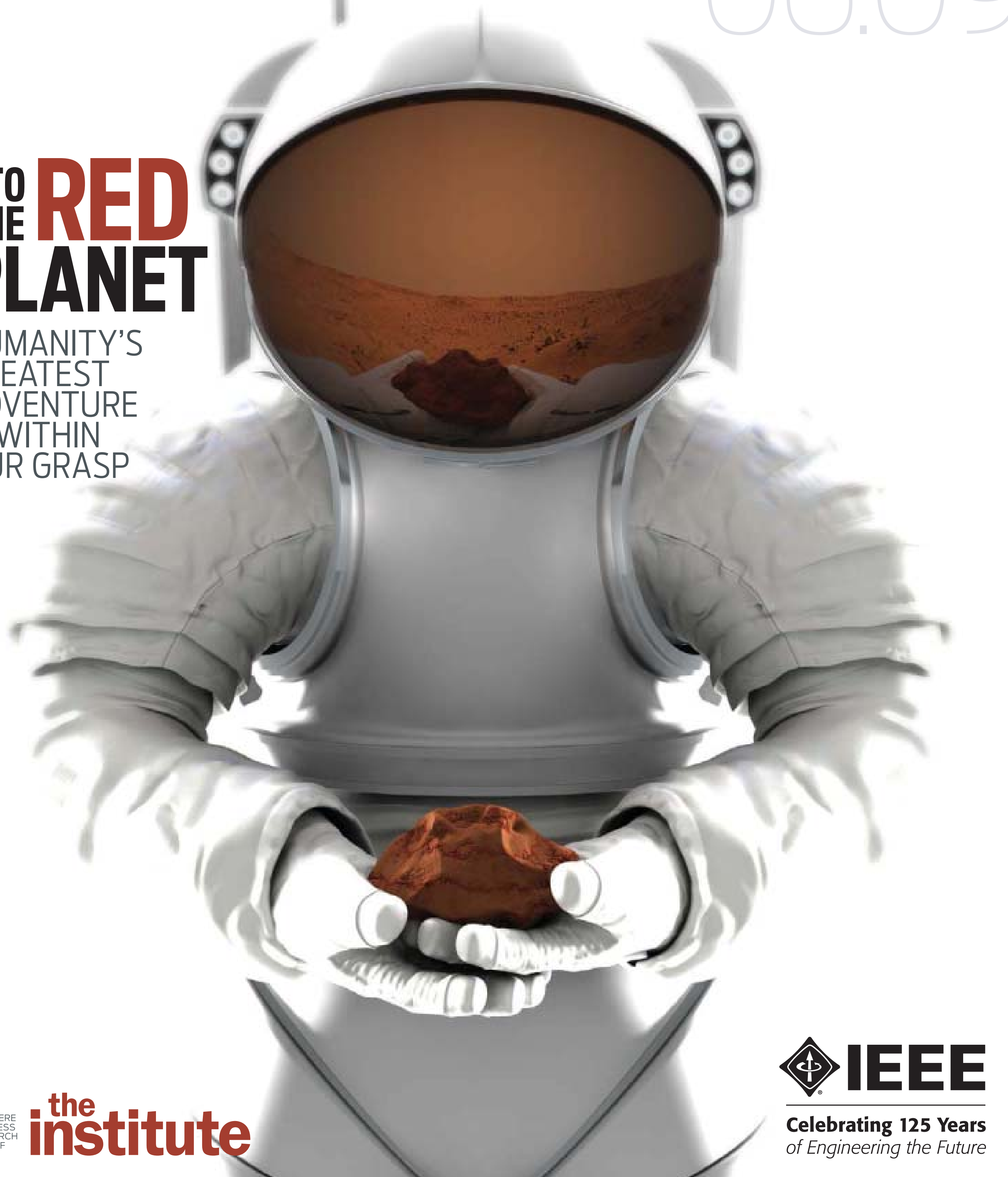
IEEE Spectrum

THE MAGAZINE OF TECHNOLOGY INSIDERS

06.09



TO THE RED PLANET

HUMANITY'S GREATEST ADVENTURE IS WITHIN OUR GRASP

CLICK HERE TO ACCESS THE MARCH ISSUE OF the institute

IEEE

Celebrating 125 Years of Engineering the Future


F-35
AA-1

volume 46 number 6 international

ieee spectrum 06.09

{ SPECIAL REPORT }

WHY MARS? WHY NOW?

COVER ILLUSTRATION: BRYAN CHRISTIE DESIGN; THIS PAGE: U.S. GEOLOGICAL SURVEY/NASA

spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | qMags

volume 46 number 6 international

ieee spectrum 06.09

SPECTRUM.IEEE.ORG

AVAILABLE 1 JUNE ON SPECTRUM ONLINE

MARS SPECIAL REPORT *continues*

PHOTO FROM SPACESUITS: WITHIN THE COLLECTIONS OF THE SMITHSONIAN NATIONAL AIR AND SPACE MUSEUM BY AMANDA YOUNG, PUBLISHED BY POWERHOUSE BOOKS

UPDATE

OPINION

DEPARTMENTS

TECH INSIDER WEBINARS

AVAILABLE JUNE 2009. REGISTER AT:
www.spectrum.ieee.org/webcasts

9 JUNE: COLLEGES ARE TRANSITIONING FOR THE FUTURE–ARE YOU?

11 JUNE: MULTIPHYSICS SIMULATION

16 JUNE: INTRO TO PGI *x*64+GPU FORTRAN AND C99 COMPILERS

IEEE.ORG/THEINSTITUTE

AVAILABLE 8 JUNE ON THE INSTITUTE ONLINE

CELEBRATING 125 YEARS

In celebration of IEEE's 125th anniversary, *The Institute* takes a look back at the history of IEEE as well as the development of three key technologies its members helped develop.

AN INSIDE LOOK AT THE PRESIDENT-ELECT CANDIDATES

The annual IEEE election gets under way in August. It's time to get to know the candidates for 2010 IEEE President-Elect: J. Roberto B. de Marca, Moshe Kam, and Joseph Lillie. Read about their personal sides—why they became engineers, their hobbies, and other interesting facts.

ONE-STOP SHOP FOR CAREER HELP

Do you need to find IEEE services that can help you land a job or improve your skills? We highlight a selection of services from the Careers section of the IEEE Web site, including job listings, career advice, continuing-education programs, and networking opportunities.

IEEE SPECTRUM (ISSN 0018-9235) is published monthly by The Institute of Electrical and Electronics Engineers, Inc. All rights reserved. © 2009 by The Institute of Electrical and Electronics Engineers, Inc., 3 Park Avenue, New York, NY 10016-5997, U.S.A. The editorial content of IEEE Spectrum magazine does not represent official positions of the IEEE or its organizational units. Canadian Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40013087. Return undeliverable Canadian addresses to: Circulation Department, IEEE Spectrum, Box 1051, Fort Erie, ON L2A 6C7. Cable address: ITRIPLEE. Fax: +1 212 419 7570. INTERNET: spectrum@ieee.org. ANNUAL SUBSCRIPTIONS: IEEE Members: $21.40 included in dues. Libraries/institutions: $399. POSTMASTER: Please send address changes to IEEE Spectrum, c/o Coding Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855. Periodicals postage paid at New York, NY, and additional mailing offices. Canadian GST #125634188. Printed at W224-N3322 Duplainville Rd., Pewaukee, WI 53072-4195, U.S.A. IEEE Spectrum circulation is audited by BPA Worldwide. IEEE Spectrum is a member of American Business Media, the Magazine Publishers of America, and the Society of National Association Publications.

ieee spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | qMags

back story

His Space

JAMES OBERG was 11 in 1955 when his grandfather gave him a copy of Jules Verne's classic *From the Earth to the Moon*. He was hooked by the 19th-century fantasy and dreamed of building spaceships—someday. Two years later, he sat on a sidewalk next to a stack of newspapers intended for his paper route and devoured the front-page stories: The Soviets had just launched *Sputnik*. No longer was space exploration the stuff of science fiction. It was happening, right now.

Then came the realization, as a teenager, that he would never travel in space. At 6 feet 8 inches (213 centimeters), nothing short of a battering ram was going to get him inside one of NASA's space capsules. But Oberg still wanted to be part of the great leap. He attended grad school at Northwestern University on a NASA fellowship. Just before Christmas in 1968, as the space agency was preparing to launch its Apollo 8 mission to orbit the moon, he and three friends drove from Evanston, Ill., to Cape Canaveral, Fla., where they sat on the beach and watched the launch.

Oberg went on to work as an aerospace engineer at NASA for 22 years. He switched to journalism in the late 1990s and now makes his living reporting on space for such outlets as *Popular Science*, NBC News, and, of course, *IEEE Spectrum*.

For this issue, he sat down with Owen [center] and Richard Garriott [left], the second father-and-son pair to reach space (albeit at different times). The interview was a reunion of old friends: Oberg knew Owen, an electrical engineer and former NASA astronaut, from Owen's Skylab and space shuttle days in the 1970s and 1980s. Richard, 47, took a more newfangled route into orbit: He made a fortune in the computer-game business and last fall paid US $30 million for a ticket to the International Space Station aboard a Russian Soyuz.

Having spent a lifetime around astronauts and cosmonauts, Oberg knows their job is as demanding as they come. "The degree of concentration and focus that they have to have in their lives, day after day, year after year, is an enormous price to pay," he says.

Still, he admits, he'd trade his reporter's notebook for a spacesuit. In a heartbeat. ❑

CITING ARTICLES IN IEEE SPECTRUM

IEEE Spectrum publishes two editions. In the international edition, the abbreviation INT appears at the foot of each page. The North American edition is identified with the letters NA. Both have the same editorial content, but because of differences in advertising, page numbers may differ. In citations, you should include the issue designation. For example, the first Update page is in *IEEE Spectrum*, Vol. 45, no. 6 (INT), June 2009, p. 9, or in *IEEE Spectrum*, Vol. 45, no. 6 (NA), June 2009, p. 11.

MATTHEW MAHON

contributors

PALLAVA BAGLA is the science editor of New Delhi Television and coauthor of *Destination Moon: India's Quest for the Moon, Mars and Beyond* (HarperCollins, 2008). For this issue, he interviewed G. Madhavan Nair, head of the Indian space agency [p. 58].

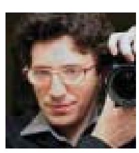
FRED GUTERL grew up building spaceships in his garage out of plywood and two by fours. He's now the assistant managing editor of *Newsweek International*. In "Mars Is Hard" [p. 26], he and Monica Heger describe a few of the many challenges in sending humans to the Red Planet.

MONICA HEGER, a science writer in New York City, came of age in a post-Apollo world and never thought much about space exploration. So she was surprised to learn of all the ongoing research on manned spaceflight, including the advanced space suit she writes about in "What to Wear on Mars" [p. 30].

DAVID A. MINDELL, in "The End of the Cult of the Astronaut" [p. 64], discusses the evolving role of humans in space exploration as machines assume an ever greater role. A professor of the history of engineering and manufacturing at MIT, he wrote the 2008 book *Digital Apollo: Human and Machine in Spaceflight* (MIT Press).

ELON MUSK, a serial entrepreneur, played key roles in starting up Tesla Motors and PayPal. He founded the rocket company Space Exploration Technologies Corp. to develop cheap, reusable launch vehicles and to help fulfill his personal quest to land a human on Mars. He describes the company's rocky road to success in "Risky Business" [p. 36].

KIM STANLEY ROBINSON made his mark as a science-fiction writer with the 1990s Mars Trilogy: *Red Mars*, *Green Mars*, and *Blue Mars*. For this issue, he sifts through more than a century's worth of fiction on the Red Planet to bring us "My 10 Favorite Mars Novels" [p. 16].



ANATOLY ZAK is a science writer, illustrator, and animator whose fascination with the history of space exploration began when he was a high school student in Moscow. In "A Russian Return to a Martian Moon" [p. 32], he explores Russia's rekindled efforts to send a mission to Phobos.

ROBERT ZUBRIN, who wrote this issue's "How to Go to Mars—Right Now!" [p. 44], says, "Growing up in the Sputnik-Apollo era, it was apparent to me that the greatest possibilities for the human future lay in space." President of the Mars Society, Zubrin has written several Mars books, including *How to Live on Mars: A Trusty Guidebook to Surviving and Thriving on the Red Planet* (Three Rivers Press, 2008).

IEEE

Celebrating 125 Years
of Engineering the Future

IEEE MEDIA

STAFF DIRECTOR; PUBLISHER, *IEEE SPECTRUM*
James A. Vick, j.vick@ieee.org
ASSOCIATE PUBLISHER, SALES & ADVERTISING DIRECTOR
Marion Delaney, m.delaney@ieee.org
RECRUITMENT SALES DEVELOPMENT MANAGER
Michael Buryk, m.buryk@ieee.org
BUSINESS MANAGER Robert T. Ross
MARKETING & PROMOTION MANAGER Blanche McGurr, b.mcgurr@ieee.org
INTERACTIVE MARKETING MANAGER Ruchika Anand, r.t.anand@ieee.org
LIST/RECRUITMENT MARKETING MANAGER Ilia Rodriguez, i.rodriguez@ieee.org
REPRINT SALES +1 212 221 9595, EXT. 319
DEPARTMENT ADMINISTRATOR Faith H. Jeanty, f.jeanty@ieee.org
ADVERTISING SALES +1 212 419 7760
TELEPHONE ADVERTISING/SALES REPRESENTATIVE
John Restchack +1 212 419 7578
ADVERTISING PRODUCTION MANAGER Felicia Spagnoli
SENIOR ADVERTISING PRODUCTION COORDINATOR Nicole Evans
ADVERTISING PRODUCTION +1 732 562 6334
IEEE STAFF EXECUTIVE, PUBLICATIONS Anthony Durniak

IEEE BOARD OF DIRECTORS

PRESIDENT & CEO John R. Vig
+1 732 562 3928 FAX: +1 732 465 6444 president@ieee.org
PRESIDENT-ELECT Pedro A. Ray
TREASURER Peter W. Staecker
SECRETARY Barry L. Shoop
PAST PRESIDENT Lewis M. Terman

VICE PRESIDENTS

Teofilo Ramos, *Educational Activities;* Jon G. Rokne, *Publication Services & Products;* Joseph V. Lillie, *Member & Geographic Activities;* W. Charlton Adams, *President, Standards Association;* Harold L. Flescher, *Technical Activities;* Gordon W. Day, *President, IEEE-USA*

DIVISION DIRECTORS

Giovanni De Micheli (I); Robert E. Hebner Jr. (II); Curtis A. Siller Jr. (III); Roger W. Sudbury (IV); Deborah M. Cooper (V); Mark I. Montrose (VI); John D. McDonald (VII); Stephen L. Diamond (VIII); Frederick C. Mintzer (IX); Richard A. Volz (X)

REGION DIRECTORS

Howard E. Michel (1); William P. Walsh Jr. (2); William B. Ratcliff (3); Don C. Bramlett (4); David J. Pierce (5); Leonard J. Bond (6); Ferial El-Hawary (7); Jozef W. Modelski (8); Enrique E. Alvarez (9); Yong Jin Park (10)

DIRECTORS EMERITUS

Eric Herz, Theodore W. Hissey

IEEE STAFF

EXECUTIVE DIRECTOR & COO James Prendergast
+1 732 502 5400, james.prendergast@ieee.org
HUMAN RESOURCES Betsy Davis, SPHR
+1 732 465 6434, e.davis@ieee.org
PUBLICATIONS Anthony Durniak
+1 732 562 3998, a.durniak@ieee.org
EDUCATIONAL ACTIVITIES Douglas Gorham
+1 732 562 5483, d.g.gorham@ieee.org
STANDARDS ACTIVITIES Judith Gorman
+1 732 562 3820, j.gorman@ieee.org
MEMBER & GEOGRAPHIC ACTIVITIES Cecelia Jankowski
+1 732 562 5504, c.jankowski@ieee.org
CORPORATE STRATEGY & COMMUNICATIONS Matthew Loeb, CAE
+1 732 562 5320, m.loeb@ieee.org
BUSINESS ADMINISTRATION Richard D. Schwartz
+1 732 562 5311, r.schwartz@ieee.org
TECHNICAL ACTIVITIES Mary Ward-Callan
+1 732 562 3850, m.ward-callan@ieee.org
MANAGING DIRECTOR, IEEE-USA Chris Brantley
+1 202 530 8349, c.brantley@ieee.org

IEEE PUBLICATION SERVICES & PRODUCTS BOARD

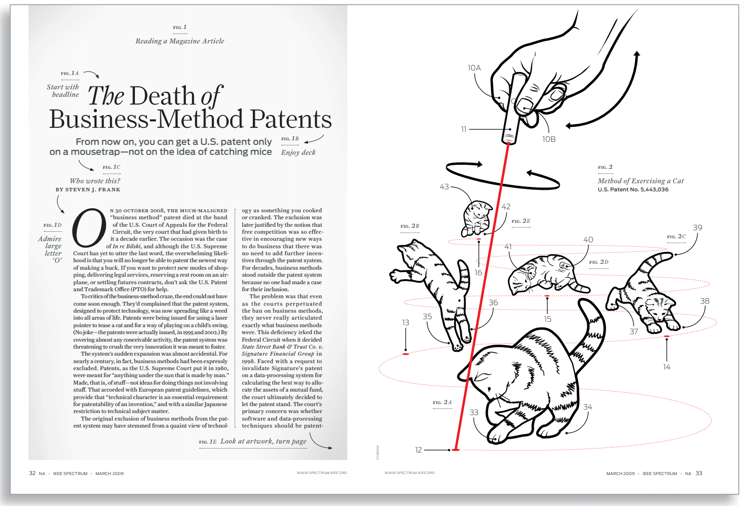
Jon G. Rokne, *Chair*; Tayfun Akgul, George W. Arnold, John Baillieul, Silvio E. Barbin, Tamer Basar, Tariq S. Durrani, Mohamed E. El-Hawary, Gerald L. Engel, Marion O. Hagler, Jens Hannemann, Lajos Hanzo, Hirohisa Kawamoto, William W. Moses, Adrian V. Pais, Edward G. Perkins, Saifur Rahman, Sorel Reisman, Edward A. Rezek, Barry L. Shoop, Emily A. Sopensky, W. Ross Stone, Ravi M. Todi, Robert J. Trew, Leung Tsang, Karl R. Varian, Stephen Yurkovich

IEEE OPERATIONS CENTER

445 Hoes Lane, Box 1331, Piscataway, NJ 08854-1331 U.S.A.
Tel: +1 732 981 0060 Fax: +1 732 981 1721

CLOCKWISE FROM TOP LEFT: SUBHADRA MENON; SPACEX; FRANÇOIS ROUILLER; ANATOLY ZAK; ROBERT ZUBRIN; DONNA COVENEY/MIT; MONICA HEGER; SETH KUSHNER

forum



LETTERS do not represent opinions of IEEE. Short, concise letters are preferred. They may be edited for space and clarity. To post your comments online, go to http://www.spectrum.ieee.org. Or write to Forum, *IEEE Spectrum*, 3 Park Ave., 17th Floor, New York, NY 10016-5997, U.S.A.; fax, +1 212 419 7570; e-mail, n.hantman@ieee.org.

PATENTABILITY

I ENJOYED "The Death of Business-Method Patents" [March]. A patent application should contain three things: (1) the work done, summarized in a paragraph indicating the contribution of the applying individual or business; (2) the applicability or utility of the patent to be sought; and (3) the requested scope of the patent. Items 1 and 3 would signal red flags if the scope of the patent sought was significantly different from the work done; items 2 and 3 would limit a patent to something less than "anything under the sun" dealing with the method or process. These items, combined with making it illegal to sell or transfer a patent, may significantly improve the patent system. The idiotic patent claims mentioned in your article tend to stem from patents involving concepts rather than items, that is, patenting "a way of doing *X*" rather than "something that does *X*" and suing anytime anyone finds a way to do *X* that may or may not be similar to yours. There should always be a way of working around a patent. If such a workaround does not exist, then you have a concept or a law of nature, not a patentable item.

MICHAEL J. LEWCHUK
IEEE Member
Edmonton, Alta., Canada

THE COST OF CONVENIENCE

IN THE article "First Affordable Fuel Cells for Mobile Gear" [Update, April], there is a subtitle that lauds the device as "cheap" and "disposable." Like many of the baby boom generation, I, too, was brought up to think that *disposable = good*, but I thought that IEEE and its membership had come to the realization that this equation is false and that actually *disposable = bad*. A rechargeable or even recyclable fuel cell would be good, but something you use once and toss in the trash? What a waste of natural resources! Additionally, according to the article, the device contains borohydride, a chemical I am not familiar with. Even if we accept the fact that we will waste all the metal and plastic in such a device, what are the environmental consequences of borohydride in a landfill?

LARRY PHILPS
IEEE Member
Toronto

A COOL CAR

AS A Ford dealer, I thought *IEEE Spectrum* readers might want to know a couple of reasons, not covered in your "Top Ten Tech Cars" article [April], why the new Ford Fusion hybrid is so uniquely efficient. The air conditioner uses a high-voltage electric compressor, and the heater system uses an auxiliary electric water pump to circulate coolant. Both of these features allow the gasoline engine to be shut off when other hybrids would be forced to keep theirs running.

LANCE DELISSA
IEEE Member
Meade, Kan.

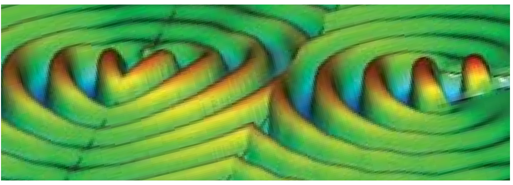
FOUR OUT OF FIVE SCIENTISTS AGREE...

I NOTE THAT most of the articles in *Spectrum* pay homage to the politically correct idea of global warming. From the data I see—much of it from government laboratories—we are now in a cooling cycle and have been since the mid-1990s. The PC terminology changed from "global warming" to "climate change" to take into account this anomaly, but the solution remains to have government tax the production of carbon dioxide. This global warming idea is said to be a "consensus" of the cognoscenti, but remember that the Earth at one time was flat, also by a consensus of those in power.

It will eventually be necessary to replace oil and coal, but it makes no sense to commit economic and social suicide by rushing into uneconomical "solutions" cobbled from the current alternate sources of energy. We need to work toward the future, but not by risking our present. All civilizations have progressed by finding cheaper sources of energy. This progression started with slaves and continued with animals, wood, and coal. Now other thermal sources have led us to our present living standard, which exceeds that of early potentates.

Remember, consensus is not proof.

ROBERT P. ALLEY
IEEE Member
N. Myrtle Beach, S.C.



update

more online at www.spectrum.ieee.org

LAID OFF: Taiwanese workers protested in Taipei last December.

PHOTO: PATRICK LIN/AFP/GETTY IMAGES

Taiwan's Troubled DRAM Plan

The island's struggling memory makers aren't buying in

THE TAIWANESE government is struggling to revive the nation's dynamic-RAM (DRAM) industry, which has been bleeding losses quarter after quarter due to both slumping prices and substantial overcapacity. The industry desperately needs to acquire new technology from foreign partners to upgrade its products.

As part of a controversial plan, the government is setting up a new corporation, Taiwan Memory Co. (TMC). It is aimed at consolidating the industry and forging deals with foreign firms that would provide technology for coming generations of DRAM chips and provide the basis for Taiwan's developing homegrown DRAM designs.

"We hope to achieve such goals within two years," John Hsuan, the foundry industry veteran tapped to lead TMC, told reporters in April. If TMC succeeds in rounding up the local industry, it will leave the Taiwanese government in control of a substantial portion of global DRAM output. According to Hsuan, the government will hold fewer than half of TMC's shares, but it would dominate strategic plans.

TMC took its first step by striking a technology deal with Japan's Elpida Memory in early April. Even with Elpida on board, TMC is having trouble enticing the island's DRAM makers to join up.

Taiwan accounts for less than 15 percent of the global DRAM market by revenue, but it is home to 6 of the 10 major manufacturers—Inotera, Nanya, Powerchip, ProMOS, Rexchip, and Winbond. Through various deals, foreign firms such as Elpida, Micron, and Hynix own stakes in several Taiwanese manufacturers and have transferred DRAM technology to them partly in exchange for a portion of their output. TMC won't change that basic formula:

update

It will sell products under its own brand for mobile devices or sell chips under the Elpida brand. It will also develop its own DRAM designs.

At this point, however, it's unclear if TMC will have anything to sell. None of Taiwan's DRAM makers have agreed to become part of TMC, and two have rejected it outright to form a competing bloc.

Boise, Idaho–based Micron Technologies was courted by TMC as a technology partner, but the American firm and its Taiwanese partners—Nanya Technology and Inotera Memories, Micron's joint venture with Nanya—have ruled out joining the restructuring plan. Judging from Micron's behavior during previous DRAM downturns, the firm is likely hunting for acquisitions among the other four Taiwanese firms, says Jim Handy, a director of the semiconductor market research firm Objective Analysis. "They've got some shrewd negotiators," he says.

Consolidation is essential to survival in DRAM, according to Handy, who is based in Los Gatos, Calif. The rise in the cost to equip a fab for a new generation of chips (about 12 percent per year) is outpacing growth in the DRAM market (about 5 percent per year). On their own, none of the Taiwanese firms have enough market share to afford a next-generation fab.

Even so, they are trying. Nanya and Inotera have sought loans under a government program to help revamp their production to accommodate newer technology from Micron."We hope the government would give our team at least the same level of financial support as it would have given to TMC," Charles Kau, president of Inotera, told reporters.

Minister of Economic Affairs Chii-ming Yiin says that the government would deal fairly with all local players. However, Yiin notes that the alliance of Micron, Nanya, and Inotera has been in operation for a while and TMC is just getting started, so TMC might require more help.

Still, the end goal is a stronger Taiwanese DRAM sector. "If the existence of a TMC-Elpida partnership pushes Micron to transfer more advanced technologies to Nanya, I'll say it's a good thing," Yiin says.

Sources say that Micron has begun to transfer a low-cost 50-nm technology to both Nanya and Inotera, hoping to launch pilot runs in the second and third quarters of this year, respectively. "We're looking forward to seeing Micron's 40-nm technology by the end of next year," says a source inside Inotera, who declined to be identified.

With Nanya and Inotera out of contention for partnership with TMC, that leaves Rexchip, Powerchip, Winbond, and ProMOS. At press time, none had even hinted at wanting to work with TMC. —Yu-Tzu Chiu & Samuel K. Moore

SUN MICROSYSTEMS

Sun's Rock CPU Could Be a Gem for Oracle

Upcoming processor first to use "transactional memory," a boon to programming multicore processors

It's clear that the main attractions for Redwood Shores, Calif.-based Oracle Corp. in its proposed US $7.4 billion acquisition of Sun Microsystems are Sun's software assets—Java and the Solaris operating system. But a bit of hardware might turn out to be a hidden gem in the deal. Some industry insiders say that the database giant has an opportunity to get ahead of competitors by pioneering the technology behind Sun's Rock CPU, which is scheduled for release later this year.

Rock will boast 16 processor cores—more than any other server CPU on the market—and, even more important, it will also be the first chip to offer a performance-enhancing feature called transactional memory. Transactional memory, or TM, allows programs simultaneously running multiple threads (short strings of instructions) the ability to read from and write to memory registers more easily and without accidentally overwriting the data that other threads require.

58.6 PERCENT Decrease in the U.S. Department of Energy's request to Congress for fuel cell research. Energy secretary Steven Chu says hydrogen cars will not be practical in the next 10 to 20 years.

For a company like Oracle seeking to boost its database software's performance—and with the number of cores per CPU and therefore the number of simultaneously executing threads expected to grow—the importance of TM should not be overlooked, says J. Bruce Daley, founder of the software testing company Test Common, in Denver, Colo.

"The advantage of a technology like Rock is that it gives Oracle the ability to optimize its database software—at the level of machine code," says Daley, who has been predicting Oracle's takeover of Sun, based in Santa Clara, Calif., since 2006.

Programs written for a single processor core had the luxury of performing each instruction serially, he says, individual step by individual step. So, to take a simplistic example, if two bank customers simultaneously withdrew $100 and $200 from the same account, a serial bank-account database program would still have to process the transactions one at a time, logging a $300 total withdrawal from the account.

But a (badly done) "parallel-threaded" program might record the proceedings as follows: Processor core A begins by reading the account balance in the register. While it's busy subtracting $100 from that value, processor core B reads the register, subtracts $200, and writes the result back to the register. Processor A finishes its subtraction and writes its total to the same spot in the register, overwriting B's answer as if the $200 withdrawal had never happened.

Of course, real-world database programs running on multicore chips are more sophisticated than that. One standard solution to the overwrite problem, in fact, is to lock down a section of memory to all other threads when one thread is already working on it. But such lockdowns can quickly become both complex for the programmer and a performance bottleneck for the database. "Locking is a conservative strategy" that wastes a lot of time and processor cycles on conflicts that rarely happen, says Doug Lea, professor of computer science at the State University of New York at Oswego, who has examined Rock's version of transactional memory.

TM balances the two extremes, allowing the programmer to give the computer high-level instructions such as "Don't split up simultaneous transactions on a single bank account" as opposed to low-level code involving, say, locking and unlocking individual memory registers containing bank balances or transaction amounts.

Software simulations of Rock have shown that its TM can speed up some parts of a database, such as its accessing hash tables, by up to a factor of 20 over a comparable chip without transactional memory.

While many researchers, notably at Microsoft and Intel, have experimented with software-based TM, Sun will be the first to incorporate TM into the chip itself.

"Sun's ahead, for now," Lea says. He notes, however, that chipmaker Advanced Micro Devices is hot on Sun's heels, having recently released specs for a TM instruction set for any future AMD chips with TM. "There are plenty of people with a vision that every [processor] will look like this," Lea says.

Cory Isaacson, CEO of the high-performance database technology company CodeFutures Corp., in Louisville, Colo., says it's practically a guarantee that hardware TM will be faster than software TM. And, Isaacson adds, TM could be a key to enabling all types of programs—not just databases—to use the increasing number of processor cores efficiently.

This could put Rock—and its new owner—in a good position, says Isaacson. "With multicore processors, you need multithreaded code," he says. "This is a big problem for every chip manufacturer. If they don't solve this problem, then the adoption of multicore processors slows down."

As a tool for programmers, TM makes a real difference, according to John Veizades, chief technology officer of the database company GroovyChannel, in San Francisco, whose company had developed its own software-based TM and then abandoned it in favor of more traditional parallel code, which he says was more efficient.

"There's a learning curve that a developer has to get through to write proper parallel code. One promising tool for helping a developer write parallel code is transactional memory," he says.

Sun and Oracle declined to comment for this story.

—Mark Anderson

news briefs

INK DISPLAY
Researchers in Ohio have created an electronic paper display that should produce full color images at nearly video rates. The display forms images by expelling and retracting a glob of ink at each pixel. See http://spectrum.ieee.org/apr09/8907.

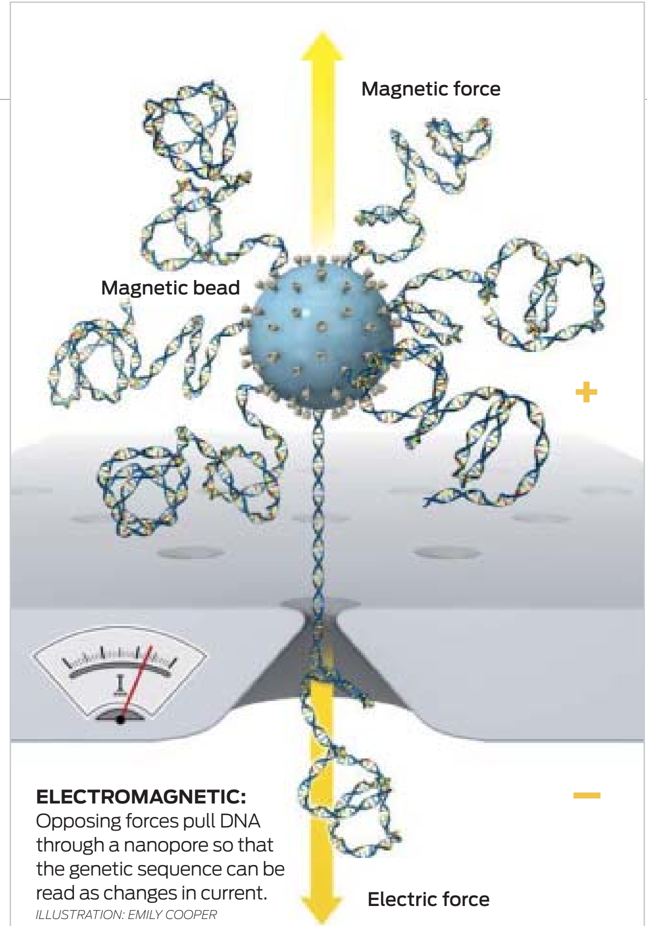
PHOTO: GAMMA DYNAMICS

IEEE Spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | qMags

update

Advance in Nanopore Gene Sequencing

Magnets help in the quest for the $1000 genome



ELECTROMAGNETIC: Opposing forces pull DNA through a nanopore so that the genetic sequence can be read as changes in current.
ILLUSTRATION: EMILY COOPER

Your DNA sequence could be the ultimate addition to your medical records, revealing disease risks and offering the possibility of tailored treatments. But first, researchers need to make the sequencing of your entire genome affordable. The National Institutes of Health, in Bethesda, Md., are pushing researchers to come up with technology that would sequence a person's entire genome for just US $1000. One of the front-runners in that race is called nanopore sequencing, and physicists at Brown University, in Providence, R.I., recently took a big step toward getting nanopore sequencing down to the $1000 mark.

Genetic information is encoded on DNA as the sequence in which four chemicals, called bases, are strung together. Using today's techniques, sequencing someone's genome can take days and cost about $100 000. Nanopore sequencing promises to speed up and simplify reading the 3 billion bases. The idea is to use an electric field to pull a DNA strand through a nanometer-scale pore. The pore is in a silicon nitride film immersed in a salt solution. A voltage drives current, in the form of ions in the water, through the nanopore, sucking the DNA through it like a child eating a noodle. As each base passes through the pore, it blocks the current to a degree specific to each of the four types of bases. The hope is to read the minute changes in current and thereby identify the sequence of bases.

However, "there's a big catch-22," says Xinsheng Sean Ling, the Brown University physics professor who led the work, which was published in the 6 May issue of the journal *Nanotechnology*. "You need a large electric field to draw the DNA molecule into the pore, but the same electric field also pushes the DNA too quickly." That reduces the technology's ability to tell one base from another.

So Ling and his colleagues attach DNA to an iron oxide bead 2.8 micrometers wide. An electric field pulls the free end of the strand through a 12-nanometer silicon nitride pore, and a magnetic field drags the bead in the other direction. Without the opposing magnetic field, DNA would typically zip through the pore at the rate of one base per microsecond, but the tug-of-war between the two fields results in a rate of one per millisecond. "So there would be less chance of error in reading the bases," says John Kasianowicz, the biophysicist at the U.S. National Institute of Standards and Technology, in Gaithersburg, Md., who invented nanopore sequencing. "This is a significant advance."

So far the researchers have demonstrated the mechanics of pulling DNA through the pore, but they have yet to prove that their trick really improves DNA sequencing accuracy. And there may turn out to be better ways to slow down DNA.

Another group has tried tugging on the DNA with highly focused laser beams. And Oxford Nanopore Technologies, in Kidlington, England, recently demonstrated that DNA squiggles through a narrower pore made from a bacterial protein at 1/25th the speed it would take to move through a silicon-based pore, according to James Clarke, a scientist at Oxford Nanopore.

Silicon pores, however, are more stable and would make for a better commercial product, says Dan Branton, a nanopore researcher at Harvard. "If you're using a protein pore, it has to be embedded in a lipid layer, and those break and are very delicate," he says.

Controlling the DNA's speed through a pore is one of the biggest challenges facing nanopore technology, Branton says, and the magnetic technique addresses that issue well. However, he thinks that the process of attaching the magnetic bead could cost time and money, possibly defeating the main purpose of using nanopores: cheap sequencing.

—Prachi Patel

ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

28 000 KILOMETERS How much farther a car could travel when charged by the electricity that comes from burning a hectare's worth of biomass instead of running on the ethanol produced by that hectare, according to scientists in California. See http://spectrum.ieee.org/may09/9147.

Two-Laser Lithography Shrinks Transistors on the Cheap

A new microscopy technique gets adapted for chipmaking

Engineers are near the outer limits of what can be done with optical lithography, the process by which light shone through a patterned mask defines the fine structures of microprocessors and memory chips. Now three teams of optics experts have independently hit upon what could turn out to be a way to extend optical lithography's use—and, what's even more critical, to do it cheaply.

All three methods are inspired by the seminal work of Stefan Hell at the Max Planck Institute for Biophysical Chemistry, in Göttingen, Germany. In 2005, Hell managed to push the resolution in an optical fluorescence microscope, used mostly in biology, well beyond its expected limits.

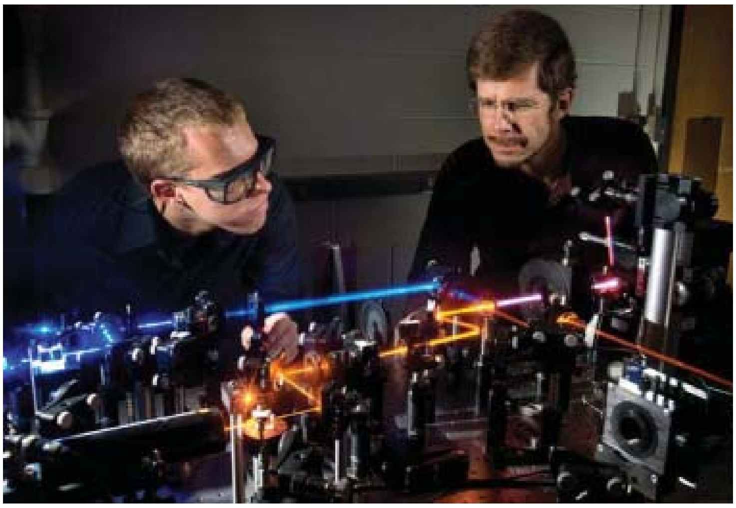
In fluorescence microscopy, the resolution is determined by the size of the spot a laser pulse makes on a material. Hell and his colleagues greatly reduced the size of the spot by following the first laser pulse with a second pulse of a longer wavelength. Tuned properly, the second pulse can create a ring of light instead of a spot. The interaction of the electromagnetic fields of the two pulses compresses the first laser's spot. Hell called the technique stimulated emission depletion (STED) microscopy.

Inspired by STED, Rajesh Menon and his colleagues at MIT have developed a photolithography method in which they place a thin film of material on top of a photoresist—a liquid that coats the silicon wafer and hardens where it is exposed to light. This film has the unusual property of being transparent to ultraviolet light but opaque to visible light. The researchers shoot lasers of both colors at the film simultaneously, which creates a small, temporary transparency in the film and sets the resist below. Menon used the process to make features 35 nm across. He says it should ultimately be possible to etch 10-nm features.

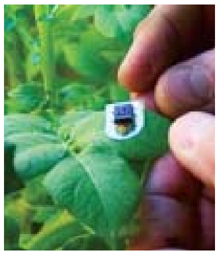
Two other groups engineered the photoresist rather than add a thin film. The resist contained molecules that promoted hardening when exposed to blue light and other molecules that inhibited hardening when exposed to UV light. Using both colors of laser at once is like drawing a line with a thick pencil and erasing the edges simultaneously. "We are basically getting the material to respond to the difference of the two light beams," says Robert McLeod, the University of Colorado assistant professor of electrical and computer engineering who led one of the research groups.

John Fourkas and his colleagues at the University of Maryland used a similar approach, except that both of their laser beams were of the same color. The laser used to cause polymerization produced short bursts of light, while the laser used to inhibit polymerization was beamed continuously.

The cost of two-laser lithography should be a fraction of that for extreme ultraviolet lithography, to which chipmakers plan to shift in the coming decade, says David Back, who managed advanced semiconductor technology development programs at the Albany Nanotech R&D center, in New York. "So far the economics look good." —Saswato R. Das



COLOR PRINTING: The University of Colorado's Robert McLeod [right] heads one of three labs that have developed a lithography technology that relies on two lasers.
PHOTO: GLENN J. ASAKAWA/UNIVERSITY OF COLORADO



news briefs

TALKING PLANTS
AgriHouse, in Berthoud, Colo., says it has developed a device that lets plants send text messages alerting growers if their water uptake is too little, too much, or just right. The sensor clips onto a plant's leaf and uses proprietary algorithms to translate its relative level of turgidity into a reading of its internal moisture content. See http://spectrum.ieee.org/may09/9029.
PHOTO: AGRIHOUSE

update

A New Approach to Predicting Epileptic Seizures

Torrents of data produced by implanted microelectrodes could finally yield a prediction system

PLUGGED IN: Sonya Hearn's brain waves could help predict seizures.
PHOTO COURTESY SONYA HEARN

In July 2006, after suffering from epilepsy for more than 30 years, 41-year-old Sonya Hearn arrived at an unusually comfortable corner room on the eighth floor of Columbia University Medical Center, in New York City. During her 20-day stay there, she had several epileptic seizures while doctors recorded the electrical activity of her brain through electrodes leading out of an 8-centimeter hole in her head.

Such observation is standard for epilepsy patients, because it allows doctors to pinpoint the part of a patient's brain where the seizures originate. But the data that neurologists gleaned from Hearn's brain was anything but standard. While at Columbia, Hearn was the first to have a new kind of brain-wave recording device implanted, a device that neurologists hope will lead to a way to predict seizures—and someday, a way to prevent them.

Anticonvulsant drugs fail to work for about 25 percent of people with epilepsy, roughly 10 million people worldwide. For this group, a dozen or so research labs are exhaustively mining brain-wave data for patterns that reliably predict an oncoming seizure.

Since the 1970s, neuroscientists have tried—unsuccessfully—to find predictive patterns in the data, which come from a set of standard 4-millimeter-wide electrodes that sit on the surface of the brain. But for Hearn and six others treated at Columbia so far, the measurements also came from an additional array of 96 closely packed 3-micrometer microelectrodes that actually penetrated the cortex.

Researchers can collect more useful information from the smaller electrodes, according to Columbia neurophysiologist Catherine Schevon. "We're finding that there's a lot of activity going on at this very tiny resolution area that we had no idea about before," she says.

The microelectrodes sample data at extremely high rates—30 000 times per second, compared with 500 times per second for standard macroelectrodes. Faster sampling means that the microelectrodes can pick up higher-frequency brain waves (1000 hertz or more), called fast ripples, which may play a role in seizures.

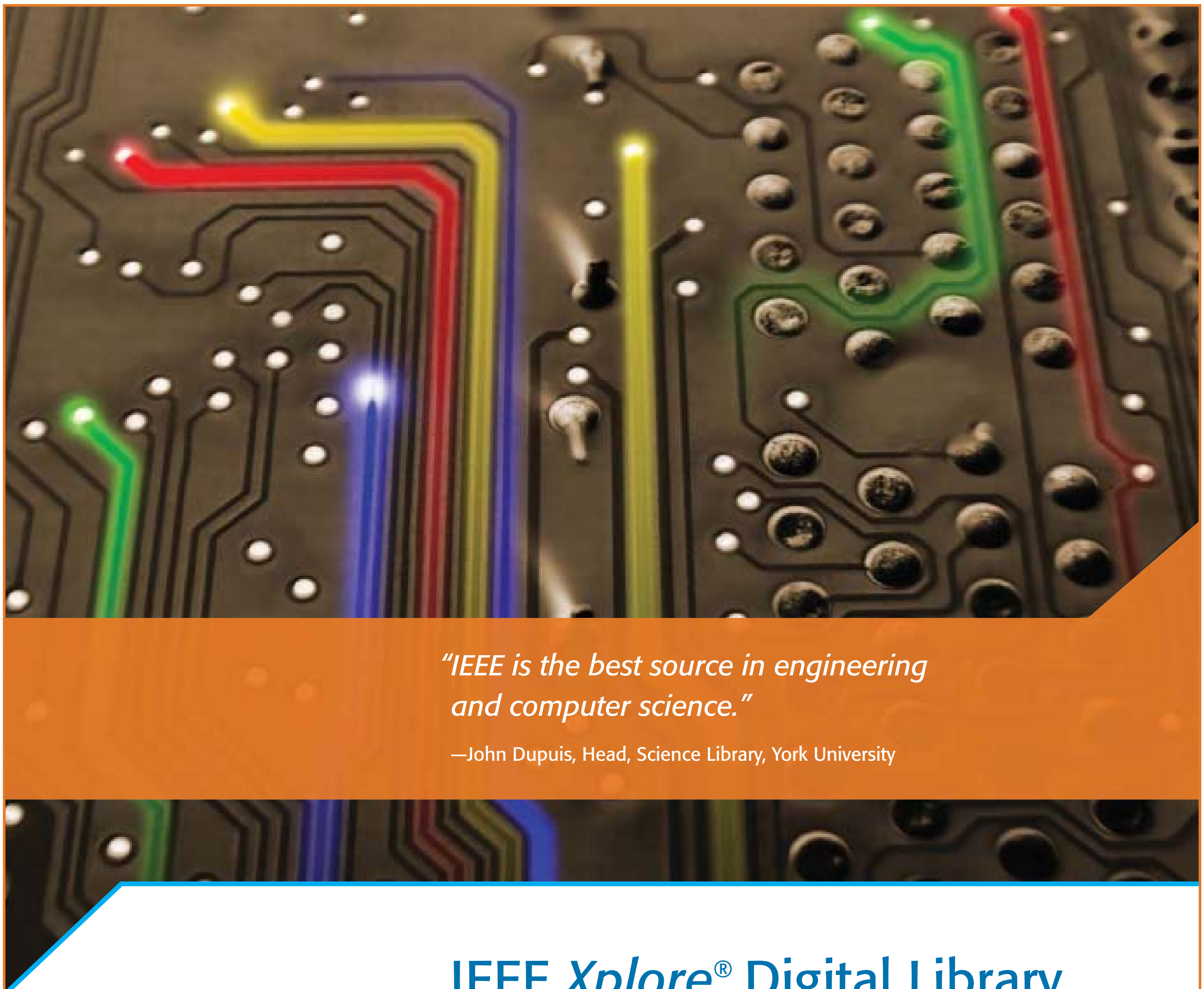
About 50 blocks south of the hospital, computer scientist David Waltz's team at Columbia's Center for Computational Learning Systems is parsing the data from two of Schevon's seven patients—all 8 terabytes' worth.

To begin processing the data, Waltz's team had to first decide where in that continuous stream of brain waves to look for patterns before the seizure. "We don't even have a good definition of what 'before' is," says Philip Gross, senior staff associate at the center. "It'd be great to find a 10-minute precursor, but maybe those things don't exist. Maybe it's 10 seconds or 24 hours. No one knows."

And they're going to need a lot more data to find out. "It's probably too much to hope that any single technique could work across all known forms of epilepsy. There's incredible variety," says Gross.

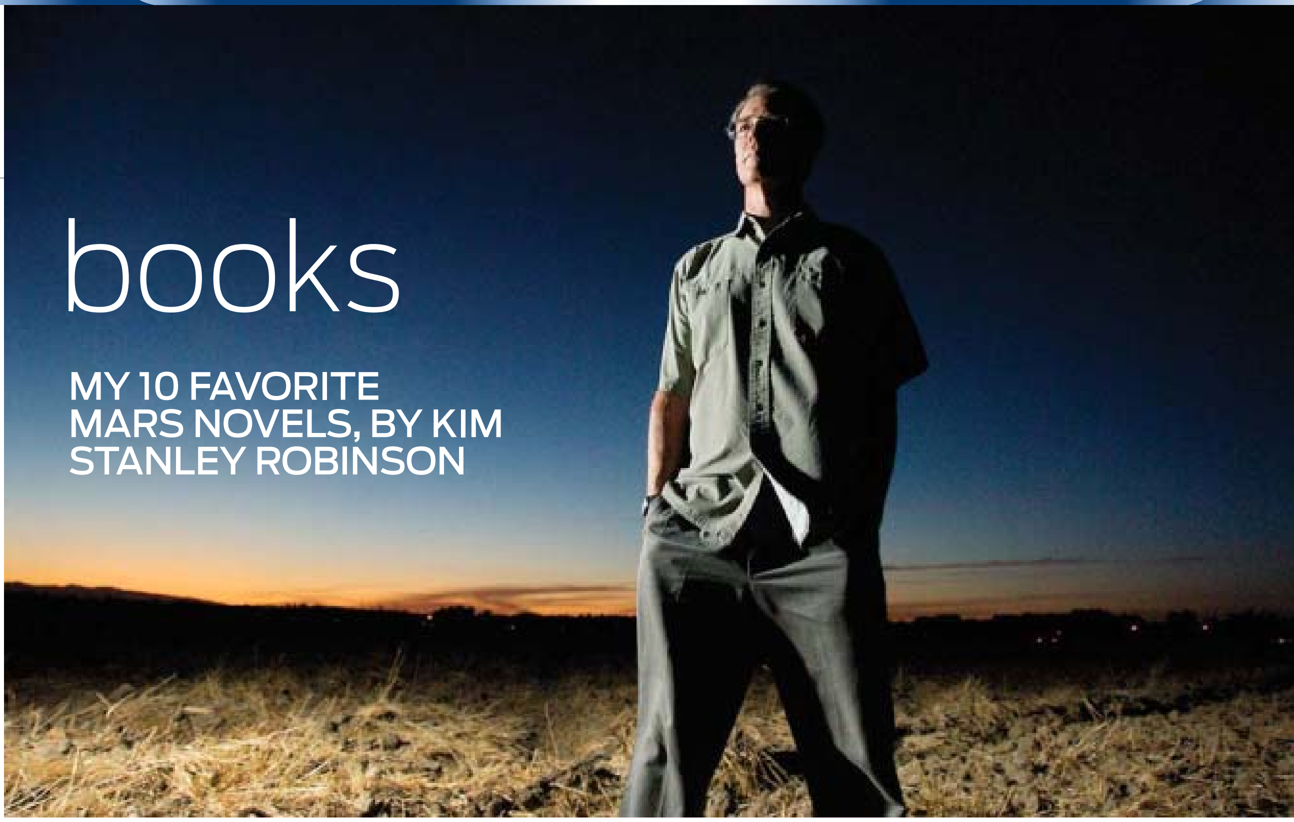
Schevon's team is one of two research groups studying seizure data from implanted microelectrodes. The other group, led by bioengineer Bradley Greger and neurosurgeon Paul House, at the University of Utah, in Salt Lake City, has recorded data from three patients so far. In April, Greger began an official data-sharing collaboration with the Columbia group. "This is absolutely necessary, because no single group has enough information to look at all types [of epilepsy]," he says.

The researchers' long-term goal is to design machine-learning interfaces that could learn what brain-wave features predict seizures in individual patients. Hypothetically, the researchers say, this system could eventually take the form of an implanted "brain pacemaker," stimulating the brain to prevent the seizure from happening in the first place. —Virginia Hughes



books

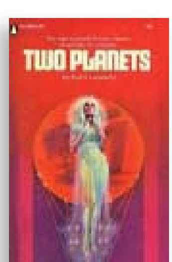
MY 10 FAVORITE MARS NOVELS, BY KIM STANLEY ROBINSON



*We asked Kim Stanley Robinson, the author of several highly regarded Mars novels, to guide us through the incredibly rich body of Mars literature. He was too modest to include his own books, so we'll do it here: Robinson's Mars Trilogy (*Red Mars, Green Mars, *and* Blue Mars*), which describes the colonization and terraforming of Mars by engineers and scientists, is published by Bantam Spectra.*

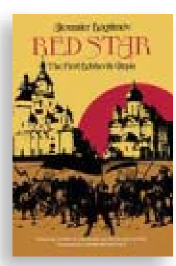
The best Mars novels have always tried to reflect our current scientific understanding of Mars, which over the years has meant very different planets. My favorites come from all periods and illustrate these changes in what we thought Mars was like.

The first big outpouring of fiction about Mars followed astronomer Percival Lowell's book **Mars**, in 1895. What he said he saw through his powerful telescope in Flagstaff, Ariz.—a planetwide complex of canals—turned out to be science fiction already, but for many years that wasn't obvious. Writers all over the world were inspired to fill in the implications of Lowell's account, according to their own characters, interests, and national styles. H.G. Wells's **The War of the Worlds** (1898) and Edgar Rice Burroughs's **A Princess of Mars** (1917) were part of this international response, but my favorites from the Lowell era are by a German and a Russian.



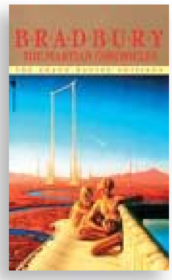
1 **Auf zwei Planeten** (1897), translated as **Two Planets** (1971). In Kurd Lasswitz's novel, advanced Martians come to Earth and try to help us. The Martians live in a technological utopia in which life is enriched by fine food, rapid transit, and flying artworks. The book's stiff, 19th-century utopian style takes some getting used to, but the prescient ideas on every page and the powerful vision of a prosperous life created by following the rational ways of science are still very attractive. The book is a fun read, and it had a huge impact in its day: Lasswitz clubs sprang up all over Germany.

Young men inspired by the book went on to found a German rocket society, the Verein für Raumschiffahrt. Among them were Willy Ley and Wernher von Braun. This genealogy—Lowell to Lasswitz to von Braun to NASA—suggests that we might not have made it to the moon in the 20th century without Lowell's hallucinated Mars and the resulting clutch of Martian romances.

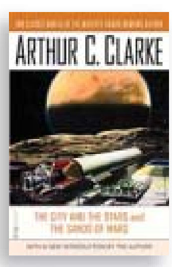


2 **Red Star**, by Alexander Bogdanov, was published in 1908, and its sequel **Engineer Menni** in 1913 (English translations of both appeared in 1984). These books describe the interaction between a backward Earth and an advanced communist utopia on Mars. Hugely popular in pre-WWI Russia, they inspired many in the revolutionary movement. The story's central romance—Martian hero meets Earth girl and takes her home for a long tutorial—is hokey in the manner typical of utopias. But laughter at its clunkiness is part of a larger pleasure in its intelligence and foresight, and the Martians' struggles to help Earth get through its primitive capitalist phase eerily foreshadow current problems. Bogdanov (real name: Alexander Malinovsky) went on to tangle with Lenin and write influential works on systems theory. Later, when Stalin began killing ideological rivals, Bogdanov saw the writing on the wall and gave his blood in a transfusion exchange with a young man suffering from malaria and tuberculosis. Bogdanov died shortly thereafter, while the youth lived on for half a century.

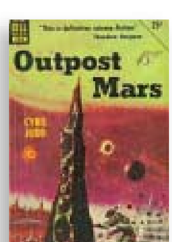
ROBINSON: WILLIAM MERCER McLEOD; BOOKS, CLOCKWISE FROM LEFT: RANDOM HOUSE (3); INDIANA UNIVERSITY PRESS; SOUTHERN ILLINOIS UNIVERSITY PRESS



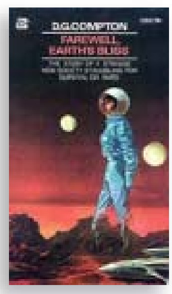
3 **The Martian Chronicles**, by Ray Bradbury (1950). By the 1930s, telescopes and radio astronomy made it seem that Mars lacked both water and oxygen, and so the Lowell dream began to die. One of the first and greatest responses to this "dry Mars" realization was Ray Bradbury's masterpiece. A series of linked stories, it was the first Mars fiction to suggest that whatever we find on Mars, we will be bringing our old dreams of the place along to haunt us. And the book's final image will always express another basic Martian truth: We are the Martians we seek.



4 With the Lowell dream dead, Mars fiction fully entered its dry phase, in which colonists were depicted as struggling on a harsh and dry world. One of the best of these books is Arthur C. Clarke's **The Sands of Mars** (1951), in which Clarke spices up the rigors of the desert life with a local population of kangaroo-like creatures. Clarke's human characters are not much more advanced than those of Bogdanov and Lasswitz, and his vision of Mars itself is about as vague, but the attempt to tell a story consistent with the science of the time is interesting.



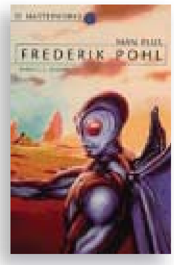
5 A good companion to Clarke's novel is **Outpost Mars** (1952) by Cyril Judd, which was a pseudonym for C.M. Kornbluth and Judith Merril in collaboration. A detailed description of a first Martian colony's struggles, the book offers a feminist perspective that brings a new emphasis on family and relationships, raising the standard of Martian fiction to a level so character-driven that a 1961 reprint was titled **Sin in Space**. The story includes the first narrative of a baby being born on Mars, and its descriptions of the landscape are as evocative as the tense relationships among the colonists. A hidden gem among Mars novels.



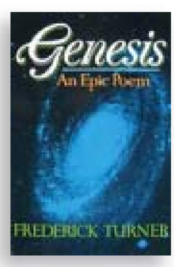
6 **Farewell, Earth's Bliss**, by D.G. Compton (1966). Mars's dry period continued in the 1960s with bleak novels by Compton and Philip K. Dick in which Mars is a powerful metaphor for the "20th-century wasteland" that so obsessed modernist culture. In Compton's dark tale, Mars is a prison colony, and the prisoners have to struggle to stay alive, construct a tolerable society, and deal with the native Martians, who are like underground rabbits. Beautifully written, like all Compton's novels, the book has a powerful and cruel ending that will not easily be forgotten.

7 Philip K. Dick's **Martian Time-Slip** (1964) is one of his best novels and one of the best Martian novels, too. This time the colonists are trying their best to be ordinary American suburbanites, led by the head of the plumbers' union, but their effort is failing. The native Martians, the Bleekmen, are wizened primitives, aborigines who wander the surface. They live in a different time and interact better with an autistic boy than with the sane but desperate colonists. Funny, sad, compact, and moving, this one shouldn't be missed. Dick also set a similar colony of desperate suburbanites on Mars in a novel from 1965, **The Three Stigmata of Palmer Eldritch**. Try both together for a bracing dose of PKD and Mars.

8 The excellent collection **Mars, We Love You**, edited by Jane Hipolito and Willis E. McNelly (published in 1971 and rereleased in 1976 as **The Book of Mars**), allows me to mention some of the really great short stories written about Mars through the years. Many of them are collected here, including Stanley G. Weinbaum's fine "A Martian Odyssey" (1934). Not in this book, alas, but well worth hunting for, are C.L. Moore's "Shambleau" (1933), Walter M. Miller Jr.'s haunting "Crucifixus Etiam" (1953), and Roger Zelazny's "A Rose for Ecclesiastes" (1963), which bids a fond farewell to the watery Lowell Mars.



9 In the 1970s, everything Martian hovered on the brink of major change. The Mariner satellites had photographed the surface, Carl Sagan and others began talking about the possibility of terraforming Mars, and then the Viking missions changed our image of Mars forever. At this moment, Frederik Pohl used the Mariner findings to portray a very realistic Mars and ask the question, How far would we go to adapt ourselves to the place, rather than the place to us? The chilling answers found in **Man Plus** (1976) make it one of Pohl's best novels.



10 **Genesis, an Epic Poem**, by Frederick Turner (1988). It doesn't seem like an epic poem about the terraforming of Mars, using characters modeled partly on Greek mythology, would be a recipe for success. But Turner is an exceptionally skillful poet, who when he wrote this book had already completed a fascinating Mars novel, **A Double Shadow** (1978), and another fine book-length narrative poem, **The New World** (1985). Here, the Olympian grandeur of the characters and plot match well with the Martian landscape, which under its rapid terraforming is still recognizably a place established in the popular imagination by the Viking landers. The result is a triumph that deserves to be better known.

In the 1990s there was a veritable flood of Mars novels, but I was so busy writing my own that I never read them! Someone else will have to sort out that part of the story. But as you can see from the above, by then we were working in a very rich tradition. ❑

A related article on Mars movies is at http://spectrum.ieee.org/aerospace/space-flight/Waiting-for-the-Great-Martian-Movie.

CLOCKWISE FROM TOP LEFT: RANDOM HOUSE; BANTAM; FREDERICK TURNER; RANDOM HOUSE (2); HACHETTE BOOK GROUP; PENGUIN BOOKS

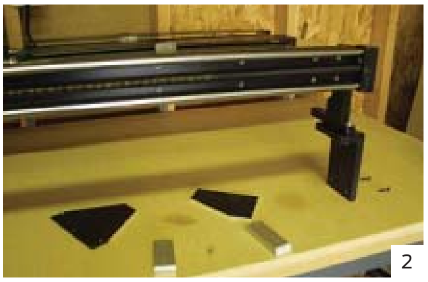
hands on

AUTOMATE YOUR HOME SHOP

Computer-controlled shop tools need not cost a fortune

1

BUILDING BLOCKS: Industrial-surplus linear actuators provide the main mechanical components.



2

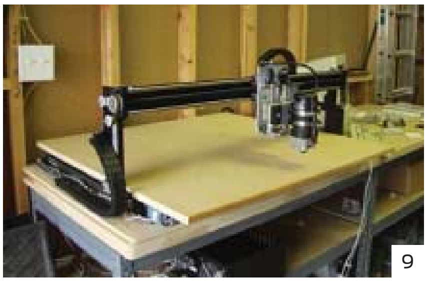
NEW FITTINGS: A few simple parts are fabricated by hand from aluminum plate and bar stock.

5

OTHER DIRECTIONS: The *y*-axis actuators that will carry the gantry are crudely laid out on the bench top, along with wooden spacers.

6

PLATFORM BED: To clear the *y*-axis actuators, the bed of the router table will sit atop a supporting wooden box.



9

ALMOST COMPLETE: An MDF (medium-density fiberboard) bed is added to the assembled mechanical components.

10

TAKING CONTROL: Three industrial-surplus stepper-motor controllers and a home-brew 32-volt power supply drive the motors.

PHOTOS: DAVID SCHNEIDER

When high-tech companies go belly-up, much of their equipment ends up on the surplus market for pennies on the dollar. I took advantage of this to cobble together a computer-numerically-controlled (CNC) router table so that I could cut complicated shapes in wood, plastic, or sheet metal without the usual hassle of making paper templates, trying to follow them by hand, filing down the rough spots, and, often enough, messing things up completely.

This is not your father's router table, the kind you might buy at your local Home Depot. Those are merely stout tables designed so that a router can be mounted underneath with the business end sticking up. They're great for shaping the edge of a straight piece of wood, but not much else. A typical CNC table, by contrast, puts the router above, with its bit pointed down and moving under computer control along the *x*, *y*, and *z* axes. While an off-the-shelf CNC router table could set you back anywhere between a few thousand and a few tens of thousands of dollars, the parts for mine cost only about US $1000.

The basic mechanical building blocks for this project are linear actuators—motorized devices for moving things in a straight line with great precision. Some CNC hobbyists build their own actuators (which are also called motion stages), using such commonplace items as threaded rod, metal pipe, and roller-skate bearings. While I applaud their pluck and ingenuity, I'm leery about such contraptions.

I chose the surer path, buying five industrial-quality motion stages on eBay for about $500 in all. This was a steal. Given the current economic malaise, I would expect more bargains to become available regularly. The largest actuator, roughly a meter long, was once used on a machine that tested integrated circuits, or so the sticker on the side suggests. It now serves as the gantry of my CNC setup, which is carried back and forth over a distance of about 60 centimeters by a pair of matching Japanese motion stages. The other two actuators are also identical and quite small, with a throw of less than 10 centimeters. One of them operates the *z*-axis of my table, with the help of parts from its mate, which I cannibalized to make the first one a little beefier.

After fabricating a few metal bits and pieces, I bolted the four stages together—the long one for *x*, two medium-size ones for *y*, and a small one for *z* [see photographs].

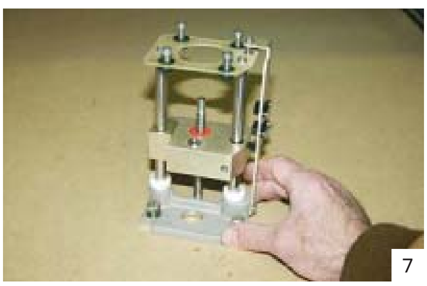
To drive the actuators, the Rolls-Royce solution would have been $100 servomotors and optical encoders, which would have provided feedback so that the computer couldn't possibly

3

LEVEL PLAY: Attaching the newly fabricated parts to the meter-long actuator creates the *x*-axis gantry.

4

BELT DRIVE: Adding a stepper motor and idler pulley completes the *x*-axis drive mechanism.



7

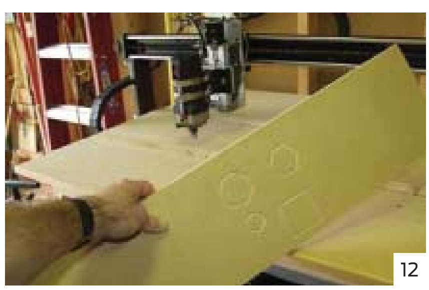
GOING UP?: A diminutive motion stage provides the makings of a *z*-axis actuator to raise and lower the spinning router.

8

SCHLEPPING WIRES: Plastic cable carriers manage the movement of the cables running to the *x*- and *z*-axis stepper motors.

11

FIRST CUTS: High-speed flash photography freezes the motion of a V-shaped router bit as it engraves simple shapes in MDF.



12

TAKING SHAPE: Carving a set of regular polygons shows off the CNC router's ability to carry out precisely defined motions.

lose track of the router. Instead, I used $15 secondhand stepper motors, which move my router around pretty briskly and with so much force I'm unable to stall its movements by hand.

Stepper motors need electronic controllers, which fortunately are widely available. For example, Xylotex offers a three-axis unit complete with stepper motors for $410. That package would take much of the pain out of building a CNC system, whether for a router table or, as is commonly done, for adding this capability to a small milling machine. Of course, you'll have to take some care to hook up your motors and limit-detecting switching properly; you'll also want to prevent the cabling from getting tangled. Check out the Web site of KabelSchlepp, a name that always makes me chuckle, for ideas.

My control box cost somewhat less than the Xylotex unit because it uses a home-brew motor-power supply and three industrial-surplus stepper controllers that I scored on eBay for $45 each. In hindsight, if I add up the time—and finger burns—involved in wiring everything together, it doesn't seem like such a bargain.

To translate movement instructions on my computer into step and direction signals for the controllers, I use a program called Mach, from ArtSoft. The free demo version is limited to 500 lines of G-code, a low-level programming language commonly used to run machine tools; a Mach license costs $175. Or you can drive your CNC setup using EMC (Enhanced Machine Controller), originally developed by the National Institute of Standards and Technology and now available for free under a public license.

To mill complex parts or make fancy engravings, you'll need computer-aided design (CAD) and computer-aided manufacturing (CAM) programs. Mach comes with a beta release of something called LazyCam, which I've not yet tried. And the Internet is overflowing with low- or no-cost CAD packages, many of which are listed at Freebyte.com.

With all the free or inexpensive resources to be found online, gearing up to do CNC machining at home won't require you to tap your dwindling 401(k). But don't let that lull you. As providers of the equipment and software caution, a computer-controlled machine, like any power tool, can be dangerously tricky.

So before spinning a sharp router bit or end mill under computer command, think about all the times your PC has done something unexpected. That should keep you in an appropriately cautious frame of mind when the chips start to fly. —David Schneider

Stepper motor:
http://www.xylotex.com
Mach software:
http://www.machsupport.com
CAD software:
http://www.freebyte.com/cad/cad.htm

ieee spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | qMags

careers

EXPERTS EXPECT RÉSUMÉ FRAUD TO RISE

In an economic downturn, the temptation to pad CVs is strong

JAMES DEHONIESTO may have considered it a small thing, just a fib really, to claim a degree in computer science from the University of Pittsburgh—he had, after all, taken classes there. But in November 2008, after the school told *The Wall Street Journal* that DeHoniesto had never earned a degree from Pitt, he resigned as chief information officer of Cabot Microelectronics, in Aurora, Ill.

Inaccuracies on a résumé—mistakes, embellishments, or outright lies—are shockingly common. According to Scott Viebranz of Kroll, a risk consultancy in New York City, more than 22 percent of the résumés the firm verified in 2007 for technology companies contained misrepresentations of academic credentials. And in dire economic times, "people are more likely to fudge a little bit in an effort to get a job," says Viebranz, who is chief sales officer in the firm's background screening division. "Given how tough the last half of 2008 was, I would expect our 2009 stats to reflect that."

High-profile cases—such as former RadioShack Corp. CEO David Edmondson, who resigned after the *Fort Worth Star-Telegram* reported he made up two degrees he never earned—may make it seem that résumé fraud is already on the rise. Yet rates of academic fraud on résumés—people misstating their educational background—have hovered between 20 and 30 percent over the past five decades, says Peter LeVine, a background checker in Delray Beach, Fla.

One reason fraud rates haven't risen might be the very real fear of getting caught. More employers are now doing stricter background checks on their potential employees, particularly for candidates who received their education or work experience abroad and for those applying for IT positions with access to confidential data. Executive and managerial level résumés also face tougher scrutiny.

In-depth investigations of a CEO or other C-level candidate's background can be expensive. They range from US $5000 to $20 000, according to the Association of Certified Fraud Examiners, in Austin, Texas. But you can weed out a lot of liars by simply picking up the telephone and checking things out yourself. RadioShack could have asked Edmondson's school back in 1994, when he was first hired, just as the *Star-Telegram* did 12 years later.

When executives are caught with inflated résumés, they've probably been living with their lies for years. "You don't wait until you're at a senior level of management to inflate your résumé," LeVine says. Some people even start believing their own made-up résumés and forget they created them, he adds.

As high as an academic fraud rate of 22 percent sounds, people are even more likely to misrepresent their employment history: More than half of the tech-industry résumés in Kroll's database had such discrepancies. Another study of erroneous résumés, by executive search firm CTPartners, found that 64 percent of candidates overstate their accomplishments, while 71 percent misrepresent the number of years they held a position. Most often, people inflate a title or salary so they can negotiate a higher one. But Kroll's Viebranz says that many times these are just mistakes, such as not remembering how long a job lasted.

And sometimes, even a lie can become true. In November, *The Wall Street Journal* reported that Jonathan Lang, the chief technology officer of aircraft-leasing company Aircastle, in Stamford, Conn., had never received his claimed bachelor's in business administration from George Washington University. Lang had earned the necessary course credit, though, and a day later the school said it would issue the degree.

—PRACHI PATEL

geek life

Getting Getting-It-Done Done

Need to get things done? You're not alone—there's now an entire category of productivity software, called GTD, that lies somewhere between the to-do list and project management. One GTD addict is comedian and former "Daily Show" correspondent Rob Corddry.

"I spend hours looking for the latest list-making and organizational software," says Corddry. "I check the tech blogs every day for updates. I have something like nine GTD products," including Evernote, Bento, and OmniFocus. Some of them let him add to-dos by sending himself e-mail from his cellphone.

"Oddly," Corddry says, "I haven't found any software to list the list-making programs."

—*Susan Karlin*

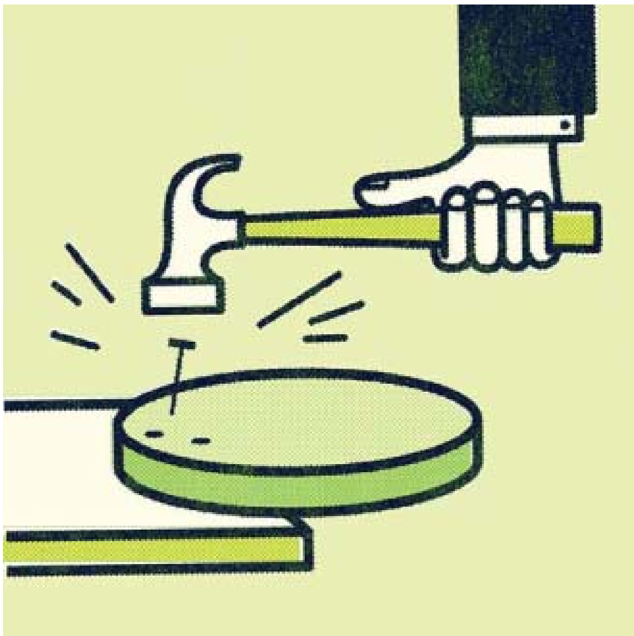
LEFT: ERMIN GUTENBERGER/ISTOCKPHOTO; RIGHT: SIRI STAFFORD/GETTY IMAGES

IEEE Spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | qMags

technically speaking BY PAUL McFEDRIES

Suffix It to Say

Implicated in "the Volgagate" are a group of liberal officers who were caught removing bugs from telephones [and] mixing actual letters and telegrams from Soviet citizens in with the usual phony ones. —*National Lampoon*, August 1973



IN THE wake of a political scandal, inevitably editorialists will harrumph and scold, angry citizens will write angry letters, and some wag columnist will tack the suffix *-gate* onto the name of whatever person, place, or thing is most closely associated with the kerfuffle. The citation above is the first recorded use of the *-gate* neologism (albeit in a humor magazine), but there have been dozens, nay, hundreds in the years since Watergate, the *ur*-gate.

The workhorse in tech circles is **-ware**, short for *software*. This suffix has programmed itself into such classics as *freeware* (free software), *shareware* (software that you can use before purchasing), and *vaporware* (a software product announced but not delivered). The dozens of recent variations include **abandonware** (the company that wrote the code has gone out of business), **beerware** (the purchase "price" is to buy the developer a beer or drink a beer in the developer's name), **careware** (the developer asks each user to do a good deed or donate something to charity), **coasterware** (named for the recommended use for the CD containing the software), **crimeware** (facilitates identity theft, phishing, or similar criminal activity), **heroinware** (an extremely addictive computer game), **ransomware** (encrypts a person's computer files and demands a ransom to decrypt them), **retroware** (two or three versions earlier than the current version), **slideware** (vaporware that currently exists only as a series of slides in a marketing presentation), and **terrorware** (software used by terrorists). And let's not forget **wearware**, a word that goes back at least to a 2003 *IEEE Computer* article about wearable computers.

The suffix **-free** is handy for saying that something lacks a quality or feature. The model for this is *fat-free*, which has spun off umpteen healthy variations, including *calorie-free*, *cholesterol-free*, *salt-free*, *MSG-free*, and even *peanut-free*. Tech varieties include **content-free** (a message big on style but lacking in substance), **fact-free** (a scientific endeavor that doesn't take into account real-world constraints such as chemical or biological data), and **office-free** (a person who uses technology to maintain remote connections to his office network and colleagues).

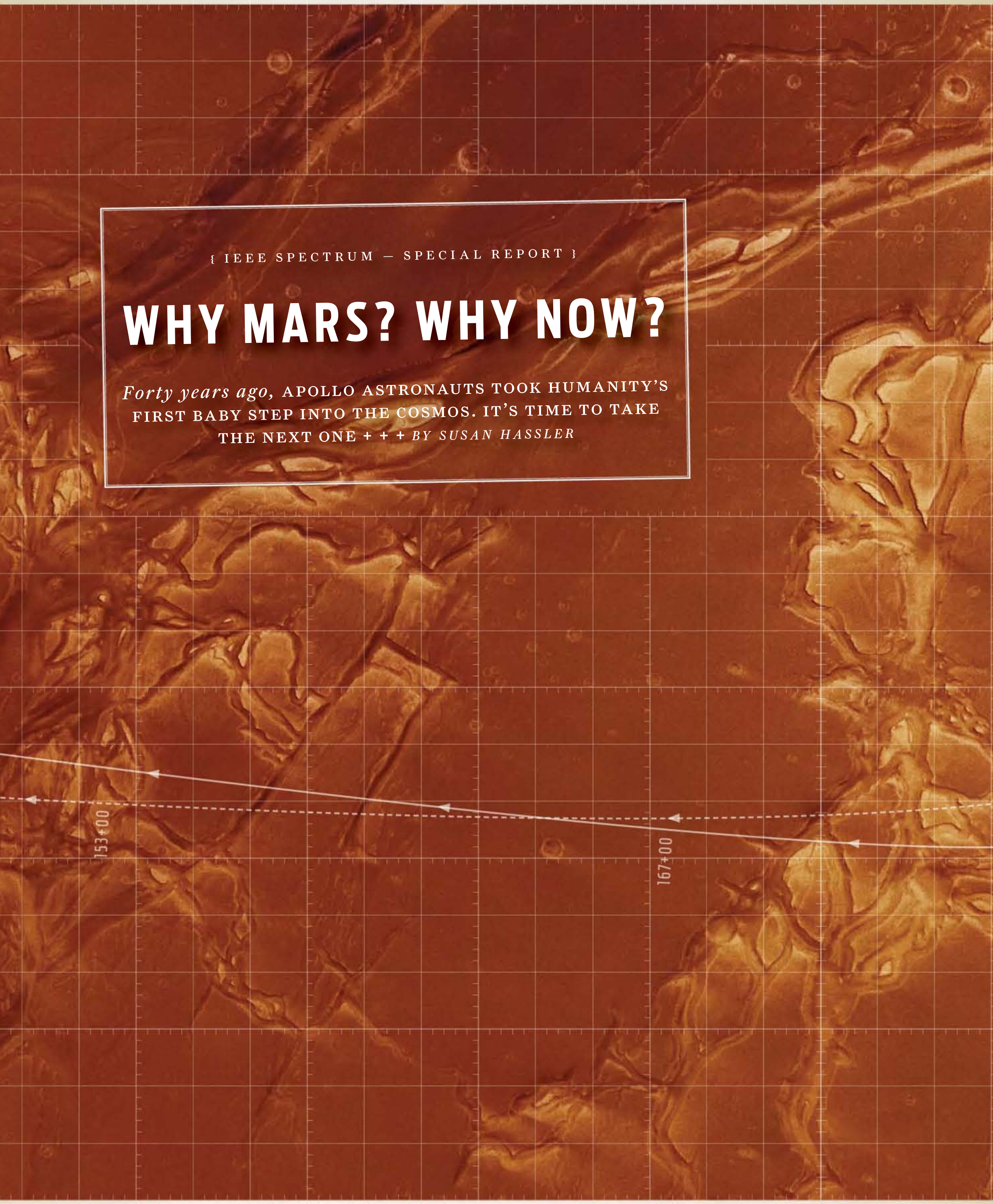
We live in a world where, it seems, everyone is addicted to something—and therefore is easily labeled by tacking on the **-aholic** (also: **-holic**, **-oholic**) suffix. The term *alcoholic* has spawned *workaholic*, *foodaholic*, and *chocoholic*. Some addicts in need of high-tech 12-step programs are **webaholics** (the Web), **Twitterholics** (Twitter), **gameaholics** (computer games in general), and **Warcraft-aholics** (*World of Warcraft* in particular).

Another suffix to watch is **-rati** (or sometimes **-erati**), which indicates the elite or the intelligentsia of a particular group. The original is *literati*: the literary intelligentsia or the educated class. Recent variations on the theme include **digerati** (the digital literati), **jitterati** (over-caffeinated digerati), **geekerati** (elite members of the digerati), **blogerati** (big-time bloggers), and **Twitterati** (those with the most Twitter followers).

If tech types want to describe the people, products, services, and technologies belonging to or associated with something, they simply attach the suffix **-verse** (short for *universe*): **Googleverse** (Google), **Twitterverse** (Twitter), **gamerverse** (gamers or gaming), and **wikiverse** (Wikipedia, or wikis in general). A similar (but perhaps slightly broader) suffix is **-sphere** (or **-osphere**; both come from *atmosphere*), which gets quite a workout these days: **blogosphere** (blogs and bloggers), **chatosphere** (chat rooms and instant messaging), **spamosphere** (junk e-mail messages and purveyors), **twitosphere** (yes, Twitter again), and **webosphere** (the Web).

The OED defines *lallapaloosa* as "something outstandingly good of its kind" and gives an earliest citation from 1904. Tech spin-offs take their cue from the variant spelling *lollapalooza*, which was the name of a series of popular multiband, alternative music summer tours in the 1990s. The suffix **-palooza** (or **-apalooza**), which, depending on the context, denotes either a large gathering or something excessive, has been sighted in the wild in **blogapalooza** (bloggers), **botapalooza** (robots), **techpalooza** (technology), and **twitapalooza** (those guys yet again). That's it for Suffixpalooza 2009! ❑

GREG MABLY

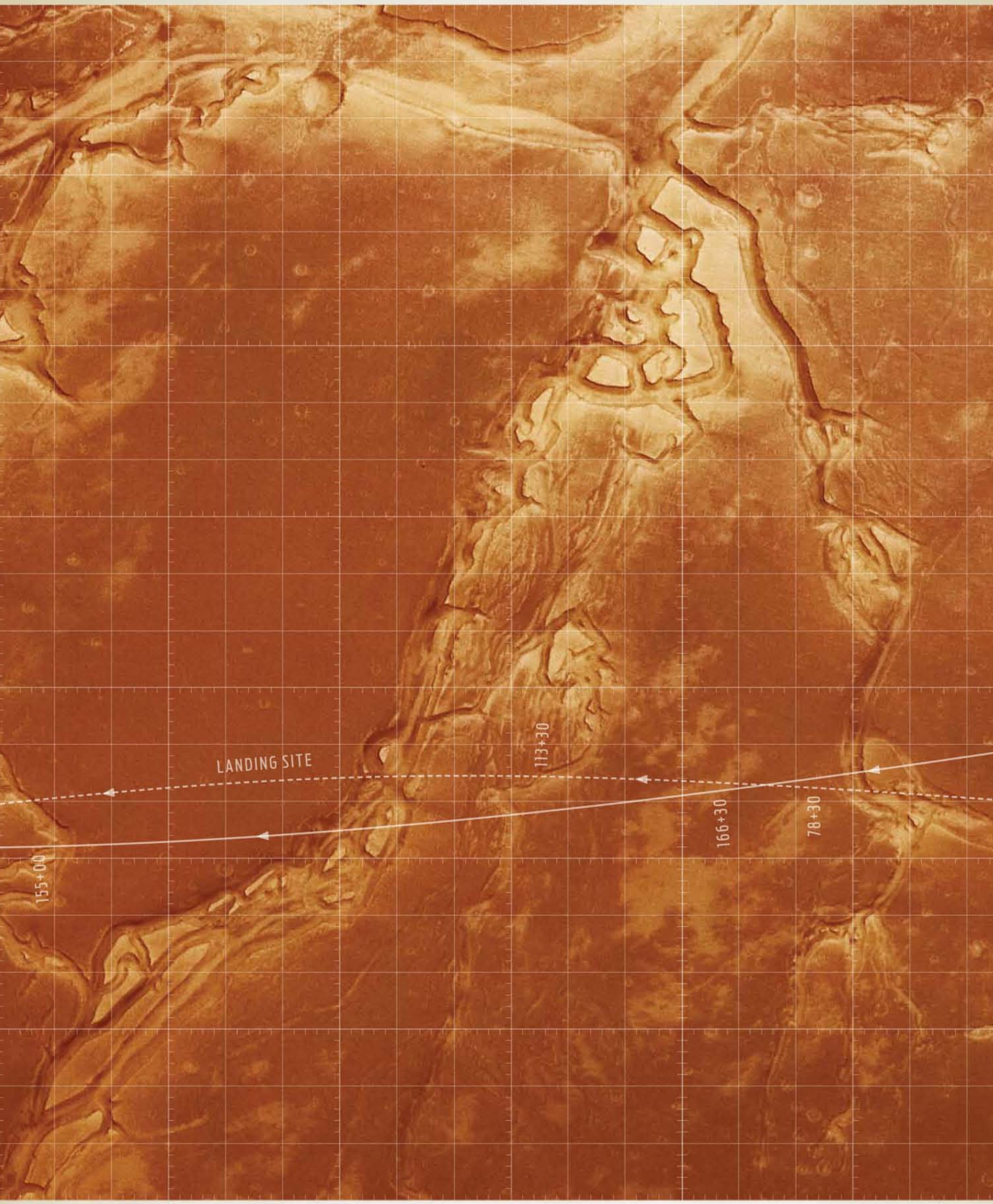


{ IEEE SPECTRUM — SPECIAL REPORT }

WHY MARS? WHY NOW?

Forty years ago, APOLLO ASTRONAUTS TOOK HUMANITY'S FIRST BABY STEP INTO THE COSMOS. IT'S TIME TO TAKE THE NEXT ONE + + + *BY SUSAN HASSLER*

ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags


LANDING SITE
113+30
155+00
166+30
78+30

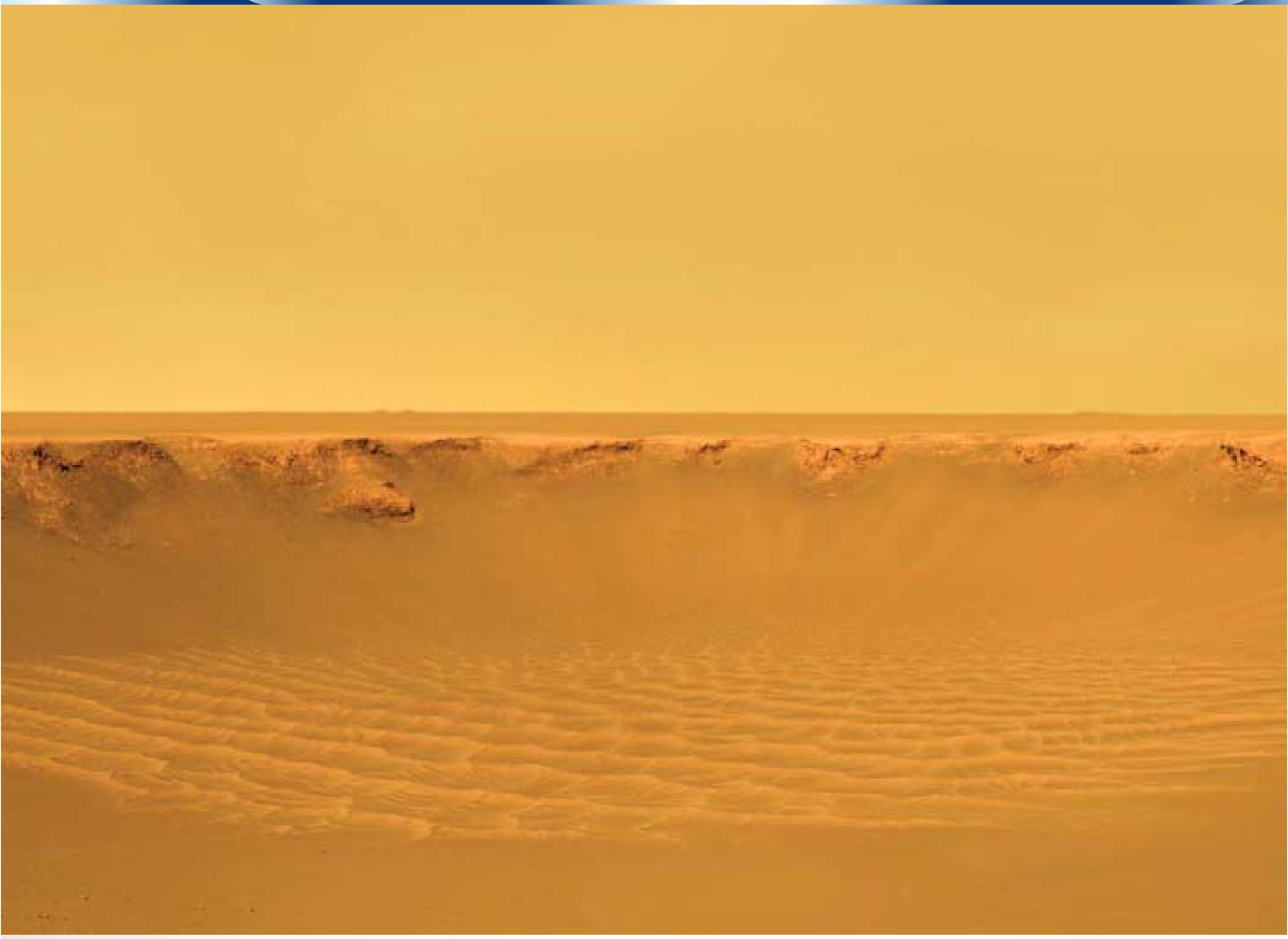
ARE WE GOING TO GO TO MARS OR NOT? Now would be a good time to decide. Are you listening, President Obama? ❡ Yes, the president has lots of things on his mind. But that's true of any president, anytime. And the fact is, the U.S. government is already spending billions of dollars a year on a space program that has a trip to Mars as its ultimate but inadequately funded and too-far-off-to-get-excited-about goal.

The signs of drift are accumulating. In April during a speech before the U.S. National Academy of Sciences, Obama spoke reverentially about the heady days of the Apollo program. But he did so not to galvanize his audience about the importance of space exploration but rather to rally them to the cause of developing alternative energy technologies. *Not once* in his eloquent speech did he mention the future of human spaceflight.

As of this writing, Obama has yet to appoint a new administrator for NASA, a job that Michael Griffin left in January (the official explanation for the delay is that the job at the top of the troubled agency has been tough to fill). Whoever takes the spot will need to convince lawmakers to spend billions, on top of the billions that have already been spent, to develop a new launch vehicle, called Ares I, for a return to the moon. The moon trip would be the first stage of NASA's Constellation program, which aims for a manned Mars mission sometime after 2030. But Congress doesn't seem terribly interested in Mars. It cut NASA's proposed budget increases repeatedly in the last years of the Bush administration.

Obama came into the Oval Office with thoughtful and detailed positions about almost everything, it would seem—except manned spaceflight. He's now asked Norm Augustine, IEEE Life Fellow and former chairman of Lockheed Martin, to head a panel that is expected, by August, to offer an opinion about whether NASA's human spaceflight efforts are worth continuing or whether the emphasis should be shifted to unmanned exploration. To the extent that the panel evaluates the controversial Ares I design, which many people both inside and outside the space agency contend has major flaws, the review may accomplish something important. But on the manned-versus-unmanned issue—and with all due respect to Dr. Augustine, a longtime friend of this magazine—you have to wonder what he and his panel will uncover that countless other panels, study groups, consultants, think tanks, academics, and assorted pundits have not already concluded about the issue over the past 50 years.

This isn't your typical irrelevant policy dustup. As you may have heard,



the space shuttle will be retired next year. And the Ares I won't be ready to fly until at least 2014. The upshot is that the United States, one of the two original space powerhouses and still the source of 80 percent of the world's noncommercial funding for space, will have no way to get even as far as the International Space Station without hitching a ride on a wheezing Russian Soyuz vehicle.

For a man of celebrated vision and conviction, President Obama is puzzlingly lax on space. Speaking on "The Tonight Show" on 19 March, he told Jay Leno: "A smart kid coming out of school—instead of wanting to be an investment banker, we need them to decide they want to be an engineer." Well, we couldn't agree more, Mr. President. But surely you realize that young people don't go into engineering because you want them to. They go into engineering because they've had their imaginations fired by a grand, awe-inspiring challenge. A challenge like going to Mars, for example.

The United States is not alone in its crisis of confidence. Other countries' space programs seem to be struggling with a perceived lack of interest in manned space exploration, a fear of human casualties, and a misguided belief that we must solve all our terrestrial problems before doing anything ambitious in space. Governments worldwide have readily bailed out banks and other scandalously mismanaged institutions, and yet they don't want to pay for space. In Europe and Japan, human missions have taken a backseat to robotic probes. Even in China and India, where space travel is still seen as an analogue of national esteem and domestic security, work goes forward in fits and starts. As it does in other endeavors, the world looks to the United States for leadership in this area, and it finds none.

HAIL, VICTORIA: Mars rover Opportunity took hundreds of images over three weeks to create this panorama of Victoria Crater [above]. Channels crisscross Granicus Valles and Tinjar Valles [opening pages], the possible results of lava flows and subsurface water on Mars.

You can't argue for human space exploration solely on economic grounds, especially not short-term ones. But there is no denying that a vigorous, focused, goal-oriented space program would bring jobs to all sorts of technical fields and industries, and open the spigots of technological innovation. In the end, though, it will be the cultural and psychic advances that will matter most.

Instead of looking inward, tethered to our computers and iPhones and thousand-channel big-screen TVs, we could start to look outward again. We and our children could gaze into the night sky and remember that the universe is very large and our understanding of it very small. Traveling to new countries on our own planet can be life-altering. Imagine what it will be like for human civilization to push its horizon out into the solar system.

It's been 400 years since Galileo first peered through his telescope. It's been 40 years since Apollo 11 took humanity's first baby step into the cosmos. Now it's time to take the next one. ❑

OPENING PAGES: G. NEUKUM/ESA/DLR/FU BERLIN; THIS PAGE: NASA/JPL-CALTECH/CORNELL


NASA

{ WHAT COULD GO WRONG? }

MARS IS HARD

Fifty years ago, SPACE EXPERTS THOUGHT WE'D BE THERE BY NOW. HERE'S WHY WE'RE NOT + + +

BY FRED GUTERL & MONICA HEGER

WERNHER VON BRAUN would be so disappointed. The German-born rocket pioneer accomplished great things in his life, including overseeing the design of the Saturn rockets, the most powerful launch vehicles ever built. But he never saw the thing he yearned for most: people walking on Mars.

He did try mightily to make it happen. Shortly after World War II, when he was living at Fort Bliss, Texas, he wrote his only novel, *Project Mars*, about an expedition to the Red Planet. The book is packed with detailed explanations of orbital physics and unintentionally hilarious mission directives: "The landing is to be carried out, if possible, with avoidance of any hostile contact with the inhabitants of Mars." Ultimately, the lead spaceship ski-lands onto the Martian snow, and its crew of 18 befriends the underground-dwelling Martians. The year is 1985.

Through the 1950s and '60s and into the '70s, von Braun tirelessly propounded his Mars vision, in a group of articles for *Collier's Weekly* and later in a series of television specials for Walt Disney. During the Nixon administration, he was still pleading for a Mars landing by 1982.

Most of the other pieces of the von Braun dream eventually came to pass: A permanent space station orbits Earth, for example, and 12 men have walked on the moon. And yet, a Mars trip seems no closer now than it did in 1977, when von Braun died.

Turns out that going to Mars is a lot harder than he let on. It's expensive, for one. In his novel, von Braun figured that a Mars expedition would cost US $2 billion—about $18 billion in today's dollars. By 1989, NASA estimated such a trip would come to half a trillion dollars; if you correct that figure for inflation, you get the current U.S. fiscal stimulus package, give or take a hundred million.

Spooked by those numbers back in 2007, when a trillion dollars still seemed like a ridiculous amount of money for even the U.S. government to spend, Congress stipulated in a NASA appropriations bill that "none of the funds… shall be used for any research, development, or demonstration activities related exclusively to the human exploration of Mars." The Red Planet has undeniable cachet, but nowhere near the geopolitical punch that the moon had in the early 1960s, in the frigid depths of the Cold War. It's hard to imagine a Mars project ever getting a presidential exhortation on the order of John F. Kennedy's 1961 speech launching the Apollo program. And with the global economy on life support, you have to wonder if we'll even get there before the century is out.

If going to the moon is a day hike, going to Mars is the Lewis and Clark expedition—a journey too long and too complex

BILL CRAMER; FENCE: MEGAN MALOY/GETTY IMAGES to carry everything that's needed. Earth and Mars ride along in their concentric orbits, getting within striking distance of each other only for a brief window every two years. The shortest one-way trip, using conventional chemical propulsion, would take six months. If you include the time spent on Mars waiting for the two planets to move back into optimal alignment and also the trip home, the total mission would last at least two and a half years. The crew would have to endure extremes of boredom, isolation, and radiation, and they would require a vast amount of fuel and rations packed into a vessel sturdy enough to shield them from the harshness of space. Simply landing a spacecraft safely on a planet with an atmosphere and substantial gravity poses stunning challenges. And then there's the matter of keeping the crew alive on the Martian surface.

In other words, the physical, technical, and economic demands of a Martian mission are too great to be overcome in a decadelong, Apollo-like sprint. The only solution is to chip away at the problems. And that's just what's happening.

Despite the congressional directive, NASA engineers have continued to move the agency slowly but inexorably in the general direction of Mars. Along with its counterparts in Europe and Asia and legions of academic researchers around the world, the space agency has spent years laying the groundwork for such a mission. The International Space Station, for example, hasn't yielded much in the way of basic science, but it's letting astronauts learn how to deal with issues like weightlessness, equipment failures, and the day-to-day routine of life beyond Earth. A lunar base will teach spacefarers and mission planners lessons about running an extraterrestrial outpost and will also push the development of NASA's Ares V booster, which will likely be needed to loft the capsules, crew, and supplies for a Mars mission, unless better alternatives come to fruition.

Meanwhile, orbiters, landers, and rovers continue to gather vital information about the Red Planet, including the best places to find water and minerals. Upcoming sample-return probes to Mars, like Europe's ExoMars and Russia's Phobos-Grunt, will let researchers back on Earth touch Martian soil for the first time. All of these efforts will help set the stage for an eventual human mission.

When that happens—if it happens—it will be the most difficult and complicated undertaking in human history.

THE LIST OF CHALLENGES is long and sobering, and it starts with propulsion. Chemical rockets are only marginally capable of getting people to Mars and back, but the main alternative, the plasma drive, is at least a couple of decades away from the day when it'll be ready to ferry folks to that red dot in the sky [see "Rockets for the Red Planet," in this issue].

Even after the propulsion problem is solved, there are at least five other really big ones: cosmic rays, muscle and bone loss, psychological stress, landing on the planet, and feeding the crew for the long haul. All of those challenges are harder with chemical rockets, because a chemically fueled trip would last much longer than one with a more advanced propulsion technology.

That time sensitivity is acute with cosmic rays, the combination of energetic protons ejected by the sun during solar storms and gamma-ray bursts from distant galaxies. You're not at risk on Earth's surface, because you're shielded by the planet's atmosphere and magnetic field. But out in space, you don't have that protection. Of particular concern are solar storms, which can toss out deadly particle showers that can kill you quickly or slowly, depending on the storm's severity. And both types of cosmic radiation can damage DNA, raising your long-term risk of cancer. Gamma rays might even make you stupid; regular doses can wreak havoc on brain cells, among other things.

Apollo astronauts were fortunate in not encountering a solar storm during their missions, none of which lasted longer than 12 days. But a Mars crew would almost certainly experience at least one solar storm and regular doses of gamma rays. Scientists estimate that astronauts on a 1000-day mission will be exposed to just over 1 sievert of radiation, equal to about 26 000 dental X-rays.

Nobody really knows exactly what such a dose would do to a crew or to what extent high-energy particles correlate to cancer rates. Officially, NASA rules dictate that any manned mission have a fatality risk below 3 percent. On paper, at least, a Mars mission isn't too far off: For a 40-year-old male astronaut, the space agency puts the mean fatality risk due to cancer at 4 percent. But few physiologists put much stock in that number, and besides, variation among individuals makes it impossible to say who will develop cancer and who won't.

One way to lower the radiation risk is to build your spacecraft with thick walls. The astronauts' sleeping quarters on the International Space Station, for instance, are lined with polyethylene, which helps block the incoming protons during a solar storm. The station is also always within the confines of Earth's magnetic field, which offers additional protection.

The 10-centimeter-thick walls of most current spacecraft block about 25 percent of cosmic rays, but there's no good way to keep out much more without making the walls so thick they'd add greatly to the weight. "The amount of material you need is enormous," says Francis Cucinotta, chief scientist in the radiation department of NASA's human research program, in Houston. You might think a lining made of lead would be effective, but when the high-energy electrons in cosmic rays hit the lead, they can trigger secondary radiation that's just as damaging.

One possibility is to re-create the physics of Earth and use a magnetic field. Last year researchers from the Rutherford Appleton Laboratory in Didcot, England, built a magnetic shield in the lab that was able to block a beam of heavy ions and protons, says physicist Ruth Bamford, who led the research. Bamford borrowed the technology from nuclear-fusion research, in which high-intensity magnetic fields are used to contain the energetic plasma where the fusion takes place. Now her team is trying to scale up their shield so that they can test it in space. She estimates that the field could be as small as 100 meters long, just large enough to form a protective bubble around the habitable parts of the spacecraft. This bubble would require a 1-tesla magnet and about a kilowatt of electricity to maintain.

Researchers are also considering new radiation-blocking materials, new drugs to treat cancer and other illnesses caused by radiation exposure, and even genetic tests that would identify cancer risk. Or maybe the answer is to choose only older male astronauts: The older you are, the less likely you are to live long enough to develop cancer, and men are less likely than women to develop breast cancer, one of the most common types of cancer linked to radiation.

"For a manned mission to Mars, I don't think there's a magic bullet," says Cucinotta. "But I think a combination of things will make it allowable."

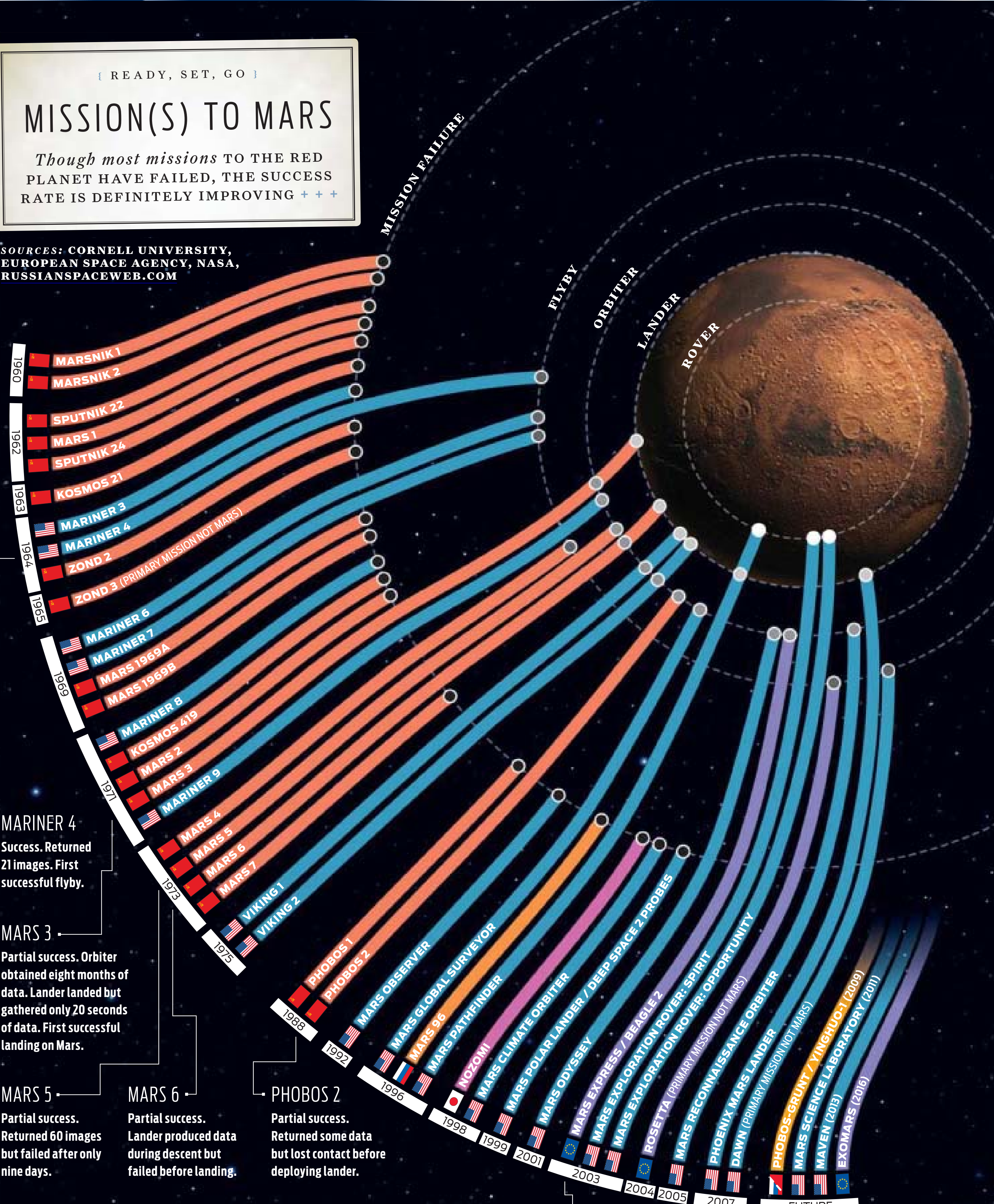
THE RAVAGES OF SPACE aren't confined to radiation; the lack of gravity is arguably even more vexing. Astronauts on average lose 1.5 percent of their bone mass for each month they spend

{ READY, SET, GO }

MISSION(S) TO MARS

Though most missions TO THE RED PLANET HAVE FAILED, THE SUCCESS RATE IS DEFINITELY IMPROVING + + +

SOURCES: CORNELL UNIVERSITY, EUROPEAN SPACE AGENCY, NASA, RUSSIANSPACEWEB.COM



MARINER 4
Success. Returned 21 images. First successful flyby.

MARS 3
Partial success. Orbiter obtained eight months of data. Lander landed but gathered only 20 seconds of data. First successful landing on Mars.

MARS 5
Partial success. Returned 60 images but failed after only nine days.

MARS 6
Partial success. Lander produced data during descent but failed before landing.

PHOBOS 2
Partial success. Returned some data but lost contact before deploying lander.

MARS EXPRESS/ BEAGLE 2
Partial success. Orbiter completed primary mission in November 2005 and is still in orbit on extended mission. Beagle 2 lander lost on arrival.

DAWN
On its way to protoplanets Vesta and Ceres. Completed Mars flyby in February 2009.

FUTURE
Phobos-Grunt/Yinghuo-1 will be a sample-return lander/orbiter, Mars Science Laboratory will be a rover, MAVEN will be an orbiter, and ExoMars will be an orbiter/lander/rover.

SOVIET UNION
UNITED STATES
RUSSIA
JAPAN
EUROPEAN SPACE AGENCY
RUSSIA/CHINA

MISSION FAILURE
FLYBY
ORBITER
LANDER
ROVER

BRYAN CHRISTIE DESIGN

{ HAUTE COUTURE }

WHAT TO WEAR ON MARS

Those bulky APOLLO-ERA SPACE SUITS ARE *SO* YESTERDAY

+ + + BY *MONICA HEGER*

THERE ARE LOTS OF UNANSWERED questions about the best way to get people to Mars. What engines should power their ship? How will the crew prevent bone and muscle loss in the weightless void? How can they land safely on the planet's surface?

And then there's this: what to wear on Mars? The lucky few who get to take those momentous first steps in the red dirt could very well be wearing something like Dava Newman's BioSuit.

Tightly tailored to the astronaut's body, the BioSuit looks like something out of a '60s Italian sci-fi flick. It's a far cry from today's bulky space apparel, because the BioSuit works on a totally different principle.

Mars has an atmospheric pressure of 0.6 kilopascals, not quite 1 percent of Earth's. If you were to venture out unprotected, many things would conspire to ruin your day. In particular, your tissues would expand, and your blood cells would come out of solution and congeal. That would kill you within minutes. So, as on the moon or in space, humans need some way to apply pressure to the body and keep those blood cells where they belong.

Current space suits rely on a mixture of pressurized gases, which fill them as if they were balloons. That also makes the suits bulky, notes Newman [right], a professor of aeronautics and astronautics at MIT. One reason that Apollo astronauts adopted a two-footed kangaroo hop on the moon, she says, was that their puffy suits severely encumbered them.

The BioSuit's tight, stretchy material applies pressure to the skin mechanically rather than barometrically, without gas and with much less restriction of movement. It's made of a mix of polymers, including nylon and spandex, so it would probably be cheap to manufacture—maybe a tenth of the US $20 million price tag of one of today's suits, Newman estimates. Her partners on the project are the industrial design firms Trotti & Associates, of Cambridge, Mass., and Dainese, based in Molvena, Italy, which specializes in gear for motorcyclists.

The suit maintains a constant 30 kPa, or about 30 percent of Earth's pressure. The wearer could stroll around on Mars for up to 8 hours without suffering any ill effects. Before stepping out, though, you might need to undergo decompression—known as a prebreathe protocol—if the pressure difference between the spacecraft and the space suit was greater than about 40 kPa. On the International Space Station, which is kept at 101 kPa, the prebreathe protocol takes 4 hours.

The BioSuit is basically a fail-safe design: If you tear its fabric, you lose pressure only around the tear. You could fix it temporarily by wrapping it up tightly like an Ace bandage. A rip in a gas-pressurized suit, by contrast, triggers an increase in gas flow to give the wearer time to retreat to a vehicle or habitat. But if no shelter is available or the leak isn't fixed quickly, even a tiny tear could become a major emergency.

Newman says she's still got a lot of work to do. "We've tested people for several hours in a vacuum chamber. But we need a suit that you're going to be able to wear for a full day's work."

She has no doubt that someday we'll see people bounding rather than hopping on the Red Planet. "The best movement on Mars is loping," she says, noting that Mars's gravity is 38 percent that of Earth's. "Long steps with lots of aerial" will let astronauts cover more ground with less effort.

"On Mars, we're all extreme athletes," she adds. ❑

JOSHUA DALSIMER

in a weightless environment, and the rate of muscle loss can be much higher. On short excursions, astronauts can lose up to 20 percent of their muscle mass; during multimonth missions, the figure can reach 50 percent. Some astronauts and cosmonauts have returned from long missions without enough musculature to walk and had to be removed from their reentry craft on stretchers.

Exercise on Earth brings back the muscles and bones. A much better solution is to do regular workouts in space that limit or even prevent the loss in the first place. That's why NASA now requires visitors to the International Space Station to spend between 30 minutes and 2 hours a day exercising. On the ISS, they have access to an exercise bicycle, a treadmill with a harness that provides a downward force, and also an Interim Resistance Exercise Device. This machine provides resistive force by means of a system of pulleys and elastomers. U.S. astronaut Daniel Tani, who spent four months on the space station in 2007, says that exercise helped him maintain most of the muscle strength in his arms and legs. Other muscles, though, like the ones needed to hold his head up, had atrophied. "If I turned my head too quickly, I'd lose my balance," he says.

Another option may be to simulate gravity by using centrifugal force. In a memorable scene from the motion picture *2001: A Space Odyssey*, an astronaut jogs within a large spinning compartment, as the spaceship in which it is mounted streaks toward Jupiter. It's a neat idea, but it could be tricky to pull off. If the habitat rotates too quickly, for instance, crew members may get dizzy or sick when they turn their heads. And if it's too small, they may feel a "gravity gradient" between their heads and feet. Studies indicate that you'd need a 56-meter-radius structure turning at 4 rotations per minute to supply about 1 *g* of artificial gravity. Alternatively, you could build a human-size centrifuge inside the spacecraft to provide short, high doses of artificial gravity—say, 1 hour a day at 2 or 3 *g*'s. But neither concept has been vetted in the microgravity environment of space.

Whatever form it takes, exercise will be vital for keeping crews healthy for the months-long journey to Mars. Peter Cavanagh, professor of orthopedics and sports medicine at the University of Washington, in Seattle, thinks crews will have to augment their exercise by taking drugs normally used to treat osteoporosis. And before they land on the Red Planet, they will have to prep themselves intensively by doing exercises that focus on reactions, quick movements, and fine motor control. "All the reflexes we depend on are gravity based, and we're going to need them again when we get back to the gravity of Mars," says Cavanagh.

MAINTAINING BONE AND MUSCLE MASS won't do much good if, in the meantime, the space travelers lose their minds. And that, unfortunately, is an all-too-real possibility.

Russia's Mir space station, which remained in orbit for 15 years before being deposited into the Pacific Ocean in 2001, is a case study in space stress. During one particularly troubling period in 1997, an onboard fire almost killed the crew. Shortly thereafter, cosmonaut Vasily Tsibliyev bungled a routine docking maneuver, sending an incoming supply ship crashing into the station; the collision knocked out power to half the orbiter. Tsibliyev soon developed an irregular heartbeat, which Russian psychologists attributed—no surprise here—to extreme stress. When his crewmates attempted to repair the power outage, someone—possibly the hapless Tsibliyev—mistakenly unplugged an onboard computer that sent the space station spinning. (Upon leaving Mir at the end of his six-month stint, the cosmonaut reportedly said, "Thank God.")

Being cooped up for months in a tin can no bigger than a two-bedroom apartment won't be easy. In Earth orbit, you at least have the comfort of knowing that you can get home, for example, by jumping into a Soyuz capsule for the hour-long descent back to Earth. A crew going to Mars would have no such easy escape from their cramped, hazardous, and isolated environment.

"Humans will experience an environment and conditions that are really unlike anything they've experienced before," notes David Dinges, who is head of the neurobehavioral and psychosocial research team at the National Space Biomedical Research Institute, in Houston. "It's not unlikely that they'll become depressed or that there will be a conflict between crew members or that they'll need to communicate with a family member," he says. Should arguments arise or loneliness, stress, or anxiety set in, crew members would have to deal with it largely on their own.

So they'll have to be chosen very carefully. The first step will probably be to weed out anyone prone to depression, anxiety, claustrophobia, or any other condition that could be a problem in deep space. After that, the criteria become more complex, in some cases even nonintuitive. For example, psychologists who've studied what types of people work best together have found that crews from different cultures tend to get along better than crews who are more like one another.

Could sexual tension doom a mission? Studies of mixed-gender crews on board space stations and submarines and at Antarctic bases, and also in simulations lasting weeks or months, have produced mixed results. On some missions, women have been credited for being peacemakers and contributing to a sense of calm. Sexual jealousies do arise, though: During a 110-day simulation in Russia in 1999, a female participant reported unwelcome advances from the team's male commander, shortly after two other male crewmates got into a bloody fistfight; the episodes prompted another team member to quit.

But single-sex teams aren't the answer either, says Jay Buckey, a former astronaut and now a professor at Dartmouth Medical School, in Hanover, N.H. Generalizations based on gender don't begin to capture people's individual differences. And in an attempt to avoid sexual rivalries, you'd exclude qualified people and limit crew diversity. "There's been a lot of discussion about gender makeup, but ultimately what you're looking for is people who can demonstrate a good ability to work together," Buckey says. Any crew bound for Mars will spend months training together before departure, he adds, giving ample time to evaluate their cohesiveness.

Once the crew is chosen, computers might help them coexist. Yes, even the unpredictable realm of human emotion is likely to be parsed by software. Dinges is working on a face-recognition program that reads expressions and detects changes in emotion. At the start of a trip, an onboard computer would have a database of the range of facial expressions for each astronaut. During the voyage, cameras positioned around the ship would capture everyone's facial expressions, which the computer would compare to its baseline images, constantly evaluating whether the astronauts are feeling emotions—happiness, sadness, anger, anxiety, or stress—strong enough to warrant a follow-up.

And if the computer spots a worrying trend? More software! (Specialization, it seems, is the trend for programs as well as professionals.) James Cartreine, a research psychologist at Harvard Medical School, is leading a group developing a multimedia program called the Virtual Space Station. It mimics behavioral therapy, a form of psychotherapy in which the patient is guided to resolve his own problem, whether it's a crewmate who snores too loud or homesickness or profound boredom.

So will astronauts really pour out their innermost frustrations and fears to a bunch of microchips? Cartreine insists they will. "People are not as likely to reveal problems they are embarrassed about to a real person," he says. A virtual therapist may even be more thorough, he argues, because it won't forget to follow up and make sure that old problems have been dealt with.

Of course, the system could be easily thwarted: Astronauts could put on a happy face or lie about their problems. Mission planners would have to convince the crew beforehand that the technology could really help them, Cartreine says.

Better communications technology, too, will help bolster weary, lonely astronauts. To reduce the isolation, you'd want the crew to be able to send and receive audio and video in real time, reliably and whenever the mood struck them. But that would tax NASA's current interplanetary communications system, known as the Deep Space Network.

NASA engineers had hoped to launch a dedicated telecommunications satellite sometime this year that would have demonstrated a laser-based technology capable of sending data at up to 30 megabits per second, about five times as fast as what's currently possible. To work, the laser beam must be pointed with great accuracy, and it's vulnerable to interruption by clouds and other obstacles. But those drawbacks aren't what doomed the Mars Telecommunications Orbiter; NASA canceled the program in 2005 to free up money for other projects.

ASSUMING THE CREW SURVIVES the long voyage without being killed or killing one another, then yet another monumental challenge will come: landing safely on the Red Planet.

Even without a crew on board, the feat is hellishly difficult. When the rover Spirit descended to the Martian surface in January 2004, NASA scientists described the white-knuckle landing as "6 minutes of terror." The spacecraft carrying the rover streaked into the atmosphere like a meteor, traveling at 19 000 kilometers per hour. A heat shield slowed the craft to 1600 km/h, still nearly twice as fast as a commercial airliner. Then followed a supersonic parachute deployment and a complex series of retro-rocket firings. Just 5 seconds before impact, the lander's air bags inflated, and it hit the ground at 87 km/h, bouncing like a beach ball in a hurricane until it finally rolled to a stop. And all that was actually part of the plan.

Bear in mind that Spirit weighed 185 kilograms, a tiny fraction of what a manned module would weigh. Had a human crew been aboard, they would have been subjected to forces of 40 *g*'s. Most people black out at between 7 and 9 *g*'s, and that's if they're wearing antigravity suits; a force of 16 *g*'s can kill you if it lasts longer than a minute. (It's also true, though, that race-car drivers have endured more than 70 *g*'s in crashes and lived to tell the story.)

The basic problem is that the Martian atmosphere is both too thin and not thin enough. It's not thin enough to allow landing solely with retro-rockets. At supersonic speeds, retro-rockets create turbulence that would make the spacecraft difficult to control and cause it to shake so badly that it could break apart. That wasn't a problem for the Apollo lunar landers, because the moon has no air and thus no turbulence. A thrusters-only landing on Mars would also consume a huge amount of fuel.

But the atmosphere is too thin (about 1/100th of what Earth has) for a craft to glide to a landing as the space shuttle does:

{ THERE AND BACK }

A RUSSIAN RETURN TO A MARTIAN MOON

Russia hopes TO REIGNITE ITS DEEP-SPACE PROGRAM WITH A MISSION TO PHOBOS + + +

BY ANATOLY ZAK

IEEE Spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | qMags

G. NEUKUM/ESA/DLR/FU BERLIN

TINY, POTATO-SHAPED PHOBOS doesn't look like a place worth visiting. But the Soviet Union tried twice, with limited success, to reach this Martian moon, the larger of two circling Earth's near neighbor. Now the Russians are working flat out on a third assault, in the form of a sample-return probe called Phobos-Grunt (*grunt* is the Russian word for "soil"). At press time, technical problems seemed likely to push back the launch by two years, to 2011. Whenever it flies, it will be Russia's most ambitious deep-space mission in years.

Why Phobos? Measuring just 27 kilometers at its widest, the satellite orbits the Red Planet about three times a day, at an altitude of 9400 km. If you were standing on Mars's equator, Phobos would appear about half as big as the sun. Planetary scientists have long debated the mysterious moon's origin. They've also proposed Phobos as a landing site for a crewed mission to Mars.

Phobos-Grunt should shed light on both matters. The spacecraft will ride on a Zenit rocket, a well-tested Soviet design. Also on board will be a life-sciences experiment from the Planetary Society and an orbiter built by the Chinese. Touching down on Phobos, the lander will use a clawlike manipulator to grab 15 to 20 samples of regolith, the loose surface material, and load them into a return capsule. The capsule will be rocketed back to Earth, leaving the lander to perform further studies.

The value of a sample-return mission is obvious, says Francis Rocard, a planetologist participating in the Phobos-Grunt mission on behalf of the French space agency, CNES. "What we can do in the lab is absolutely different from what we can do in situ," Rocard says. "Sample-return missions always lead to discoveries." Although other kinds of probes have yielded groundbreaking results—take the NASA Phoenix lander's recent discovery of water ice on Mars—they can't do the most complex analyses, such as carbon dating, electron microscope scans, or precise isotopic measurements. For that, you need to bring the specimens home. Doing so also lets separate groups of scientists study the samples using different methods, a critical step for achieving widely accepted conclusions.

Phobos-Grunt could, serendipitously, retrieve samples from Mars itself, Rocard adds. During the violent youth of the solar system, space rocks carpet-bombed the Martian surface for eons, and some of the debris from those impacts may have ended up on low-orbiting Phobos.

DESPITE THEIR VALUE, sample-return missions are rare, largely because of their complexity. During the launch into orbit, the landing and sample retrieval, and the journey back to Earth, many things can go wrong. And when it comes to Mars, something usually does. Before its dissolution, the Soviet Union sent 19 spacecraft to Mars, including the two Phobos probes in 1988. Only four of them reached the Martian system, and none completed more than a fraction of its scientific work. The first and only post-Soviet attempt to explore the Red Planet—Mars 96—never made it out of low Earth orbit.

Since then, Russian scientists have mostly looked on as U.S. and European missions produced a wealth of new data on the dramatic geological history of Mars. The Russians contributed instruments and experiments to these projects, but their own planetary exploration program remained grounded and short of funds.

Despite the chronic lack of resources, investigators at the Space Research Institute of the Russian Academy of Sciences, known by its Russian acronym, IKI, have remained committed to Mars. They first proposed Phobos-Grunt in the late 1990s and, with the mission in mind, slowly rebuilt their scientific team, which suffered considerably after the fall of the Soviet Union. "With the brain drain of the 1990s, we kind of lost a middle generation who would have now been able to transfer their experience to young specialists. It is almost like during the war. We have a generation gap," says Lev Zelenyi, director of IKI.

In terms of gravity and orbital mechanics, the mission will be easier to pull off than landing a probe on the Red Planet itself. But retrieving soil samples will be tricky. Scientists thought they could repurpose drilling hardware designed for the 1970s Soviet lunar missions. Then they realized that given the gravity on Phobos—which is all but nonexistent—the equipment would likely overturn the spacecraft. Eventually, they settled on the robotic manipulator.

All that remains after the samples are collected is to take off from the surface, escape from orbit around Mars, cruise millions of kilometers through interplanetary space, and survive the plunge into Earth's atmosphere. As if those things aren't chancy enough, for its final descent, the return capsule won't use a parachute. The craft will rely instead on a lining of crushable materials to absorb the impact.

THAT, AT LEAST, is the plan. Although the mission has been in the works for more than a decade, major funding for Phobos-Grunt materialized only two years ago, and equipment development and construction have had to come together quickly. Too quickly, perhaps: In April, people familiar with the project said the launch date would be delayed from October of this year to 2011.

Assuming that happens, Phobos-Grunt won't be the only Mars mission to suffer setbacks. Recently, two other projects announced delays: NASA's Mars Science Laboratory, the agency's largest rover yet, and the European Space Agency's ExoMars rover, designed to search for signs of life.

Meanwhile, Russian researchers are already looking beyond Phobos-Grunt. At NPO Lavochkin, a spacecraft company near Moscow, engineers are trying to reinvent planetary spacecraft. The complex vehicle they have in mind builds on the Phobos-Grunt platform but has improved flight-control and propulsion systems. It also features an upper stage that's designed to be maneuverable, versatile, and durable.

Such a spacecraft could be used for flights to the moon, Mars, and beyond. One day, it might even land on the ice-covered oceans of the Jovian moon Europa. Last year, the Russian government provided IKI with seed money to study such a mission. NASA and ESA also recently backed a mission to Europa, notes IKI's Zelenyi. "If everything goes as we conceive it, an international flotilla of spacecraft could be heading to Jupiter," he says. ❑

{ THE INNER ASTRONAUT }

THE KIND OF PEOPLE WHO WILL GO TO MARS

They won't lack fear—THEY'LL BE ABLE TO OPERATE WELL IN THE FACE OF IT

+ + + *BY DAVID A. WOLF*

LIVING IN SPACE REQUIRES near-perfect planning. The International Space Station is an ideal place to practice and iron out the technologies. We can try new things and launch new equipment, and compared to Mars, the station is very close. Once we set off for Mars, we need to have the technologies and human factors well worked out, because there will be no reasonable return, support, or resupply.

We need a mix of people to do a Mars trip—a good psychological mix as well as a good technical-background mix. Each person will become a leader at times, and each will become a follower at times. We need people who are flexible enough to assume each of those roles at the appropriate time. We need people who are physically in excellent condition, of course.

One characteristic we look for is the ability to act correctly in the face of incomplete information, because rarely do we have everything we need to know. If we did, we'd be paralyzed; we'd have paralysis by analysis. We like people who thrive on stress—people who are alert to problems as they evolve and who react to them appropriately in real time. We need people who when faced with large amounts of information are able to pick out the important parts. The early astronaut selections called that characteristic "perspicuity."

A zero-risk approach isn't possible. In order to push the frontiers, there are inherent dangers and risks. A courageous person, I read recently, isn't someone who has no fear. It's a person who is able to operate effectively in the face of fear.

—As told to Susan Hassler

DAVID A. WOLF is a NASA astronaut and an IEEE member. He has logged 158 days in space during three missions; at press time he was preparing for his fourth, to deliver and install the final components of the Japanese experimental module to the International Space Station. He holds a B.S. in electrical engineering from Purdue University and an M.D. from Indiana University.

There's too little atmospheric friction to slow the vehicle down. A spacecraft would still be going thousands of kilometers an hour just 10 km from the surface. Maddeningly, though, Mars's slight atmosphere is just enough to cause heat from friction, so the spacecraft needs an aerodynamic design and thermal shielding to keep from burning up as it descends.

NASA engineers think the best approach is a two-phase landing. In the first phase, the ship would slow itself down to about 1600 km/h, perhaps using small retro-rockets on the spacecraft's belly. To avoid creating turbulence, the rockets could be angled away from each other so that their exhaust plumes wouldn't envelop the spacecraft's nose. That solution is now being studied by Rob Manning and his team at NASA's Jet Propulsion Laboratory (JPL), in Pasadena, Calif. They engineered the successful landings of the Mars rovers Sojourner, Spirit, and Opportunity, and they are now trying to figure out the best way to land the Mars Science Laboratory, or MSL, a robotic mission to be launched in 2011. At 900 kg, it will be the largest payload yet to land on Mars, Manning notes, but that's peanuts compared to a crewed module, which will weigh 40 to 70 times as much. "If we're having a hard time landing 900 kilograms, how the heck are we going to land 40 tons?" says Manning.

Another option for the first phase is to deploy a huge inflatable "anchor" to create drag. Vertigo, a small company in Lake Elsinore, Calif., is working on such a device, which it calls the Hypercone Supersonic Decelerator. Made from lightweight fabric, it would rapidly inflate, air-bag style, into a flattened cone about the size of a Boeing 747.

The second phase of landing would start once the spacecraft had slowed to 1600 km/h. Manning's engineers at JPL haven't yet figured out the optimal answer for that either, but it may involve a quick deployment of parachutes followed by more thrusters.

Complicating matters is the fact that landing techniques for Mars can't be fully tested on Earth, because the gravity and atmospheric density here are so much greater. "There are a lot of unknowns," notes Bret Drake, chief architect for NASA's moon-Mars program. He's optimistic that people can be safely landed on Mars, but it won't happen soon. "It will be at least 20 years before we have a viable solution," he says.

IF YOU THINK SORTING CANS AND BOTTLES is a pain, consider the extreme recycling you'd need to do on a Mars trip. Start with water: The average astronaut aboard the space station uses about 11 liters of it a day. So for a five-person crew on a 1000-day trip, you'd need 55 000 liters. That's enough to fill about 350 bathtubs, and it would weigh 55 000 kg—way too much to carry aboard a spacecraft.

It should be possible, though, to recycle up to 90 percent of all the water an astronaut consumes, says Robert Zubrin, president of Pioneer Astronautics and founder of the Mars Society. To do that, the crew would have to capture, clean, and reuse every drop of water involved in cooking and bathing—and peeing and sweating, too. Once on Mars, additional water could be extracted by melting and purifying the planet's permafrost. In places where the water ice is buried deep, microwaves could penetrate the soil and melt the ice, says NASA scientist Edwin Ethridge.

The crew should also be able to produce oxygen on Mars from the carbon dioxide that makes up 95 percent of the thin Martian atmosphere. All it would take is a small amount of hydrogen, which the crew could bring. The hydrogen would react with the CO_2 to produce water, which could then be elec-

JACOB THOMAS (2)

trolyzed to make oxygen, methane, and more hydrogen. The methane could be used as fuel, and the hydrogen could be reused to produce more oxygen.

Dining on a Mars voyage also poses some challenges. A 1000-day, five-person mission would require 8000 kg of food, of which about 15 percent would be packaging. NASA scientists are developing new techniques for preserving the food and reducing the packaging. Tests show that heating food to 120 °C for 2 to 3 minutes and then placing it under high pressure (about 600 megapascals) for another few minutes will kill any harmful microorganisms without damaging the food. Bombarding the food with microwaves for 5 to 10 minutes will also do the trick.

Either method would increase shelf life to five years. That may sound like overkill, but getting provisions to Mars for an extended stay might mean first sending supplies aboard an unmanned shuttle, with the crewed mission following two years later, says Michele Perchonok, manager of advanced food technology at NASA. She says the space agency will soon ask for approval from the U.S. Food and Drug Administration for its first Martian prepackaged food product: mashed potatoes.

Of course, you could just dehydrate everything and then reconstitute as needed. But Zubrin advises against it. To simulate life on Mars, he has spent weeks at a time living with a small crew of scientists and students on remote Devon Island in the Canadian Arctic and in the southern Utah desert. They eat only what a Mars-bound crew would likely take with them.

"Our first year in the Arctic, it was all crackers," Zubrin recalls. On later visits, they brought along a lightweight electric bread maker and began serving bread, pasta, and rice. The addition of a few simple cooked items, he says, was a huge boost to the crew's morale. The crew ate together and took turns preparing meals. "We'd have contests over who could cook the best meals with limited ingredients," Zubrin says.

Growing food on Mars would cut down on payload weight and give astronauts a chance to munch on fresh produce. Lettuce and tomatoes, for instance, could be grown hydroponically in a greenhouse. Soybeans, wheat, peanuts, and other dried beans could be used to make pasta, bread, and cereal. But cultivating a garden, grinding flour, and cooking from scratch would all divert efforts from life-sustaining chores like finding water and repairing equipment. Salad or survival: The choice is pretty clear.

SO, YES, MARS IS HARD. Wernher von Braun knew it, and yet the planet remained ever in his sights. In his novel, he included a 62-page scientific appendix dense with tables of rocketry data, landing maneuver calculations, and hand-drawn diagrams. Getting to Mars, to von Braun, was not some fantastic dream; it was a workable, solvable problem and an engineering challenge of the best kind, because it inspires us, builds us up, and unites us as a society. He saw his book not so much as a work of fiction but as a practical guide, a road map, a way forward.

"It is the vision of tomorrow which breeds the power of action," he wrote in the novel's preface. "Thousands of scientists and engineers are laboring constantly to perfect our knowledge of rocketry and rocket propulsion, and millions of dollars are spent yearly to advance such research. What the results will be is beyond the public ken, but they will surely exert a vital influence upon the future of the entire Earth and well beyond its present confines."

"When referring to technological advances," he added, "the word 'impossible' must be used, if at all, with utmost caution." ❑

[THE RIGHT STUFF]

WHAT TO PACK FOR MARS

A successful mission REQUIRES A WELL-PLANNED SUPPLY STRATEGY + + +

BY OLIVIER L. DE WECK

YOU CAN'T TAKE MUCH INTO SPACE. When a rocket is on the launchpad, 99.9 percent of the mass is the fuel and the vehicle itself. That leaves 0.1 percent for everything else—the crew and all their supplies. When considering what to bring, how do we trade off between consumables (needed for survival), spare parts (for safety), and research equipment (which gives the mission value)?

Starting in 2005, NASA asked my group at MIT to develop SpaceNet, software that helps mission planners evaluate these trade-offs. The program manages and models the complex supply chain of vehicles and supplies along with the processes and orbital dynamics required for manned missions, whether they're to Mars, the International Space Station (ISS), or a lunar outpost. We designed our software to model each step in a mission as well as a whole campaign of missions. SpaceNet allows planners to quantitatively compare different mission architectures to optimize the exploration capability and launch mass. We also want to make supply chains robust so that one failed or delayed mission doesn't ruin the whole plan.

In 2005, we tested our computer models by participating in the Haughton-Mars Project, in which a small group of researchers live in an Arctic base as if they were on Mars. The experience was enlightening. We found that of the operational inventory (that 0.1 percent of launch mass), two-thirds went to ground vehicles and fuel for powering the base. From this experience, we've calculated that each crew member added to a 600-day Mars mission would require sending 13 metric tons more cargo to the Martian surface.

But even if you deliver the right amount of supplies, it matters how they are organized. For example, there are between 15 000 and 20 000 objects on the ISS. If you take the total number of useful crew hours in a year and divide by the total operating budget, you find that the value of 1 hour of an astronaut's time on the ISS is US $186 000. So 5 minutes spent looking for one hard-to-find item wastes $15 000.

On a Mars mission, time will be even more valuable. Storage should be reconfigurable so that the most needed items are always accessible and everything else is out of the way. We're now working on an RFID system that tracks the location of each piece of inventory at all times. The ultimate goal is to create smart, self-aware environments that are both safe and effective for exploration far from Earth. We hope that better space logistics will give future astronauts more time to do valuable work.

—As told to Joshua J. Romero

OLIVIER L. DE WECK is the leader of the MIT Strategic Engineering Research Group.

{ NO PAIN, NO GAIN }

RISKY BUSINESS

Why Mars is MORE IMPORTANT THAN COSMETICS AND WHY A FAILED LAUNCH IS ALSO A PARTIAL SUCCESS + + + *BY ELON MUSK*

IN THE HISTORY OF LIFE ITSELF, there are only a handful of really big milestones: single-celled life, multicellular life, differentiation of plants and animals, life extending from the oceans to land, mammals, consciousness. On that scale, the next important step is obvious: making life multiplanetary. By that I mean the permanent extension of life beyond Earth.

A goal like that, something that is important on the scale of life itself, deserves at least a small amount of our resources—less than we spend on health care but probably more than we spend on cosmetics.

To me, making life multiplanetary means going to Mars. We can skip Venus, whose atmosphere is highly acidic and roasting hot; Mercury, which is too close to the sun; and the moons of the gas giants, which are too far away from the sun. Mars alone is doable.

SUCCESS, FINALLY: SpaceX's fourth launch of a Falcon 1 rocket from Kwajalein Atoll goes off without a hitch.
PHOTO: SPACEX

When I was studying physics in college, it seemed to me that space exploration was one of the three areas that would most affect the future of humanity, along with the Internet and sustainable energy. At the time, I didn't expect to be personally involved in space, an arena I thought was so expensive that it could only be the province of government. As for the Internet, I wasn't sure how I could earn a living in an industry that barely existed apart from university and government networks. Therefore, I started on the sustainable energy problem by trying to develop ultrahigh-energy capacitors for electric vehicles.

But in the summer of 1995, just before embarking on a Ph.D. program in materials science and applied physics at Stanford University, I realized that the Internet was entering a phase of exponential growth. I had the choice of either watching the Internet get built or helping to build it, and I felt pretty sure I could do something useful there while earning at least enough money to pay the rent (although at the time no one had made any significant money on the Internet). The capacitor research, on the other hand, seemed much less likely to succeed.

I applied to Netscape, the only major Internet software company at the time, but got no response, so I deferred grad studies to start my own company, Zip2. About four years later, Compaq bought Zip2 for US $300 million, allowing me to cofound PayPal, which eBay bought in 2002 for $1.5 billion. I then had enough capital to think seriously about space exploration (and sustainable energy, too—but that's another story).

At first, I thought I'd use some of my PayPal money to popularize the idea of life on Mars. I settled on a mission called Mars Oasis, which would land a small robotic greenhouse that would establish life on another planet and show great images of green plants on a red background. It would get the public excited, and we'd learn a lot about what it takes to sustain plant life on the surface of Mars.

I quickly found that the biggest obstacle was the cost of the launch. A U.S. Delta II rocket would cost $60 million, while a refurbished Russian intercontinental ballistic missile would cost $10 million—without the necessary third stage.

I gathered a group of engineers from the space industry to find a way to get the launch cost down. We determined that we could do it by optimizing the design for cost and by making the rocket reusable. Of course, we also had to ensure that it performed at least as well as other available rockets. I dropped the greenhouse idea; my goal now was to make it technically and financially possible to extend life to Mars. In 2002 I founded Space Exploration Technologies.

The question was whether I could finance SpaceX myself. I didn't expect anyone to invest with me until I had demonstrated success. Ironically, with my track record, I could have gotten funding for almost any business except rockets.

WE LAUNCHED OUR FIRST FALCON 1 rocket in 2006 from the Kwajalein Atoll in the Marshall Islands. Unfortunately, an engine fire started on liftoff, and the engine lost power after 30 seconds in the air. It really hurt seeing four years of work come crashing down.

I had realized going in that we faced steep odds. We had built an entire rocket from the ground up, with almost no legacy hardware. The reason was simple: If you use legacy parts, you'll limit opportunities to reduce costs; if you don't use them, the risk of failure goes up. We traced the engine fire to fuel leaking through a nut that had cracked on ignition due to stress corrosion, so we replaced the aluminum nuts with stainless steel.

The second flight almost made orbital velocity before the second-stage engine flamed out. It turned out that the liquid oxygen sloshing in the tank, coupled with the engine-control system, had caused the second stage to revolve in a conelike motion around the insertion vector, a process called mode coupling. This motion centrifuged propellant to one side of the tank, prematurely uncovering the propellant outlet. The engine then slurped in a helium bubble, and that's what made it flame out. So we added a baffle to eliminate the sloshing that caused the wobble, and we lowered the gains on the engine to make mode coupling less likely.

Flight three would have worked if we hadn't changed anything else from flight two—but we did. We chose to test our new Merlin engine on this flight, rather than on a future flight of the Falcon 9, which we had under development. Instead of cooling the combustion chamber ablatively, by letting the chamber burn away slowly from the inside, the Merlin cooled it regeneratively, by flowing fuel through a jacket around the chamber. However, that flow left just enough fuel in the jacket to extend the thrust enough to make the first stage lightly recontact the second stage. When the second-stage engine ignited, this contact reflected back the engine's own exhaust, and the second stage fried itself.

That was a tough blow, but the SpaceX team rallied hard, and we launched flight four last September, just a month later. Our only change was to extend the time between the main engine cutoff and stage separation by a few seconds. Flight four was a complete success, including the restarting of the upper stage on the other side of Earth.

Before that launch, I'd talked to everyone working on the project. I said that if flight four failed we'd do flight five, and if flight five failed we'd do flight six. I would never give up on something as long as I believed there was a reasonable chance of success.

Space is risky, and we knew it. The phrase "It ain't rocket science" implies that rocket science is pretty hard—and it is. Only a few countries in the world have gotten anything at all into orbit.

While our first three test flights did not reach orbit, it would be inaccurate to call them failures, as each one taught us a lot about the design of the rocket. And none of the problems were related to production or quality assurance. So even though we had only one success out of four flights, that doesn't mean our success rate is 25 percent. In principle, all our future flights should work if we build them the same way.

GOING UP: From their command van, Elon Musk [tan shirt] and SpaceX staff watch flight four's picture-perfect liftoff [top]. An engine fire that began on the launchpad doomed SpaceX's first Falcon 1 rocket, in 2006 [bottom]. The problem turned out to be a fuel leak caused by a corroded aluminum nut.

PHOTOS: TOP: SPACEX; BOTTOM: THOM ROGERS/SPACEX

Reusability will come later. It's hard; nobody has ever really achieved it. Even the space shuttle isn't really reusable, in that it costs more per flight than it would to buy a new expendable launch vehicle of greater cargo capacity. I think we can do it. So far, though, we haven't even been able to recover the first stage; on flight four, it didn't have enough thermal protection and was fried on reentry. On flight five, which is coming up later this year, we took off the recovery system to give us more room in the payload module. But on flight six we plan to make a strong effort to recover the rocket. Reusability is critical to making multiplanetary life financially possible, so this is something we have to get right and hone to perfection. ❑

spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

ROCKET STAR: Franklin R. Chang Díaz, a former astronaut, is building a rocket that might get people to Mars.
PHOTO: RANDI SILBERMAN

{ THE HARDEST PART }

ROCKETS FOR THE RED PLANET

Engineers rethink HOW TO GET TO MARS AND BACK

+ + + *BY SANDRA UPSON*

FROM HIS CORNER OFFICE at Ad Astra Rocket headquarters near Houston, Franklin R. Chang Díaz hatches big plans. He's tucked away behind a strip mall on a bland suburban street, but his mind is wandering the cosmos. He envisions multibillion-dollar mining operations extracting iron, cobalt, and platinum from asteroids for use in cities on the moon and Mars. He dreams of space infrastructures so evolved that astronauts freely roam the moons of Jupiter and Saturn. He sees parallel societies grown teeming and rich, and Earth gradually transformed into a grand nature preserve.

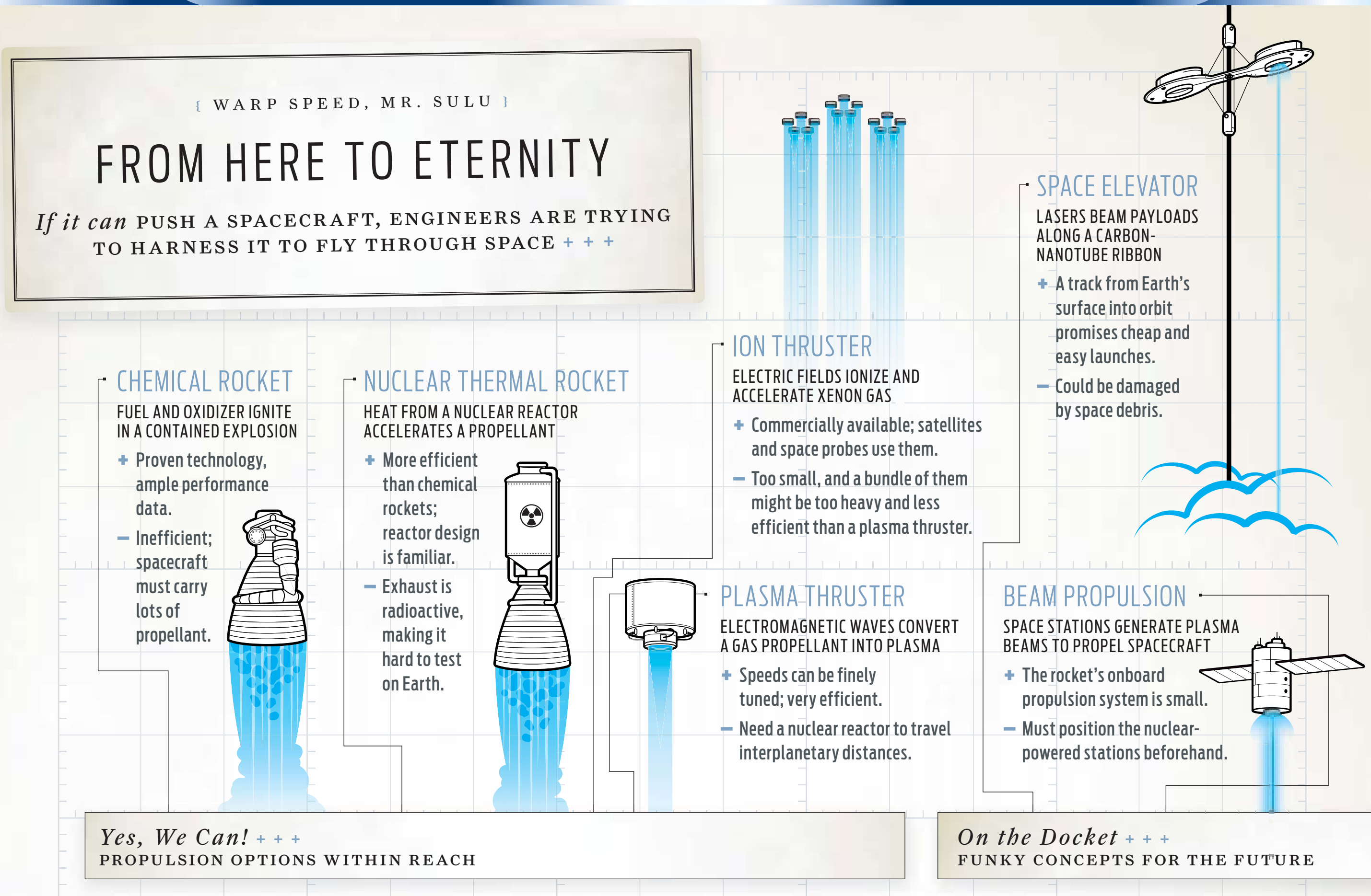
But first, he confides, he hopes to trade his comfy landing pad in Houston for an office on the moon.

If anyone can help launch a spacefaring society, it'll be Chang Díaz. The former astronaut has spent more than two months in space during seven space-shuttle missions. Three times he has gazed down through his helmet's mirrored faceplate at his white-swirled, blue-green ball of a home. Now he's building the rocket engine that might make some of those galactic fantasies come true.

Decades ago, Chang Díaz, who holds a Ph.D. in applied plasma physics, concluded that chemical rockets were a dead end, owing to their modest performance specs and huge appetite for fuel. Voyaging in a chemical rocket is the celestial analogue of drifting around the world on a yacht that got its one burst of speed by charging out of port like an angry elephant. It's heavy, it's inflexible, and it breaks all the rules of sensible travel. So in the late 1970s he began developing an alternative technology he calls VASIMR, for "variable specific impulse magnetoplasma rocket." In its most ambitious form, VASIMR would be a nuclear-electric rocket engine—a fission reactor with a plasma thruster that could potentially push people to Mars and back using a fraction of the propellant and time needed for a chemical rocket.

With a power plant similar to the ones on nuclear submarines, the plasma rocket could carry several people from Earth to Mars in 39 days, as opposed to what would be at least a 180-day journey on a chemical rocket, Chang Díaz says. The savings in food, water, air, tedium, and cosmic-ray exposure would be immense. In 2012, Ad Astra plans to test a prototype—using solar power rather than nuclear—on the International Space Station. An astronaut will spacewalk out to attach the 200-kilowatt engine, and if all goes well, it will bump the ISS into a more attractive orbit with about 5 newtons of thrust. The tests will begin to indicate whether VASIMR can figure in NASA's grand plan to shuttle people and cargo to the moon and perhaps Mars over the next couple

IEEE Spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | qMags



of decades. In particular, engineers will analyze two things: how efficiently the engine uses its electricity to produce plasma and how fast its radiator can siphon away excess heat.

ON A HOT, CLOUDLESS February day in Costa Rica, that radiator is undergoing intense scrutiny. Its home is a sleek white warehouse that hulks in a meadow of feathery grasses, an awkward edifice that looks like it dropped from the sky in a space-age remake of *The Wizard of Oz*. Next to the building, six cars are parked with sun shields propped against their front windshields.

A bumpy dirt road links the warehouse, with its zippy Ad Astra logo, to an unnamed highway, one of two thoroughfares that connect the city of Liberia to the rest of Costa Rica. Rental-car agencies hawking rugged vehicles line the highway. In the window of one agency, a poster advertises a "Race to Space." Silhouetted runners glide across the surface of some space orb, with Earth hovering behind them on a field of luminous blue. In the foreground, Chang Díaz, who was born in Costa Rica, smiles benevolently in a bright orange space suit. The footrace is to raise money to build roads, but Chang Díaz's engine may reach Mars before Liberia gets good roads.

Ad Astra's warehouse lab in this Central American burg is the world's foremost—and only—dedicated center for heat management in plasma rockets. With an average age of 28, the engineers make up a team as remarkable as it is improbable. The story begins in 2004, when Chang Díaz tapped his younger brother, Ronald, then running a construction company in the city of San José, to start up an Ad Astra office in Liberia. At age 42, Ronald embarked on a real-life Costa Rican version of *Rocket Boys*. He skimmed the best and brightest from local tech companies and Costa Rica's universities. He added others as people showed up whose drive and aptitude appealed to him.

One electrical engineering grad appeared at the facility's ribbon-cutting ceremony and refused to leave. Ronald hired him. The 21-year-old master of the machine shop, an immigrant from Nicaragua, was plucked from a local gas station, where he was an attendant. He's now also the electrical technician, and he dabbles in computer-aided design.

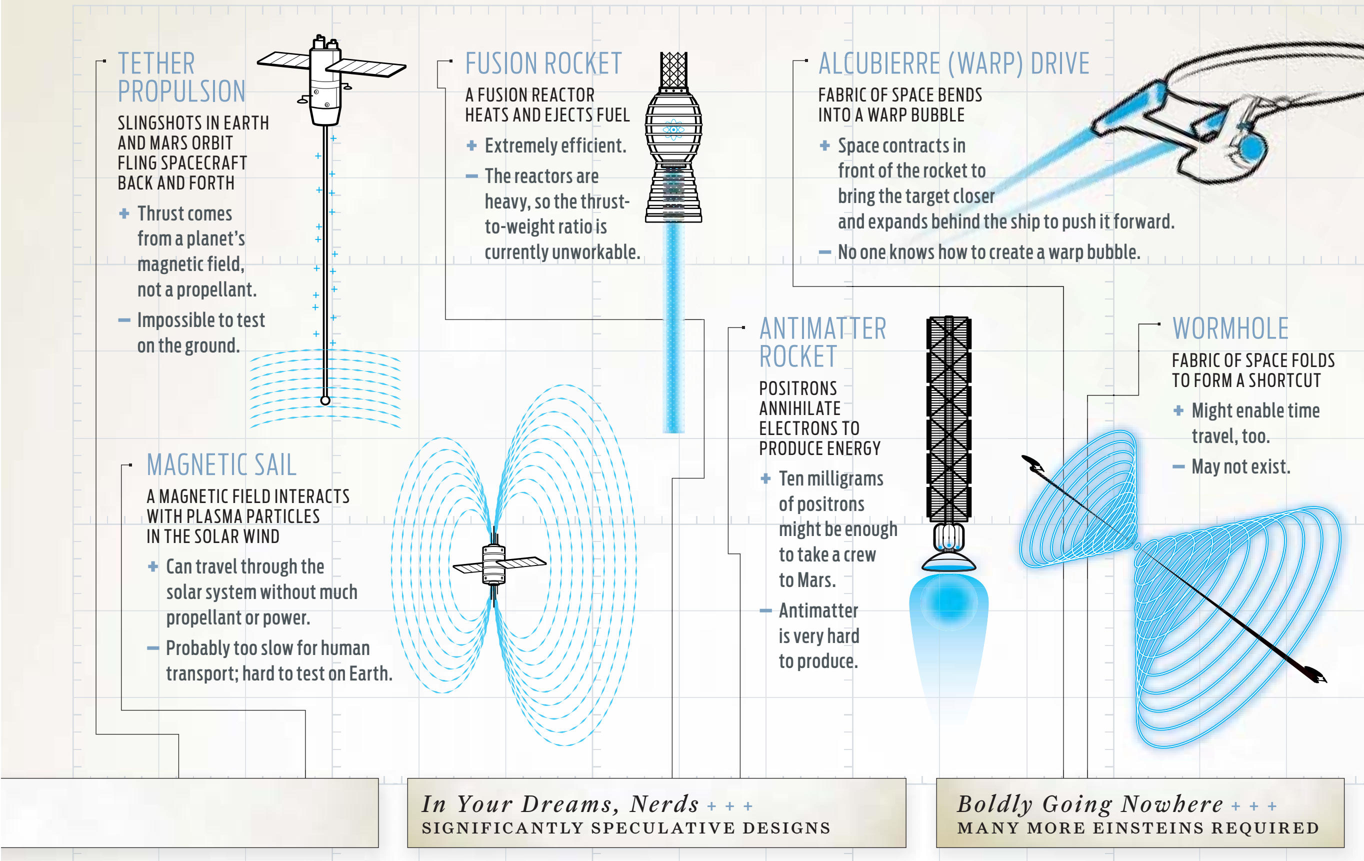
On this sunny February day, the dozen engineers in the warehouse are scattered around a 50-kW version of the engine. They must design a lightweight thermal jacket for the thruster. The challenge lies in choosing a material that conducts heat well but electricity poorly, perhaps a ceramic made from silicon nitride.

The jacket would collect the heat between the magnetic fields and the thruster's walls, radiating some of it back to the plasma and some of it into space. The engineers' task is formidable: Many experts suspect that the combined weight of VASIMR's power plant and radiator will bog it down too much.

To test their radiator, the engineers prepare to fire the thruster. They settle into chairs at a row of desks facing a vacuum chamber the size of a school bus. Attached to one side is the business end of the apparatus: permanent magnets, a radio-frequency generator, a tank of argon gas, and the tube where they will generate the plasma before venting it into the vacuum chamber. The argon is flowing, and the magnets are powered up.

"*Cinco, cuatro, tres*," Jorge Oguilve-Araya, a lead engineer, chants into a walkie-talkie. "*Dos, uno. Pulso!*" The RF generator switches on and releases a torrent of RF waves into the argon stream. The gas heats up and ionizes, turning into a plasma of about 50 000 kelvin. Magnetic fields generated by the permanent magnets hold and channel the viciously hot material, protecting the thruster walls from melting on contact. A pur-

MCKIBILLO



plish light fills the vacuum chamber before fading to black.

There's a similar setup in Houston, but with one more stage. Another antenna generates an electric field to heat the plasma to a million kelvin. When the ions' rotation frequency matches the frequency of the field, the potential energy in the electric field changes into kinetic energy for the ions, accelerating them in a direction perpendicular to the magnetic field lines. This configuration forms a magnetic beach—waves on which the particles then surf their way out of the rocket.

Because it can modulate how the power is distributed between the two heating stages, this rocket has one unique and extremely desirable feature, one that explains much of the effort and expense: It can vary its specific impulse.

A rocket's specific impulse reflects the efficiency with which it consumes its propellant, which depends heavily on the rocket's mass. "Impulse" refers to a change in momentum, and it can become "specific" when divided by a mass. Dividing the rocket's thrust by the amount of exhaust it produces per unit time results in a value whose unit is given in seconds.

Rocket engineers love the idea of variable specific impulse, because it allows a spacecraft to behave more like a race car, adjusting its acceleration at each turn around a track. Chemical rockets are fixed at a relatively low specific impulse of around 450 seconds. They need lots of propellant and can produce lots of thrust. Heading off to Mars, a chemical rocket would thrust for half an hour to escape Earth's gravitational well and then coast the rest of the way. VASIMR, on the other hand, can run at specific impulses between 5000 and 15 000 seconds using deuterium or as low as 4000 with argon. For wandering the interplanetary voids, high specific impulse—or low thrust—is good: With highly efficient propulsion, the engine can keep firing until it reaches a high velocity, generating minimum thrust near the middle of the trip.

But first, the thruster must escape terra firma. For that to happen, the Costa Ricans must master the heat problem, and the Houstonians must resolve the closely tied power problem. The Houston thruster's 200-kW rating is impressive when compared with other electric thrusters, but it's not enough. The engine will need 5 to 10 megawatts—and possibly as much as 200 MW—to send people from Earth to Mars.

THERE'S NO EASY WAY OUT. Using existing technology—chemical rockets—a human trip would cost hundreds of billions of dollars. Previous missions have shown that a spaceship can deposit a package the size of a refrigerator on the Martian surface. Sporty rovers can explore their environs with minimal solar energy and a 19-minute communications delay. But hoisting fragile, needy humans to Mars and then returning them complicates the mission by an order of magnitude, if not two.

Chemical rockets move by virtue of a contained explosion. In one form, liquid hydrogen and oxygen are pumped from separate tanks into a combustion chamber. They react to produce water vapor and lots of energy, which blasts the vapor out through a nozzle and pushes the spacecraft in the opposite direction. Those tanks account for about 90 percent of a mission's initial mass.

A space agency *could* send people on a round-trip jaunt to Mars using only chemical rockets. But that approach undervalues the basic metric of celestial shipping—that a trip's cost often boils down to a spacecraft's mass. Even if a crew traveled without fuel for the return trip, the passengers would be facing the most massive camping trip ever undertaken. Aside from Robert Zubrin's spartan visions [see "How to Go to Mars—Right Now!" in this issue], most chemical-rocket scenarios are

VASIMR'S VACUUM: In Houston, a 200-kilowatt thruster sits inside a vacuum chamber, with RF generators, magnets, and a cooling system outside it.

RANDI SILBERMAN

leviathan operations with numerous heavy-lift launches to heave all the components into orbit. Space tankers carrying only propellant would depart early to sit in Mars orbit, ready for the return flight. So would all the other necessities: a landing vehicle, some kind of power plant, rovers to let the astronauts explore, and a preassembled habitat—the Martian equivalent of a welcome mat and logs crackling in the fireplace.

Robert Braun, an aerospace engineering professor at Georgia Tech, estimates that the total mass in low Earth orbit would add up to almost eight International Space Stations, or about 1.8 million kilograms. To put that in perspective, the Saturn V rocket, which launched men to the moon and back and remains the biggest thing to leave Earth's surface, could deliver 119 000 kg per launch. That works out to 15 Saturn Vs to lift the propellant, engines, and payload to start the outbound voyage.

By one common estimate, it costs US $20 000 to place 1 kg in low Earth orbit using a standard launch vehicle. So getting everything floating in the thermosphere would have a starting price tag of about $36 billion, or double this year's budget for NASA, the world's largest space agency. After getting to orbit, as many as 400 million kilometers of travel would remain.

Dozens of mission architects have drafted their own flight plans, but each one faces the same trade-off: The less beefy the propulsion system and its fuel, the less preposterous the mission starts to look. For human space transport, there's only one plausible alternative to chemical reactions, and that's nuclear power [see illustration, "From Here to Eternity"]. In an electric rocket like VASIMR, the reactor's heat would be converted into electricity. A competing configuration, called nuclear thermal propulsion, is more basic: A nuclear reactor heats a gas and blasts it directly out a nozzle. It doesn't dabble in antennas or magnets or variable specific impulse. When official committees assess future rocket technologies, it always gets a nod. But nuclear rockets have one troubling feature: their radioactive exhaust.

NASA HAS ALWAYS WANTED A NUCLEAR ROCKET. Almost immediately after the agency was formed in 1958, it began working on nuclear reactors for space, under a program known as Rover/NERVA, which stands for "nuclear engine for rocket vehicle application." In the spring of 1969, just before Neil Armstrong planted his boot in the Sea of Tranquility, the NERVA team finished ground testing its first complete mock-up of a nuclear reactor, the NRX-XE. The reactor went through 28 start-and-shutdown cycles at the Nevada Test Site, where the United States tested nuclear bombs.

During the 13 years of its existence, the program's engineers built and tested 20 reactors and nearly produced a flight-qualified propulsion system. They measured thrust and vented radioactive exhaust at an isolated spot known as Jackass Flats, bordered by mountains and mesas. They demonstrated systems with half the mass of a chemical rocket and a specific impulse of about 845 seconds. They tested engines that could get a crew to Mars and back in 80 days. But before the reactors could fly, the program ended. It was the 1970s, and political pressures were marginalizing space science.

The Soviet Union kept nuclear reactors in play a bit longer. Between 1965 and 1988, it launched a series of naval satellites with small reactors on board. At least two of them failed, releasing radioactive materials and spooking politicians worldwide.

To use nuclear reactors for a trip to Mars safely, a launch vehicle would deliver a spacecraft with three inactive nuclear engines to low Earth orbit. Around 220 nautical miles up, at roughly the altitude of the International Space Station, the reactors would start up. They'd run for no more than 45 minutes, producing about 330 000 newtons of thrust and kicking the ship beyond gravity's grip. Like a chemical rocket, the vehicle would coast most of the way to Mars and then fire its engines briefly to decelerate. The vehicle would ease into orbit and be greeted by a lander vehicle. The lander would ferry the astronauts to the surface, where the real mission would begin.

At the peak of nuclear rocket research, engineers were reaching thrust levels of almost a million newtons, well beyond what they'd need. "We're the only propulsion technology that I think is scaling down in size," says Stan Borowski, an engineer pursuing nuclear thermal propulsion at NASA's Glenn Research Center, in Sandusky, Ohio. In a typical nuclear rocket design, the fuel consists of graphite pellets mixed with particles of uranium-235 and bundled into fuel rods. Channels perforate the bundle, enabling hydrogen or helium coolant, which is also the propellant, to flow through. The nuclear reaction heats the rods and the propellant, which blasts out into space.

There is a problem, though. Tiny cracks can form in the core, releasing some of the uranium into the propellant. In space, radioactive sputter isn't a big deal. But without ground testing, the reactors won't ever get to space. "If we're trying to sell the public on a Mars mission and the image is of us leaking a radioactive gas, that's going to be a problem," notes Steven Howe, the director of the Center for Space Nuclear Research at the Idaho National Laboratory, in Idaho Falls.

Because human exploration of Mars has yet to receive its mandate, none of the work-arounds that could save nuclear propulsion is getting more than theoretical consideration. No space agency is building big enough reactors, and there's a solid chance they will live on just as a testament to the scientific exuberance of the 1960s. Any dream of humans harnessing the great beyond would be mothballed, with an unbuilt Martian settlement languishing next to a missing philosopher's stone and a nonexistent flying car.

That's not to say humans will never make it. A chemical rocket may indeed deliver a small crew to Mars [see sidebar, "Exotic Options for Chemical Rockets"]. But it wouldn't be for much more than bragging rights: Humans went all the way to Mars and they didn't even get the lousy T-shirt or the reinvention of life science—and they certainly didn't get the space colony.

AD ASTRA'S VASIMR shares some of the technical and political problems of nuclear thermal propulsion. Only a nuclear reactor can deliver the megawatts needed for a Mars mission. But given a reactor, Chang Díaz is confident he can easily convert at least 60 percent of its electrical power into rocket power. For now, he plans to build his business around closer targets, such as solar-powered moon visits and trips to investigate near-Earth objects.

The ventures would be scaled-up versions of the activities now performed by Hall thrusters and other ion engines, whose related technologies propel space probes and nudge satellites. Ion thrusters have taken European Space Agency and Japanese probes to the moon and to an asteroid named 25143 Itokawa, and one spacecraft is now hurtling toward another asteroid and the dwarf planet Ceres. Solar panels power the thrusters, which rarely use more than a couple of kilowatts.

Size is everything. Says Brent Sherwood, a space architect at NASA's Jet Propulsion Laboratory, in Pasadena, Calif.: "The real question is, how do you scale up from a thing that's got a blue glow in a lab to a thing that sends half a dozen people to Mars and back?" To test higher-powered VASIMRs, Ad Astra will need a vacuum chamber even bigger than the aluminum monolith it has in Houston. In fact, it would be so big and expensive that Chang Díaz figures he might as well test the rocket in space.

Under this model, Ad Astra employees would blast off on assignment to the moon for a few months at a time, touching down near a facility surrounded by vast arrays of solar panels. Working within the moon's peculiar schedule—two weeks of light followed by two weeks of night—the lunar operatives would fire their engine, accumulating performance data in preparation for an eventual flight to Mars.

Then will come the hard part. No amount of testing can mimic humanity's first flight to Mars. That knowledge gap could be Ad Astra's greatest challenge. Les Johnson, deputy manager for the Advanced Concepts Office at NASA's Marshall Space Flight Center, in Huntsville, Ala., puts it this way: "Imagine getting in a Winnebago with your four best friends and saying, 'We're not going to leave this Winnebago for three years.' And between us and complete death is a thin aluminum skin, and the lowest bidder is going to send us out." Then he pauses. "I would be a bit more mundane," he says. That is, he would rather see the advanced technology invested in better life-support systems, perhaps in the form of artificial gravity on board a familiar chemical rocket.

In rocket science as in life, differences of opinion are often cultural. On a table next to Chang Díaz's desk in Houston lies a DVD of a television show he grew up watching in the 1950s. It's about an eccentric scientist named Captain Video who defended law and order by jumping into his spaceship from his mountain retreat. Before each episode, a voice booms across the mountaintops: "Captaaaaaaiinn Video! And his Videoooo Rangers!" Then antics ensue. Chang Díaz's name may not echo across the suburbs of Texas, but in the world of rockets, his presence is booming. ❑

EXOTIC OPTIONS FOR CHEMICAL ROCKETS

To salvage the chemical rocket, engineers have found a few ways to carry less fuel. They could make propellant, perhaps propane, on Mars by separating hydrogen and oxygen from the water in Martian soil and storing the propane in a tank.

That sounds convenient, but imagine that a critical onboard system fails midflight. For the astronauts to survive, the spacecraft must return home—which means it must carry enough return propellant. Relying on robotic industry on Mars has another drawback. "With my luck, a micrometeor will zip by and punch a hole in that propane tank just as my landing craft touches down, ending my prospects of return," muses Narayanan Komerath, an aerospace professor at Georgia Tech. "Sorry, I am too chicken to buy a ticket on that sort of premise."

Another approach is to use aerocapture to decelerate into Mars orbit. Instead of using propellant, the vehicle skims into Mars orbit with a balloonlike parachute and uses the drag from the atmosphere to slow down. In theory, aerocapture could cut a mission's initial mass in half, according to Robert Braun, also at Georgia Tech. But the need for a precise control system to enter at the right angle and avoid burning up in Mars's unfamiliar atmosphere makes this option risky as well. *—S.U.*

ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

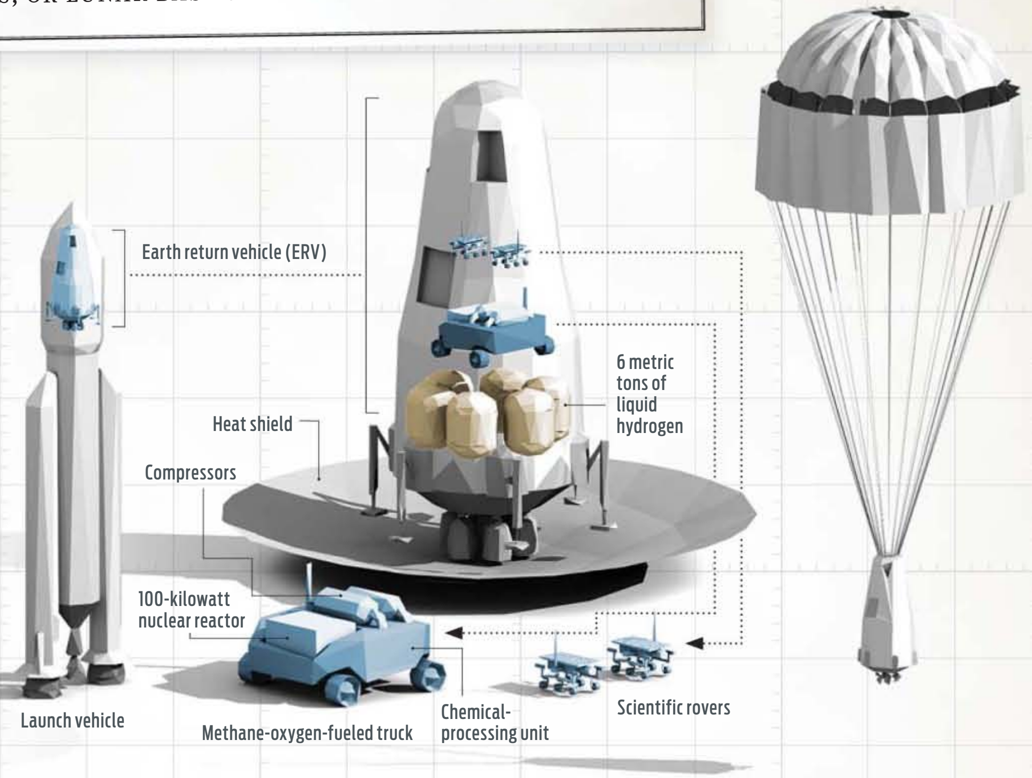
{ THE DIRECT APPROACH }

HOW TO GO TO MARS—RIGHT NOW!

Human exploration of Mars DOESN'T NEED TO WAIT FOR ADVANCED ROCKETS, GIANT SPACESHIPS, OR LUNAR BASE STATIONS + + + *BY ROBERT ZUBRIN*

PHASE 1

In spring 2014, a heavy-lift booster heads for Mars. The unmanned payload includes a methane-oxygen-fueled Earth return vehicle (ERV), 6 metric tons of liquid hydrogen, a small nuclear reactor mounted in the back of a truck, a set of compressors, an automated chemical-processing unit, and a few scientific rovers. The spacecraft lands on Mars eight months later, and the chemical-processing unit begins producing methane and oxygen, which are stored in the ERV's fuel tanks.



MANY PEOPLE BELIEVE that a manned mission to Mars is a venture best left to the next generation. They're wrong. We have in hand all the required technologies; we don't need to build giant spaceships, a lunar base, or a space station grander than the one we have. Instead, we can go straight to Mars in relatively small spacecraft powered by boosters like those that carried Apollo astronauts to the moon 40 years ago.

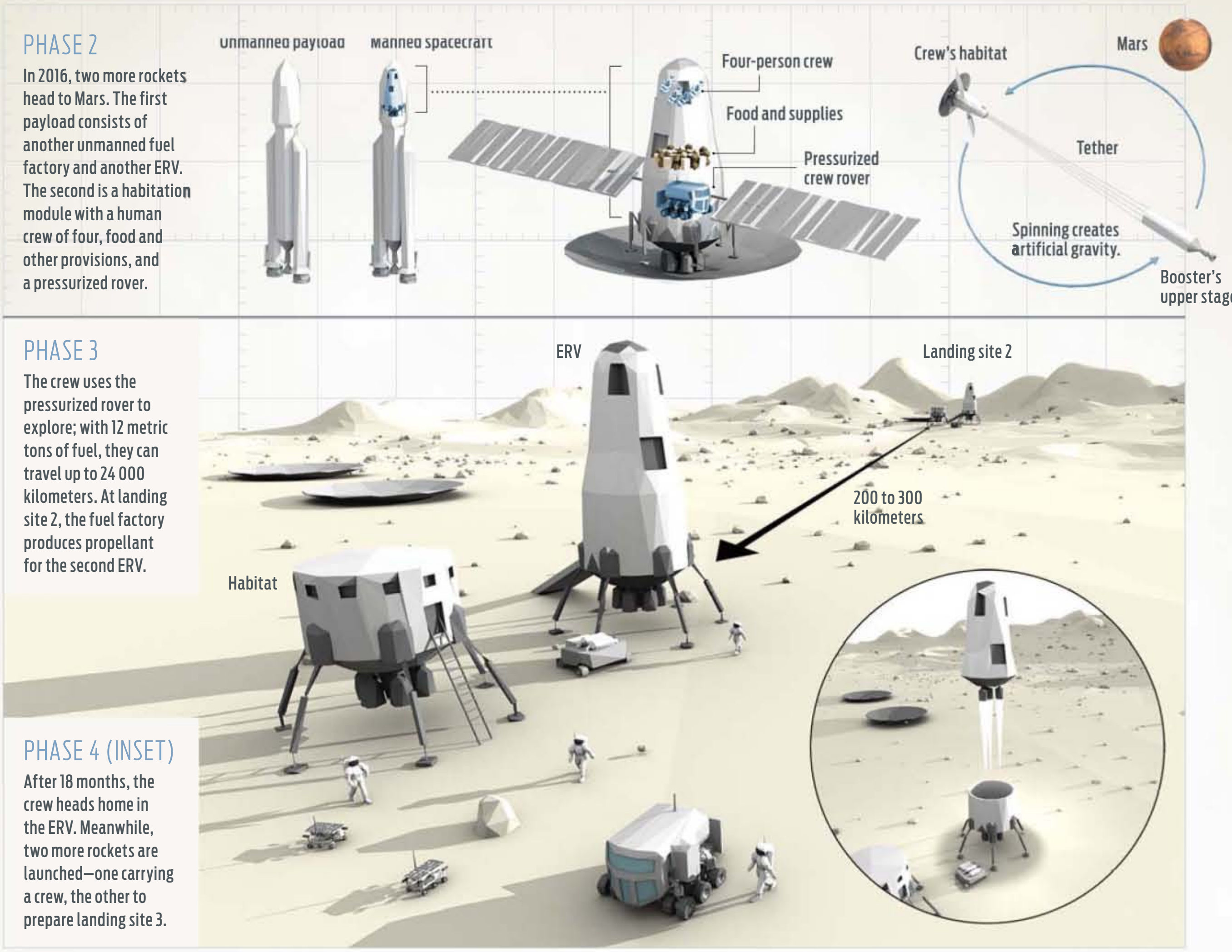
With this "Mars Direct" approach, traveling light and living off the land whenever possible, humans could reach the Red Planet within a decade. Here's how it might work.

In the spring of 2014, a heavy-lift booster similar to Apollo's Saturn V launches from Cape Canaveral and uses its upper stage to throw an unmanned payload weighing 40 metric tons onto a trajectory to Mars. The payload includes an Earth return vehicle (ERV) that will eventually bring a human crew home; it's carried to Mars with its two methane-oxygen propulsion stages empty. Also on board are 6 metric tons of liquid hydrogen, a 100-kilowatt nuclear reactor mounted in the back of a truck that is also fueled by methane and oxygen, a set of compressors, an automated chemical-processing unit, and a few scientific rovers.

Arriving at Mars eight months later, the payload uses atmospheric friction to brake its way into orbit and then lands with the help of a parachute. Next, the rovers explore and characterize the landing site while a human operator back on Earth telerobotically drives the truck a few hundred meters and then deploys the reactor, which powers the chemical-processing unit and the compressors. The chemical-processing unit begins to create a reaction between the bottled hydrogen brought from Earth and the Martian atmosphere, which consists largely of carbon dioxide, to produce methane and water. It electrolyzes the water, producing oxygen and hydrogen, and the compressors liquefy the methane and the oxygen, which are stored in the propellant tank of the ERV. The hydrogen, meanwhile, is recycled to produce more methane. Still more oxygen is produced by dissociating carbon dioxide in what's called a reverse water-gas-shift reactor; some of that oxygen will go into the ERV's tanks, and the rest will be stockpiled, both for breathing and for synthesizing water later on.

From start to finish, the process takes 10 months and yields 108 metric tons of methane-oxygen propellant. That's 18 times as much as the amount of hydrogen brought from Earth. Of that, 96 metric tons will fuel the ERV for the flight back to Earth, and 12 metric tons will be stored for later use by human crews.

Two more rockets fly in 2016—the next good launch window. The first payload is another unmanned fuel factory and an ERV. The second is a habitation module containing a human crew of four, food and other provisions sufficient for three years, and a pressurized rover fueled by methane and oxygen. During the six-month trip, the habitat spins around the burned-out upper stage of the booster, attached by a tether. The spinning creates enough artificial gravity to counter bone loss and



BRYAN CHRISTIE DESIGN

other physiological problems brought on by weightlessness.

Arriving at Mars, the manned craft drops the tether, aerobrakes, and lands at the 2014 landing site, where a fully fueled ERV awaits. The second ERV lands several hundred kilometers away, at landing site 2, and starts making propellant for the third mission, to take place in 2018. The third mission, in turn, will fly a crew to site 2 and an additional ERV to open up landing site number 3, and so on.

The first crew spends 18 months exploring Mars; they'll have enough fuel to drive the pressurized rover a total of 24 000 kilometers. That should suffice: The circumference of Mars is about 21 000 km. Among other things, the crew will be able to conduct a serious search for evidence of past or present life.

By remaining on the surface, the crew will benefit from the planet's natural gravity (about one-third that of Earth) and will be protected by the Martian environment against most of the cosmic rays and all of the solar flares. Thus there will be no need for a quick return to Earth, a problem that plagues conventional Mars mission plans that envision living aboard an orbiting mother ship that sends down landing parties for brief jaunts.

Finally, the crew returns to Earth in the ERV. Meanwhile, a second crew is on its way to Mars. Thus every other year, two heavy-lift boosters are launched: one to carry a crew, the other to prepare a site for the next mission. As the missions progress, they leave behind a string of bases that open up ever broader stretches of territory. At an average launch rate of just one booster per year to pursue a continuing program of Mars exploration, this plan is clearly affordable. In effect, it removes the manned Mars mission from the realm of megafantasy and reduces it to a task whose difficulty is comparable to that faced in launching the Apollo missions to the moon.

But why do it? First, for the knowledge. We are now fairly certain that Mars once possessed oceans in which life could have developed. If we discover fossils on Mars or extant life surviving in subsurface water, it would be the most important discovery since Copernicus theorized that Earth revolves around the sun.

Second, for the challenge. People thrive on challenge and wither without it. The space program also needs a challenge. Between 1961 and 1973, with the impetus of the moon race, NASA produced a rate of technological innovation immeasurably greater than anything it has shown since, for an average budget that was only about 25 percent bigger than today's. It did so because it was reaching for a seemingly impossible goal. The Apollo program also strongly stimulated the U.S. economy and inspired a generation of schoolkids to pursue science and engineering. A humans-to-Mars program would do the same.

Third, for our future. Mars is not just a scientific curiosity. It is our New World. Someday, millions of people could live there. Today we have the opportunity to be the founders, the parents, and the shapers of a new and dynamic branch of the human family. It is a privilege we should embrace. ❑

[JUMPING THE QUEUE]

COULD CHINA GET TO MARS FIRST?

Maybe—if it ADOPTS A LESS TOP-DOWN APPROACH + + + *BY JAMES OBERG*

LAST SEPTEMBER, the People's Republic of China conducted its first three-person space mission—Shenzhou-7—featuring the country's inaugural space walk, taken by a taikonaut wearing a made-in-China space suit. Concurrently, its orbital mission to the moon, Chang'e-1, was sending back to Earth superb images of the lunar surface. Both were startling achievements by a relative newcomer to space.

Indeed, in the last decade, the Chinese have burst into manned and unmanned spaceflight. Michael Griffin, the former NASA administrator who drove the U.S. moon-then-Mars strategy, has opined that China could beat the United States back to the moon's surface—or at least be the first to put people back in lunar orbit—and do so within 10 years. Boris Chertok, the 97-year-old patriarch of Russia's space program, seems even more impressed with China's accomplishments, predicting last February that it will be the Chinese who first "people Mars."

Could that happen? Maybe. If China were to accelerate its rate of progress, it might succeed in sending teams of astronauts to Mars and other enticing destinations within two decades. But to do so it would have to depart from the top-down, by-the-book, party-line decision making that now prevails.

CHINA HAS BEEN RAPIDLY recapitulating what the Soviet and American space programs did in their early years, but with modernized systems that could soon be almost as good as—or perhaps as good as—the space hardware that the United States, Europe, and Russia will be deploying in the near future. China's plan to send a small satellite to Mars as part of Russia's Phobos-Grunt mission testifies to the scope of the country's ambitions.

Yet a white paper released by the Chinese government in 2000 reveals much about the country's approach to space. The document, still considered the official manual of long-term space planning, calls for hierarchical decision making, with "the state [guiding] the development of space activities through macro-control." Luan Enjie, director of China's State Aerospace Center, described the official approach as "concentrating superior forces to fight the tough battle and persisting in accomplishing something while putting some other things aside."

But that kind of rhetoric does *not* correspond to the spirit of the new China that's impressed the world in manufacturing, technology, sports, and nearly every other realm. And while the top-down approach may have worked adequately when the country was just copying earlier achievements by others, it will turn into an impediment as China tries to do things never done before.

READY TO GO: Taikonauts prepare for China's first three-person spaceflight.
PHOTO: JIUQUAN LAUNCH CENTER/COLOR CHINA PHOTO/AP PHOTO

In fact, China's progress in space to date has not quite matched public perceptions. Following a well-worn path, the Chinese have required just a single mission to accomplish each step, but they have needed more time—not less—than their predecessors to reach each new level. Both the United States and the Soviet Union went from their first orbital flight to multimanned flights and space walks in three to four years, but China took five. And while the two big competitors of the 1950s and 1960s got to orbital rendezvous in four to six years, the Chinese expect it to take them seven or eight. Pushing into the unknown, physically and technologically, could be asking for trouble if the space program is too narrow and decision making overly concentrated. "They are not building the science and technology infrastructure necessary for a broad program," comments Joan Johnson-Freese, head of the national security decision-making department at the U.S. Naval War College and an expert on China's space efforts.

But what Johnson-Freese sees as a deficiency, others see as an asset. "The program does not try to do everything. Instead it focuses on four or five key areas, which it does well," observes Irish space historian Brian Harvey, author of two books on the Chinese space program. "And its infrastructure of launch sites, mission-control centers, and tracking ships is so new it must make the neighboring Russians weep—that infrastructure will be good for 30 years.

"This is a program that thinks long term," Harvey adds. "The rocket was invented in China, after all, and their space program was formally founded in 1956, before Sputnik."

LOOKING TO THE FUTURE, China intends to pick up the pace. The next challenge to be tackled is space docking; for that, China will build an 8-metric-ton space station named Tiangong ("heavenly palace") to be launched in late 2010. Months later, an unmanned Shenzhou-8 is supposed to perform automated rendezvous and docking, followed by manned dockings and a brief occupation of the small space station.

Those flights will set the stage for construction and launch of a second space station two or three times as large as Tiangong. Meanwhile, the Chinese might visit the International Space Station, but they've made it clear they are not interested in being a junior partner in somebody else's project.

Building their bigger station will require a more powerful booster, called the Long March 5. Equivalent in size and power to the Ariane 5, Delta IV, or Ares I, it will hoist 25 000 kilograms, two and a half times as much as today's Long March rockets lift. Long March 5 will be able to carry heavy communications satellites and send spacecraft into Earth-escape trajectories.

ANOTHER STEP: Zhai Zhigang takes China's first space walk [top]. Mission controllers at Jiuquan Satellite Launch Center [bottom] watch the blastoff of the rocket carrying Zhai and his two fellow taikonauts.
PHOTOS: IMAGINECHINA (2)

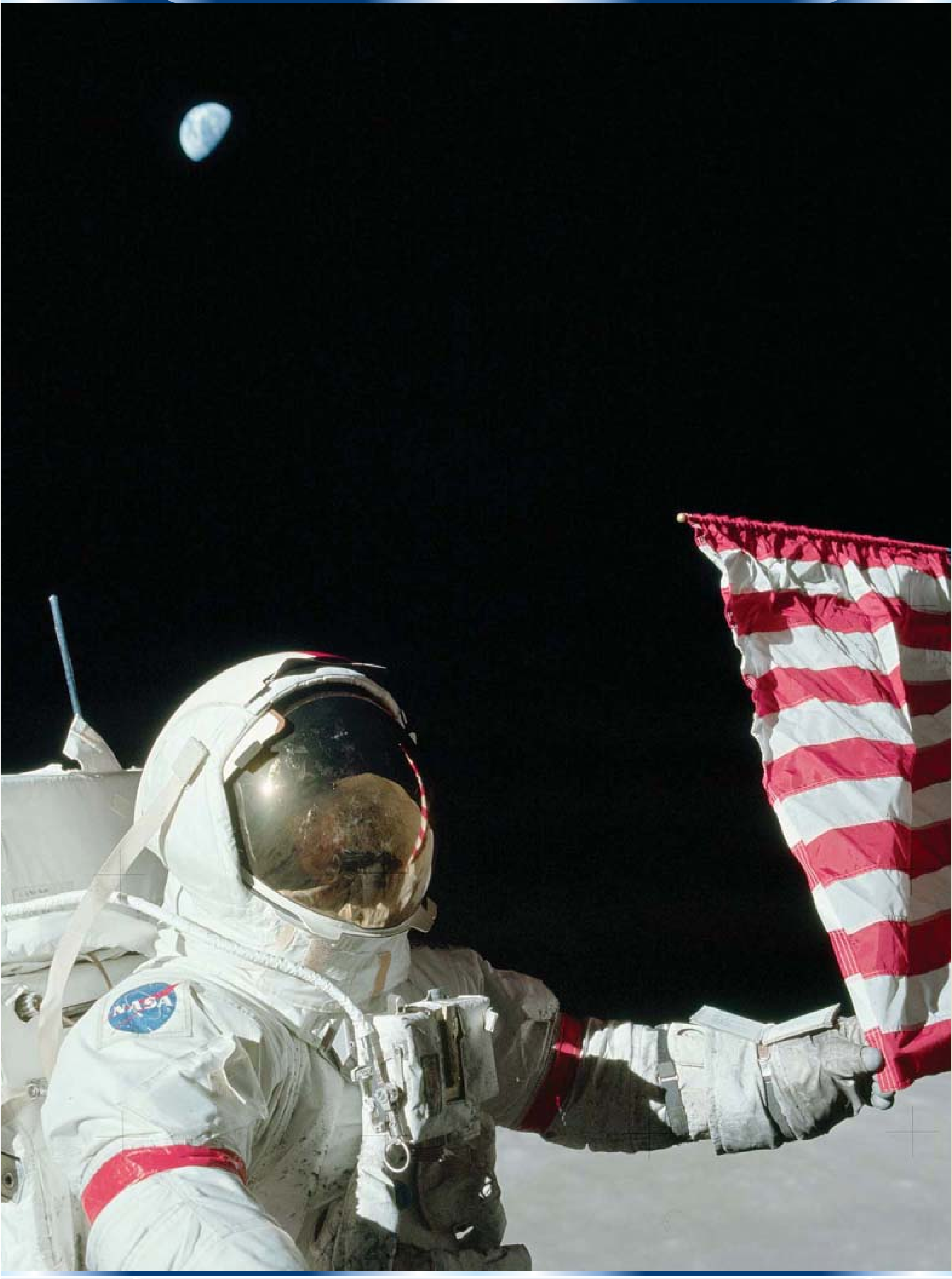
Ye Peijan, chief designer of the Chang'e-1 lunar probe, recently disclosed a schedule that calls for Chang'e-2 by 2011 (to test soft landing) and Chang'e-3 in 2013 (to land instruments on the lunar surface). Beginning in 2017, a new phase of lunar exploration will begin using heavier spacecraft launched by the Long March 5. These later vehicles will include rovers and sample-return craft.

So far, the Chinese have proven to be masters at adapting technology from other countries. The Russian Orlan-M space suit, for example, was the model for the Chinese-made suit used by its first spacewalker last year. But one design feature—an overhead window in the rigid-mounted helmet nicknamed the "moon roof"—was not required in the Chinese suit, so they simply omitted it.

Chinese space engineers have also seamlessly repurposed domestic designs taken from other industries. For the Chang'e-1 lunar orbiter, its builders adapted the design of a geosynchronous communications satellite and modified the launch profile of its booster. With mission-specific instrumentation, they achieved an impressive success on their first launch.

These kinds of tricks could provide China with shortcuts into deep space, enabling it to outcompete countries with deeper pockets and more experience. By the end of the next decade, space station Tiangong-2 could make an ideal habitat for long cruises in lunar orbit or to the Earth–moon Lagrangian points, where the two bodies' gravity fields are in equilibrium. Later, aboard a Shenzhou/Tiangong-class habitat, taikonauts could venture into interplanetary space to scout out the sun–Earth Lagrangian points, which could someday serve as jumping-off points for missions to Mars and other deep-space destinations. Several years ago, a panel led by NASA's former associate administrator for space science Wesley Huntress proposed that kind of step-by-step strategy for the United States, as an alternative to its moon-then-Mars program, which is named Constellation.

China's space engineers have learned quickly—not just from their own experiences but from other people's as well (a commendable trait that NASA would do well to copy). If they can overcome obsolete managerial attitudes, they could become even faster learners. The average age of the Chinese teams now at work is much lower than that of their American or European counterparts. That means the Chinese will be hitting their peak productive years in a decade or two, just as Mars comes into focus. ❑


NASA

{ JUST 384 000 KILOMETERS AWAY }

MOONSTRUCK

There's a palpable longing TO GO BACK. BUT DOES IT MAKE SENSE? + + + *BY WILLIAM SWEET*

IT'S AN IRRATIONAL THING, the pull of the moon. From time immemorial, the White Goddess has been held responsible for menstrual cycles, moods, and madness; she's the mythic governess of our dreams and emotions.

In 1969, Neil Armstrong's small step for man electrified people around the world, and in the United States it provided a momentary respite from social upheaval. Work done by Armstrong and his successors transformed our understanding of the moon, setting in motion research that continues to this day.

Of course, nobody pretends that the United States went to the moon mainly for science, and if people return to the moon now, it won't be all for science, either. In the 1960s, the point was to win a race with the Soviet Union. Today the supposed point is to use the moon as a stepping-stone to Mars.

Of the nearly 7 billion people on Earth today, four out of five were not alive when the first lunar landing took place. Without a doubt, a great many of them would love to see people back on the moon again. But does it make sense to spend the US $50 billion it might cost to get them there? Do we need a base on the moon to get to Mars? And if not, should we bother going to the moon at all?

PLAYING PERHAPS MORE TO OUR PASSIONS than our reason, in January 2004 President George W. Bush promulgated a program to return to the moon by 2020 and make it a staging area for a mission to Mars, perhaps two decades later. His father, President George H.W. Bush, had suggested essentially the same plan in 1989, but because of the enormous expense and conflicting U.S. commitments in space, it was dead on arrival. The second time around the vision fared better, eventually winning the endorsement—at least on paper—of all the world's space powers.

But you didn't have to scratch very hard to discover that such support was often only skin deep, even in the United States itself. Bush never actually mentioned his vision again, and the U.S. Congress promptly excised funding for the Mars part, instructing NASA to focus strictly on the moon. The effect was to radically disconnect the moon from Mars planning, even though going to Mars was supposedly the main rationale for returning to the moon.

Recognizing the vulnerability of the moon-Mars enterprise, Bush's NASA administrator, the hard-driving if abrasive Michael Griffin, made it his business to push ahead with the program so fast that ultimately it could not be

LAST HURRAH: In 1972 Apollo 17, the sixth and final manned mission to the moon, landed In the area pictured below. It was here that geologist Harrison H. Schmitt [opening page] showed the American flag.
PHOTOS: OPENING PAGE: NASA; BELOW: JAXA/NHK

reversed without incurring unacceptable economic and political costs. He may have succeeded. Even though he would fall out with President Barack Obama's transition team—informing team members bluntly that it was his job, not theirs, to "look under the hood" at NASA—by the time Griffin stepped down in January, development work on key moon-mission elements was far advanced. The feeling was that the plan would proceed, whether or not it really made sense.

The moon mission, dubbed Constellation, will use an Ares I rocket to transport crew and cargo as well as exploration and lunar-landing vehicles to low Earth orbit and eventually to the moon. The heavy-lift Ares V will take robotic machinery to the moon and perhaps beyond. The lifters derive conceptually from Wernher von Braun's Redstone and Saturn rockets, which put the first Americans into orbit and then onto the moon, and the design approach closely follows von Braun's trademark conservative philosophy.

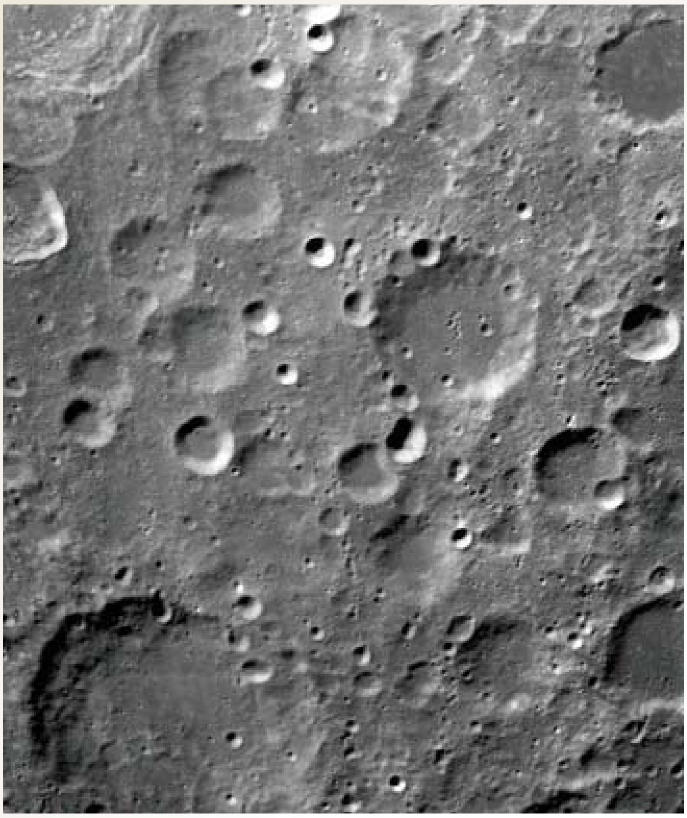
"We're capitalizing on the nation's prior investments in space technology wherever possible," Griffin said in a talk in January 2008. After decades of embarrassing delays and setbacks with the U.S. shuttle program and the International Space Station (ISS), Griffin wanted to be safe, not sorry.

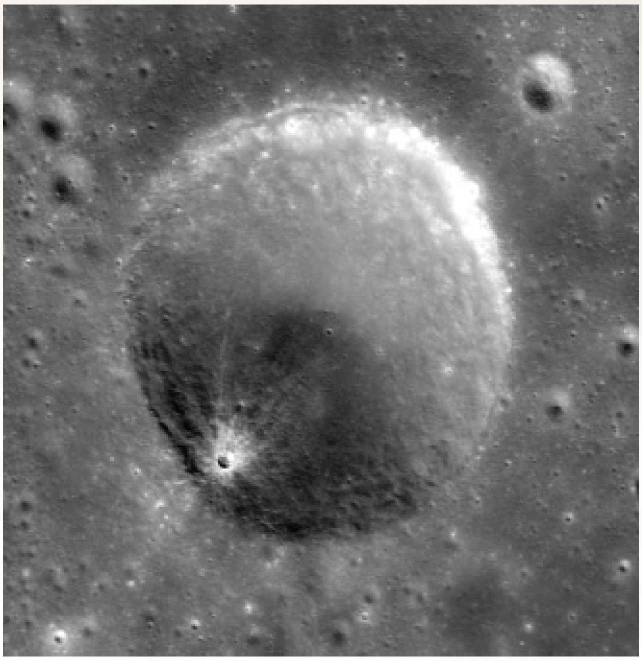
But stripped down and conservative as it was, the Constellation program was open to complaints that its most exciting elements—those pertaining to Mars—had been jettisoned and that the surviving elements were underfunded. "Each year since 2004," former astronaut Kathryn C. Thornton told the U.S. Congress last spring, "the NASA budget has fallen short of that required to achieve the mandated exploration goals and milestones."

A month before Thornton's testimony, a conference held in Tempe, Ariz., brought home how stultifying a redo of the Apollo program threatened to be. When aging Apollo engineers and astronauts were talking, the mood was electric: Participants were on the edge of their seats listening, for example, to accounts of how mission commanders had trained for lunar landings in an incredibly weird simulator designed by veterans of the X-15 suborbital jet program. But when the talk turned to subjects like the selection of landing sites for a new mission, avoiding dust and assuring visibility, and landing techniques, the feeling set in that young engineers were being asked to re-solve problems that had already been solved brilliantly with less sophisticated technology 40 years ago.

Griffin himself was highly sensitive to the dilemma. In his January 2008 talk, he conceded that one of the most common criticisms he heard about Constellation was that "it looks too much like Apollo." He was also touchy on the subject of the moon-Mars connection. Even as he took note of unequivocal congressional restrictions on Mars-oriented R&D, Griffin deemed it "not credible…that we will return to the moon and then start with a 'clean sheet of paper' to design a system for Mars." In a September 2007 talk, he specified that the Ares V launcher, with no more than half a dozen launches, would be able to lift the 500 metric tons (into low Earth or lunar orbit) considered necessary for a Mars mission. "By the 2020s, we will be well positioned to begin the Mars effort in earnest," he said.

Without knowing, however, what propulsion technology will actually take people to Mars [see "Rockets for the Red Planet," in this issue], how is it possible to specify how much mass we will need to loft? And how can we know whether or how the moon figures in a Mars staging operation? "If the ultimate goal is to organize a mission to Mars within the next several decades, then that goal needs to be clearly articulated now," concludes a report written late last year under the direction of





NEW CONTENDERS: China's Chang'e-1 orbiter captured an area of the moon [left] measuring 460 by 280 kilometers. The digital elevation model [right] was constructed from images delivered by India's Chandrayaan-1.

PHOTOS: LEFT: CHINA NATIONAL SPACE AGENCY; RIGHT: ISRO

David A. Mindell, a professor of engineering history at MIT. The report pointedly observes that the space architecture currently envisioned "for trips to the moon...is not extensible to missions to Mars."

DO WE NEED TO RETURN to the moon to get to Mars? Intuitively, it feels like the obvious way to go. In fact, it's not obvious at all.

Take propulsion dynamics. If we were to lift everything needed for a Mars mission first to the moon—above all, the propellant—that would mean having to take enough propellant to escape not only the gravitational field of Earth but also that of the moon. And although the moon's gravity is only a sixth that of Earth's, the penalty is not trivial. Payload-to-propellant ratios are poor in any chemically fueled deep-space mission and at the margin of what's tolerable in a Mars mission; tacking on gratuitous trips to the moon makes the ratio even worse.

Rocket scientists frame these questions in terms of delta-v, the change in velocity needed to transfer a space vehicle from one path to another. Leaving Earth is one delta-v; leaving low Earth orbit adds another. Going from that orbit to the moon needs a third, and getting from the moon to Mars requires a fourth. Add them up and you end up with a larger total than you'd get by just going directly to Mars or by mounting a Mars mission from, say, a Lagrangian point where the gravitational fields of the sun and Earth cancel.

Donald Rapp, the author of a useful textbook that lays out the enabling technologies needed for human Mars missions, has little use for the notion that the moon is a stepping-stone to the Red Planet. The moon is so much closer to Earth that there's an exponential difference between moon and Mars missions, he points out: "Saying we have to go to the moon to get to Mars is kind of like saying that in order to get to Europe from New York City, we need to go to Montauk Point on eastern Long Island first."

The one thing that could redeem the moon as a stepping-stone, Rapp and others argue, is if you could produce propellant on the moon to use in the rocket that went to Mars. But Rapp points out that the prospects for extracting oxygen on the moon are not promising. [For a radically opposing view, see http://spectrum.ieee.org/aerospace/space-flight/Mining-the-Moon.] One approach is to mine oxygen near the moon's equator from regolith, the fluffy, silicate-rich material that covers most of the lunar surface. But the silicates, which are about 30 or 40 percent oxygen, would have to be heated to 2600 °C, too hot for any known container. Or you could mine iron oxide from the regolith and then make water by reacting it with hydrogen carried from Earth, which can be done at 1200 °C. (Rapp would prefer to just ship oxygen from Earth in the first place.) Alternatively, it might be possible to extract hydrogen and oxygen from water at the poles, if such water exists and proves accessible. But even that would be no mean trick. At 40 kelvin, ice is very hard; processing it would be power intensive, and the work would have to be done in total darkness, in difficult, rocky terrain.

Taking all those considerations into account, Rapp concludes caustically that for Martian voyagers, at least, "the one thing we know for sure, it makes no sense to go back to the moon."

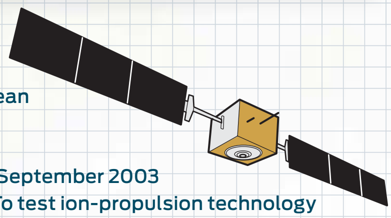
BUT EVEN IF THE MOON-MARS VISION makes no sense in terms of propulsion dynamics, a case can still be made for a lunar relanding. The moon may yet teach us things we'll need to know once we get to Mars. Learning how to mine, process, and store materials on the moon could be useful, even though the resources and procedures are somewhat different from those that would ultimately be used on Mars. Terrestrial help is just

IEEE Spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | qMags

{ BEYOND APOLLO }

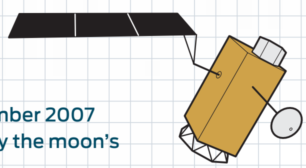
THE LATEST LUNAR LAUNCHES

Geopolitics still motivates MOON MISSIONS, BUT SCIENCE BENEFITS, TOO



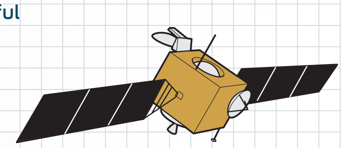
SMART-1

SPONSOR: European Space Agency
WHAT: Orbiter
WHEN: Launched September 2003
PRIMARY GOAL: To test ion-propulsion technology for future space missions.
OUTCOME: Successful



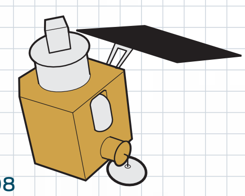
KAGUYA (SELENE)

SPONSOR: Japan
WHAT: Orbiter and two smaller satellites
WHEN: Launched September 2007
PRIMARY GOAL: To study the moon's origins and geology.
OUTCOME: Successful



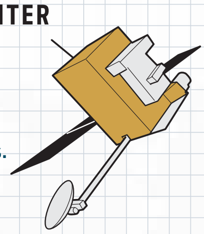
CHANG'E-1

SPONSOR: China
WHAT: Orbiter
WHEN: Launched October 2007
PRIMARY GOAL: To test technology and study the moon's environment.
OUTCOME: Successful



CHANDRAYAAN-1

SPONSOR: India
WHAT: Orbiter and impact probe
WHEN: Launched October 2008
PRIMARY GOAL: To test technology and collect data.
OUTCOME: Successful



LUNAR RECONNAISSANCE ORBITER

SPONSOR: United States
WHAT: Orbiter
WHEN: June 2009 or later
PRIMARY GOAL: To map the surface and identify landing sites.

FUTURE MISSIONS

2010: Japan's Selene 2. **2011:** China's Chang'e-2; the United States' Gravity Recovery and Interior Laboratory (GRAIL) and Lunar Atmosphere and Dust Environment Explorer (LADEE). **2012:** Russia's Luna Glob 1 and 2. **2012–13:** Germany's Lunar Exploration Orbiter; India's Chandrayaan-2.

three days away on the moon but at least six months away on Mars. In either case, you wouldn't be able to just go down the street to the corner hardware store whenever an unexpected problem arose. Both situations would demand the practicality and inventiveness of the true pioneer.

Some things might be much easier on the moon, of course, but sometimes the opposite will be true, because Mars resembles Earth more than the moon does in some ways. Take landing: It was devilishly difficult to anticipate the feel of putting down on the moon, where the gravitational tug is weak and there is virtually no atmosphere to provide lift and drag. (Armstrong, who had crashed a landing simulator on Earth, landed the Apollo vehicle on the moon much more actively than generally appreciated; to avoid unexpected boulders, he searched for a suitable site until the last possible second and almost ran out of gas.) The feel of landing a vehicle on Mars would be more familiar. And of course, many related aspects—having vehicles meet in orbit, descend, and reascend—could be practiced in lunar orbit for the Martian analogues.

But a strongly opposing school of thought sees little or no merit in such speculation. We could just as well practice orbital maneuvers in Earth's vicinity, the argument goes, and the conditions would be more Martian than those found near the moon. And if you want to see how small groups of people get along during long periods of isolation, there's no need to go to the moon; just go to the ISS, which after all cost tens of billions to build and has a projected lifetime cost of about $100 billion, according to the European Space Agency (ESA).

ARGUABLY, WE SHOULD EXPLOIT the station to the hilt, not only because it's up and running but also because it's an international collaboration. The United States will need all the help it can get to mount something as costly as a manned mission to Mars. Yet, strangely, it has given the station short shrift, most recently in its decision to stop shuttle flights next year. That will leave the station dependent on the aging Russian Soyuz spacecraft.

If you ask European astronautics experts about the U.S. vision, they tend to echo a refrain—that we should focus on testing technologies on the moon that someday will be relevant to Mars. But the more you ask about just what's on that list of technologies, the shorter it seems to get.

Britain's Surrey Satellite Technology has proposed a MoonLite mission, calling for swarms of artillery-like penetrators to be launched at the moon's surface from small orbiters; a similar kind of sensing could be done on Mars from dirigibles, suggests Sir Martin Sweeting, Surrey's founding chairman. Sweeting also talks about supporting lunar or Martian operations with orbit-to-surface telecommunications, a field in which the United Kingdom feels it has a comparative advantage. ESA, having just sent Europe's first cargo vessel successfully to the space station, now has issued a "request for information" to develop a cargo lander for a moon mission between 2017 and 2020, to complement NASA's human landing.

Europeans have not, however, proposed to contribute to any of the major elements of the moon return—the development of the big launchers, the crew exploration vehicle, or the astronaut lander—nor, say some, have they even been asked. Their preference for robotic exploration and their skepticism about the moon venture are obvious to all.

Even so, Europeans have been reluctant to come right out and reject a moon return. After all, they aren't paying for it, and

ILLUSTRATIONS: JASON LEE

what harm can it do to talk about going to Mars via the moon so long as somebody else is footing the bill?

Two years ago, the European space powers, plus Australia, Canada, China, India, Japan, Russia, South Korea, and Ukraine, joined with the United States in issuing a report that seemingly endorsed the U.S. space vision. Their global exploration strategy, released in May 2007, called the moon "our nearest and first goal" and Mars "also a prime target." Spelling out the lunar rationale, the report said that "to sustain human presence beyond Earth, we must learn from science 'on the moon' how to live and work on other celestial bodies." (Note the anomalous quotation marks, which are in the original.) The moon, said the report, "is the ideal place for humanity to develop the capability to journey to Mars and beyond." That's because the moon "has a strong place in the culture of many peoples and it instinctively appeals to the human imagination."

Fine words, but what do they mean? They certainly don't imply that any of those partner countries are getting ready to pump tens of billions of dollars into human exploration of the moon. On the contrary, the Europeans are deeply suspicious of any big international space venture. In the last such endeavor, the ISS, the Europeans were burned and burned badly by the severe delays that were mainly associated with problems in the U.S. shuttle program. Now they are having to contemplate the additional inconveniences connected with the early retirement of the shuttle.

At the 2008 International Astronautical Congress, in Glasgow, ESA Director General Jean-Jacques Dordain complained that by the time the ISS opened shop—more than a decade behind schedule—its original clients had lost interest and moved on. The payoff also came too late, he said, for the younger generation. For the future, therefore, "we have to define milestones that are challenging enough" to engage youth's interest and keep it engaged.

You don't have to think too hard to wonder whether a repeat mission to the moon can inspire the younger generation or whether the Mars prospect is just too distant to turn anybody on. Will a 15-year-old girl get excited about putting a man on Mars if it won't happen until she's in her 40s or 50s?

THE GLOBAL COMMITMENT to the moon-Mars vision may be thin and fragile, but that doesn't mean that interest in the moon itself is weak. In fact, her allure is greater than ever: All the world's aspiring space cavaliers want to visit her as soon as possible. China, India, Russia, and Japan all have major missions in the works. Flaunting national prowess is the name of the game.

In Europe, to be sure, lunar missions are not high on national agendas, although ESA did mount a very successful and innovative moon mission in 2003 powered by ion propulsion. Germany, which hopes to launch its Lunar Exploration Orbiter in 2012, is Europe's rule-proving exception. The country was barred after World War II from pursuing work on missiles. Yet European propulsion work is now centered at the Bremen quarters of EADS Astrium (a subsidiary of the European Aeronautic Defence and Space Company), not far from the Peenemünde test grounds, where von Braun and his hugely talented associates invented modern rocketry. Why is Germany so singularly interested in a moon mission? The question arose in conversation with a senior space manager at Thales Alenia Space, in Turin, Italy, which has built about half the ISS's habitable space. With a diffident shrug, he replied quietly, "Power."

The same logic guides China's space program, whose official 20-year goal is to "utilize space resources to...enhance overall national power."

All this is not to suggest that lunar science as such is without interest. On the contrary. Just this February, Japanese researchers reported that images sent back by their Kaguya (Selene) lunar orbiters indicate that the moon's crust is more rigid than Earth's and may therefore lack water and other compounds that easily evaporate. In January, researchers at MIT and at the Berkeley Geochronology Center, in California, published an analysis of an ancient lunar rock showing that the early moon must have had a metallic core and a magnetic dynamo. It was Apollo astronaut Harrison H. Schmitt, a Ph.D. geologist and later a U.S. senator, who picked up that little rock; by general consent, it is easily the most interesting thing anybody has ever found on the moon.

People used to regard the moon as a big hunk of dead, inert matter, but Apollo data proved that the early moon consisted of an "ocean magma." Evidently, the heat generated by the impact of some huge object with Earth was so great, it liquefied the material it hurled into orbit. And so, says David L. Schuster of the Berkeley Geochronology Center, "in what was probably a well-mixed molten mass, the denser materials might have cohered into a core."

A decade ago, Schuster and MIT's Ben Weiss looked at samples of the Martian atmosphere brought back by a spacecraft and found that its mixture of gases was exactly the same as that in certain peculiar meteorites found on Earth. Since then, researchers have found 31 more such "Martian" meteorites, dating in age from a few hundred million to 4.1 billion years. The scientists were astonished, recalls Schuster, at how much attention their findings got. Evidently, the public is more interested in planetary science than it generally gets credit for.

THE MOON HAS ALWAYS EXERCISED a profound hold on the human imagination. Surely, millions of people would love to see a return to the moon and perhaps even the establishment of a permanent colony there. What difference does it make, then, whether it makes sense to go back to the moon? If we want to go there, let's just go!

The lunar enterprise, however, is meant in some sense to be a template for the much bigger mission to Mars. Why, then, is the moon mission almost strictly made in the U.S.A.? This isn't the Cold War; the United States doesn't have to go to the moon to win a missile race with the USSR. Yet the U.S. government is proposing to shoulder pretty much the whole cost of returning to the moon, not to mention Mars, which it can't actually afford. Italy's space commissioner, Enrico Saggese, speaking to reporters last fall in Glasgow, estimated the cost of returning to the moon at $50 billion and of going to Mars at $500 billion—a lot to spend during a stubborn world recession.

The diplomatic impediments to globalization of the moon mission are not trivial, to be sure. The Europeans are in a slow-burning rage over the ISS. Though Russia's space experts are highly respected, their national space agency is a skeleton, and nobody trusts their government. China, Germany, India, Japan—they'd all much prefer to strut their stuff in national showcase missions, not join as junior partners in a big, complicated international effort.

If only the problems were mainly technical. But they're not. Returning to the moon is not all that technically challenging. What's challenging is to make it an international effort that puts behind past grievances and sets the stage for a truly challenging international mission to Mars. ❑

spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

{ RACE TO THE MOON }

IT'S ONLY ROCKET SCIENCE

For the Carnegie Mellon team VYING FOR THE GOOGLE LUNAR X PRIZE, FAILURE TO LAUNCH—AND LAND—IS NOT AN OPTION + + + *BY PRACHI PATEL*

THE ROVER HAS GONE BLIND. It had been running all night, its two mast-mounted cameras capturing high-resolution stereo images of its surroundings. Now it's sitting idly in the middle of the room. Fixing the thing is not how Ross Finman had planned to start his day at the lab.

Finman, a 19-year-old undergraduate wearing wrinkled black trousers and an old brown leather jacket, uses a laptop to log on wirelessly to the rover's computer. "That's weird," he says, and tries to restart the cameras. Still no go. Definitely not a good day.

"Who touched it?" he says.

"I did," a student nearby shouts back. "That's why it *shouldn't* be broken."

Finman summons Michael Furlong, a grad student and the camera wizard around here. Furlong pulls up a diagnostics screen on the laptop. Some log files had grown excessively large, eating up CPU cycles. He deletes the files and reboots the computer. Seconds later, the rover can see again.

"Mike is the man," Finman says, grinning at Furlong, who doesn't take his eyes off the screen.

It's just another day at the Field Robotics Center, part of Carnegie Mellon University's Robotics Institute, in Pittsburgh. Led by renowned roboticist William "Red" Whittaker, the center has built robots for exploring ice fields, deserts, volcanoes, and coal mines. Now his team is designing a robot to go somewhere else entirely—a crater-scarred rock 380 000 kilometers from here. The moon.

Whittaker's Astrobotic team is one of the competitors vying for the Google Lunar X Prize. The challenge, announced by Google and the X Prize Foundation in September 2007, will give US $20 million to the first privately funded team whose robot lands on the moon, travels 500 meters, and beams back photos and video. It all has to happen by 2012.

Hours after the announcement, Whittaker sent in the $10 000 registration fee. Within weeks he had mobilized some 60 researchers and students to develop the rover and also a lander to gently deposit it on lunar soil. He set up a company, Astrobotic Technology, to find ways of funding the project, which may cost much more than the prize. And he recruited two strategic partners: The University of Arizona's Lunar and Planetary Laboratory, in Tucson, which brings imaging and mission-planning

ALL PHOTOGRAPHS: BILL CRAMER/WONDERFUL MACHINE

READYING THE ROVER: Preceding page: Astrobotic team members [from left] Nisarg Kothari, James Lee, Ross Finman [in foreground], Ethan Minogue, and Charlie Munoz gather for a test run of the Red Rover. This page, clockwise from top left: Munoz and Minogue remove the main cover to inspect the rover's electronics; Mike Furlong develops software to control the cameras and convert their images into three-dimensional maps; the current rover prototype uses mostly off-the-shelf hardware, which will later be upgraded to space-rated components; Erika Bannon, in charge of the rover's thermal design, holds a cold plate used in heat-dissipation tests; Finman operates the rover's wheels and cameras using a control interface on a laptop. Opposite page: The rover's mobility is put to the test.

IEEE Spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | qMags

expertise, and defense contractor Raytheon, which brings the precision-landing technology.

There were 17 teams officially registered in the competition when this article went to press. But talk to Astrobotic team members and you get the feeling that there are no other contenders. Their plan is not only to be first; they intend to beat the X Prize deadline by more than a year. Their shot at the moon is scheduled for December 2010. It's a feat they hope to pull off, as Whittaker puts it, "without raising a heartbeat."

IN A WEEKLY MEETING with two dozen students, Whittaker, a former U.S. Marine with a charismatic and intimidating style, makes it clear that he expects utter commitment from everyone, no excuses, "be it love or dirty laundry."

"Remember," he says, "this is a team, not a democracy."

The students listen in silence and appear to experience a mix of awe and fear. They know they'll have to work hard to live up to their master's expectations. But they seem content to be a part of what promises to be a successful effort: If anyone can put a robot on the moon, that person is Red Whittaker.

To see how the project is materializing, head for the High Bay, a hangar-like laboratory where the Red Rover, as it's known, is taking shape. Bleary-eyed students hunch over handbooks on aerospace engineering and toy with computer simulations. You can sense the urgency in the air—it's not just the smell of pizza brought in during the long days of work. Team members are so immersed in their tasks that they don't even flinch when a stranger with a microphone stands next to them, peering at their computer screens.

"I pretty much live here," says Finman, who leads the rover's field tests. That an undergraduate was put in charge of such a critical task is no surprise when it comes to Whittaker's projects. The energetic Finman, a rocket enthusiast since childhood and also an avid skydiver, is just the type of student Whittaker seeks.

On a typical day at the High Bay, Red's recruits work on a host of jobs dealing with mechanical structures, electronic modules, control systems, vision, and avionics. The plan is to go through several design iterations, building prototypes, evaluating them, and making improvements until the final rover emerges.

The current version looks like a small pyramid plastered with solar cells. It has four metal-mesh wheels with a suspension system that has no axles or springs, ideal for climbing over large obstacles. Atop the chassis, a short mast holds a pan-tilt head with two cameras.

This design, the second iteration, uses off-the-shelf hardware. The team plans to build a third version, with enhancements, and then a fourth and final version, which will be upgraded with space-rated components. That means the fat power cord that now trails the rover will be replaced by high-efficiency solar cells and packs of lithium-ion-phosphate batteries. The current PC-based control system will give way to a $2 million radiation-hardened RAD750 computer by BAE Systems.

The rover is controlled remotely, so it doesn't need sophisticated self-driving systems or lots of sensors. What it needs is to be small and light, because sending things into space is expensive. It also has to be reliable and resilient enough to withstand harsh conditions that include 9 *g*'s of acceleration and heavy showers of cosmic rays. Scurrying around on the moon, it will experience extreme heat, with temperatures reaching 120 °C at noon.

Making sure the rover doesn't have a meltdown—literally—is Erika Bannon's department. Sitting at her computer, headphones on, she balances a phonebook-thick tome—*Radiative Heat Transfer*—on her lap. The moon has no atmosphere, so dissipating heat is a big challenge. "Air makes everything easier," she says. "You put on a fan and it's good."

Bannon explains that the rover will use radiators to emanate infrared energy into space to cool its computers. Carbon plates with high heat conductivity will prevent solar cells from overheating, which would cause a drop in voltage.

The thermal design is only one piece in a complex system of systems. A lot remains to be done. But the Astrobotic team members—perhaps infused with a good dose of Red-high readiness—seem to know exactly how to proceed.

"'Keep it simple, stupid' is the motto around here," a student tells a colleague as they evaluate three-dimensional models of rover components on a computer.

"Yeah!" the other pipes up. "It's only rocket science."

OF COURSE, before the Red Rover can leave its tread marks on the lunar soil, it has to get there. Astrobotic's plan is to buy space on a commercial satellite-launching rocket for its payload—the rover and the lander. The lander will use retro-rockets to decelerate and guide its descent.

This is where Raytheon comes in. The craft's landing system is based on missile technologies in the company's arsenal. One is a propulsion system that guides missiles to intercept enemy aircraft. The other is a navigation technology used on cruise missiles. The landing system will kick in just 60 seconds before touchdown, continuously taking images of the lunar surface, comparing them with a reference map, and propelling the lander toward the exact target point.

Team members are now piecing the parts together into a mission plan, which calls for landing a few kilometers from the Apollo 11 site. The researchers will have two weeks to explore the area and send back images. After that, the sun will set and temperatures will plunge to –170 °C, at which point electronic components will rip apart, and the rover will die quietly in the vastness of the Sea of Tranquility.

Back at the High Bay, Finman is checking the rover's computers and cameras for a new round of field tests. He toggles buttons on a control panel. Motors whir and the cameras tilt up and down. They turn to the left, smoothly at first, then with a quick jerk, and then smoothly again before they stop. A gear tooth is broken.

Finman says there's no need to fix it. A new rover prototype is already taking shape on a nearby worktable. He's confident it will soon evolve into the hardy little robot that will get to the moon and send back beautiful pictures. It will all come together in the end. It's only rocket science. ❑

spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

{ FIRST PERSON }

INDIA JOINS LEAGUE OF LUNAR NATIONS

G. Madhavan Nair, HEAD OF THE INDIAN SPACE AGENCY, TALKS ABOUT HIS COUNTRY'S FIRST ROBOTIC LUNAR MISSION AND PLANS FOR LANDING AN INDIAN ON THE MOON AND MARS + + +

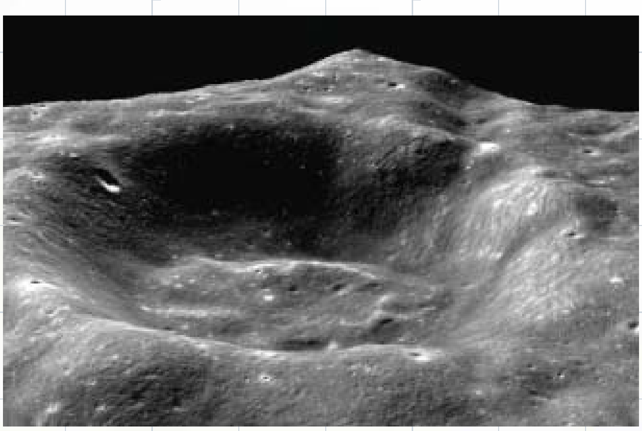
LAST NOVEMBER, INDIA REACHED THE MOON, the fifth country to do so after the United States, Russia, Japan, and China. Its Chandrayaan-1 spacecraft went into a polar orbit 100 kilometers above the lunar surface early in the month; a week later it sent a probe to the surface, the probe snapping pictures and spectroscopically analyzing the superthin lunar atmosphere. It disintegrated on impact, but not before accomplishing its final task: depositing an Indian flag.

Incorporating scientific instruments from NASA, the European Space Agency, and the government of Bulgaria, the US $100 million Chandrayaan mission is helping scientists better understand the moon's topography and the distribution of chemicals and minerals on its surface. The orbiter's camera, which can resolve surface objects 5 meters across, has sent back thousands of stunning images. One of the mission's chief goals is to search for water. Moon bases would need it to keep people alive and to manufacture propellant for missions to Mars and elsewhere.

No one relished the Indian triumph more than G. Madhavan Nair, the head of the country's national space agency, the Indian Space Research Organization (ISRO), based in Bangalore. Not only had the 66-year old electrical engineer chaperoned the mission, he had earlier led the effort to build the Polar Satellite Launch Vehicle (PSLV), a version of which propelled the Chandrayaan-1 on its voyage as the first Indian craft to escape Earth's gravity. During his 42-year career at the ISRO he has tackled such diverse challenges as completing India's liquid-hydrogen and -oxygen rocket engine and setting up rural offices that let farmers get up-to-date information from weather and Earth-sensing satellites.

With a workforce of 16 000, the ISRO is among a handful of space agencies in the world capable of designing, building, and launching its own satellites. Besides the PSLV, it also operates the Geosynchronous Satellite Launch Vehicle (GSLV). The ISRO's 2008 budget of $1 billion was not quite one-seventeenth of NASA's, yet the Indian agency operates the largest constellation of civilian remote-sensing satellites in the world, with eight orbiters, including a few capable of mapping to a resolution of less than 1 meter. In January 2007, the ISRO safely brought back an orbiting satellite as part of an effort to understand reentry technology—an essential step for undertaking human spaceflight.

Nair usually works 11 hours a day, seven days a week, but he found time on a recent balmy Saturday afternoon in Bangalore to sit down with technology and science journalist **PALLAVA BAGLA.** Nair described his dream of launching an Indian into orbit on an Indian rocket within the next six years, as well as his plans for missions to the moon and Mars.



FAR SIDE: The Coulomb C crater is captured in a stereoscopic image by the Terrain Mapping Camera on board India's Chandrayaan-1 lunar probe.

TOP: JACOB THOMAS; BOTTOM: INDIAN SPACE RESEARCH ORGANIZATION

Q: CHANDRAYAAN-1 IS NOW IN ORBIT AROUND THE MOON. ARE YOU HAPPY WITH THE ENGINEERING PART OF THE MISSION?

A: That we were able to place the Indian flag on the surface of the moon at the designated place with a timing accuracy of some 20 seconds—this is, I would say, one of the most precise orbits anybody would have got in the first mission. Every instrument is working very well, and the scientists have started looking at the data that has come out of it.

Q: HAVE YOU DETECTED ANY WATER ICE YET?

A: No, none at all. Chandrayaan-1 is a polar mission, and in its two-year mission it will conduct the most intense search for water ice in the deep craters that pockmark the north and south poles of the moon.

Q: WHAT ARE YOUR PLANS FOR CHANDRAYAAN-2?

A: Once we know the type of features, the type of mineral deposits, one would like to go to the surface. So what we are planning is a lander and a rover which will go around and pick up samples, analyze in situ, and send back the data. Chandrayaan-2 is slated for the 2012 to 2013 time frame. It would cost 4800 million or so rupees [US $96 million]. We will have cooperation from the Russian space agency because they have got lunar landing and rover technology.

Q: YOU SEEM TO HAVE A FULL PLATE.

A: Yeah, the moon, Mars, and beyond are all on ISRO's horizon. Maybe, if everything goes all right, maybe we could establish a presence on the moon in 2020 and a manned mission to Mars between 2030 and 2040.

Q: "IN 2020" MEANING AN INDIAN ON THE MOON?

A: I will not comment on that, but yes, we have such dreams.

Q: BEFORE GOING TO THE MOON, YOU WOULD HAVE TO PUT INDIANS IN ORBIT AROUND EARTH. CAN YOU ELABORATE?

A: We have prepared a project report which envisages the development of a capsule which can carry two to three passengers on board the GSLV. We plan to be in space for about a week or so.

Q: WHICH INDIAN ROCKET COULD YOU USE FOR A MANNED MISSION?

A: The GSLV Mark II and Mark III. Mark II can take just two passengers, but Mark III will be more comfortable when we want to carry three. By about 2015, we should have such a capability.

Q: SO CAN YOU HOPE TO PUT AN INDIAN INTO SPACE, USING AN INDIAN ROCKET LAUNCHED FROM INDIAN SOIL, IN 2015?

A: Yes. It will cost money, about 120 000 million rupees [$2.4 billion]. If we are able to spend that kind of money, yes, it is possible. This is nothing compared to the overall expenditure that we are making in the science and technology area, and it not only gives you that additional technology capability, but also it opens up a vast avenue of research related to the human body, human psychology. And the technology spin-offs could also be of tremendous value. So 120 000 million rupees over the next six years is peanuts.

Q: ARE YOU PLANNING TO HAVE ANY COLLABORATION WITH THE AMERICANS?

A: NASA had suggested training astronauts in their facility. We asked specifically, could they take these trained Indian astronauts in their space shuttle? But unfortunately, there is no slot available in the space shuttle [which is being decommissioned in 2010]. So because of this we didn't pursue the topic. But the first priority is to evolve a highly reliable launch system. We must develop access to space ourselves because rocket technologies are highly guarded. Beyond that, there can always be collaboration in space exploration like there is in Chandrayaan-1.

Q: YOU ALSO HAVE PLANS FOR REACHING MARS.

A: Technically, we have the capability to go there. Our GSLV Mark II can carry a spacecraft similar to a Chandrayaan-1 to a Mars orbit. But we don't want to do such a sophisticated mission just to repeat what others have done. If everything goes all right, by about 2013 to 2015 we should be able to attempt a Mars mission.

Q: HOW MUCH WOULD IT COST TO GO TO MARS?

A: It could be about 6000 million to 7000 million rupees [$120 million to $140 million] for an unmanned mission. But more than the money, what is important is getting the right kind of scientific groups [to work on Mars], of which there is a dearth [in India] today.

Q: SHOULD HUMANS GO TO MARS?

A: Well, if one wants to establish a colony, Mars could be more amenable than the moon. The NASA missions have spotted ice, and also there is an atmosphere, though it is a hostile atmosphere. Perhaps we can derive livable conditions from those components. A small portion of our budget is set aside for such advanced missions [*Editor's note: It is 16 percent*]. In the long run I think if you want to maintain a leadership position in space, such sophisticated missions will become important.

Q: WHAT NEW TECHNOLOGIES WILL YOU NEED?

A: For interplanetary travel, nuclear propulsion may become essential. But there are a lot of hazards associated with handling nuclear fuel and technologies. Maybe the intermediate solution could be ion propulsion with solar energy.

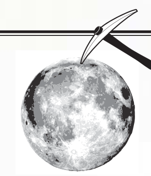
Q: DO YOU THINK HUMANS WILL BE ABLE TO ENDURE THE FLIGHT TO MARS?

A: New findings have always come because of an adventurous approach to facing such challenges. I think human beings are endowed with such a capability. The long duration of travel in space, that becomes really complex. First of all, without gravity the human body behaves in an entirely different manner, and so we must learn how to compensate for it and how to make sure that no disintegration or damage happens.

Q: ATROPHY OF THE MUSCLES…

A: All those muscles, bones, and even the blood flow, you know, all these things become question marks. Then comes the radiation, sustained radiation for long duration. A lot needs to be done. It won't be an easy job. ❑

{ EXPLORE MORE ONLINE }



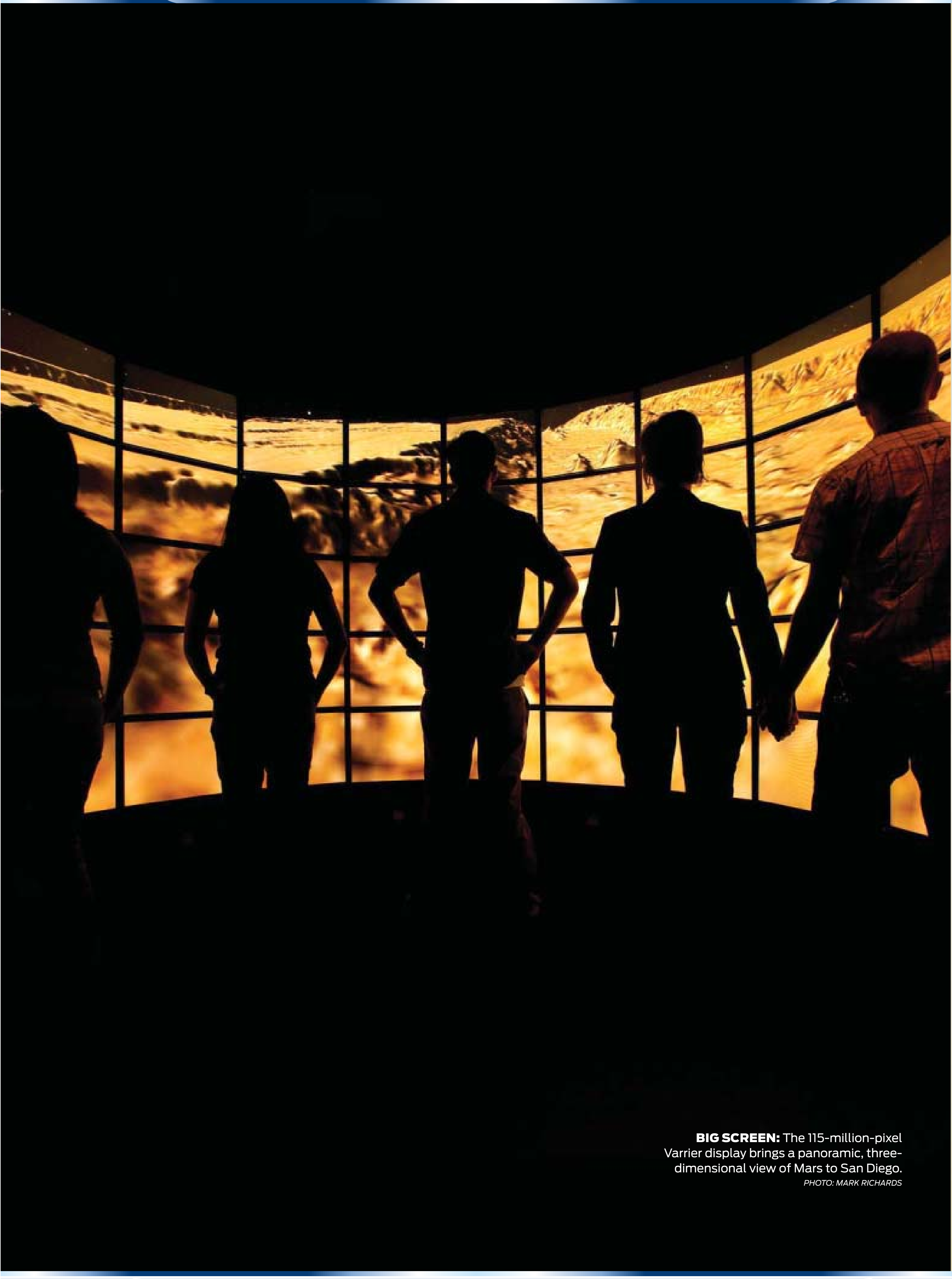
MINING THE MOON

Explorer/engineer Bill Stone ON HOW LUNAR HYDROGEN COULD FUEL SPACE EXPLORATION

"Planetary geologists have posited that the moon's polar craters may hold perhaps billions of metric tons of hydrogen or even water ice. Discovering rich concentrations of hydrogen or ice would open up a universe of possibilities—literally. Rocket fuels and consumables that now must be launched from Earth at great cost could instead be produced on the moon and sold at lunar and low Earth orbit 'service stations.' That in turn would spur new ventures, including space-power beaming, space tourism, space-debris cleanup, and interplanetary voyages. For the first time, access to space would be truly economical…"

ONLY AT HTTP://SPECTRUM.IEEE.ORG/AEROSPACE/SPACE-FLIGHT/MINING-THE-MOON

IEEE Spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | qMags



BIG SCREEN: The 115-million-pixel Varrier display brings a panoramic, three-dimensional view of Mars to San Diego.
PHOTO: MARK RICHARDS

PART I: CHALLENGES
PART II: VOYAGE
PART III: STRATEGY
PART IV: EXPLORATION

{ SPACE 2.0 }

MARS FOR THE REST OF US

Better cameras, greater bandwidth, and bigger displays PUT MARS WITHIN REACH OF ARMCHAIR EXPLORERS + + + *BY JOSHUA J. ROMERO*

I SLOWLY SCAN THE NEARBY ROCKS AND CRAGS, letting my gaze drift up toward the horizon. My eyes are searching for a recognizable shape—anything that's not a rock—to give me a sense of scale. I come up empty.

Mars is all around me, here in the StarCAVE, a virtual reality enclosure at the University of California, San Diego. Five projectors transform a room the size of a walk-in closet into a 360-degree panorama of the view from the basin of the large Gusev Crater.

For the near future at least, only robots will touch Martian soil. But even after the rusty surface becomes a trampled mess of human boot prints, we—you and I—probably won't qualify for the trip. So even if "mankind" one day reaches the Red Planet, most of us are destined, at best, to experience its exploration secondhand.

The good news is that such secondhand participation is likely to be a lot better than it is today. Improved communications, imaging, and visualization technologies will allow NASA to bring much of the experience of being on Mars back to those of us stuck on Earth.

To obtain this one view, for instance, the Mars rover Spirit parked on a small hill near the Home Plate plateau and began snapping a few pictures a day as it waited out the Martian winter in 2006. Over the next four months, it gathered more than 1400 images, which NASA digitally stitched together into a single 130-megapixel panorama. Standing in the middle of it is so immersive that I immediately feel the urge to explore the scene, to peer around rocks and see what's behind them.

"You can go into a room, and you're on Mars," says Larry Smarr, director of the California Institute for Telecommunications and Information Technology, or Calit2, which runs the StarCAVE. The idea of re-creating Mars here sounds appealing, but it is not just fantasy—only by maximizing what can be done from the ground can NASA make Mars exploration politically sustainable and financially worthwhile.

From their inception, U.S. and Soviet space agencies recognized the value in connecting with the public directly. When Sputnik became the first artificial satellite, in 1957, it carried a radio transmitter instead of a scientific payload. If you had a shortwave radio, you could hear the beeps from the craft as it passed overhead, proving beyond all doubt that the Soviet Union had conquered space. The Apollo 11 moon landing had similar public-relations value. It would have been considered a great engineering feat in any case, but the event became a shared global experience when its live video broadcast brought the lunar surface into living rooms around the world.

Since winning the space race, however, NASA has abandoned such showmanship in favor of more rational, pragmatic, and scientific pursuits: remotely exploring the solar system and learning how to live in orbit. The unfortunate side effect is that the public's engagement with the space program has waned, even if inherent interest in space hasn't. The draw of Mars, in particular, goes back centuries, and every time a new technology has provided better access to the most Earth-like planet in the solar system, the public has embraced it.

Take the Pathfinder mission, which carried the first rover to Mars in 1997. Individual shots from the lander didn't look much better than the photos the Viking missions had gathered two decades earlier. But this time there was one big difference: the emergence of the World Wide Web. NASA put the Pathfinder photos online as soon as they came back from Mars, sparking an Internet sensation. The images attracted 47 million hits in a single day, one of the biggest 24-hour bursts of traffic in the history of the Internet to that point.

We're now on the cusp of another revolution in Mars exploration, where public outreach and scientific investigation will go hand in hand. Increasingly sophisticated imaging systems will allow robots to transmit not just individual photos but also enough data to create huge panoramas and virtual environments for anyone to explore. The sheer amount of information will require and reward more human scrutiny than professionals alone can provide. NASA is also learning, if a bit haphazardly, how to leverage Web 2.0 technologies to make missions interactive. Directly connecting with constituents in this way will be no easy task, but it's NASA's best opportunity to create a sustainable future for the space program.

THE TWO VIKING MISSIONS, in the 1970s, were a great success, providing more than 50 000 images of Mars, including the earliest photos from the surface. But the most powerful imagers, the twin cameras on each Viking orbiter, had a resolution that was no better than what you'd find on a cellphone camera today. Compare that with the Mars Reconnaissance Orbiter (MRO), which has been circling the planet since 2006. Among its science instruments is the High-Resolution Imaging Science Experiment (HiRISE), a camera capable of taking 1200-megapixel black-and-white images and resolving features as small as a meter in size (including the tracks left by the rovers).

MRO sends the images to Earth via the fastest connection in deep space, capable of transmitting nearly 6 megabits per second. It has already sent back 80 terabits of data, more than all the other deep-space missions combined. After it's finished collecting data, MRO is slated to remain in orbit to serve as a high-speed communications link for future missions.

Once Mars pictures make it to Earth, however, NASA faces an enviable problem: The resolution of the stitched-together panoramas is so great that agency scientists have no way to view them with conventional monitors. At Calit2 the institute has another display called Varrier, around the corner from the StarCAVE. It consists of 60 liquid-crystal displays arranged in a half-cylinder with a total of 115 million pixels. A photographic-film screen affixed to a glass panel is mounted in front of each LCD and, combined with a head-tracking system, provides stereoscopic three-dimensional images without the need for special glasses. "When you map a panorama into this," Smarr says, "you see the global structure of this place but also the fine details."

Starting with a view of the whole planet, I use a wireless handheld controller to zoom in and swoop down inside Valles Marineris, a vast chasm that puts the Grand Canyon to shame. I can sense the depths of the canyon from the steep walls at the periphery of my vision. In February, Calit2 and the NASA Lunar Science Institute set up a smaller three-by-three grid of screens—which they call an OptIPortal—giving NASA its first 40-million-pixel display. It may be small compared to the Varrier, but it's a huge improvement over any other NASA screen. The agency is interested in building more.

But NASA is not alone in noticing the potential of the new technologies. The U.S. Congress also seems to have some sense of how these technologies might benefit the people who, after all, pay the space program's bills. In the 2008 NASA Authorization Act, the House of Representatives stipulated that the agency "develop a technology plan to enable dissemination of information to the public to allow the public to experience missions to the moon, Mars, or other bodies within our solar system by leveraging advanced exploration technologies."

"There are people who view projects as having a scientific part and an outreach part. To me, the boundary is artificial and not particularly useful," says Michael Sims, an intelligent-systems scientist at NASA's Ames Research Center, in Mountain View, Calif. Sims helped develop the Mars rover that captured the images projected in the StarCAVE. The seamless vistas came courtesy of the Pancam, a robotic pan-and-tilt camera system created in a collaboration between Ames, Carnegie Mellon University, and Google. (The team created a commercial spin-off of the technology, called GigaPan, in 2008.)

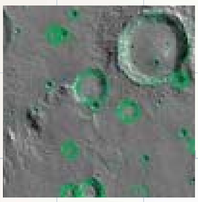
As he talks, Sims sits in front of his computer, manipulating a photo that looks like the mouth of a cave. It's actually a GigaPan image of a lava tube in New Mexico. He begins zooming in—and in and in—and within a second, the picture has gone from one that shows the tube opening and its desert surroundings to one that fills the monitor

[HELP WANTED]

MAKE YOUR MARK

There are plenty OF WAYS TO PARTICIPATE IN EXPLORATION. HERE ARE OUR FAVORITES, PAST AND PRESENT

NOT ALL participatory experiments go as planned. In an online contest, fans of Comedy Central's "The Colbert Report" overwhelmingly voted for "Colbert" as the name of a new module on the International Space Station. Instead of bowing to the public, NASA chose the name "Tranquility" instead. As a consolation, however, the agency renamed a piece of fitness equipment: the Combined Operational Load Bearing External Resistance Treadmill, or COLBERT. The projects here have a bit more substance.



CLICKWORKERS

WHAT IT IS: *Data analysis.* Look at snippets of HiRISE images from Mars and identify gullies, dust-devil tracks, lava flows, and more.

WHY DO IT: The features are much smaller than what NASA scientists tend to look at—which means a greater chance to find something cool.

SKILLS REQUIRED: None—example images show you how to identify objects.

PARTICIPANTS: 80 000

GALAXY ZOO

WHAT IT IS: *Data analysis.* Classify distant galaxies from the Sloan Digital Sky Survey.

WHY DO IT: The galaxy photos are stunning, and an active community makes it easy to share great finds, like merging galaxies.

SKILLS REQUIRED: None—a training session teaches anyone how to do it.

PARTICIPANTS: 82 000

STARDUST @HOME

WHAT IT IS: *Data analysis.* Use a virtual microscope to look for tracks of interstellar dust in slices of aerogel.

WHY DO IT: There's a scoring system and a chance to be listed as a coauthor on a scientific paper.

SKILLS REQUIRED: Good eyesight, patience.

PARTICIPANTS: 26 000

TEAM FREDNET

WHAT IT IS: *Robotics.* Open-source team competing for Google Lunar X Prize.

WHY DO IT: It's the only open-source team vying to win the US $30 million prize for a robotic moon mission.

SKILLS REQUIRED: Communications, hardware, imaging, propulsion, or software expertise.

PARTICIPANTS: 524 forum users

OPEN LUNA FOUNDATION

WHAT IT IS: *Robotics.* Group aiming to return mankind to the moon through private enterprise.

WHY DO IT: There's something for everyone. Long-term goal is to send humans to the moon without NASA.

SKILLS REQUIRED: Any—especially those of webmasters, writers, lawyers, engineers, and business managers.

PARTICIPANTS: A handful so far

COSMOSCODE

WHAT IT IS: *Programming.* Open-source projects to replace space and astronautics code, which normally costs millions of dollars for development and testing.

WHY DO IT: The resulting code is free to NASA, the public, and private companies.

SKILLS REQUIRED: Programming, aerospace expertise.

PARTICIPANTS: Presently limited to NASA alpha testers

with the details of a single rock. "Everyone is not going to go into caves [even] where we have wonderful caving," says Sims. "But there's no reason why we can't all experience that."

PROBING MARTIAN IMAGES, however, can be an enormous job. "If I showed each HiRISE image for 10 seconds, it would take me about four years to show them all," says Alfred McEwen, the instrument's principal investigator. There's simply too much data for the agency to handle by hand, and computers are notoriously bad at image analysis. NASA scientists will need assistance from the public, and some of them have already begun experimenting with crowd sourcing to help process large amounts of image data.

Through NASA's Clickworkers program, users look at tiny slices of HiRISE images and mark off features such as channels, gullies, dust-devil tracks, boulder fields, and lava flows. This helps NASA scientists identify interesting features that they would otherwise miss in unexpected places. Users can also examine older photos from the Mars Orbiter Camera (MOC), which flew on the Mars Global Surveyor from 1997 to 2006, and even suggest targets for HiRISE to reimage.

Taking a closer look at old images can certainly pay off: When NASA scientists compared MOC images of the same crater taken in 1999 and 2005, they found a new gully deposit, the first evidence that liquid water still occasionally flows on the surface.

Another such effort to engage the public involves the Stardust spacecraft, which flew through the tail of a comet in 2004, collecting particles in aerogel. On its way there, the probe also passed through regions of interstellar dust. Mission scientists took more than 1.6 million photographs of the gel under a microscope, but they only expect to find maybe 45 grains of interstellar dust. The Stardust@home project provides users with a Web browser–based virtual microscope to search for the telltale tracks in the images.

The project directly contributes to science: The user who first identifies a speck that turns out to be interstellar dust will be automatically included as a coauthor on the scientific publication of the results. Part of what makes Stardust@home work is its scoring system, which rewards users for corroborating the findings of other participants. And scoring high requires skill—each image is, in fact, a collection of scans taken with focal planes set at different depths in the gel, which provides the virtual equivalent of adjusting the microscope's focus as they examine a speck to discern whether it's truly interstellar dust.

But even the excitement of improving your score can eventually wear off as you adjust the focus on the 20th grayscale image filled with nothing but bubbles and imperfections. Would people actually want to help out with all the tedious work of science? Yes—or so they claim.

Dittmar Associates, a consulting firm, has conducted surveys for NASA during the last five years to understand the public perception of the agency. While most respondents generally support the space program, they've said they want to feel more engaged, more a part of the action. The surveys asked disengaged 18- to 25-year-olds, "What would get you interested in and excited by NASA?" The top answers: being able to go into space themselves, participating in missions in some other way, and having the ability to view what robots and astronauts are seeing in real time (or as quickly as NASA gets the images).

The first request is difficult to grant, but Stardust@home's crowd-sourcing program addresses the second wish. The project has attracted more than 26 000 "dusters," who have collectively analyzed some 40 000 000 images. The Clickworkers program, which initially involved the much duller task of marking the edges of craters, attracted more than 80 000 participants [see sidebar of participatory programs, "Make Your Mark"].

BUT WHAT ABOUT BEING ABLE TO SEE what the robots see? NASA may just be able to go one better, by placing you in the rover's treads, so to speak.

"In the past 25 years in field robotics, one of the greatest advances in autonomy is virtual environments," says Sims, the scientist at NASA Ames. Sims and his colleagues developed a program called Viz, which uses the stereo cameras on the Mars exploration rovers Spirit and Opportunity to create a virtual version of the rovers' surroundings. "It's a way to give a better perspective on what you're seeing in images," he says. Round-trip communication to Mars can take up to 40 minutes, so direct control of rovers isn't possible. Instead, while they wait for new data, operators can fly around virtual environments and plan their next moves.

The Pathfinder mission was one of the first to use virtual worlds to improve *Continued on page 66*

[PAST, PRESENT, FUTURE]

THE END OF THE CULT OF THE ASTRONAUT

How do you JUSTIFY HUMAN SPACEFLIGHT? + + + *BY DAVID A. MINDELL*

THE SPACE SHUTTLE *COLUMBIA* has a problem: During launch, foam from the external tank breaks off, strikes the orbiter's wing, and damages the heat shield. Because the crew members don't know how the problem will affect reentry, they evacuate to the International Space Station and place *Columbia* on autopilot, which guides the shuttle to a near-perfect landing. NASA engineers then spend months testing the shuttle during fully automated flights. Crewed flights resume only after the problem has been resolved.

Of course, that scenario never happened, nor could it. The space shuttle has no capability for fully unmanned flights. It's not just a matter of technology. NASA made sure the shuttle couldn't fly itself, because the agency feared that such automation might undermine the primacy of the astronaut. Yet if NASA ever wants to see human beings walk on Mars, the cult of the astronaut must end.

The cult blossomed during the earliest days of NASA's manned space program. Back in the late 1950s and early 1960s, the Mercury astronauts enjoyed rock-star popularity; they were walking embodiments of American individualism, military might, and middle-class values. Later astronauts, including Neil Armstrong and the other moonwalkers, had more education and engineering skill than their predecessors, but their technical prowess was overshadowed by their public personae, promoted by an eager NASA that sent them on world tours after their flights.

NASA's engineering culture supported the centrality of the astronaut. Initially designated "capsules," crew vehicles were renamed "spacecraft" to signify the human pilot's mastery and control. The terminology matched the technology: The spacecraft's controls, displays, and overall structure were designed with the pilot in mind. Yet many steps in the flights were automated, from the closed-loop launches to the predominantly automatic reentries. No human being could have handled all the complex tasks involved in orbital rendezvous and lunar landings without the aid of computers and fly-by-wire systems.

Some things that could have been automated, though, were not. During the Apollo era, engineers suggested landing the lunar module on the moon first without a crew, before exposing humans to the risky descent. NASA management rejected the plan. Engineers also designed the module so that it could land automatically. That feature was never used on any of the six Apollo landings; pilots switched it off, preferring to have their hands on the control stick. The space shuttle, likewise,

STAR POWER: Apollo 10 commander Thomas P. Stafford and his crew head for the launchpad on 18 May 1969.
PHOTO: NASA

has never flown an unmanned flight, nor has its automatic landing feature ever been used.

THE LAST APOLLO FLIGHT, in 1972, signaled the beginning of a shift in thinking. For the first time, the crew included an astronaut who was not a career aviator. Geologist Harrison "Jack" Schmitt was there because the U.S. scientific community had demanded it. The nonpilots who followed him became known as "mission specialists" (although some say they are really more mission generalists).

Since then, astronaut demographics have steadily expanded from the exclusively white male, all-American-boy military test pilots of the Mercury era to a more diverse population of engineers, scientists, women, and other ethnicities and nationalities. They made possible the spectacular accomplishments of the space shuttle era, including the repairs to the Hubble Space Telescope and the construction of the International Space Station.

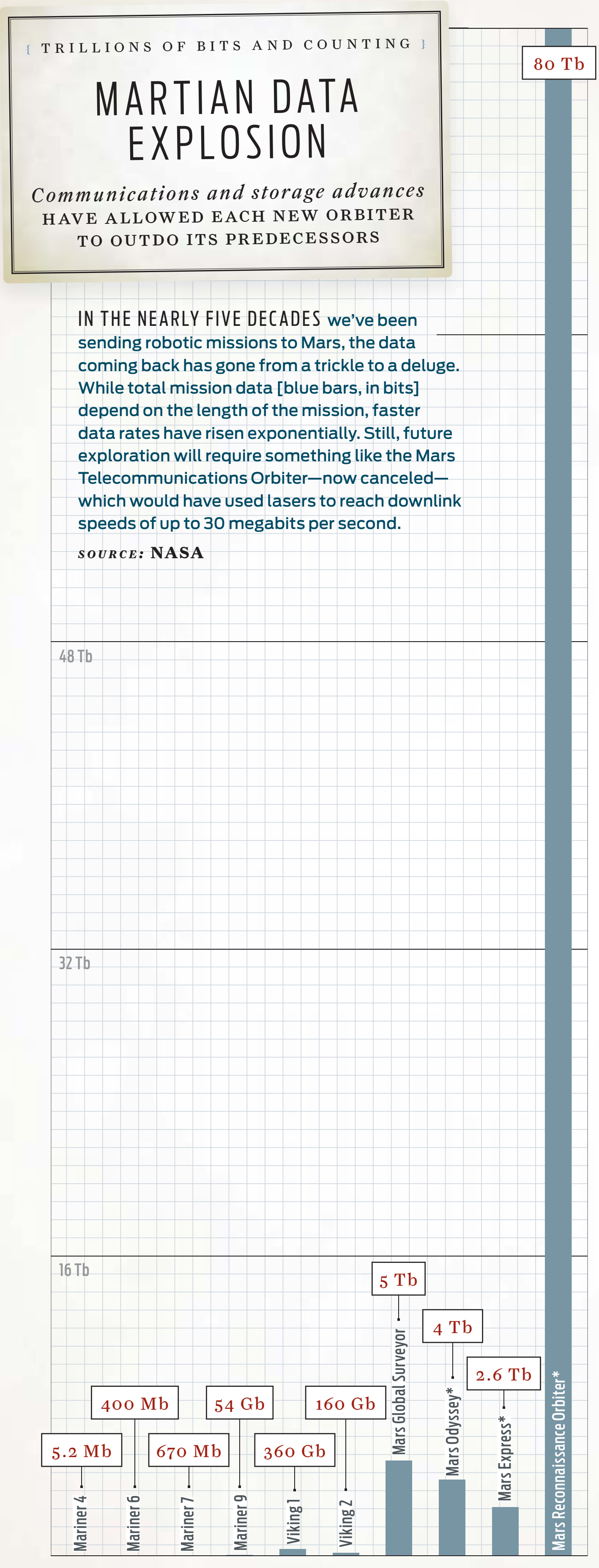
But in the public's eyes, at least, astronauts just aren't what they used to be. Their image has downshifted from bold frontiersmen to more functionary heroes. Few Americans today can name a single active astronaut. The arrest of Lisa Marie Nowak in 2007 on charges of attempting to kidnap a romantic rival symbolized a new fallibility—some might say humanity—in the astronaut image.

IF NASA AIMS TO SEND HUMANS TO MARS, it will have to rethink its entire approach to spaceflight. At present, the space agency maintains a rigid dichotomy between manned and unmanned missions. But a months-long journey to Mars would involve physical challenges—including radiation and bone loss—that we cannot currently counter. It would demand greater reliance on automation, robotics, and telepresence—the use of technologies that allow people to see and otherwise experience a far-off location. In the first missions, human crews might not even touch down on Martian soil but instead remain in orbit and remotely operate vehicles on the surface. Going to Mars would forever blur the line between human and remote missions.

So why keep people in the loop at all? And how do you justify expensive, state-sponsored human spaceflight programs when robotic missions cost so much less? Leaps in technologies such as high-bandwidth communications, high-definition video, and in situ sample processing mean that human spaceflight can't be justified solely on the principle that people are more capable than machines.

No, the best reason for putting humans in space is to expand the human experience. Such expeditions place people in unique situations and onto unique worlds in ways that broaden our understanding of ourselves. The first crew to reach Mars will have the great fortune to experience a new world, and it will be up to them to convey the wonder of that event to the rest of humanity. We should therefore send people who, in addition to having the usual technical talents and training, are skilled at communicating. They will show how exploration has changed in the decades since the space shuttle and the space station were conceived: more networked, virtually present, and dependent on technology, not just for the air that spacefarers breathe but for their very perceptions of the world. ❑

IEEE Spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | qMags



Continued from page 64 rover operation. When its Sojourner rover was preparing to roll off the lander and onto Martian soil, one of the ramps to the surface was stuck in midair—a fact that was obvious in the virtual environment but difficult to discern from images alone. In another instance, an examination of the virtual world prevented the rover from gouging itself on an overhang it was approaching.

Besides just avoiding unseen obstacles, modeling a robot's surroundings can help NASA do real science. With Spirit and Opportunity, planetary scientists have used virtual environments to investigate how rock strata formed and changed over time. Sims compares this approach with the utility of multiple viewpoints in a video game. "For problem solving, it's nice to be able to have the bird's-eye view," he says. The fact that NASA is already creating gamelike virtual environments is good news for the rest of us.

Mainstream audiences got their first glimpse of the virtual-reality future when Google added Mars to its Google Earth application in February. Microsoft's WorldWide Telescope program plans to follow suit shortly. For a more up-close look at the surface, NASA has used the virtual world Second Life to build a visualization of Mars's Victoria Crater. It's rendered at nearly one-third its actual scale, making it one of the largest features that virtual visitors can fly over and explore. NASA even has plans for a massively multiplayer online game that may incorporate planetary environments from real data.

The visualizations created for Spirit and Opportunity were available only to the team controlling the rovers. The next step is to make such spaces more sharable. "You can imagine scientists working in these virtual worlds and planning the mission in real time," Smarr says.

Already Calit2 and the Lunar Science Institute have connected their giant displays via dedicated fiber optics to view huge lunar vistas while simultaneously teleconferencing in high-definition video. If the same connectivity extended beyond the professional network, "everyone in the world could be in that room with them, making contributions in real time," says Smarr. But before we can entertain such a notion, NASA will have to figure out how to make sense of so many voices.

TWITTER, THE MICROBLOGGING SERVICE, provides one means to deal with cacophony by at least keeping comments short. Veronica McGregor, a communications officer at the Jet Propulsion Laboratory, in Pasadena, Calif., started a Twitter feed for the Mars Phoenix mission, a lander that traveled to Mars last year. In a stroke of inspiration, she decided to tweet in the first person. What started as a way to save characters ("I" instead of "the lander" or "Phoenix") soon gave birth to the first Mars robot with personality.

Tweets such as "Are you ready to celebrate? Well, get ready: We have ICE!!!!! Yes, ICE, *WATER ICE* on Mars! woot!!! Best day ever!!" eventually attracted

ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

more than 40 000 followers, making @marsphoenix the 30th most popular account on Twitter at one point during the mission.

That represents a different type of participatory exploration—where Web 2.0 technologies make it easier to have personal contact with the space program. Twitter's short format allowed McGregor to respond in real time to hundreds of questions from readers who followed the feed.

Since then, almost all NASA missions and centers have started Twitter accounts. But only a few have really recaptured the same magic. Viral success is hard to repeat, and not every communications officer has McGregor's flair. What NASA needs is a group that can help teach the agency how to break out of its insular traditions.

With that objective in mind, S. Pete Worden, the director of NASA Ames, decided in 2006 to turn loose a bunch of twentysomethings on the center. They formed the Collaborative Space Exploration Laboratory, or CoLab, which became the focal point of the participatory exploration movement within NASA. In June 2007, CoLab and NASA Ames hosted the Participatory Exploration Summit, which sought to link like-minded projects from across the agency with partners "outside the gates."

Taking many of their goals and ideals from the interactivity of Web 2.0 applications, the center has tried to spark collaborations that go beyond the traditional aerospace companies with NASA contracts. Lab members have used the experience of Stardust@home and similar projects to help the scientists running new missions connect with amateurs. CoLab is also behind the CosmosCode project, which is designed to provide an open-source collection of aeronautics and astronautics software.

Somewhat fittingly, CoLab's biggest presence has been in that most ephemeral of digital spaces: Second Life. Volunteers helped build CoLab Island, which serves as the virtual location of weekly meetings between NASA and outside volunteers.

But making space accessible is difficult. Web 2.0 platforms—Twitter, Facebook, Second Life—are a great way to reach a certain type of Web-savvy amateur, but they leave out a big part of the potential audience. There's no one-size-fits-all solution to engaging the public. While the Clickworkers project is as easy a way to kill time as playing solitaire, the work eventually gets repetitive. Contributing to NASA's open-source software is much more intellectually stimulating, but it's an option only for those who know how to code.

Another problem is that even innovative programs have trouble shaking off the stigma of being mere "outreach and education" activities—in other words, not important. "We're going for 'inreach' as well," CoLab project coordinator Delia Santiago told me when I visited in October, referring to contributions from the outside that demonstrably help NASA rather than just cost it money. But she knew that CoLab still needed to prove its case. "We have to show our relevance," she said. "We have to show that we actually add value."

The CoLab staff was seeking no less than a cultural change within NASA, quite an undertaking in a big, lumbering bureaucracy. Since my visit, the CoLab program has "paused for a bit," according to Santiago, although many of the programs it championed live on.

Maybe NASA wasn't quite ready for such a big shift. Take the case of Ariel Waldman. She was hired at CoLab specifically for her social-networking skills, but the contractor she worked under had standard rules that expressly prohibited using social-networking sites at the workplace. After trying without success to get permission for three months to use the tools she needed, Waldman gave up and started her own Web site, Spacehack.org. It collects and organizes the disparate and jumbled set of events, projects, and communities for amateurs interested in space—and it does so better than any NASA site.

IT'S A LONG-HELD AXIOM among some segments of the space community that while robotic missions are great for doing science, you have to have a human program, because that's what excites constituents and Congress enough to pay the bills. Others perceive a true need for people in space.

"Robots discover. Humans *explore*," Kent Joosten, a systems engineer at Johnson Space Center, said at a space conference last year. "Exploration is a personal endeavor. There are hundreds of thousands of boot prints on the moon." He has a point—astronauts on Mars could think on their feet, without relying on delayed radio instructions. Even roboticists agree. "Some aspects of exploration will never be done by a robot," Sims says.

But rather than a human spaceflight program that supports the rest of NASA, interactive robotics might become the new public crowd-pleaser, if it hasn't already. Dittmar Associates' surveys of 18- to 25-year-olds found that they had little interest in or knowledge about either NASA or Constellation, the program to return to the moon, but they were excited by Spirit and Opportunity.

Generation Y represents only about 15 percent of the workforce in the United States today, but experts predict that percentage to nearly double in five years. Persuading this group to take part in virtual space exploration could extend political support for the U.S. space program beyond Texas and Florida.

And the next generation of Mars robots is likely to be even better, eventually providing streaming high-definition video and more. "The vision is sort of the *Star Trek* holodeck," says NASA Ames's Worden. "What does the Martian wind feel like on your face?" he asks, a question that can be answered only in virtual reality, not in Mars's thin carbon dioxide atmosphere.

Assuming that NASA realizes the benefits of bringing Mars back to Earth, we might eventually have thousands of answers to that question. ❑


R. GARRIOTT
Р. ГЭРРИОТТ

{ FIRST PERSON }

THE AMAZING ORBITING GARRIOTTS

Owen and Richard Garriott, THE SECOND FATHER-AND-SON PAIR TO HAVE TRAVELED IN SPACE, OFFER THEIR THOUGHTS ON WEIGHTLESSNESS, HAM RADIO, AND WHY THE SPACE STATION IS LIKE THE MOVIE *METROPOLIS* + + +

IN 1973, OWEN GARRIOTT made electrical engineering history as the first EE astronaut to travel into space, spending 60 days aboard Skylab, the U.S.-run space station. The stay set a new record for duration in space, and *IEEE Spectrum* commemorated the achievement with a photo of a spacewalking Garriott on the cover of its July 1974 issue. He went into orbit again in 1983, this time aboard the space shuttle *Columbia*, and he remained in the NASA astronaut corps until 1986. Between missions, he was based at Johnson Space Center, overseeing research in the physical sciences and advising on plans for what would become the International Space Station (ISS).

A quarter century after Garriott's Skylab excursion, his son, computer-game designer Richard Garriott, took a 21st-century trajectory into space. The sixth self-paying tourist—or "private astronaut," as Richard prefers to be called—he took a Soyuz spacecraft to the ISS last October. Owen was on hand at Baikonur Cosmodrome in Kazakhstan to watch his son's liftoff and also greeted him upon his return 12 days later.

Richard and Owen are now the second family to have visited space, albeit in different decades. (Cosmonauts Alexander and Sergei Volkov hold the distinction of being the first father and son to go into orbit.) In March, veteran space journalist **JAMES OBERG** interviewed the Garriotts at Richard's mansion, Britannia Manor, on the outskirts of Austin, Texas. Here are excerpts from the interview.

Q: OWEN, WHAT ADVICE DID YOU GIVE YOUR SON?

OWEN: Actually, I did not need to give Richard much information or guidance. He grew up in this kind of environment; he knows the situation. So my only advice was, don't worry about feeling a little uncomfortable at the beginning of the flight. Almost everyone does. Just hang in there and it'll be fine.

Q: RICHARD, HOW DID YOU FEEL?

RICHARD: I feel very lucky that I was relatively free of motion sickness. But I did have a different, related problem. Starting 15 or 20 minutes after being in orbit, you begin to feel like you're lying head down—in fact, it felt a lot like the tilt-table preparations we did. For 5 or 10 minutes, that's not such a big deal. But when you do it for 5 or 10 hours, that gets pretty annoying. By day three or four, I was having substantial headaches from fluid shift and increased blood pressure in my head.

One of the other great pieces of advice [my dad] gave me was how to structure my flight. I devoted about a third of the time to looking out the window, because we knew that would be a very pleasurable activity. We planned another good chunk of time for ham radio. As you know, Dad took the first ham radio up [on the space shuttle *Columbia*] 25 years ago, and so I had this interesting historical chance to reverse the call, so to speak.

The ham radio operations, by far, became the most entertaining activity I did in orbit. My other cosmonaut buddies now do this commonly, and everyone says they really appreciate the chance to talk with people who have this very low probability of contacting the station. But when they do reach somebody, they have made this very personal connection to someone in a very unusual circumstance. The joy the ground person gets out of that contact is infectious. A lot of them have gotten their whole school together and they've been trying every day for a week to pull it off, and the whole class—you can hear them clapping or cheering.

Q: WERE THE COMMUNICATIONS ADEQUATE? OWEN, THERE WERE LONG TIMES IN SKYLAB YOU COULDN'T EVEN TALK TO HOUSTON.

OWEN: We had long breaks, that's true, somewhat like the Russians have on their side now. But I never felt disconnected from the Earth. Intermittent communication is just fine. In Skylab we had an opportunity to talk once a week, or really more if we wanted to, with our families. [Back home] we had a speakerphone sitting on the kitchen table, and Richard and his siblings would all gather around and we could talk for a few minutes. And I was extremely busy, probably as busy as I've ever been in my life, during the two months on Skylab. So I thought it all right and did not feel disconnected from the Earth in any way.

RICHARD: [On the ISS] there was almost always someone on station talking to someone on the ground. Worse yet, there was a HAL kind of thing watching. There's cameras all over the ISS that are generally always broadcasting. So I think the problem has almost swung the other way. These guys now feel like they're in the middle of a fishbowl. I remember a few times we moved a camera or turned it to the wall, and a couple hours later a ground call would come up: "Hey, we're no longer getting a signal from that camera. What's wrong?" So it's not only a fishbowl but one that notices when you're off camera.

MATTHEW MAHON

Q: OWEN, WHAT DID YOU AND YOUR FAMILY TALK ABOUT? THINGS HAPPEN BACK ON EARTH THAT THEY MAY NOT WANT TO TELL YOU.

OWEN: That kind of thing occurred in the Skylab era. There was some editing done on the news. But if you were to talk with Richard and his mother at home in the kitchen, then you felt that you were getting the straight information without too much bias.

RICHARD: My friend Charles Simonyi paid to use NASA's e-mail service [*Editor's note: Simonyi completed his second paid visit to the ISS in April*]. Charles would make a daily blog of "here's what happened today in space." He had kids following along on his whole mission. It's very timely news. It needs to go on [his] Web site immediately.

NASA says that they're involved in the communication and therefore have some official responsibility for it. So their desire to look at it meant it was three or four days before the e-mail reached Charles's ground team, which is already too long. But then they actually made edits. When Charles referred to things like, "Hey, when I get back I want to have a Coke and a cheeseburger," they wouldn't let him say "Coke." It made it to his destination as a "soda and a hamburger." And he's going, "That's not what I said."

I understand what NASA's worried about, I really do. I just think they're shooting themselves in the foot by not realizing that by being so oppressive, they're [not] creating a sense of wonder and glory and enthusiasm for the program. What ends up coming out is this sterilized, ultrasafe output that actually doesn't serve their purposes the way more free communication would.

There was a practical joke I really wanted to play while I was in orbit. I was going to get on the VHF radio and make a joke about seeing a UFO out the window. Of course, my crew members were saying, "Please, Richard, please, please don't." What they're doing by trying to censor is feeding directly into those conspiracy theories.

Q: IN THE RUSSIAN SEGMENT OF THE ISS, THE CONTROLS LOOK LIKE SUBMARINE CONTROLS, BUT IN THE U.S. SEGMENT IT'S CONTROLLED THROUGH LAPTOPS AND WIRELESS INPUT. HOW WOULD YOU DESIGN A USER INTERFACE FOR A FUTURE SPACECRAFT?

OWEN: Back in the 1970s we did not have the computer capabilities we have now—there was no way to have a software interface. Not even in the '80s was it possible to do that. That was a sign of the times. If we want to make decisions as to how we're going to go to Mars, we need to [think about] how we can make that flexible. And the only way to make it flexible is through software and therefore have something which we can change 5, 10, 15 years from now as we find better ways to do things.

RICHARD: You can see the switch beginning to occur. Already in the ISS there is an Ethernet backbone that runs through the whole thing. You can plug in laptops anywhere, and that is the standard method of command and control to a wide variety of the systems, because the ground needs that same remote access. I remained phenomenally impressed with how good the Ethernet backbone is up there. They can use off-the-shelf inkjet printers, and the laptops are, you know, quite conventional. So I think they're absolutely making the right moves.

Q: INVESTIGATORS ON THE GROUND CAN OPERATE EQUIPMENT ON THE STATION. RICHARD, WERE YOU TOLD, "THIS SCIENCE GEAR'S WORKING, DON'T TOUCH IT"?

RICHARD: It was very common. There were times when we avoided going into a module because we didn't want to vibrate an experiment that was being operated by a ground team. Seeing it up there in operation is very impressive.

As we refocus government spending on going back to the moon and/or going to Mars, [there is] a big risk of eliminating funding or focus on the station. I think they have to find a way to open up access to the station to private industry or university research. And that's what I don't think they're doing yet. No one can get through the red tape because of the current structure.

Q: RICHARD, SOMETHING ABOUT THE FLIGHT REMINDED YOU OF FRITZ LANG'S CLASSIC 1927 FILM *METROPOLIS*.

RICHARD: Yes, I was struck by how much like *Metropolis* the space station was. The movie is about a future society where there's basically two classes of citizen: those who live belowground, who work on the machinery that keeps the power and water and lights on for the upper-class people, who live aboveground in relative comfort and opulence.

If you go on the Russian segment [of the ISS], it is less voluminous; it's more dimly lit. It is where all of what I would call the dirty and maintenance-heavy functions of the space station take place. It's where the water is recycled and purified. [*Editor's note: A new urine processor was installed on the U.S. side of the ISS last November.*] It's where the galley is. It's where, up until quite recently, the only toilet facilities were. It's where the central command post is for navigating the space station. It's where all the thrusting and maneuvering engines are that keep the space station in orbit.

In my mind, it's where all the work that keeps the space station alive is really happening. And because of all the water and food and other activity, it also tends to be prone to bacterial outgrowth, mold, and things of that nature.

But then you go through a hatchway into the U.S. segments, and immediately the volume is dramatically increased. Immediately the lighting level is dramatically increased. It is completely sterile. The crew discourages you from taking food or water in there to help keep it sterile. We have gleaming scientific racks for potential use, and we've spent 10 years and a hundred billion dollars or so building the ISS, but so far there's really not much happening in the U.S. segment. It's very striking, the difference between the Russian segment and the U.S. segment. ❏

{ EXPLORE MORE ONLINE }

INVESTING IN SPACE

Angel investor Burton H. Lee ON HOW TO MAKE PROFITS THAT ARE OUT OF THIS WORLD

"There's money to be made in space; besides, it's just cool to play with rocket engines and satellites and brag to your friends that you own a piece of the space business. As cofounder of Space Angels Network, I evaluate dozens of space, aviation, clean-tech, and information technology start-ups each year. With the world economy down and concern over carbon emissions and global warming up, space is still a good investment. I'll tell you why, and what space-related technologies make good bets, as well as what space investments I consider risky..."

ONLY AT HTTP://SPECTRUM.IEEE.ORG/AEROSPACE/SPACE-FLIGHT/INVESTORS-GUIDE-TO-SPACE

{ THE LAST WORD }

THE MARS CHALLENGE

Human exploration OF THE RED PLANET WILL INSPIRE NEW GENERATIONS OF ENGINEERS

+ + + *BY LEAH H. JAMIESON WITH JOHN NORBERG*

THIS PAST AUTUMN, I met with all 1700 first-year engineering students at Purdue University. I asked them what their generation's greatest technological legacy might be. Repeatedly, they told me: sending people to Mars.

I was surprised, but I shouldn't have been. Human achievement takes countless forms, and none has proved more revolutionary than space exploration. It energizes engineering, resuscitates research, and galvanizes new generations. After all, fearless optimism and an accompanying willingness to do what's hard are what set great engineers apart. As U.S. President Dwight D. Eisenhower once said, engineers "build not merely for the needs of men but for their dreams as well."

Ironically, it wasn't dreams but rather fear that triggered the race to space. The October 1957 launch of Sputnik set in motion a wave of technological advancement unsurpassed in history, the ripples of which are still being felt today. For more than a decade, policy-makers and the public genuinely believed that the future depended on engineers and scientists and that education would have to inspire young people to pursue those careers.

In the United States, Congress provided loans for college students and funded improvements in science, mathematics, and foreign-language instruction at elementary and secondary schools. In Europe, NATO set up a science committee, which proposed to launch "a satellite for peaceful outer space research...and circling the earth by 1960."

MOON SHOT: President Kennedy's 1961 speech launching the Apollo program helped set in motion a wave of technological advancement.
PHOTO: NASA

Glorious things came out of that era. On 25 May 1961, President John F. Kennedy delivered his legendary man-on-the-moon speech, and eight years later, Apollo 11 made good on it. It was one of the United States' finest hours, and for a time, at least, virtually anything seemed possible. And so the impact continued to reverberate through the rest of the 20th century and on into this one, albeit as an increasingly weakened echo.

Nevertheless, innovation and technology directly or indirectly inspired by the space race still shape the way we live and work. And I'm not talking about Tang or the Space Pen: Satellite communications, satellite navigation, photovoltaics, fault-tolerant computing, and countless specialty materials and biomedical sensors all came out of the space program.

The International Space Station demonstrated that after the Cold War, industrialized nations could work together in space without requiring the motivation of fear or nationalism. That's important, because fear and nationalism can't get us to Mars. It's too big an undertaking for any one country, and the commitment will have to persist despite changes in world politics. It's an undertaking on a scale that will require many of the world's best minds.

Yet developed nations are seeing far too many of their best and brightest shunning engineering as a career. Countless panels and study groups have lamented the problem and proposed solutions. Common to all these solutions is the conviction that engineering once again needs to inspire—that we need to harness the power of dreams with projects like a human mission to Mars.

Here at Purdue, I get to see some of those dreams made real. Hundreds of our engineers now work in the aerospace industry, among them William H. Gerstenmaier, who directs NASA's human exploration program. And 22 Purdue graduates have become astronauts, including Neil Armstrong, the first man to walk on the moon, and Eugene Cernan, the last—or as he would say, "the most recent."

Cernan, who earned a bachelor's degree in electrical engineering from Purdue in 1956, finds my students' vision of reaching for the Red Planet not at all far-fetched. "As long as we give them the tools, as long as we give them the education and the inspiration, there's no question in my mind that they will take us to Mars," he says. "Where it's going to lead, who knows? But I can tell you this with absolute certainty: It's going to happen." ❑

LEAH H. JAMIESON is the John A. Edwardson Dean of Engineering at Purdue University, in West Lafayette, Ind. She served as president of IEEE in 2007. JOHN NORBERG, a senior writer at Purdue, is author of Wings of Their Dreams: Purdue in Flight *(Purdue University Press, 2003).*

ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

NANYANG TECHNOLOGICAL UNIVERSITY

The Nanyang Technological University, Singapore, invites applications for the following position:

DEAN, COLLEGE OF ENGINEERING

About Singapore

Singapore is a centre of new and exciting academic opportunities. Targets for the development of Singapore as a world centre for academic excellence have been set and this has been supported by major public sector investments which give traction to the further development of a vibrant environment for higher education and research. Singapore has also been able to establish lasting and synergistic business and academic relationships with China, India and other South East Asian countries.

About the University

Nanyang Technological University (NTU) is an internationally reputed research-intensive university with globally acknowledged strengths in Science, Engineering and Technology. Currently ranked 26th among technology universities, and well within the top 100 among the comprehensive universities by the Times Higher Education-QS World University Rankings, the university's academic and research programmes, with real-world relevance, have reaped dividends in the form of strong support from major corporations and industry leaders, in terms of both research funding and partnerships and global internship opportunities for the students.

The University provides a high-quality comprehensive and global education to more than 21,700 undergraduates and 9,400 graduate students. Together with the university's 2,700-strong faculty and research staff who bring international academic perspectives and depth of experience, the University's main 200-ha residential and garden campus, located at the south-western part of Singapore, is an international hub of academic vibrancy and endeavors.

About the College

NTU has four colleges - College of Engineering; College of Science; College of Business; College of Humanities, Arts and Social Sciences - with 12 component schools. The College of Engineering is one of the largest engineering colleges in the world, consisting of six schools, 16,000 students, 600 faculty and 1,200 staff. The six constituent schools are the School of Electrical and Electronic Engineering, School of Chemical and Biomedical Engineering, the School of Computer Engineering, the School of Civil and Environmental Engineering, the School of Materials Engineering and the School of Mechanical and Aerospace Engineering.

The College enjoys a growing reputation for its multidisciplinary academic pursuits and research enterprises, achieved through constant diligence in striving for excellence and effective use of resources. Some of the research firsts and breakthroughs developed at the College include the World's Smallest Integrated Circuit Transformer, the World's First Diode pumped Yb:Y2O3 Ceramic Lasers and the World's First Multiple Drug-eluting Biodegradable Stent.

In 2008, the College won four prestigious Competitive Research Program grants from the Singapore National Research Foundation totalling USD24 million in Photonics, Clean Energy and EWT, Biomedical Devices and Printed Carbon Nanotubes. An institute in Environment & Water Technology has won USD55 million over a 3-year period. Another major strength in Nanoscience & Nanotechnology has garnered USD20 million since 2007. More information on the College can be accessed at the following website: http://coe.ntu.edu.sg/Pages/CoEHome.aspx.

About the Appointment

The University is seeking an accomplished, visionary and pragmatic academic leader for the position of the Dean of the College of Engineering, who will also be appointed as a tenured professor. This is an outstanding opportunity for an individual who is passionate about growing and strengthening a dynamic College, and taking it to greater heights of research and teaching excellence and scholarly achievements.

Reporting to the Provost, the Dean will provide foundational vision, leadership and oversight for the strategic, academic, intellectual and administrative affairs of the College and its constituent Schools. Essential responsibilities include sharpening and directing the College's focus to align with the University's mission and strategic directions, cultivating areas of academic and research excellence, providing leadership in fundraising through cooperation with the University's Development Office and strengthening ties with alumni, stakeholders, community partners, external organizations and industry to raise the College's profile and standing. The Dean is also a member of the University Cabinet, the highest decision making body of the faculty and a number of Provost and University's senior leadership committees and teams.

The appointee must have an outstanding record of academic leadership, research and teaching in a reputable University or academic institution. The appointee must demonstrate vision and the ability to raise the reputation of the College and to enhance its existing research and teaching strengths. Other essential attributes include, excellent ability to communicate and work collaboratively on inter-disciplinary research, with faculty and, students, both intra-university and externally, and a commitment to faculty-shared governance.

To apply, please send curriculum vitae, accompanied by a cover letter, to:

The Chairman of the Search Committee,
Professor Haresh Shah

c/o Office of Human Resources
Nanyang Technological University
Level 4, Administration Building
50, Nanyang Avenue
Singapore 639798

Fax: (65) 67919340
Email: CHRO@NTU.EDU.SG

Closing Date: 31 August 2009

All applications and materials submitted will be held in strict confidence.

[DOLLARS AND SENSE]

SPACE IS BIG BUSINESS

FIFTY YEARS AGO, the space economy consisted almost entirely of a Soviet budget that paid for Sputnik and a second one for a newly formed U.S. agency, NASA. According to *Space Report 2009*, compiled by the Space Foundation, in Colorado Springs, 13 governments spent US $83 billion last year on space, with the United States accounting for four-fifths of that amount. By itself, NASA outspent the other 12 countries taken together, and the U.S. Department of Defense spent even more—quite a bit more, in fact.

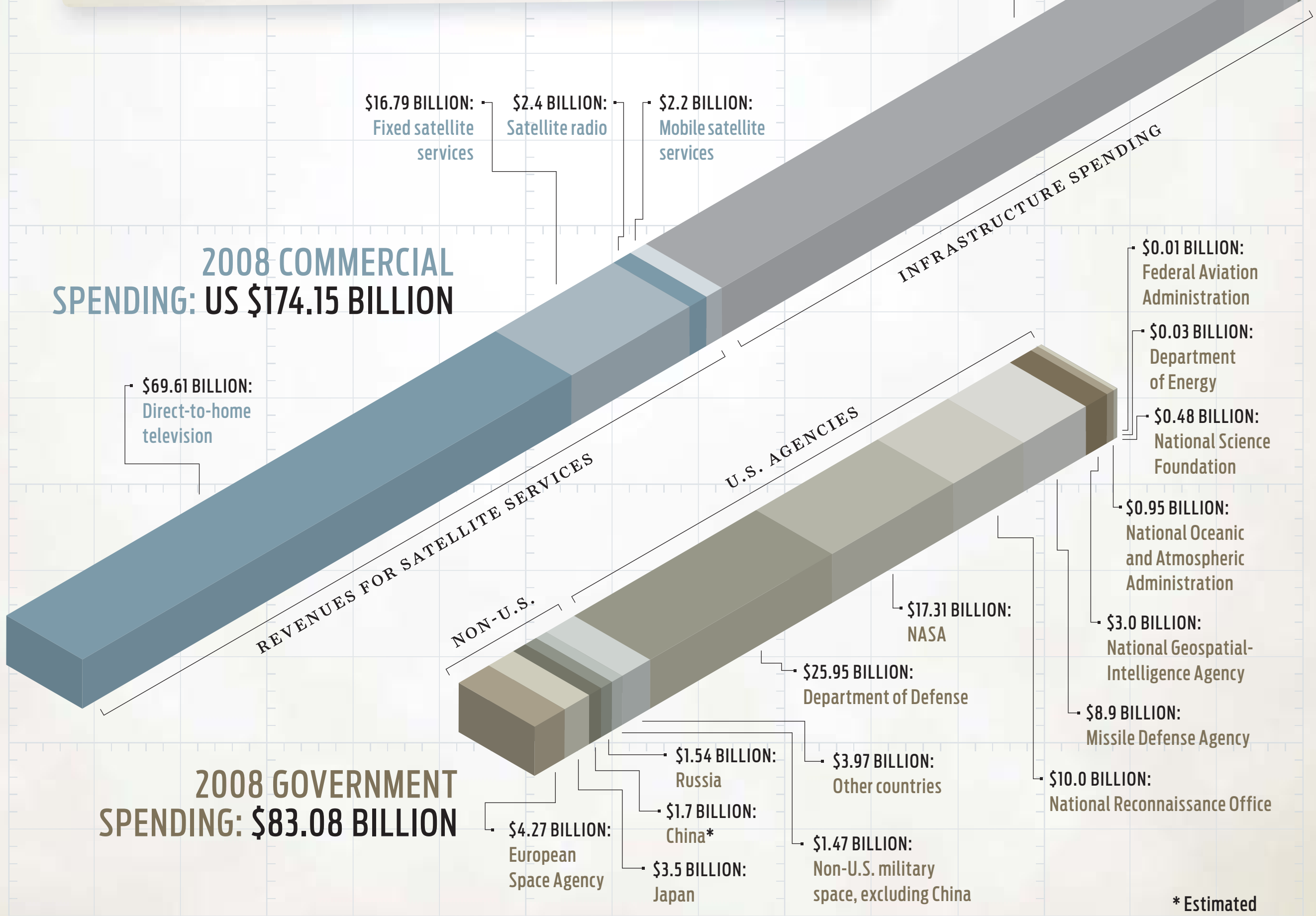
Yet for every dollar governments spent, corporations spent two. A little over half of that commercial spending was on satellite services, mainly direct-to-home television; most of the rest went to infrastructure.

None of that commercial activity would exist if we couldn't get the satellites up into space, though, and on that score, the Russians, as they were in the late 1950s, are the clear leaders. Of the 106 commercial launches made in the past five years, the erstwhile Soviets accounted for 45.

—*Steven Cherry*

COMMERCIAL ORBITAL LAUNCHES 2004–2008

RUSSIA:	45
EUROPE:	22
U.S.:	18
CHINA:	1
INDIA:	1
MULTINATIONAL:	19



* Estimated

SOURCES: Space Foundation, U.S. Federal Aviation Administration


We're still looking
for the final frontier.
The sky is never the limit for IEEE members. From yesterday's Mercury missions, to today's satellite constellations, to tomorrow's landing on Mars, we're bringing expertise and innovation where no one has gone before.
In fact, IEEE members have been part of nearly every major technical development of the last 125 years. So when you need to draw on the most advanced technical knowledge on Earth, or anywhere else, you'll see that IEEE members aren't just waiting for the future, they're engineering it—one trek at a time.
Celebrating 125 Years of Engineering the Future
www.ieee125.org
IEEE
Celebrating 125 Years
of Engineering the Future