Auction Catalog Cover, 2007.*

where the key to the locker was, and the officers did not provide binoculars to the lookouts. (The key to access the binoculars was later found and auctioned in the United Kingdom in 2007 for £90,000.) Finally, at 11:40 p.m., lookout Frederick Fleet confirmed sighting an iceberg, but it was too late. *Titanic* would hit the iceberg 37 seconds later.

During the hearings, the lookout said in his testimony that "… if he had been supplied with binoculars, which were denied him by officers, he could have seen earlier the iceberg with which *Titanic* collided soon enough to get out of the way …." Almost one hundred years later, computer simulations proved that, had *Titanic* lookouts seen the iceberg a few seconds earlier, the disasters could have been avoided.

Build and Train Your Team Across Project Phases and Functions

The *Titanic*'s officers and crew were not trained as a team in the handling of lifeboats, nor were they aware of lifeboat tests done during the construction phase. Their lack of knowledge, training, and shared experience made the lifeboat situation even worse.

According to the disaster hearing reports:

> "Officers and crew were strangers to one another. … When the crisis came there was a state of absolute unpreparedness … *Titanic*'s crew had never acted as a team to lower the ship's boats. … Untrained and untried, and … unfamiliar with the lifeboats' capacity … [they failed] to utilize lifeboats to their capacity … [resulting] in the needless sacrifice of several hundred lives which might otherwise have been saved."

Preventing Future Disasters

As a consequence of the *Titanic* disaster, the International Convention for the Safety of Life at Sea was created to apply lessons learned from the tragedy. The many factors leading to the sinking of the *Titanic* clearly demonstrate that crises do not just happen, they are created by a chain of events and conditions that can potentially be recognized and responded to before the damage is done. Learning from crises is important, but it is too expensive when the cost is measured in human lives as well as money. That unacceptably high cost makes it even more important to use the lessons of past disasters to avoid future ones.

In addition, we need to start learning before crises happen by investing in learning skills, processes, tools, and new thinking models for teams and for leaders at all levels in the early identification and prevention of crises. In the centenary year of the loss of the *Titanic*, we should remember that crisis prevention is possible but depends on leadership, alertness, cooperation, and communication at all levels of the organization.

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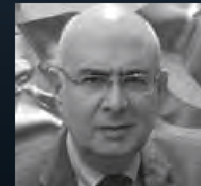


Being able to use their own space transportation systems was an important part of ISS negotiations with international partners. In this photo, ESA's "Jules Verne" ATV separates from the ISS on Sept. 5, 2008.

Photo Credit: NASA

The challenge of collaboration

BASED ON AN INTERVIEW WITH LYN WIGBELS

The International Space Station (ISS) is a technological marvel. The size of a football field, with a mass of almost one million pounds, it has been continuously inhabited by astronauts and cosmonauts for more than ten years. A complex of modules that include laboratories, living quarters, a gymnasium, and observation areas, it circles Earth nearly sixteen times a day at an altitude of more than 200 miles.

The ISS is also a marvel of international cooperation. Somehow the space agencies and governments of multiple countries found a way to agree, not only on the technical standards that allow components developed by the agencies of different nations to function as a single unit, but also on issues of management and usage. Lyn Wigbels, who participated in planning and negotiation for NASA, reflects on the long, complex, and ultimately successful process.

It began around 1980, with preliminary studies of how a permanently orbiting facility might be used. Applying lessons learned from international cooperation on the Space Shuttle, NASA engaged directly with Canadian, European, and Japanese space agencies from the beginning, prior to a U.S. decision to develop the space station. NASA realized that it was necessary to develop a different cooperative relationship for the next human spaceflight program, one giving all partners a stake in its long-term operation and utilization. Although each of those agencies and NASA conducted their own utilization studies, the teams met regularly to discuss their ideas as well as potential hardware contributions to the finished space station. These Phase A, preliminary analysis studies were hypothetical—how might an international space station be used if it were built?—but the process of developing utilization concepts began to build the relationships that the later agreement would depend on. And they generated shared ideas of what an international framework for cooperation might look like.

… THE AGREEMENT WOULD NEED TO BE CLEAR AND SPECIFIC ENOUGH TO AVOID DISPUTES AND INCOMPATIBILITIES BUT ALSO FLEXIBLE ENOUGH TO DEAL WITH THE UNEXPECTED SITUATIONS THAT WOULD UNDOUBTEDLY ARISE DURING THE STATION'S LIFETIME OF THIRTY YEARS OR MORE.

ISS continues to provide new and interesting observations from space, including this image of Aurora Australis, accompanied by star streaks and air glow, recorded by one of the ISS Expedition 31 crew members.

Photo Credit: NASA

From Concept to Commitment

In his 1984 State of the Union speech, President Ronald Reagan directed NASA to "develop a permanently manned space station" within a decade and invited other countries to participate in the effort and share in the benefits an orbiting laboratory could provide. The space station went from being a possibility to being a program, at least on the United States' part.

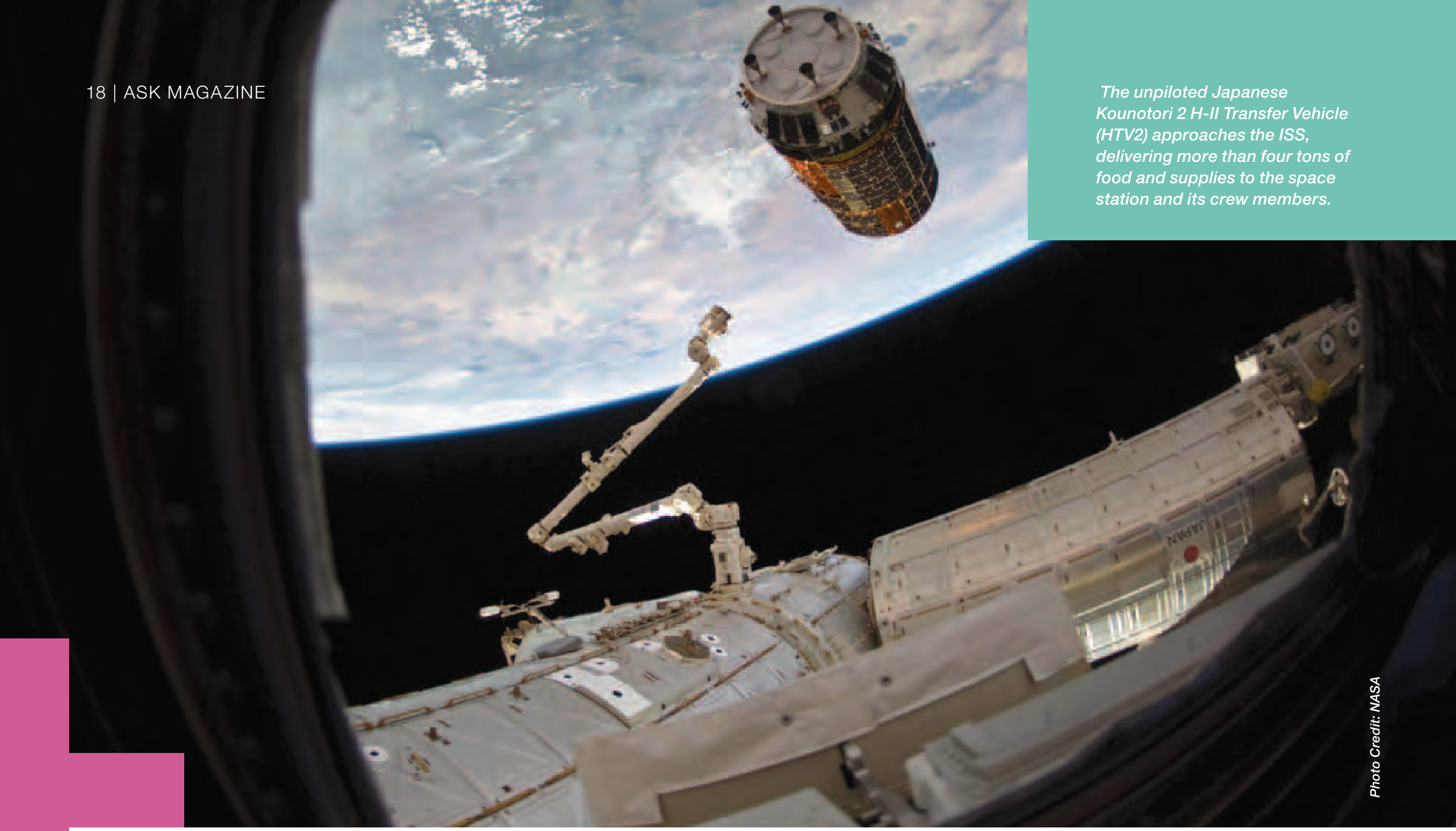
Discussions began at the political as well as the technical level, involving the governments of the United States, major European spacefaring nations (the United Kingdom, Germany, France, Italy), Japan, and Canada. Meanwhile, the space agencies negotiated agreements covering cooperative activities during the next phase of the program, the preliminary design phase. As with the first phase, there was no commitment to future cooperation at this time, but efforts began to construct an agreement that would cover commitments for the lifetime of the space station program.

Wigbels led the internal agency process of drafting NASA's version of an international agreement for the design, development, operation, and utilization of the station. The challenge was considerable: to come up with a plan that would satisfy groups within NASA and the U.S. government and would also be acceptable to other space agencies and their governments. The team working on the draft had to understand what NASA needed and the U.S. government required as well as what the partners needed to make the political decision to invest in the space station. In addition, the agreement would need to be clear and specific enough to avoid disputes and incompatibilities but also flexible enough to deal with the unexpected situations that would undoubtedly arise during the station's lifetime of thirty years or more.

One of the trickiest issues was how to devise a management structure that would give all the partners a say but would ensure clear, timely decisions about station development and operations. Another was to develop rules to organize use that would satisfy all the participants. For instance, would research projects be chosen by peer review (as at CERN, the international high-energy physics facility), or would each partner make its own choices; and would the partners use only their own research facilities or would they share them?

Two factors made this process successful. One was involving all interested parties at NASA in the formulation of the initial agreement that would be used to initiate the international negotiations. The International Cooperation Working Group (ICWG) included members from affected NASA program offices and centers. It had technical and operations people as well as lawyers and management. Simultaneously, Peggy Finarelli led discussions with the State Department and other government agencies to ensure the agreement would address the complex political needs of other agencies in the U.S. government, as well as the U.S. Congress. This process resulted in an agreement that NASA presented to its potential international partners early in the preliminary design phase. It then took months of bilateral and multilateral discussions and consultations between and among space agencies and their governments to arrive at decisions that these many and varied parties could agree on. Wigbels was a key member of NASA's negotiating team, which was led by Finarelli. Wigbels was responsible for updating the agreements following each negotiation session. She continued to work with the ICWG to develop solutions to issues raised in the negotiations.

Simultaneously, NASA worked with the State Department on negotiations with the governments of Canada, Japan, and European Space Agency member nations on an intergovernmental agreement that would capture the political commitments of these governments and address government-level policy and legal issues. The space agencies participated in the government-level negotiations, which were paced in a way to enable the space agencies to develop the technical, programmatic, and management structure for the program in the agency-to-agency negotiations. Wigbels notes that this process was essential. Otherwise, the governments might have made choices that could have been unworkable in the implementation of this large-scale research and development project. Likewise, the space agencies could have made programmatic decisions that might not have received government approval.



The unpiloted Japanese Kounotori 2 H-II Transfer Vehicle (HTV2) approaches the ISS, delivering more than four tons of food and supplies to the space station and its crew members.

Photo Credit: NASA

The success of the negotiations was based on understanding and respecting international partners' needs. Multiple negotiation sessions were held on numerous drafts of the agreement that led to an understanding of what each partner needed in order to be able to enter into cooperation. While some of these needs were known at the beginning, such as matching the benefits received to the investments made, others, such as the management structure and how the utilization would be apportioned, were only understood as the partners grappled with the many facets of the long-term program. Respecting each partner's needs and working through various alternatives to address them ultimately led the partners to decisions that all could embrace. For example, two provisions—agreeing that the international partners would try to minimize the exchange of funds, including the use of barter, to offset their launch and operations costs, and giving partners the right to use their own government or industry transportation systems as long as they were compatible with the station—were key steps toward concluding the agreements. These laid the groundwork for subsequent agreements with Europe and Japan on the use of the European automated transfer vehicle (ATV) and the Japanese H-II transfer vehicle (HTV) in the second round of space negotiations involving the Russians. (The negotiations with the Russians are another story, as complex as this one.)

Not surprisingly, management issues proved trickier than technological decisions. In keeping with the international, cooperative nature of the ISS, consensus is an important principle. A spacecraft cannot be run by committee, however. As the Japanese negotiators remarked, "It's one big boat out there in space." Ultimately, if consensus cannot be reached, *someone* has to be responsible for clear and timely decisions, especially in potential emergency situations. As the biggest contributor to the ISS, NASA has that final say when consensus cannot be readily achieved. When and if partners disagree with a decision, they can appeal to a program coordination committee for development issues or the multilateral coordination board for operations and utilizations issues and, if that proves unsatisfactory, to the heads of agencies. While many big challenges have confronted the ISS partnership, the management mechanisms have stood up to the tasks. Importantly, since the agreements were signed, the partners have sought and almost always achieved consensus through the lifetime of the ISS.

Flexibility Put to the Test

The flexibility built into the agreement includes the provision that current partners can share their utilization allotments with others, and Wigbels led the NASA negotiations with the Italian Space Agency to provide logistics modules under this provision. The *Columbia* accident, which created delays and higher costs, was obviously unforeseen, but the flexibility of the agreement and the strength of the ISS partnership made the necessary adjustments possible. Russia's Soyuz and Progress vehicles filled the void left by *Columbia* until the Space Shuttles began flying again and continue in that role today along with the European ATV and Japanese HTV. Now the likelihood of U.S. commercial providers supplying the station is another development in the evolving International Space Station partnership. ●

There to Help: NASA's Ombudsman Program

BY RUTH McWILLIAMS AND REX ELLIOTT

"Chris" works on a project with a tight deadline as part of a small team at a fairly remote site. The new head of his group has been with NASA for six months, after a long hiring process that resulted in the selection of an external candidate. Chris's new supervisor is technically knowledgeable but has found fault with almost every aspect of the team's work. He shows his dissatisfaction by making belittling remarks and swearing at the employees. In one-on-one discussions, he makes personal and derogatory comments about people not in the room.

Chris isn't sleeping well. He knows his work is suffering because the work environment has become so unpleasant and he's worried about meeting all the deadlines. He heard that one coworker received a prescription for anti-anxiety medication. Chris doubts his boss will listen to his concerns; he thinks the project manager is unlikely to fix the situation because of the intensity of the project deadline pressure and the length of time it took to hire the new boss. He doesn't know where to turn for help.

One source for advice is the NASA Ombudsman program.

The Ombudsman Program

The NASA Ombudsman program operates in accordance with the International Ombudsman Association rules and guidelines. It provides an independent, neutral, confidential, and impartial environment for employees and managers to raise issues and learn what alternatives are available for dealing with them. Every NASA center has at least one ombudsman, and most have two or more.

If you've never heard of the Ombudsman program, you may have questions about it, such as the following:

- What do ombudsmen mean by independence, neutrality, confidentiality, and impartiality?
- How does the NASA Ombudsman program guarantee these protections?
- What's the process to ask for help from your center ombudsman?
- What can the Ombudsman program do for me?
- What are some examples of issues the ombudsmen see and how do they resolve them?

The service provided by the independent Ombudsman office is not a part of any formal process. Discussing an issue with an ombudsman does not result in official notification to the agency of issues, as it would if you went to the inspector general or to the human resources director. The ombudsman can, however, provide the timelines associated with using one of the formal notification processes, in addition to other advice.

Neutrality means that the ombudsman does not represent either the agency or the visitor and ensures the ombudsman listens and advises without presenting a particular viewpoint of either management or labor. The ombudsman can report trends to the highest levels of the agency while maintaining the confidentiality of the visitors. The ombudsmen are not in a position of authority that would prevent them from listening openly and providing a range of alternatives. Ombudsmen are not advocates for any parties in a dispute. They are a resource for all parties.

Confidentiality mandates that all communications are held in strict confidence, with one exception. If the ombudsman perceives an "imminent risk of serious harm," then she may seek immediate outside help. Otherwise, the ombudsman doesn't reveal information about visitors (as those who bring issues to ombudsmen are called) unless given express permission. This also means that the ombudsman can't be called to testify within the agency, if a formal process occurs. Communications between the ombudsman and visitor are not subject to the Freedom of Information Act (FOIA) process.

Informality ensures that conversations between visitors and ombudsmen are off the record. The ombudsman is the person who can listen and develop alternatives with an impartial view of the situation. She doesn't take sides and is an advocate only for seeking a peaceful resolution of workplace issues.

NASA's ombudsmen are all civil servants who perform the collateral duty of being an agency ombudsman. Their primary jobs and, typically, experience in a variety of jobs during their careers bring them a wealth of organizational understanding that informs their ombudsman work. All NASA ombudsmen are required to complete the International Ombudsman Association training course for new ombudsmen. In addition, NASA provides supplemental annual training. The agency's ombudsmen also have monthly video teleconferences to share ideas and issues, while maintaining the confidentiality of their visitors. The NASA administrator has designated the assistant administrator for the Office of Strategic Infrastructure, Olga Dominguez, as the program coordinator.

The NASA Ombudsman program guarantees independence, neutrality, confidentiality, and informality by setting the conditions and policies to ensure they are supported. Some centers have a separate area for ombudsmen to meet with visitors, ensuring confidentiality. Others meet in different locations around their campuses, ensuring there is no direct linkage between visitors and the ombudsman. At some centers, ombudsmen have a phone number that is separate from the main system and accessible only by the ombudsman.

Any employee, civil servant, or contractor can contact any NASA ombudsman. NASA's ombudsman web site lists the individual points of contact for all NASA ombudsmen. The link to the NASA Ombudsman program is ombuds.hq.nasa.gov/index.html. This is different from the NASA Procurement Ombudsman Program, which exists primarily for contractors and potential contractors bidding on NASA contract opportunities (discussed at prod.nais.nasa.gov/pub/pub_library/Omb.html).

Phone calls are preferred, but e-mail can also be a way to initiate contact. If e-mailing, visitors should keep the message and subject line as neutral as possible.

Ombudsmen meet with each visitor at least once and often several times. They listen with an open mind to help clarify the issue or issues. They work with visitors to develop options for issue resolution and understand the pros and cons of each

THE SERVICE PROVIDED BY THE INDEPENDENT OMBUDSMAN OFFICE IS NOT A PART OF ANY FORMAL PROCESS. DISCUSSING AN ISSUE WITH AN OMBUDSMAN DOES NOT RESULT IN OFFICIAL NOTIFICATION TO THE AGENCY OF ISSUES, AS IT WOULD IF YOU WENT TO THE INSPECTOR GENERAL OR TO THE HUMAN RESOURCES DIRECTOR.

option. Visitors can be coached on how to communicate their concerns effectively when speaking with leadership or coworkers. The ombudsman can facilitate discussions between the visitor and other participants, if given express permission by the visitor. One outcome could be a referral to a formal process. In those cases, the ombudsman provides information about how to reach the formal process point of contact. Once a year, all agency ombudsmen compile general demographic and trend information, which is reported to the agency leadership in an annual report.

The ombudsmen's activities don't supersede any formal resources or processes. They can't conduct formal investigations or make binding decisions.

Helping "Chris"

In the hypothetical case of Chris, the employee with the disparaging supervisor, the ombudsman might suggest a variety of ways to address the situation. Chris then decides what steps to take next, if any.

The first option might be to do nothing. Many people choose the path of least resistance. They're afraid to make waves or appear to not be a team player. But this creates stress and does nothing to fix the problem.

Another option could be to document the situation, with the intention of presenting the information through a formal process like notifying the program manager or contacting the Anti-Harassment Program. The ombudsman would likely advise Chris to clearly and carefully distinguish between facts and his perceptions and feelings. He should try to document incidents as soon as possible after they happen to record events while they are fresh in his mind.

Chris could meet with the supervisor, either on his own, with the rest of the team, or with a mediator. This could be an informal meeting or a formal one. The ombudsman can serve as the mediator or as a nonparticipating observer.

Appealing to the next levels of supervision would be another option that Chris and the ombudsman might consider. Finally, an option to file a formal complaint under one of the employee-protection programs might be a step Chris would take (for instance, the EEO complaint process or the administrative grievance process).

The ombudsman would work with Chris to look at the pros and cons of each course of action, trying to anticipate the secondary and tertiary effects of each choice. After Chris makes his decision, the Ombudsman office remains a place where Chris can return for more ideas or alternatives.

Broad Benefits

Program and project managers look for every tool and technique that will help ensure the smooth functioning of their teams and successful completion of their missions within budget and on time. Sometimes things happen that derail progress. Parts are delayed, funding is cut, or the team suddenly stops working cooperatively and starts exhibiting destructive behaviors. While the NASA Ombudsman program can't speed up a production line or increase the budget, it can provide a safe, neutral, informal, confidential, and independent environment for the employee or the manager to identify issues affecting the workplace and potential ways to resolve them. The NASA Ombudsman program is here to serve. ●

RUTH McWILLIAMS has been with NASA for six years, having spent the majority of her government career as an active-duty army officer and army civil servant. She's served in four countries and multiple duty locations. At NASA, she's been a resource manager and mission support council executive secretary, and is now an executive officer.

In addition to being one of the Headquarters ombudsmen, **REX ELLIOTT** is NASA's contractor industrial relations officer, the NASA policy person for employee exchanges, and he also performs a number of procurement functions for NASA's Logistics Division.

SCIENTIFIC VISUALIZATION: WHERE ART MEETS SCIENCE & TECHNOLOGY

BY HELEN-NICOLE KOSTIS AND DON COHEN

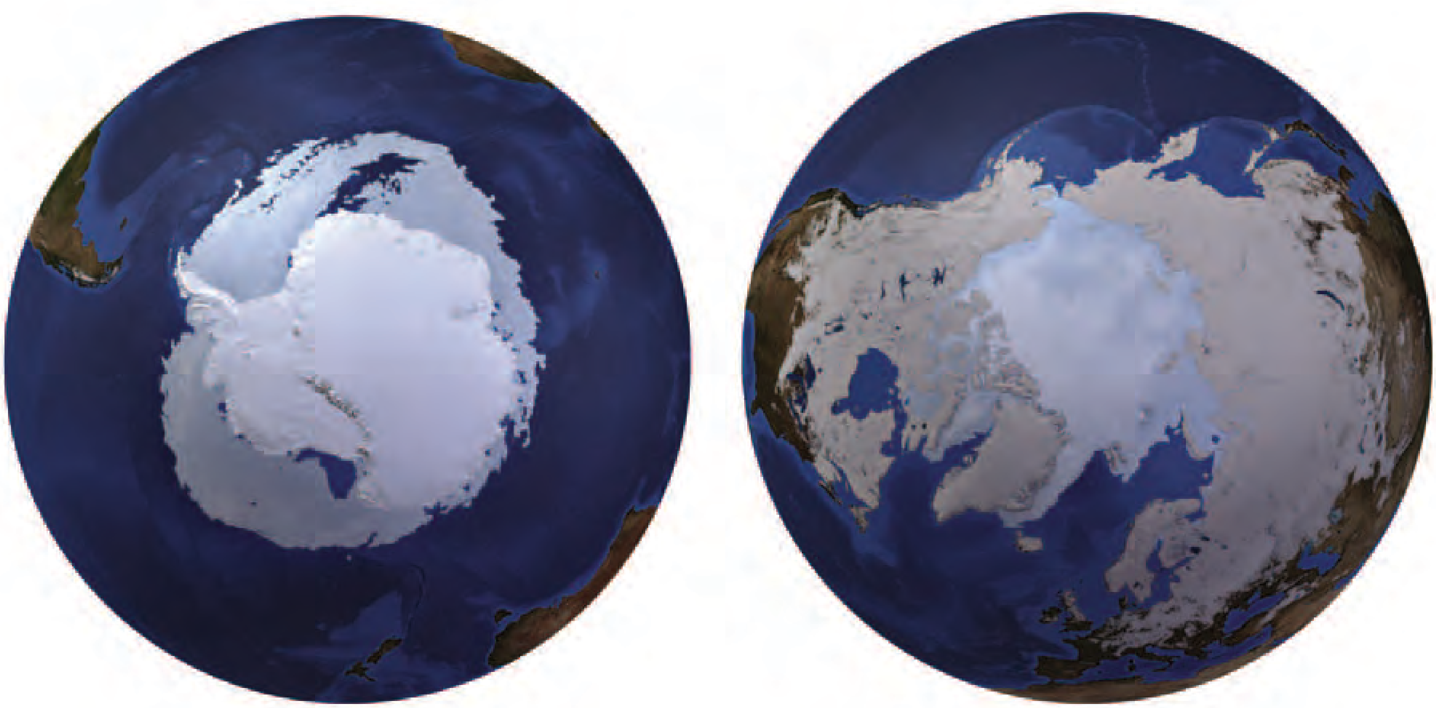


Image Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio

Snow and sea ice in the Northern and Southern Hemispheres grow and shrink at exact opposite times of year, constantly out of phase.


In this visualization from "Let It Snow," a massive snowstorm covers much of continental Europe and the United Kingdom on December 29, 2010.

Image Credit: NASA/Goddard Space Flight Center

At the start of the video, we see a bright sliver of Earth against a background of the star-speckled blackness of space. As we move toward the turning globe, a now-familiar sunlit scene is revealed: the swirls of white cloud, blue oceans, and brownish continents first seen when Apollo astronauts photographed Earth from space. We zoom closer, moving in on the north Pacific, while a narrator explains that Earth's clouds reflect solar radiation and that atmospheric pollution can increase cloud cover. As we come even closer, we begin to see thin, curved tracks of cloud, which the narrator tells us form around sulfate particles in the exhausts of ships as they cross the ocean. These clouds have been recorded and revealed by the moderate resolution imaging spectroradiometer (MODIS) on NASA's Terra and Aqua satellites.

But no spacecraft has followed the trajectory that has brought us to this spot above the Pacific. The video has been constructed of hundreds of separate images. Even that first view of the cloud-covered sunlit Earth is made up of several hundred images artfully stitched together. Creating high-quality computer graphics and videos from massive quantities of data from NASA satellites and other spacecraft is what we do at NASA's Scientific Visualization Studio (SVS)[1] at the Goddard Space Flight Center.

The Process

It took two weeks of full-time work to build the two-minute video that incorporates data received from MODIS. The time it takes to develop a visualization varies from project to project and as a result of many different parameters. Some visualizations may take a day; other, complex ones may take many months.

At SVS, we use the same computer graphics animation software Pixar employs to create animated films like *Toy Story* and *Wall-E*, but we have added our own software modules to the commercial software to ensure the images we create reflect as accurately as possible the data they are based on. Faithfully representing that data is as essential to the value of scientific visualization as telling a good science story. In the recently published paper *Scientific Storytelling Using Visualization*,[2] we describe in detail the production process at SVS, including skill sets, techniques, types, formats, and the breadth of our work. In the MODIS video, we even made sure that the stars in the background matched what an astronaut would actually see from that point in space. Although that view is not, strictly speaking, part of the MODIS "story," portraying the scene accurately helps establish the credibility of the visualization as a whole, just as a random or fictional pattern of stars would undermine it.

Not every detail of the video can be derived directly from

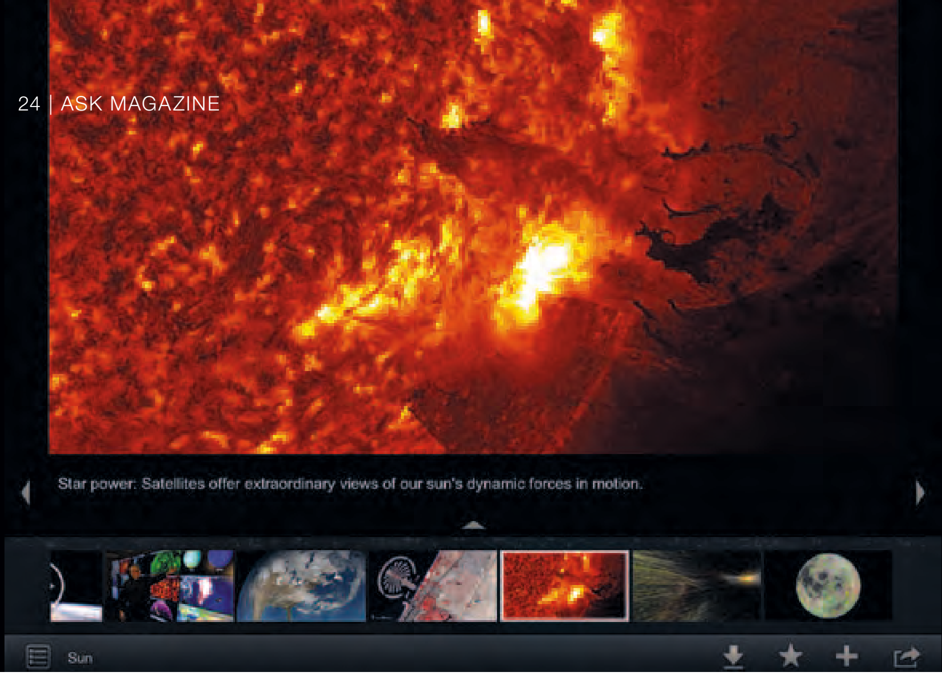


Image courtesy of Helen-Nicole Kostis

The NASA Viz app shares scientific stories through images, animations, articles, and more.

satellite data, however. There are moments of transition—for instance, when the "camera" zooms in—for which no data exist. And there are data from different sources with different resolutions that must be seamlessly stitched together. One of the big challenges in scientific visualization is understanding how to fill in those gaps and connect those disparate sources without compromising the accuracy of the video as a whole, creating, in this case, a smooth transition from a more distant view to a closer one. An accurate portrayal of the science is essential, but so is the artistic component. An artist's understanding of composition, color, and lighting helps guide the choices we make. So does a kind of educated intuition—a hard-to-pin-down sense, based on a lot of experience, of what feels right. The process involves a lot of trial and error, and frequent consultation with colleagues. At SVS we work in an open environment, so it is easy—and common practice—to discuss among team members our problems and choices and consult each other on how to generate solutions. For example, in order to position the starfield background in the MODIS video, I collaborated with my colleagues Ernie Wright and Greg Shirah. Ernie, an amateur astronomer, has "starfield" expertise while Greg developed software to put everything in place accurately. Every project brings with it unique issues and challenges.

Learning the Trade

I have been working at the SVS since 2007. Led by director Horace Mitchell, SVS is a world-class computer graphics production studio for scientific visualization of Earth, planetary sciences, and heliophysics. The knowledge and infrastructure that reside in the SVS are impressive. The backgrounds and expertise of SVS members are diverse, but we share a passion for computer graphics, an appreciation or passion for art, and an interest or expertise in science.

I have a passion for bringing moving images to life and relish the challenge of balancing art and technology while maintaining the integrity of the data. Combining art and technology to serve science is an exciting challenge. I was lucky to begin developing the necessary skills during my years of graduate work, when I found myself at the Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago (UIC). Since its founding in 1973 as the Circle Graphics Habitat by artist and physicist Daniel Sandin and computer scientist Tom DeFanti, EVL has been a bridge between technology and the arts. A joint program of UIC's College of Engineering and the School of Art and Design, it was one of the nation's first such labs.[3]

The best way I can describe EVL is to call it an endless creative playground. EVL is not only home to some wonderful people, but it is also an environment for visionaries who experiment with advanced visualization and networking technologies and support high-tech artistic experiments in an open culture. The lab emphasized and celebrated collaboration between art and technology, high-quality work, immersive experiences, and artistic vision. During my studies for a master of fine arts in electronic visualization, I worked and studied under the mentorship of Daniel Sandin, who is a computer graphics pioneer and a visionary artist. Dan builds the technology[4] and develops the software to make his art a reality. Working with him and in EVL fed my own interests in artworks[5] that could not exist without the cutting-edge technologies used to create them.

Art is not my only passion. In various phases of my life, I taught in schools and community colleges and connected with students. I am deeply interested in merging art and technology for informal educational purposes, especially building novel platforms that distribute engaging scientific storytelling content using visualization. An example of such a platform is the NASA Visualization Explorer (NASA Viz) iPad app,[6] which we released on July 26, 2011.[7]

A group of media experts at Goddard brought this app to life. The multidisciplinary team includes members of the SVS, the Science Data Processing Branch, and Goddard Television. With story contributions from writers, producers, data visualizers, and scientists, the app features images, videos, and text that provide information from NASA's science research

… WE EVEN MADE SURE THAT THE STARS IN THE BACKGROUND MATCHED WHAT AN ASTRONAUT WOULD ACTUALLY SEE FROM THAT POINT IN SPACE. ALTHOUGH THAT VIEW IS NOT, STRICTLY SPEAKING, PART OF THE MODIS "STORY," PORTRAYING THE SCENE ACCURATELY HELPS ESTABLISH THE CREDIBILITY OF THE VISUALIZATION AS A WHOLE, JUST AS A RANDOM OR FICTIONAL PATTERN OF STARS WOULD UNDERMINE IT.

projects in a clear and lively form. The stories vividly portray findings in Earth science, ranging from wind and water patterns to seasonal changes in vegetation to fires to shrinking glaciers, as well as discoveries about the sun, planets, moons, and the universe beyond our solar system. As of May 2012, more than 600,000 users have downloaded the NASA Viz app.

The contribution of artists in technology projects to science is not something new, but it is definitely not mainstream. Scientific and technology fields have their own metrics for measuring contribution and success, but what about the contribution of arts? One of my other interests is to work with fellow artists who are collaborators in science education projects and discover how we can articulate the contribution of such fields. A first attempt toward this direction is a collaborative paper, *Media Arts in Support of Science Education*.[8]

Visualizations vary in subject area, style, and duration. For instance, the "Snow Leads, Sea Ice Follows" and "Let It Snow"[9] set of visualizations developed collaboratively with colleague Cindy Starr have been especially popular in the educational community, as they showcase how seasons change, and especially the difference in seasons between Arctic and Antarctic regions. These visualizations were produced in close collaboration with NASA scientist Thorsten Markus and are now used in many educational events. For the development of these visualizations, layers of different data sets blend together, including bathymetry in the oceans, Next Generation Blue Marble in the Land, AMSR-E sea-ice data, and Terra MODIS daily snow cover.

An example of a powerful educational and scientific use of these visualizations is in a recent live event combining music, art, and science with education in the NASA-sponsored program "Beautiful Earth: Learning and Experiencing Science in a New and Engaging Way." Visualizations of snow cover and sea ice over the poles showcase dramatic changes occurring over seasons and demonstrate the relationship of snow cover and sea ice.

Principal investigator Valerie Casasanto believes that "audiences won't be able to grasp such complex scientific concepts or even pay attention unless they are visually appealing. Through the use of SVS visuals combined with music, an audience can understand a scientific concept without being lectured to. In one look, the whole story is told. This may help inspire young people to study these sciences or take action for better stewardship of our home planet."

The Audience for Scientific Visualization

The primary purpose of works like the MODIS video and the "Pulse of Snow and Sea Ice" visualizations are to help NASA scientists advance their research and support outreach communication and scholarly work (presentations, publications). The visualizations also support NASA's education and public outreach activities that engage the public about research efforts. They present the story of scientific findings in a form that students and the public can readily grasp. Our job comes down to effective and accurate storytelling—creating a visual narrative that will be informative, visually compelling, and scientifically accurate.

The visualization-driven products are archived in the SVS repository (svs.gsfc.nasa.gov), which is a free and publicly accessible database with more than 3,000 entries. The products span many visualization forms, including 2-D, 3-D stereoscopic, Science on a Sphere, Hyperwall, Dome Show, and even touch display. Each production includes various formats, including frame sets, still images, movies, and, when appropriate, data in a wide gamut of resolutions. Upon release, the products often take on a life of their own, since the public can use them freely and without restriction. ●

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THE SKY CRANE SOLUTION

BY DON COHEN

Photo Credit: NASA/JPL-Caltech/Lockheed Martin

The finished heat shield for Mars Science Laboratory, with a diameter of 4.5 meters, is the largest ever built for descending through the atmosphere of any planet.

The challenge was clear: how do you safely land a 2,000-lb. rover on the surface of Mars? Curiosity, as the Mars Science Laboratory is called, has nearly twice the mass of the landers that put Spirit and Opportunity on Mars in early 2004, and more than three times that of the Pathfinder lander that reached the planet in 1997. It is significantly larger than the Viking landers that touched down in the seventies.

For all these missions, entering and descending through the Martian atmosphere and putting an undamaged lander on the surface (the mission phase known as EDL, for entry, descent, and landing) has been technically demanding. It is much harder than landing on the moon—in part because of the planet's greater mass and gravitational pull, but especially because Mars has an atmosphere that heats and exerts shear forces on objects moving rapidly through it, as well as strong winds that can blow a spacecraft off course. And the relative thinness of Mars's atmosphere (it is less than 1 percent as dense as Earth's and as rarified at the surface as our atmosphere is at 100,000 feet) means it is not substantial enough to slow and land a sizeable spacecraft with frictional heating and parachute drag alone—the method used for Apollo and Soyuz space capsules returning to Earth.

Past Mars missions have used a variety of techniques to solve the problem. The Pathfinder and Mars Exploration Rover (MER) missions used parachutes and retrorockets to slow the spacecraft and airbags to cushion the landers and rovers when they dropped to the surface. But the Mars Science Lab (MSL) team quickly determined that airbags would not be a viable solution for something as big as Curiosity. An airbag system designed to accommodate the size and mass of Curiosity would be very large and heavy and significantly different from the Pathfinder and MER designs. In addition, egress from the top of the deflated airbags and lander platform is a complex and tricky maneuver; it would be even more complex with an airbag design large enough for Curiosity.

Along with the huge difficulties presented by the physics of landing a large spacecraft on Mars, there are the challenges and pitfalls inherent in any ambitious mission—the mistakes to be avoided, the risks to be anticipated and eliminated or minimized. As Miguel San Martin, who designed the guidance and navigational controls for the mission, says, "There are the problems Mars creates for you, and the problems you create for yourself." A lot of learning, experience, design, testing, and review has gone into solving or avoiding both kinds of problems.

The novel solution the MSL team has developed is what they refer to as a "sky crane." After reducing its speed through a combination of atmospheric friction, parachute, and retrorockets, a descent stage with Curiosity hanging from it in a bridle of nylon tethers will use its thrusters to essentially hover as it lowers the rover to the surface—"a way of landing without landing," in the words of Steven Sell, who is responsible for verification of the EDL system. After touchdown, the bridle will be cut and a 6-second burn will ensure the descent stage crashes some 400 meters away.

Learning from the Past

After the failures of the Mars Surveyor and Mars Climate Orbiter missions in the late 1990s, it became clear that a Mars sample-return mission projected to launch in 2003 would be canceled. Knowing the mission would not go forward but still funded for a time, the sample-return team decided to devote their efforts to going back to first principles and think about all the ways to design a lander and put it safely on the surface. One of the questions they explored was whether it was possible to get velocity control so good that you could land a wheeled rover directly on the surface, rather than cocooned in a lander. (At the time and for a couple of years afterward, the answer was "no.") Rob Manning, now the chief engineer for Curiosity and, years earlier, the chief engineer for Mars Pathfinder, wrote to the chief engineer of the sample-return team, asking, "Have you thought about 'helicopter mode?'"—what was also known at the time as "rover on a rope." This was 1999, and they passed on the idea for fear of the two-body pendulum dynamics inherent in the architecture. With two bodies connected by tethers, there was concern over the potentially chaotic dynamics of the swinging pendulum motion that might result. Ultimately, this was a controls problem.

The concerns of the sample-return team represented an essential hurdle for the creation of Curiosity and the sky crane. Perhaps the key ingredient to getting past that hurdle was the experience San Martin had taken from MER development. MER had taught San Martin that he could effectively steer the pendulum and control the two-body dynamics, the key requirement to attempt what would be called the sky crane maneuver. The MSL EDL team even brought in a helicopter pilot from Sikorksy to apply his experience to plans for EDL. As Manning says, "Had they started from scratch, they never could have achieved this."

The sources of earlier experience they drew on included the Viking mission, which reached Mars more than three decades earlier. The engines on Curiosity's descent stage are an upgraded "reinvention" of Viking's throttleable engines, which the MSL team developed by studying available Viking documentation (which was not as comprehensive as they'd hoped), talking with Viking people, and reverse engineering still existing Viking-era engines. According to one team member, they "scrounged up" all the Viking data they could, a search that included locating an informative film of a Viking parachute test in the attic of a NASA retiree.

Parachute experience on Pathfinder and MER has also contributed to the MSL design. Getting as much information as possible about the behavior of large supersonic parachutes has been essential, especially since the MSL chute will be larger and will deploy at a higher speed than similar systems on past missions.

Another issue is the danger of aerodynamic interactions between the reaction-control system thrusters and the atmosphere, which, in the worst cases, can result in control reversal. As the plumes of retrorockets flow over the backshell of the descent stage, they can generate forces—like the lift created by air flowing over an airplane wing—that create undesired motion contrary to the intended one. The MSL design had to avoid that possibility. The team again went back to study their history, looking at Mercury, Gemini, and Apollo data; they even took a trip to the Virginia Air and Space museum to look at one of the few Apollo capsules. The EDL team deployed a series of cutting-edge computational fluid dynamics analyses and scaled tests to select thruster positions and orientations and verify that the resulting aerodynamic interactions were acceptable. The MSL team even passed on their finding to the Phoenix team, a tip that led the Phoenix staff to choose to turn off their entry reaction-control system for fear it might generate control reversals.

MSL's large heat shield was another challenge. The team determined that the shield material they originally planned to use would not survive the shear forces created as the spacecraft entered the Martian atmosphere at high speed. The team wanted to use SLA-561V, which had worked on all the past Mars missions from Viking on. They baselined SLA and started testing it. The old standard seemed to be working until some of the final tests in June 2007, when things went very wrong.

"I was presenting the state of our EDL development at the project CDR [critical design review]. We thought everything was going well, including the TPS [thermal-protection system] testing, which was almost complete," said Adam Steltzner, who led the EDL development for MSL, "when all of a sudden my cell phone starts vibrating in my pocket with news of a TPS testing failure. The SLA had just dissolved in testing—complete failure!"

They were short on time for the 2009 launch and needed to solve this problem quickly. The team conducted a rapid search of possible replacement materials in a short-turnaround, make-or-break trade. "We really did not have much time to make the 2009 launch date," said Steltzner. They ended up with a heat shield made of PICA (phenolic impregnated carbon ablator). A lightweight PICA heat shield had been used on the Stardust sample-return mission, and SpaceX uses a PICA shield on its Dragon capsule. NASA's Crew Exploration Vehicle (CEV) team studied the material extensively. Although they eventually decided not to use PICA, their research was a tremendous boon to the MSL team.

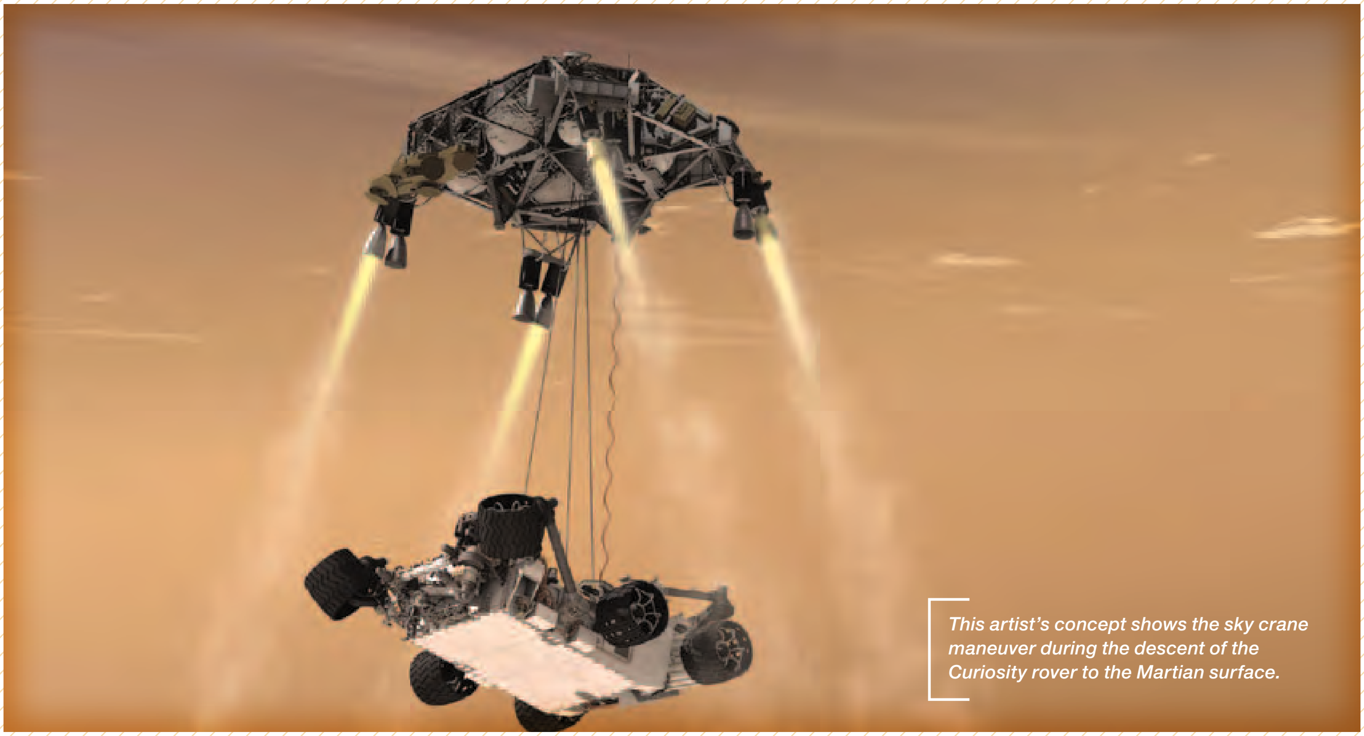
That CEV work is one of many examples of research and experience elsewhere in NASA contributing essential knowledge to Curiosity. As Manning says, "The NASA community as a whole should be proud of MSL. Only Apollo and shuttle have brought NASA together to this extent."

There were challenges, but, says San Martin, "No developmental shoe dropped during design and development"—that is, no major weaknesses in the concept were uncovered. Early, relatively small surprises meant small tweaks, but, he adds, "The final product looked like the early sketches." That is a testament to a well-conceived design, a point of pride for San Martin, arguably the most important contributor to the sky crane's architecture.

Although the team was able to get the EDL systems for Curiosity ready in time for the 2009 launch, the rover's wheel-drive actuators and avionics hardware could not make the launch date. The project ultimately slipped to the next favorable date for launch to Mars, in 2011.

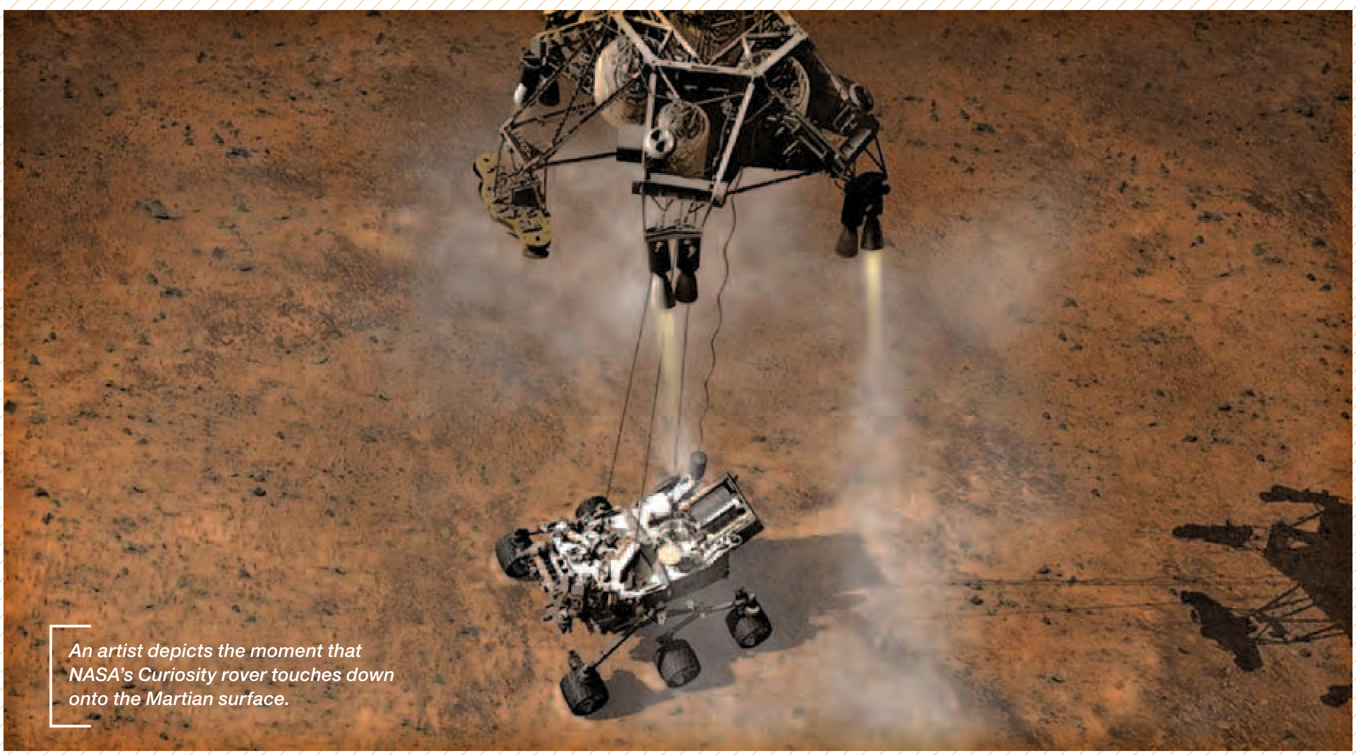
The Skeptics Test

Convincing people outside the team that the sky crane was the right solution for Curiosity took some doing, maybe because it is hard for people to give up their long-standing idea of what the "right" landing architecture is—that is, setting down on legs with the engines below the lander. That describes the lunar landings, of course, as well as



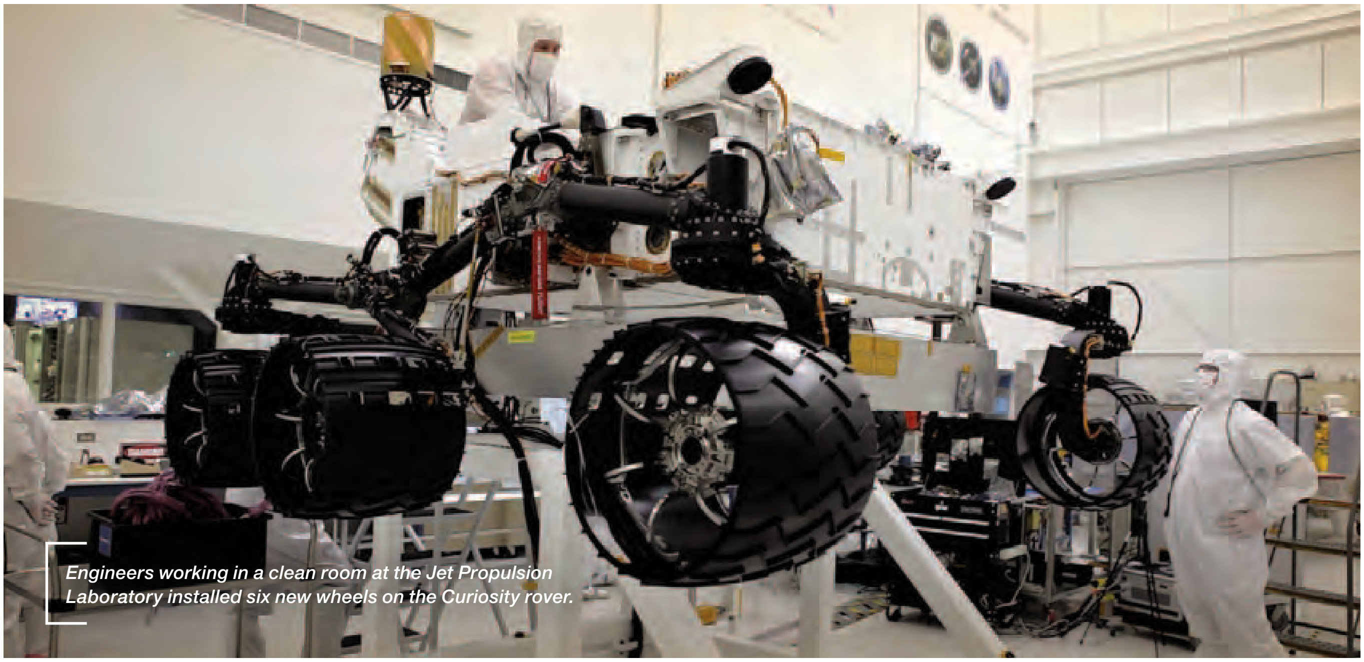
This artist's concept shows the sky crane maneuver during the descent of the Curiosity rover to the Martian surface.

Image Credit: NASA/JPL-Caltech



An artist depicts the moment that NASA's Curiosity rover touches down onto the Martian surface.

Image Credit: NASA/JPL-Caltech



Engineers working in a clean room at the Jet Propulsion Laboratory installed six new wheels on the Curiosity rover.

Photo Credit: NASA/JPL-Caltech

the classic landing procedure in hundreds or thousands of science fiction stories and films.

The MSL team rounded up skeptics—veterans of Viking, Apollo, and the Delta Clipper reusable launch vehicle program, among others—to test themselves, to "make sure we're not all drinking the Kool-Aid together." As expected, the assembled skeptics picked at details of the plan, saying, "I don't trust this; I don't trust that." A main concern was those two-body pendulum dynamics that had stopped the use of the architecture the first time back in 1999.

A year later, when they brought the group together again, the team had solid answers to all those concerns. The process was repeated—more doubts expressed; those doubts set to rest a year later—until the skeptics were convinced and the team was confident that the sky crane would work.

No Mars mission is certain, obviously, but the team believes the likelihood of a successful EDL is very high. "We have margin all over the place," says system engineer Al Chen. Other team members agree that the risks are lower and the margin for error greater than on past Mars landings. In part, that is the result of having analysis and simulation tools that are an order of magnitude better than what was available for earlier missions. More computer power means better virtual testing; they have carried out more than 2,000,000 Monte Carlo landing simulations—randomly generated possible sequences of events played out on computers.

Partly, though, the sky crane landing architecture is clearly more robust than other options. For instance, landing on Curiosity's six wheels is inherently more stable than landing on legs. With a landing on legs, accurate touchdown detection is critical because a retrorocket burn of even a few milliseconds too long threatens to tip over the lander. A wheeled rover like Curiosity has much more leeway—a full 1.5 seconds for cutting the bridle connecting the rover and the descent stage.

Planning for the Future

As ambitious as it is, the Mars Science Laboratory mission is only one step in the ongoing history of planetary exploration. Vividly aware of how important their own learning from past missions has been, the MSL team is taking care to store documents detailing their work in an EDL repository that will be available to future project teams.

Equally or more important, they say, at least in the near term, is that "people will spread out." Just as veterans of Pathfinder and MER brought their hard-earned expertise to MSL, members of the MSL team will go on to join other project teams and apply the knowledge they gained from their Curiosity work to the next generation of entry, descent, and landing challenges. ●

"RU" READY FOR THE FUTURE?

ROCKET UNIVERSITY helps pave the way

BY STEVEN SULLIVAN AND CHRIS IANNELLO

As the Space Shuttle program came to a close in 2011, hundreds of engineers at Kennedy Space Center began redirecting their efforts from shuttle processing toward flight-systems engineering. To support this new focus, Kennedy managers developed a small, low-cost training program: Rocket University. Rocket University, or RU, is a HOPE-style (Hands-On Project Experience) program that promotes agencywide collaboration, technical skill development, and technical team building while simultaneously fostering systems engineering skills. RU classes and labs provide valuable experiences similar to those gained during long-term, large-scale flight projects, but on a smaller, short-term, low-cost scale.

Good systems engineers can handle technical leadership and systems management. Both skills are critical when developing and operating any space-related system. We developed RU's curriculum around this idea and built it using a combination of vendor-purchased training and civil-servant-developed courses.

An important goal of the RU curriculum is to incorporate the teachings of NASA's well-respected APPEL (Academy of Program/Project and Engineering Leadership) training into its program. By incorporating a technical curriculum to compliment the APPEL program, RU focuses on teaching systems engineering of the integrated project as well as within each discipline. RU students take classes that combine APPEL's broad systems engineering training with technical training in unfamiliar disciplines. Once trained, the students are challenged to use their new skills as part of a project team to conduct a lab flight project or experiment. They must work on this project from its inception to its completion, immediately demonstrating their new skills as they simultaneously apply their systems engineering training throughout a complete project life cycle.

This immediate application of newly learned technical and managerial skills is what makes RU different from other training programs.

Balloon Payload Launch and Recovery Lab

In October 2011, RU began offering weather-balloon courses as part of its near-space environments lab curriculum. These classes were meant to introduce Kennedy engineers to the benefits of using balloons to achieve inexpensive and long-term science and technology objectives. The labs include a series of iterative challenges to be achieved during four incremental test flights.

According to one RU mentor, Nicole Dawkins, "Participants of Rocket University's near-space environments team are developing expertise in everything from composite manufacturing to the latest in avionic and software design techniques. The added bonus is that the engineers are learning these skills as they build and fly real products that impact future NASA programs."

Photo courtesy of Steven Sullivan and Chris Iannello

Students fill a balloon for the team's project test flight with the Rocket University payload launch and recovery lab.

For test flights, Johnson Space Center is the principal investigator. The students' main flight objective is to provide Johnson with test-flight data that will help them create the final design for an unmanned capsule that can be deployed from the International Space Station to Earth.

The first balloon-lab test flight has been completed. For this flight, RU students designed and built an instrumented payload, launched and tracked a balloon from the Kennedy Visitor's Center, and tracked a dummy payload receiver using a global-positioning system (GPS). The balloon reached 95,000 ft., but the payload landed 45 miles offshore and was not retrieved. This balloon flight was the first step in incremental development, where RU coursework and projects evolve into the avionics that will support our aeroshell drop-test customers as well as all other RU flight objectives. The lessons learned from this first lab will also be used to improve the second balloon-flight test, which will feature additional challenges, such as using a flight computer, providing two-way telemetry that handles commands and responses, establishing a flight-termination system, providing data-recording capabilities, and predicting the balloon's landing location within 1 mile.

"Every time the near-space environments team successfully launches a balloon payload, we are demonstrating new skills and techniques learned within the curriculum of Rocket University," explained Dawkins. "There is a lot of satisfaction in knowing that we designed, built, tested, and flew a product that will impact future NASA programs."

Lessons learned from the second test flight will be used to plan and conduct the third flight, which will include deploying a small (7- to 8-lb.) capsule that will land in the ocean. This aeroshell-scale drop test will require new design efforts such as creating the small-scale test capsule and designing the landing parachute. Performing this small-scale model drop test will help the Johnson design team catch failures early as the data generated during the test will be used to design a larger, 200-lb. aeroshell capsule. This larger capsule will eventually fly on a stadium-sized balloon in Fort Sumner, N.M., and is being offered by the Wallops Balloon Program Office and the NASA Columbia Scientific Balloon Facility in Palestine, Tex. The capsule will be dropped at around 120,000 ft. to collect data that can be used by Johnson to design their final product.

Focusing on the Individual

RU's "technical discipline leads" teach a variety of classes. In several cases, the technical discipline training classes were conducted in collaboration with experts from other NASA centers who developed coursework and taught the classes. The curriculum also covers major technical discipline areas:

- Systems engineering (provided through APPEL training)
- Flight structures
- Avionics/embedded systems
- Propulsion (liquid and solid rocket)

Once students complete their technical discipline classwork, they apply their newly gained knowledge and can test their proficiency on a lab project or experiment. The final exam for the lab is the flight project itself.

RU currently has four main lab/experiment project types:

1. Near-space environments
2. Unmanned aerial systems
3. Rocketry (transonic and hypersonic)
4. Propulsion system test beds

Photo courtesy of Steven Sullivan and Chris Iannello

The RU team shows the Kennedy Space Center Engineering director the analysis associated with the team's first certification build.

To date, these labs have resulted in more than a dozen rocket launches and two balloon launches, each of which involved incrementally designing custom flight hardware and software.

RU labs operate with a large number of project teams, but each team is fairly small and given very small budgets. Limited manpower and a low budget: these realities set the stage for team labs.

The NASA model rarely leaves one person solely responsible for building a critical subsystem, but this is not the case at RU where, because of limited manpower, one engineer can sometimes be assigned to work within an entire system. This means a lot of hands-on engineering that provides lessons and insights that can't be gained in any other way. Thomas Edison said, "Opportunity is missed by most people because it is dressed in overalls and looks a lot like work." At RU, our labs provide each student with lots of "overalls" moments and opportunities for personal and team successes.

Students work with a principal investigator to set project objectives as well as with mentors, who support them throughout the project. As students begin their work, they become believers in applying agency guidelines for program management because they quickly learn that organization can solve a lot of frustrations between systems engineers. They also soon realize that agency collaboration is required to help find technical solutions from experts across NASA and across different disciplines. Finally, the project team must report to all levels of management (that is, engineering director, chief, division/branch chiefs), who actively participate in major project reviews. Given the limited manpower assigned to each project team, the entire process stresses responsibility and leadership on the part of each individual.

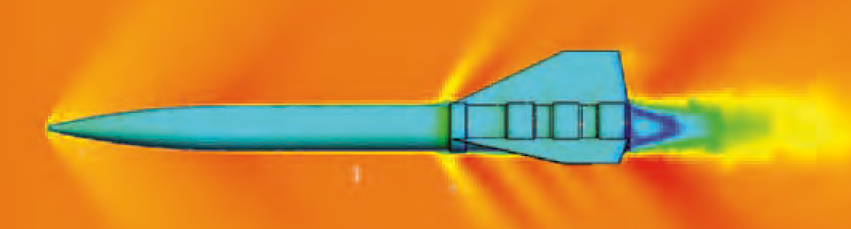
In addition, small budgets often force team members to build, by themselves, the functions or systems they require to complete their project (for instance, data-logging telemetry downlinks or inertial navigation systems). Doing this work gives team members a deeper understanding of flight functions than they would get if they could simply buy technical solutions. It also forces them to find and use low-cost materials and resources. Many students have become more knowledgeable about how to apply commercially available hardware and software to their projects, which opens their minds about using commercial-grade constituent parts as they create custom-built hardware and software designs to meet lab requirements.

Additional Accomplishments

In addition to the success achieved with RU's near-space balloon launches, several other labs have seen similar accomplishments since RU began in the early fall of 2011.

Avionics

The RU avionics discipline supported the balloon lab's first untethered launch by designing a custom avionics system that used the latest in mixed-signal embedded electronics. This system is much more capable than similar systems available either commercially or within academia. Amazingly, the hardware cost of the system was under $350, with the majority of the expense going toward purchasing the downlink transceiver and the Ublox GPS with integrated antenna. The system consists of a 32-bit microchip PIC with 512 KB of flash RAM and, stretching outward from the microcontroller, high-speed synchronous and asynchronous serial busses that connect sensors as well as radiofrequency links. The low-cost, high-performance embedded



Computational fluid dynamics analysis for the Rocket University advanced rockets workshop. The second stage was analyzed at Mach 1.4 to determine the aerodynamic performance of the rocket at its maximum expected velocity. The colors in the image correspond to velocity of the air, with multiple minor shockwaves seen emanating from the rocket as it flies supersonic.

Image courtesy of Steven Sullivan and Chris Iannello

electronics used in this flight served to further develop RU's technical skills in that we learned to use nontraditional hardware types. This avionics package is in its first revision and will be improved upon by RU avionics students with each balloon-lab test flight.

Transonic Rocketry

During the introductory class on basic rocketry, students learned about center-of-pressure calculations, center of gravity, available models and simulations, and their accuracy. In the lab, students handcrafted their own high-powered rockets and flew them with rocket-enthusiast clubs sanctioned by the Federal Aviation Administration. From these launches, students learned lessons regarding the performance of off-the-shelf accelerometer data-collection devices; the benefits of live video and sound streams to examine the environments, rate, and violence rockets are exposed to; and parachute deployments that resulted in either reparable rocket damage upon landing or no recovery due to high-wind conditions. The class was a great start for future transonic-rocketry studies.

Unmanned Aerial Systems (UAS)

A series of training sessions provided students with an introduction to UAS: practices and principles; flight dynamics; modeling and simulation; guidance, navigation, and control; communication systems; composite-material manufacturing complete with a familiarization of Kennedy's prototype shop; and systems engineering and integration workshops. These courses were taught through a collaborative effort between NASA and Embry-Riddle Aeronautical University (ERAU). The extremely challenging lab project for UAS students involves designing, manufacturing, and testing a viable UAS. The project anticipates flight testing to begin in summer 2012, culminating in a planned autonomous UAS mission.

Educational Outreach

As RU progresses, it seems natural that the university and its curriculum could also be used to foster outreach opportunities between NASA and public/private engineering institutions. Since all RU classes are videotaped, they can easily be offered to outside universities; and because of the low cost of lab materials, the program is affordable to implement. Already the University of Central Florida and ERAU have sent faculty to teach at RU. These institutions are also providing students to work as special teams to assist NASA engineers during design, manufacturing, and testing procedures.

Hands-on opportunities and working side by side with NASA engineers help make these students workforce-ready. As RU's educational outreach expands, it could also be disseminated to high-school or middle-school levels to support national science, technology, engineering, and math initiatives. The collaborative possibilities between educational institutions and government agencies will continue to grow.

What Lies Ahead

Rocket University continues to expand its curriculum, finalize "graduation" requirements, further identify opportunities to collaborate with educational institutions, and work toward creating an exciting agencywide technical challenge. This challenge would be offered to all NASA centers and would culminate in a competitive, yet collaborative, effort among the centers. Each team would congregate at one NASA location to present their concept and design, conduct a demonstration to show how their design satisfies challenge requirements, and, finally, discuss their results and lessons learned. ●

RU interested? If so, please contact the Rocket University program manager, Kathleen O'Brady, at 321-861-3300 for more information.

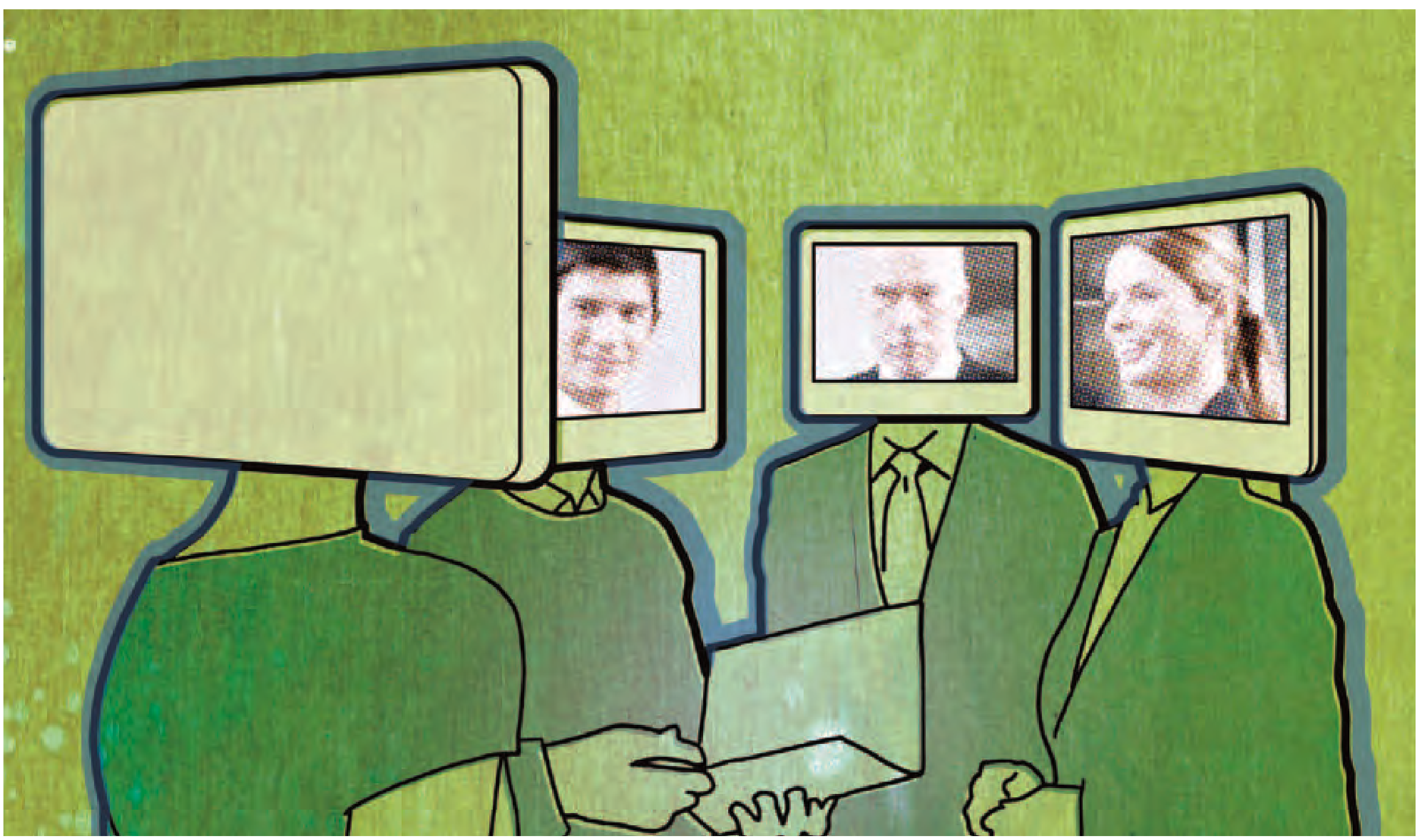
STEVEN SULLIVAN is the chief engineer of NASA's Commercial Crew Program at Kennedy Space Center. He began his NASA career in 1985 as a shuttle engineer and served in various roles within the Space Shuttle program, including branch chief and later division chief for electrical systems and chief engineer of launch-vehicle processing in Kennedy's Engineering Directorate. He also led resolution of engineering issues related to processing and launching shuttles *Discovery*, *Atlantis*, and *Endeavour*.

CHRIS IANNELLO began his career at Kennedy Space Center in 1989 in the ground power systems group and has more than twenty years' experience in power systems. He has been involved in some of manned spaceflight's most challenging technical issues, and he has served or led on assessments for the NASA Engineering and Safety Center. As a researcher, he has published over twenty papers in engineering journals, leading discipline conferences, and tutorial seminars.

The People Behind the NASA Engineering Network

BY MANSON YEW

This article has been several years in the writing. Sure, part of the reason it took so long was lack of time; part of the reason was fear of putting words out there, though I had no problem talking about the NASA Engineering Network (NEN). I have done presentations about NEN at countless meetings, at all NASA centers, and at conferences here and abroad. I talked about the ability of NASA engineers to search for knowledge across three million documents in forty repositories, and about leveraging the official lessons learned from NASA's past, including more than two hundred new lessons from the Space Shuttle program. I talked about the resources from the twenty-eight communities of practice representing core engineering disciplines. But I wanted to write a story for the *ASK* audience that would show readers how and why NEN worked.



I found that story at the NASA PM Challenge in February 2012, at a session titled "Building Communities of Engineers to Share Technical Expertise" and co-presented by Daria Topousis, NEN's lead for the communities of practice task; Lorraine Fesq; and Rich Mrozinski. As these three wonderful presenters interacted at the podium with grace and trust, it occurred to me: the story was not just about the NASA Engineering Network. The story was about people: Daria at the Jet Propulsion Laboratory (JPL), Neil Dennehy at Goddard Space Flight Center, Dawn Schaible, Lorraine Fesq, Ed Strong, Michael Bell, and countless engineers, scientists, and managers who are working to make NASA better by building networks across distance, time, and disciplines.

The Origins of NEN

NEN started as the vision of Greg Robinson, NASA's deputy chief engineer. When he first assembled the NASA Lessons Learned Steering Committee, he heard about all the different ways lessons learned were missed—perhaps due to time pressures or culture or a lack of information technology and knowledge management sophistication. He reached out to Pat Dunnington, then NASA's chief information officer, who brought Jeanne Holm from JPL, a recognized expert in knowledge management, into the conversation. From the beginning, we knew that what was required was more than just an upgrade of the Lessons Learned Information System. In the shadow of the *Columbia* tragedy and the accident investigation board's conclusion that NASA did not demonstrate the characteristics of a learning organization, the task had even greater importance. We felt that the solution required much more than tools at hand, more than discussion forums, wikis, search engines, lessons learned databases, and content management systems.

We learned to take a chapter from the past, when communities of shared practices would congregate in lunchrooms, at water coolers, and around common activities to share knowledge. The advent of technology had created a different way of doing business that allowed greater personal efficiencies at the expense of social interaction. What technology took away, technology could perhaps recreate. An online collaboration space for a specific discipline might help reestablish these crucial interactions, creating virtual watering holes where people could find knowledge and experts in their area of practice and interact with other practitioners.

The beginnings were rocky. Having observed many instances on the web of discussion boards where people sign up, ask questions, present problems, and have a community of people provide answers and feedback, we focused on discussion forums. We seeded the forums with questions, we presented trivia and challenges, we asked people to post. Nothing much happened.

Success

The work of Daria and Neil changed that. The Guidance, Navigation, and Control community of practice was one of the first communities on NEN and a source of experiments, lessons learned, successes, and failures in establishing a vibrant community. Neil is the NASA tech fellow for guidance, navigation, and control (GN&C), and the lead of the GN&C community of practice. He did not need to be sold on the benefits of sharing knowledge and building a community of practice. He was excited to have a virtual community that would reach out to all the practitioners, junior and senior, across NASA. Though Neil was a highly in-demand resource at NASA, a person whose voicemail would fill up within hours every morning, he committed to working with Daria to establish his community.

She started with two requirements: a picture of Neil and a community charter. They worked together to establish the charter so that members understood the mission of the community (the picture was harder to come by). Neil recruited Ken Lebsock, his deputy, to work with the practitioners to collect key documents, standards, lessons learned, and best practices. They also published the "State of the Discipline." The strategy was to create vibrant engagement among a small group of practitioners, and then slowly build the membership. The plan also recognized that there were different modes of engagement. There would be a core group, but there would also be lurkers and seekers who visited to see if they could find a solution to an immediate problem; there would be people interested in periodic messages and announcements and people

WHEN TRUSTED MEMBERS OF THE GROUP BRING IDEAS, TOOLS, OR TECHNOLOGIES THEY HAVE TRIED, VETTED, AND CAN RECOMMEND, HOWEVER, THOSE TECHNOLOGIES HAVE A GREATER CHANCE OF BEING ADOPTED.

who belonged in another discipline that is loosely coupled to GN&C. The collaboration tools, resources, and knowledge base were engineered so each type of member would find something that catered to their needs.

But perhaps the key ingredient of success was that Neil recognized that Daria was a part of the community, alongside the PhDs and branch chiefs. Her contribution was expertise in the practices and technologies of knowledge sharing. She participated in every teleconference for GN&C, listening for opportunities that would benefit the community as a whole if it were put up on NEN. She was invited to the annual GN&C face-to-face meeting. Kayaking with other members, catching lunch and dinner with them, and talking in the hallways during breaks, she heard suggestions for knowledge to share and was asked about improved capabilities. Community members collaborated with her on deciding what online tools would enable their work.

Her role as community facilitator evolved into the role of technology steward. Groups often resist new technologies that outside organizations try to get them to use; like the door-to-door vacuum cleaner salesmen of old, people selling tools are looked on with suspicion. When trusted members of the group bring ideas, tools, or technologies they have tried, vetted, and can recommend, however, those technologies have a greater chance of being adopted. With Daria as technology steward, the community tool set grew to include a vendor database, "Ask an Expert," ratings, reading room, standards, and advanced search. Most recently, the community rolled out a monthly webcast covering such topics as "Fundamentals of Deep Space Mission Design" and "Space Situational Awareness." NASA personnel can participate live or watch the webcasts online afterward.

But the community was not mainly about the tools and technologies; the most remarkable activities were people helping people. Recently, when a member used "Ask an Expert" to gather information about reaction-wheel failures, Neil surveyed his core team, then contacted an expert in the Mechanical Systems community of practice, and personally assembled the response. This led to other members providing input from their experience.

The story of the GN&C community teaches two essential lessons about what makes online communities successful:

- They work best when community members also meet and work together in person and regularly connect in various ways (for instance, through teleconferences).
- They need to be actively facilitated by people who understand the community and are trusted by its members.

The Autonomous Rendezvous and Docking Community

The GN&C community of practice grew from approximately fifteen members in the first year to nearly two hundred registered members, plus countless visitors. Recently, the lessons it offered about creating a successful community have been applied to the Autonomous Rendezvous and Docking (AR&D) community, whose formation Daria has supported. Accomplishing their work is helped by a synergistic blend of meeting face to face; sharing knowledge in person, online, and by telecon; and providing energetic, informed facilitation. Despite the challenges of limited budget and changing priorities, the community has grown to ninety-eight. The persistent knowledge that emerged from those interactions can be found on NEN, including the seminal white paper on AR&D, "A Proposed Strategy for the U.S. to Develop and Maintain a Mainstream Capability Suite ('Warehouse') for Automated/Autonomous Rendezvous and Docking in Low-Earth Orbit and Beyond."

Since the early nineties, NASA had identified as a fundamental technology for all classes of future missions the ability for space assets to rendezvous and dock without human intervention. This technology requires the expertise of various sciences and disciplines, including guidance, navigation, software, sensors, flight, and aerosciences. No single mission could fund the complete suite of AR&D capabilities, and various missions that require AR&D have developed what their resources allowed, often trading long-term effectiveness for short-term capabilities. Despite these challenges, experts at NASA have continued to figure out ways to advance NASA's capabilities. But 2009 saw perhaps their biggest setback, with the near simultaneous cancellation of the Space Shuttle and Constellation programs.

As they picked up the pieces of their work, the champions of AR&D assembled a team of experts at Johnson Space Center in the spring of 2010 to ensure that NASA would not lose its hard-earned AR&D expertise. The synergy exceeded expectations. Participants were energized by the new possibilities of working together as a community. But Neil understood that this commitment would not last long before the daily grind back at each person's home center would dilute their enthusiasm. Having worked with Daria on the Guidance, Navigation, and Control community of practice, he invited her to join and facilitate this community's development. Drawing on her expertise in the art of creating virtual communities, she led the group in formulating their charter, gathered key knowledge, helped members collaborate and share their plans, and established the AR&D community of practice on NEN. Though the experts dispersed to their various centers, they now had an online touchstone where they could continue their collaboration and knowledge sharing. The community was further invigorated by their work developing a coordinated flagship technology demonstration for AR&D, and the collaboration tools on the AR&D community of practice proved invaluable. They held a telecon at least monthly and shared their best technologies, practices, and theories toward developing the demonstration, and along the way used each other's expertise to assist with other tasks and research at their centers.

In 2011, the flagship technology demonstration went away amid budget and strategy constraints, but the momentum of the community was not slowed. Now they met weekly. They uncovered opportunities to work together across centers and across projects; trust among participants allowed Langley Research Center, JPL, and Johnson to develop joint proposals and develop common sensors; Goddard offered their test bed for AR&D; others explored opportunities to collect data from existing missions to further AR&D; and Rich Mrozinski of Johnson led the writing of an AR&D strategy white paper that assembled NASA's best practices and proposed a capability warehouse to ensure future efficiencies of their tool suite. When the Office of the Chief Technologist issued a new announcement of opportunity for AR&D, the community felt that NASA would be best served with a joint proposal from the community, not competing ones.

The story of AR&D at NASA continues to be written. The artifacts of their trust and collaboration, including the aforementioned white paper, can be found on NEN, but that's just a small part of an amazing effort.

All forty engineering communities of practice on NEN have similar stories. Fault Management just held a workshop and is working to implement a new NASA standard and handbook on this critical discipline. The Structures community of practice has a thread of "Greybeards' Advice for Young Engineers;" the Passive Thermal and Mechanical Systems communities have a cross-discipline discussion on piezo motors and actuators. NASA Deep Space Navigation holds monthly knowledge-sharing meetings. Program, Planning, and Control just came online after participants at the 2011 PM Challenge suggested it. And Daria or a member of her team continues to participate in the telecons with each community and to speak at face-to-face meetings, pushing people to continue sharing knowledge. Neil continues to shepherd the GN&C discipline as the NASA tech fellow.

Despite budget constraints, strategic course corrections, and any number of challenges our missions face on a regular basis, our engineers endeavor to come together and build the creative connections that contribute to solutions. I can honestly say that there is a seat at the table for anyone to contribute to our shared mission and shared future. Wherever one finds him or herself in their career at NASA, they are welcome in any of the communities on the NASA Engineering Network. ●

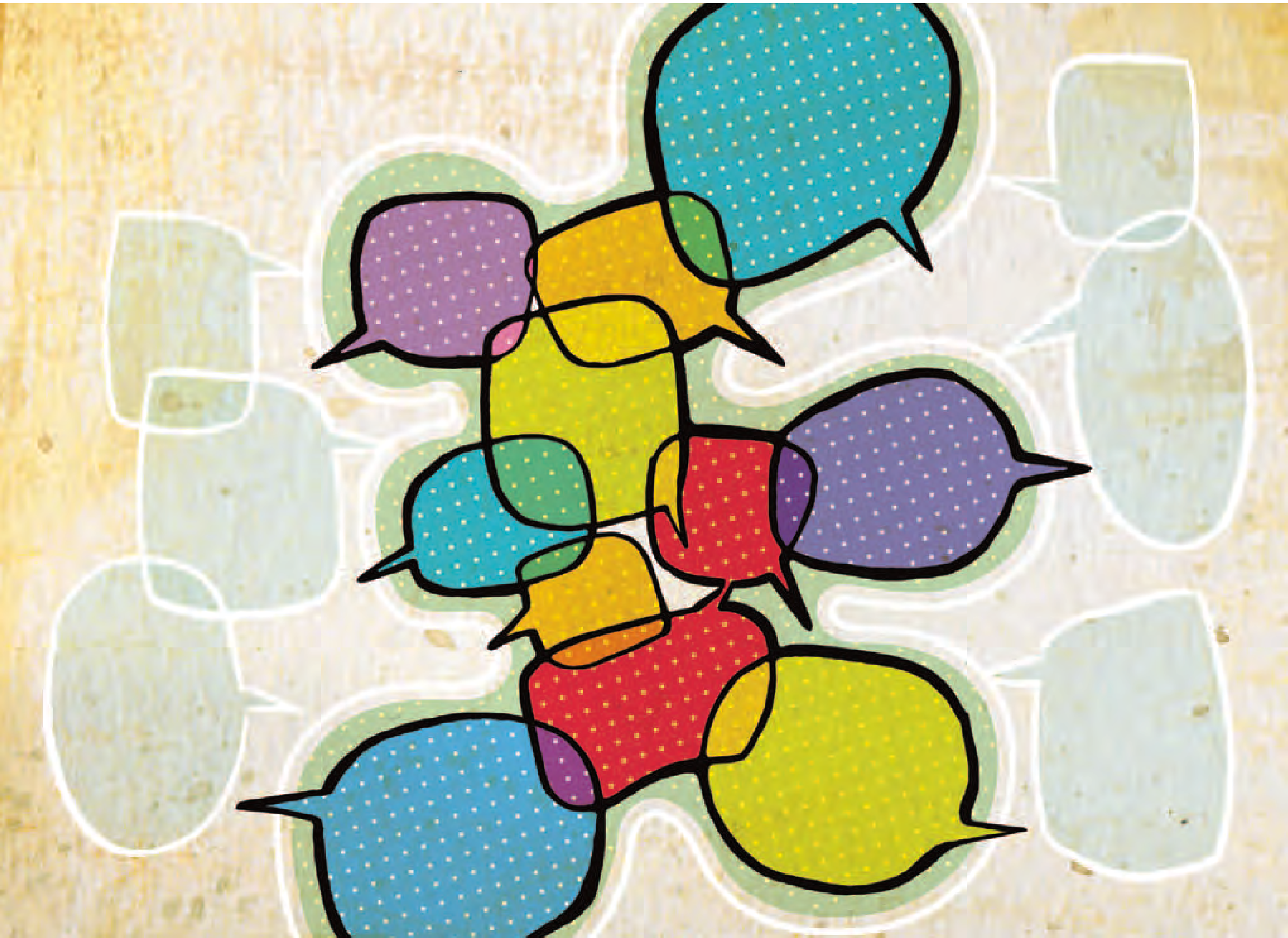
Note: This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

MANSON YEW is the enterprise systems project manager at the Jet Propulsion Laboratory.

Knowledge Topics: A Vital Project Resource

BY DON COHEN

NASA projects require a variety of resources. Money, of course. Appropriate technical and management skills. Raw materials and (often) existing components, an infrastructure of equipment for building and testing hardware, a launch vehicle or aircraft for flight projects. Enough time to get the work done.



There is another resource vital to successful projects that is unlikely to be mentioned in plans, budgets, or technical documents: social capital.

What Is Social Capital?

To put it in the simplest terms, social capital is the value of the connections between people. An individual's social capital typically consists of an informal network of relationships—the people you can go to for advice, information, knowledge, and assistance. (And those same people will come to you for similar help.) In organizations, these personal-professional networks are essential to getting a lot of work done, but they are not recognized on org charts or other official documents.

People naturally seek out colleagues they have gotten to know over the course of their careers whose abilities they respect and—equally important—whom they trust to understand their requests and respond to them constructively. When faced with an especially tricky problem, established professionals are much more likely to go to these colleagues for help than they are to consult a database or other "knowledge repository." Almost by definition, the tricky problem involves subtleties that cannot be explained in a written report or database entry, subtleties that can be teased out and understood in conversation between professionals. Discussing an issue with a colleague usually involves more than being handed an answer; it is an opportunity to collaborate on your problem, to think it through together.

That preference for going to a trusted person for help is doubly strong when the issue involves judgment and not just technical expertise. In fact, though the personal connections of social-capital networks are essential pathways for the transfer of technical knowledge, they are at least as important as sources of information and advice about "how things are really done around here"—the political realities, workarounds, unwritten rules and expectations, and influences that have such a powerful effect on project and personal success.

How Is Social Capital Developed?

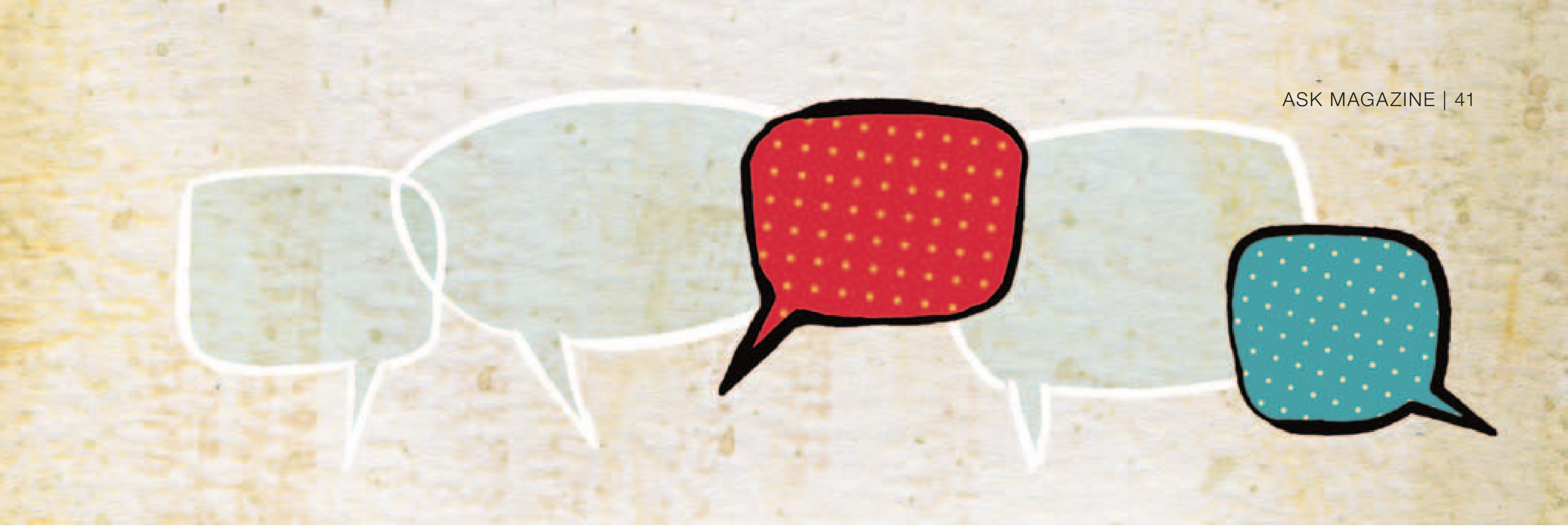
Probably the most important builders of these social-capital networks in organizations are the experiences people have working together over time. In an organization like NASA, where most work is project work, being part of a series of project teams with overlapping but changing membership creates opportunities to form lasting relationships that are career-long sources of knowledge and assistance. Opportunities to spend time with people involved in similar work at conferences and workshops also help build these personal networks.

But there is nothing automatic or certain about that relationship building. It depends on and benefits from a set of conditions that may or may not exist in a given organization or part of an organization. Foremost among them is a culture of trust—a sense that good will, honesty, and cooperation (though not universal in any organization) are the norm rather than the exception.

Trust in organizations develops over time, built by interacting with leaders, managers, and colleagues who are trustworthy, by the experience of fairness in promotion and giving credit for accomplishments, and by people being trusted enough to be given some autonomy in deciding how best to get their work done. Many experienced project managers at NASA and elsewhere talk about telling their team members *what* needs to be done and *when* it needs to be finished, but leaving the *how* up to them. (The opposite of this kind of trusting behavior is micromanagement that overwhelms the micromanager with work even as it undermines the initiative, talent, and goodwill of the person being managed.)

For obvious reasons, having a shared meaningful goal enhances trust and cooperation. Knowing that both you and your colleagues are working toward an aim that you all value and that is larger than personal success or advancement is a solid foundation for a collaborative relationship. It can counterbalance some personal differences that might otherwise stand in the way of helping one another.

Long tenure is also a social-capital builder. The longer individuals are in an organization, the more people they meet, and the more chances they have to solidify relationships through repeated work together and opportunities to meet. And, in most cases, the more they know about the organization and how to do their work—that is, the more knowledge they have to share.



No organization is uniform. NASA, like every diverse and dispersed organization of any size, has many subcultures and different employee experiences good and bad. So it is not possible to generalize confidently about social capital at NASA. But there are features of the organization that strongly encourage these networks. I have already mentioned the extensive project work. As much as any organization in the world, NASA is characterized by important shared goals. The vast majority of civil servants and contractors are passionate believers in NASA's missions to advance science, technology, and exploration. Experienced project managers talk about how reminding teams of their shared mission has the power to counteract personal disagreements and potential discouragement over budget constraints or intractable technical problems. And people who work at NASA tend to stay many years, building up their networks over decades. Even many retirees stay involved, offering their "graybeard" expertise to younger colleagues both informally and through their involvement in review boards and advisory groups.

Some NASA Examples

Probably every NASA project can offer multiple examples of social capital at work—instances where team members went to trusted mentors or former colleagues or other professional acquaintances for help solving a technical problem or an issue related to how their project is being carried out or how it is perceived or supported by others.

Here is one example of the power of social-capital connections to address a tricky technical issue.

"Give Me Two Pictures"

Rob Manning, chief engineer of the Mars Exploration program at the Jet Propulsion Laboratory, tells this story about a design breakthrough for entry, descent, and landing of the Spirit and Opportunity rovers:

> We put these three rockets in the backshell and a little inertial sensor that allows us to figure out which way was up. The problem is, winds could be pushing along horizontally. I'm thinking, I've got to get a horizontal velocity sensor. If there's a big steady wind pushing it along horizontally, right now the vehicle has no idea that's happening. If the spacecraft knew the velocity, it could use the small rockets to adjust for that. I told my friend Miguel San Martin, "I need to get Doppler radar on the vehicle to measure velocity." He puts two fingers up and says, "Give me two pictures." I said, "Oh, my God, what a brilliant idea. Who should I talk to?" He says, "Call Andrew Johnson. He does two-dimensional image-correlation algorithms." I knew this was not going to go over well with the project management. Emergency systems engineering, adding new subsystems at the last minute, is a sign of weakness. Luckily, it turns out we built rover electronics with ten camera ports but only nine were needed. We wanted to modify one of the existing science cameras and put it looking down and have it take pictures on the way down. It could compare two pictures. If they shifted by a certain amount and if you knew the time between them, you'd know how fast you were moving. We took three pictures—to double-check. Within six months it was in the design. Had we not used it, we would have ended up bouncing at 60 mph right toward the southern rim of Bonneville crater, where those sharp, wind-carved rocks called ventifacts lived.

Manning's story offers a vivid picture of social capital at work. A conversation with a friend quickly leads to an innovative technical solution to a problem that a much longer formal knowledge search of documents and databases would probably never have found. And the friend directs Manning to someone in *his* personal network who has the specialized expertise needed to make the idea work. Getting that new contact shows another aspect of the power of social networks: they frequently provide access to the acquaintances of one's acquaintances, vastly expanding the potential resources of knowledge and support.

The Orbital Boom Sensor System

After the *Columbia* accident, the shuttle fleet was grounded until the orbiters could check for thermal-protection system damage

TELECONFERENCES WERE IMPORTANT FOR SHARING INFORMATION, BUT, SHE SAYS, "TRAVEL, TRAVEL, TRAVEL WAS THE MOST IMPORTANT PART OF OUR COMMUNICATION STRATEGY." IT WAS THE ONLY WAY FOR PEOPLE TO DEVELOP REAL WORKING RELATIONSHIPS—ROBUST SOCIAL CAPITAL.

before returning to Earth. Kim Ess was project manager for the orbital boom sensor system, which gave them that capability. She notes:

> We didn't have to convince anyone that the work mattered to the space program and to the safety of our astronauts. And the importance of returning to flight and preventing future catastrophes gave us a defining and unifying goal that inspired hard work and cooperation, although, as with any project, it was important to help team members keep the goal in view as they dealt with the details, complexities, and inevitable frustrations of their parts of the work.

An important shared goal—a "unifying aim"—fostered cooperation, building trust-based social capital. Ess also emphasizes the importance of personal contact. Teleconferences were important for sharing information, but, she says, "Travel, travel, travel was the most important part of our communication strategy." It was the only way for people to develop real working relationships—robust social capital. She adds:

> Over time, we established a we-have-a-problem attitude rather than a they-have-a-problem attitude. Having people travel from site to site contributed to this change. As people got to know and trust each other and recognize that we were all working toward the same goal, information about problems became just data for the team to work with, not indications of failure.

Reviews and Social Capital

The reviews that are a standard part of NASA projects are an interesting example of a meeting place of formal process and informal social capital. Most NASA projects include milestone reviews (such as preliminary design review and critical design review) during which a board of experts from outside the project examines its progress and questions project team members to determine if the work is technically sound enough and adhering to schedules, budgets, and other managerial requirements well enough to proceed to the next stage of development. They often pose tough questions that show the project team where serious work needs to be done.

Part of the process—the social-capital part—involves both the formation of the review panels and their questions and recommendations. Often, the project team leaders have some say in who will be on the boards and suggest members whose expertise and commitment they especially respect. So, although they are outside the project and likely to be tough critics, they are generally trusted colleagues, not strangers. Often, too, when they find a weakness or risk in the project that needs to be addressed, the review board members bring *their* social networks into the picture, saying, "You probably want to talk to X at Langley," or, "Y at Goddard is an expert in this." So the review process helps expand the network and the knowledge resources of the project team.

Maintaining the Resource

Managers who recognize the importance of social capital as a project resource will take steps to protect and enhance it with the same kind of care they devote to other vital resources. Investing in social capital is not expensive and the dividends it pays are immense. These are, in summary, a few of the ways project leaders can help develop and maintain it:

- Trust team members to make decisions about how best to do their work.
- Give people time and space to talk to colleagues inside and outside the project. Recognize that informal conversations away from the computer or workbench (over coffee or a meal) often contribute to knowledge sharing and problem solving.
- Invest in travel for yourself and others on the team: face-to-face meeting matters.
- Help the team keep their shared goal in mind.
- Be open to good new ideas from any source.
- Give team members enthusiastic, public credit for the good work they do. ●

A floor-level look at the huge Apollo- and shuttle-era platforms that will be removed from high bay 3 of the VAB.

Photo Credit: NASA

REFURBISHING THE VAB

BY JOSE LOPEZ

How do you prepare for the next generation of spaceflight at NASA? Well, at Kennedy Space Center's Vehicle Assembly Building, or VAB, it requires a lot of creative renovations. Actually, it's more like a home improvement project on steroids. Ultimately, the upgrades will allow more flexibility and reliability, as well as a safer environment, to service vehicles for the next forty years of space exploration. As the deputy project manager for the VAB, it has been an honor to be tasked with this undertaking.

The 46-year-old VAB is a massive structure, originally built to service Apollo Saturn V vehicles that were 363 feet tall. The building itself stands 525 feet tall on a footprint that takes up 8.5 acres. The Statue of Liberty could easily fit into each of its four high bays. The VAB is so large, it even has its own weather. Under certain conditions, small cloud formations have developed near the ceiling.

The building was modified for the Space Shuttle program to assemble and service the solid rocket boosters, external tank, and orbiter. Now, the VAB will again be modified and refurbished to service not only NASA's next-generation Space Launch System (SLS) program, but also other commercial launch vehicles. Being very conscious of federal funding challenges, we thoroughly studied options that involved a third modification to the original Apollo "box platform" concept. This would have been similar to the transition from Apollo to shuttle. The type of modifications, the cost, and the limitations to future operations made that option impractical.

The challenge is twofold. First, as with any aging structure, much of the piping, HVAC, fire-protection, electrical, communications, and other systems are outdated or beyond their intended lifespan. In addition, the improvements must take into consideration the servicing of more than just one launch-vehicle configuration.

The existing VAB access platforms used in previous programs are not able to be reused and must be demolished to make way for new platforms and infrastructure that can accommodate more than one launch vehicle. The challenge is to design and construct systems that are relocatable and able to access critical areas of multiple launch-vehicle configurations. It affects not only work platforms for personnel access, but also access for commodities such as power, communications, nitrogen, helium, compressed air, and other gasses. Given the variety of vehicles that will be serviced in the VAB in the future, including some that have not yet been designed, it was essential that the new access system be moveable and adjustable. In order to advance the concept of relocatable platforms, the VAB team consulted with operations and safety experts to understand the steps and duration involved with reconfiguring a high bay. We also coordinated with commercial and industrial entities to brainstorm various concepts to move massive steel structures with greater precision.

To arrive at our selected concepts for the overall VAB infrastructure, we developed an extensive partnering process between our project management team, the vehicle-processing operations, facilities operations, and safety communities. We know very well that without the collective buy-in of the larger NASA organization, we would not be assured of the success of our vision.

Much of the VAB's current infrastructure, which is more than four decades old, is also in need of refurbishment. This massive building is as old as I am, and even I can admit to needing an occasional visit to a doctor, so why shouldn't the VAB?

The first major renovation project consists of demolishing the seven access platforms in high bay 3 and replacing them with new platforms. The entire system will be vertically relocatable and able to translate horizontally to accommodate access points on different launch vehicles. Each platform of the new design will also be equipped with its own lighting, fire sprinklers, and interface panels for commodities. Other systems in the VAB structure, such as elevator landings and emergency egress paths, are also affected and must be considered in the overall operational design of the facility.

The refurbishment of the VAB will include removing seven Apollo-era platforms from high bay 3 and replacing them with modern versions that can be relocated and reconfigured for multiple launch vehicles.

Photo Credit: NASA

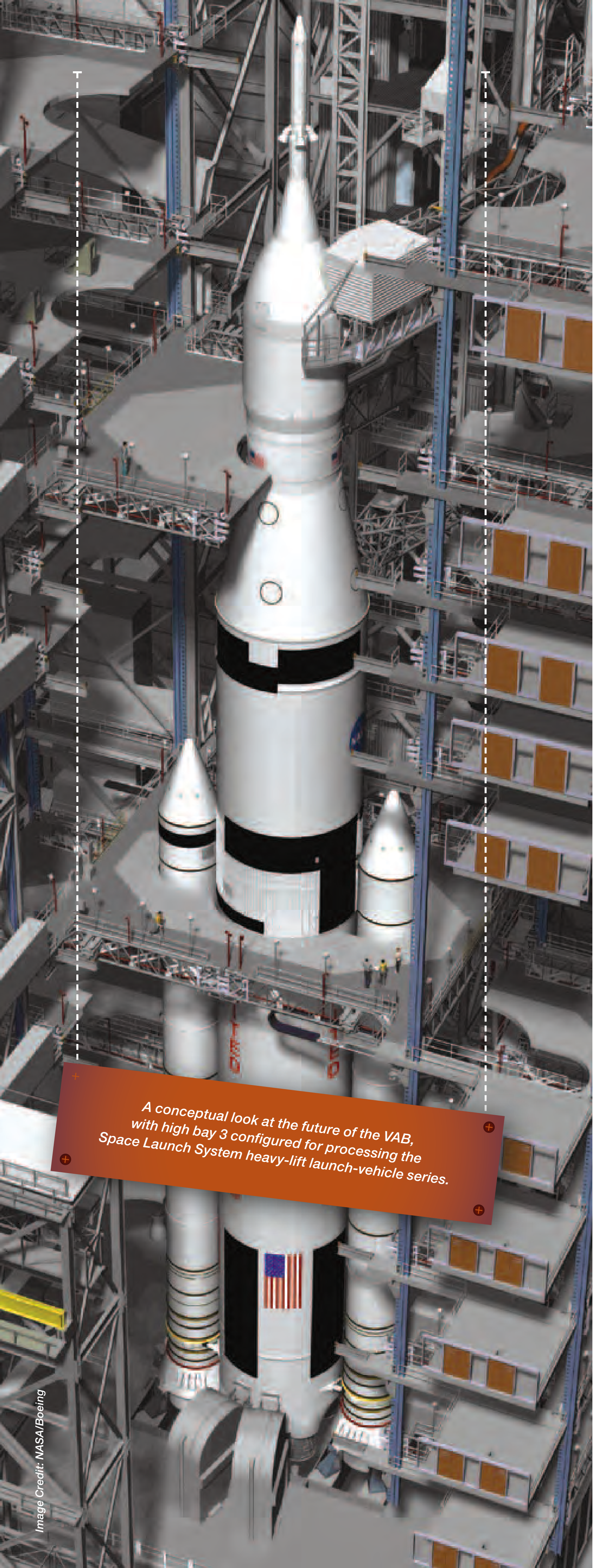
With the advances in communications technology, much of the existing communications cabling in the VAB is now abandoned or antiquated. One project consists of removing about 150 miles of old lead and copper cables and replacing them with a state-of-the-art fiber-optic communications backbone. The backbone will provide the communications infrastructure needed to support multiple users during vehicle processing.

The mechanisms that move the 45-story high-bay doors are being refurbished. Each of the four high bays contains a door that consists of two horizontal sliding sections and seven vertical lift leaves. Each door leaf is powered by a separate motor and is suspended on three wire-rope cables. The motors are being fitted with a secondary brake system and the wire ropes that move the doors, a total of 8 miles of cable, are being replaced. Not only will these changes make the doors more reliable, they will also be safer to operate. The mechanisms that operate the doors will have a backup brake system and new electronic controls that will enable smoother emergency braking operations. Other work is also being performed to improve access and lighting to be able to service and maintain the doors more efficiently in the future.

The VAB also houses five primary cranes ranging from 175 to 325 tons in capacity. The 175-ton crane is receiving upgrades to its control systems. Installing advanced technology equipment will allow the cranes to operate more reliably with enhanced precision. This is a must when lifting and assembling critical flight hardware. These improvements require the cranes to be out of service for extended periods of time, making this the ideal time to perform these types of upgrades.

The fire protection and detection system in the VAB is in the process of being upgraded to support processing of future launch vehicles. Much of the fire distribution piping is at the end of its usable life and undersized to facilitate future operations. Additionally, the pumps that provide water to the fire sprinklers are being replaced with upgraded, larger, and more reliable pumps that can be serviced and maintained without affecting operations in the VAB.

Other building infrastructure such as potable water, sanitary sewer, storm-drainage piping, and low-voltage power systems are "original equipment" that was installed when the building was first constructed. After forty-six years, some cast-iron pipe systems have deteriorated, and electrical wiring and equipment have reached the end of their usable life.



A conceptual look at the future of the VAB, with high bay 3 configured for processing the Space Launch System heavy-lift launch-vehicle series.

The launch vehicles are assembled on mobile launcher platforms that sit on top of a crawler transporter that moves from the VAB to the launchpad. Once the vehicles are stacked, the VAB floor, foundations, and other structural elements must be able to support the weight of the entire system. The previous Apollo and shuttle launch systems weighed about 18 million pounds. The new SLS system will weigh considerably more—on the order of 25 million pounds. Consequently, the floor, foundations, and building threshold, as well as the crawler transporter itself, are undergoing modifications and upgrades to accommodate the additional weight of the new launch system.

All in all, it really is building renovation on a grand scale. The end of the shuttle program has provided a window of opportunity for us to perform necessary modifications to the VAB in preparation for future launch-vehicle processing at Kennedy—without the added expense and much greater complexity of doing the work while still processing flight vehicles at the same time. The work will require multiple construction contractors to work within the building confines simultaneously, safely, and efficiently. When it is all done, we will be able to assemble, service, process, and test America's next generation of launch vehicles. On that day, we take a step back and reflect on the accomplishments that make us proud to be Americans—and say, "We are ready for tomorrow."

If I were to capture some of the most crucial lessons learned during these critical phases of a project, I would remind anyone in my position to closely listen to the project managers and engineers that came before you, and capitalize on the nuggets of information from the years of excellent mentoring you received. Some of that great knowledge comes from engineers who were involved with the first major modifications to the VAB, between the Apollo and shuttle programs—some of whom are still here.

Over the years, I have worked with many brilliant engineers. Most of them were great for providing "don't do" lessons from their own experience: "Don't limit your future load limits on …," "Don't underestimate your future power loads on …," "Don't forget to provide access to …." It's amazing how much wisdom we gain from our failures and successes.

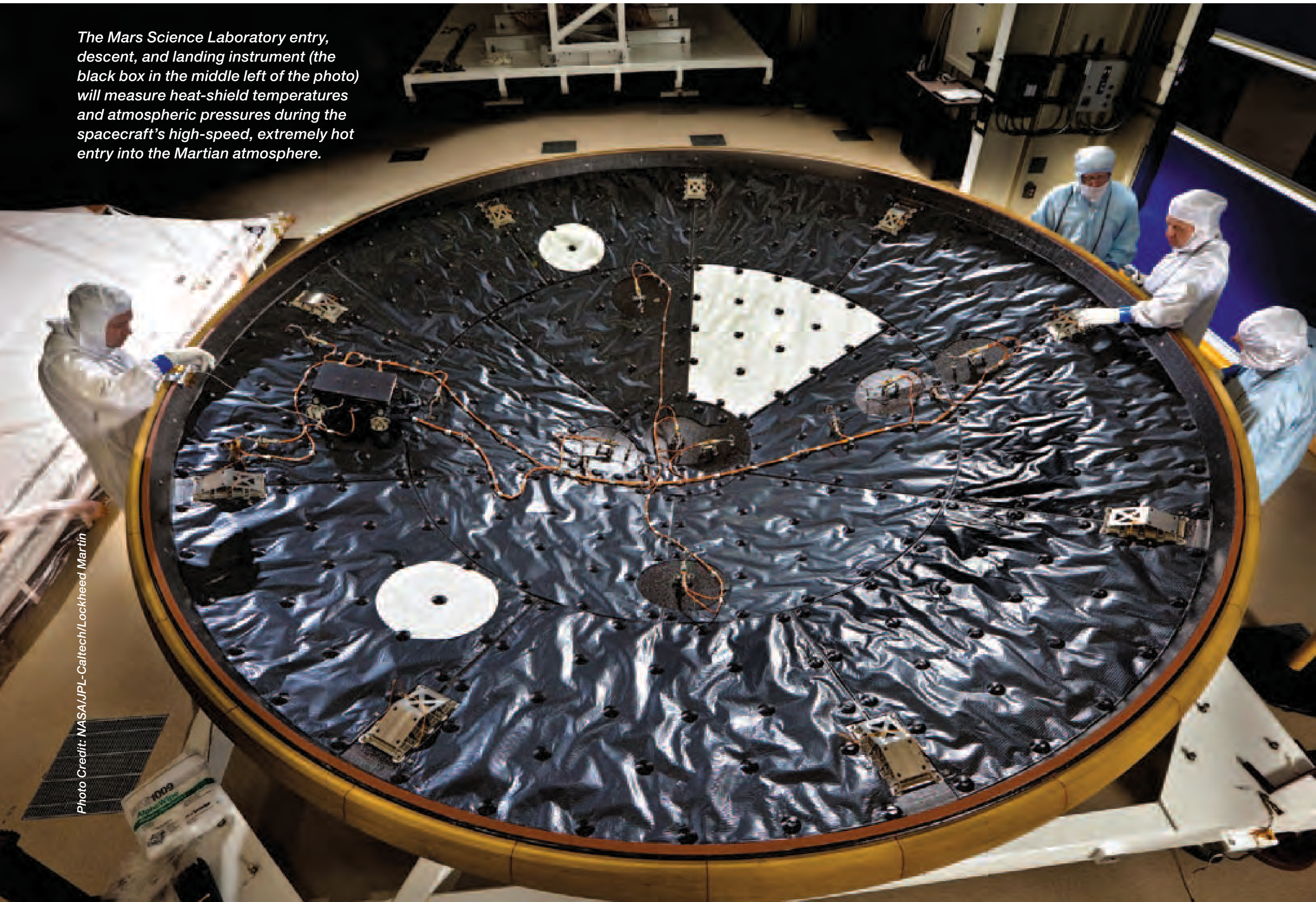
Remember, we don't always need to reinvent the wheel—we just need to keep making it better. ●

JOSE LOPEZ's twenty-five-year career at Kennedy Space Center spans the areas of shuttle facilities systems operations and maintenance, facilities electrical-controls design, expendable launch-vehicle operations, base operations contract management, and project integration under the Constellation program. His current role as VAB deputy project manager for the Ground Systems Development and Operations program has been his most challenging and rewarding position—in all his years with the administration and the military.

Is Your Project Viable?

BY KEITH L. WOODMAN AND PAUL W. KRASA

Requirements change. Policies change. Personnel change. Projects are constantly exposed to internal and external challenges, and an inability to respond has been many a project's demise. To survive, projects must learn to adapt. Stafford Beer, author of *Brain of the Firm*, created a model—the Viable System Model, or VSM—capable of determining an organization's viability, that is, its ability to adapt to change. NASA project managers can use this model to help determine and maintain their projects' viability.



The Mars Science Laboratory entry, descent, and landing instrument (the black box in the middle left of the photo) will measure heat-shield temperatures and atmospheric pressures during the spacecraft's high-speed, extremely hot entry into the Martian atmosphere.

Photo Credit: NASA/JPL-Caltech/Lockheed Martin

The Viable System Model

According to VSM, viable systems must have five functional subsystems: policy making, intelligence, adjustment, coordination/monitoring, and implementation. It is also a recursive model, meaning each subsystem must itself be viable down to the lowest subsystem. Ensuring a system has this recursion is extremely important as it allows a system to adapt more quickly to changes in the environment.

To determine whether or not their projects have well-functioning subsystems, NASA project managers should be able to answer several questions.

Policy Making

1. Which elements of the project are responsible for setting its policies and requirements?
2. Do these elements have the authority required to make and implement decisions?

Intelligence

1. How does the project connect with and monitor the outside environment?
2. What information is the project monitoring in the outside environment?
3. How is important information from the environment being collected and then disseminated to the rest of the project?
4. How does the project market itself, and to whom should it be marketing?

Adjustment

1. How is compliance to project policies and requirements ensured?
2. How is project performance captured and reported?
3. Which project element(s) can negotiate adjustments to project policies and requirements?

Coordination/Monitoring

1. How is coordination between project elements handled?
2. Is there an established channel to report progress and problems?
3. Can the project's elements handle the amount of internal communication they are getting?

Implementation

1. What are the project's technical elements?
2. Is each element its own viable system?
3. How do the project's technical elements connect to and monitor the outside environment?

To determine whether or not one of our projects was viable, we applied these questions to the Exploration Technology Development Program's (ETDP) Entry, Descent, and Landing (EDL) project. The goals of the EDL project were to develop and test new thermal-protection systems and materials, modeling and simulation tools, and supersonic retropropulsion technologies to support human Mars-exploration missions.

EDL as a Viable System

To ensure the new EDL project was set up to be viable, then–project manager (PM) Paul Krasa from Langley Research Center worked closely with the principal investigator (PI), Mike Wright from Ames Research Center. The PI was in charge of technical direction while the PM monitored and controlled managerial aspects such as performance, cost, and schedule. There was also a business office staffed to monitor the project's risks, schedule, budget, and configuration control. But did the project successfully implement the five VSM subsystems?

Policy-Making Subsystem

The PM and PI initially set the vision and overall direction for EDL. As the team grew, the vision and direction changed through a collaborative process that involved key individuals from the project, including the PM, PI, deputy PM and PI, deputy PM for resources, and element leads. Their decisions also included input from their ETDP customer, key subject-matter experts, and systems analysis, as well as knowledge of other NASA EDL project activities.

While the PI set technical goals for the elements, the PM determined how and when progress toward those goals would be set, and they mutually determined financial splits between technical elements. This information was captured and distributed through the official project plan developed by the PM and PI, and approved by ETDP. In addition, the PM and PI had total authority over their project and were able to control all resources and personnel issues. We knew who was responsible for which elements, and the responsible party had the authority to make decisions. Based on this, we knew the EDL project had a viable policy-making subsystem.

Intelligence Subsystem

Tying into and collecting data from the environment was crucial to the EDL team. Project leaders and personnel participated in weekly and quarterly meetings with ETDP and also communicated regularly with sister EDL projects (for instance, hypersonics efforts in aeronautics and planetary-landing efforts in science). EDL's project leadership used this communication to collect needs and requirements while simultaneously conveying their own project's mission, capabilities, and importance. In other words, while we were collecting information, we were also marketing. The project was very active with outreach and educational activities.

Photo Credits: NASA/Sean Smith

Project leadership encouraged members to present their work at conferences. As important information was collected from the environment, project leadership ensured that it flowed to the project through e-mail, weekly staff meetings, and quarterly EDL project meetings—face-to-face gatherings that included representatives from the program, EDL sister projects, and other individuals who were influential in the community. We carefully developed agendas to foster a relaxed and open communication environment that resulted in active feedback and, thus, active intelligence gathering. By building relationships with customers and stakeholders, encouraging other outreach activities, and ensuring dissemination of information to all project personnel, EDL's project leadership ensured the project had a viable intelligence subsystem.

Adjustment Subsystem

EDL's adjustment subsystem consisted of the PM, PI, business office, and the project's technical leaders (the lead engineers of its major technical elements). The project's policies and requirements were captured in the project plan, which was updated annually by project management and technical leads. The task plans developed by the technical element leads were integrated "up" into the project plan, which was reviewed regularly and updated based on progress made, new or evolving requirements, and resource adjustments. The business office tracked financial and schedule resources and produced reports for review. Before being finalized, the project plan would be distributed for comments to all project personnel, usually at the project's quarterly meetings. This made the development of the project plan a collaborative effort of leadership and a broad cross-section of technical staff.

When problems arose—for instance, difficulty reaching a milestone—the PM, PI, business office, and technical leads would discuss and decide upon the best remedy, which might include slipping the schedule (if possible), descoping the work, or adding resources. For example, a milestone requiring a downselect of materials was approaching, but the element manager made the case that a downselect would be invalid because of a lack of data from vendors and testing. The element lead said another year would be required to make the downselect correctly. After much debate, the project's management decided that a delay was warranted. Once a decision like this was made, the change was communicated to the rest of the project and captured in the project plan. By ensuring that progress was being monitored and actively adjusting the project plan to meet fluid program requirements, EDL's project leadership created a viable adjustment subsystem.

Coordination/Monitoring Subsystem

Project elements use the coordination channel to let each other know what they are doing and what they think other elements should be doing. For example, project leaders would use the coordination channel to communicate requirements and policies to their project's technical elements.

EDL's project leadership knew coordination and monitoring would be crucial to success and established how these functions would work before the project began. The plan established that information would be transmitted and progress tracked through e-mail, telephone calls, and meetings. EDL monitored project progress by having the technical elements report their accomplishments and problems at weekly staff meetings. Special meetings such as the EDL quarterly also enhanced project coordination and monitoring.

The element leads had their own weekly meetings. On a monthly or quarterly basis, element leads would invite their NASA counterparts from other EDL projects to discuss issues and work across the agency. This allowed the EDL project to continuously monitor the program's mandate to ensure the project's portfolio of investment was complementary with other NASA EDL investments. This strong coordination and monitoring subsystem helped ensure the EDL project remained viable.

Photo captions from left to right

Much of Mars Science Laboratory entry, descent, and landing instrument, including the sensor support electronics box, was designed, built, and tested at Langley Research Center.

Ronnie Barnes, of the Aerospace Composite Model Development Section at Langley, assembles one of forty-four arc-jet models for the Mars Science Laboratory entry, descent, and landing instrumentation program.

Chuck Antill (NASA, right) and Lewis Horsley (SSAI) perform verification testing on a flight board of the Mars Science Laboratory entry, descent, and landing instrumentation signal-support electronics.

Implementation Subsystem

All project elements that develop and deliver products or services to customers make up the implementation subsystem. EDL's subsystem consisted of three technology-development elements: thermal-protection systems that developed materials for reentry systems and conducted tests of those materials; supersonic retropropulsion that developed propulsion systems for landing heavy payloads on the Martian surface; and models and tools development that studied and created new computational tools critical for developing EDL systems.

Project leadership chose a technical leader for each of these elements, and each was expected to implement policies and meet requirements set by the PM and PI, regularly report progress toward these goals, and coordinate and communicate with the other elements. In addition, each technical element was expected to communicate to the rest of the system any pertinent information gathered from the environment.

When conducting an evaluation of the viability of each technical element, EDL's project leadership felt the elements' intelligence subsystems were performing inadequately. There was a serious lack of coordination with the EDL sister project in aeronautics. To address this issue, both EDL projects decided to share the same principal investigator. While this greatly increased the PI's workload, it was considered necessary to improve information flow between the two projects. After this change, the technical element leaders of both projects began to communicate more and build working relationships. Also, the leadership of each of these projects began attending each other's meetings, helping increase efficiencies and decrease redundancy. By improving the communication between the two projects, the viability of both was greatly increased.

Results

In EDL's two short years of existence, the project experienced two major changes to its primary stakeholder. To begin with, ETDP was mandated to form the EDL project; they were not given a choice, which initially caused an uneasy relationship between the project and the program. EDL worked diligently to meet the program's needs, and by the end of the first year was highly rated for its performance. In the second year, ETDP was completely reformulated, including the program's top level of management. These changes at the program level led to many budgetary and scope problems for the EDL project. Even with these programatic challenges, though, the EDL project accomplished great things, such as the first design-to-test of a supersonic retropropulsion model in more than twenty years, and completion of tests to prove the viability of flexible ablative materials for EDL purposes. Because of the forethought of the project management to ensure their organization was a viable system, the EDL project was able to quickly adapt and succeed in meeting the constantly shifting goals and requirements of their stakeholders.

VSM can be a good lens through which to view NASA projects to determine if they have the necessary subsystems and communication channels. Doing so can help ensure these projects can withstand the changes inevitable in our complex and dynamic environment. ●

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The Knowledge Notebook

The Real Value of Knowledge

BY LAURENCE PRUSAK

The question I most often hear when I speak to people about how to work with knowledge is some variation of "How can we measure the value of knowledge activities or projects? What is the return on knowledge projects?" Since knowledge is intangible, it is, not surprisingly, notoriously difficult to measure. Think of measuring the value of some other intangibles: love or honesty or the relationship between parent and child. (I am writing this on Father's Day!) But saying that knowledge value can't really be measured seldom satisfies budget-conscious mangers. We have to come up with something better.

Happily, there has been some real progress in this area. A volume published last year by the National Bureau of Economic Research entitled *Measuring Capital in the New Economy* is the first sustained effort to apply rigorous methods to measuring intangibles, including knowledge, in our economy, and to specify how these methods can be used to take a better shot at resolving this thorny issue.

Some of you may be thinking, "Why bother to do this?" Whether or not you can measure its value precisely, knowledge is obviously very important in organizations, and possibly the most important resource. Without knowledge, organizations wouldn't know how to get things done. So any attempt to make it more efficient, effective, or innovative must be a good thing, right? How could anyone think otherwise? Well, many people do. They feel that, without some logical and robust measures, attempts to work with knowledge and learning can never have the impact they may well deserve and will have a hard time getting the necessary support from leaders.

So what can we say to those people?

For a start, we can examine what organizations actually spend on knowledge. How much do you think an organization spends on knowledge as a percentage of all spending in any given year? When I ask audiences this question, I almost always get an answer that ranges from 3 to 8 percent or thereabouts. What if the real answer is much higher? What if it were more than 25 percent, and even higher in some industries and fields? Wouldn't that fact make for a strong case for actually managing this resource to optimize its use? After all, 25 percent or more of spending is a big investment.

How do we get this higher number? One way that is both rigorous and makes intuitive sense is to look at the salaries paid to workers who share the same formal qualifications but differ in the extent of their experience. I'll use myself as an example. I joined IBM when I was about fifty years old. I was paid quite a bit more than the typical salary offered to a thirty-year-old junior manager who had equivalent degrees from equivalent schools. So what did IBM buy with that additional money? Why pay me more when I had less energy, not to mention less hair and a few other effects of two more decades of wear and tear?

The only thing that made me worth more than that bright young man or woman was the knowledge I had developed over time—knowledge "measured" by my work history, accomplishments, publications, and reputation. Even if you assume that knowledge was only part of the value I brought to IBM, it was a big part. When you add the premium paid for my knowledge to money paid to attract the 250,000 mostly quite knowledgeable employees IBM then had, you are dealing with a huge outlay for knowledge. Add to that the cost of training, R&D, and all other knowledge development activities, and you reach a number that commands attention.

This is only one way to make the case for the value of knowledge and the importance of investing in the structures and strategies that support its effective development and use. This book from the Bureau of Economic Research—admittedly a rather difficult read unless you posses an economics degree or two—offers several others. For instance, read the chapter on organizational capital, a subject one rarely hears about. It suggests many ideas about the true worth of an organization and how it might be measured.

Wall Street and our own government oversight agencies rarely, if ever, use any of these new metrics. They assume that the level of success of these organizations will tell them something about the value of their knowledge. For those of us who actually work in organizations, though, the time to act is now, not after the results are in. We need to figure out how to use these new methods to make a stronger, more convincing case for working to enhance this most elusive yet critical resource. ●

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NP-2012-07-887-HQ