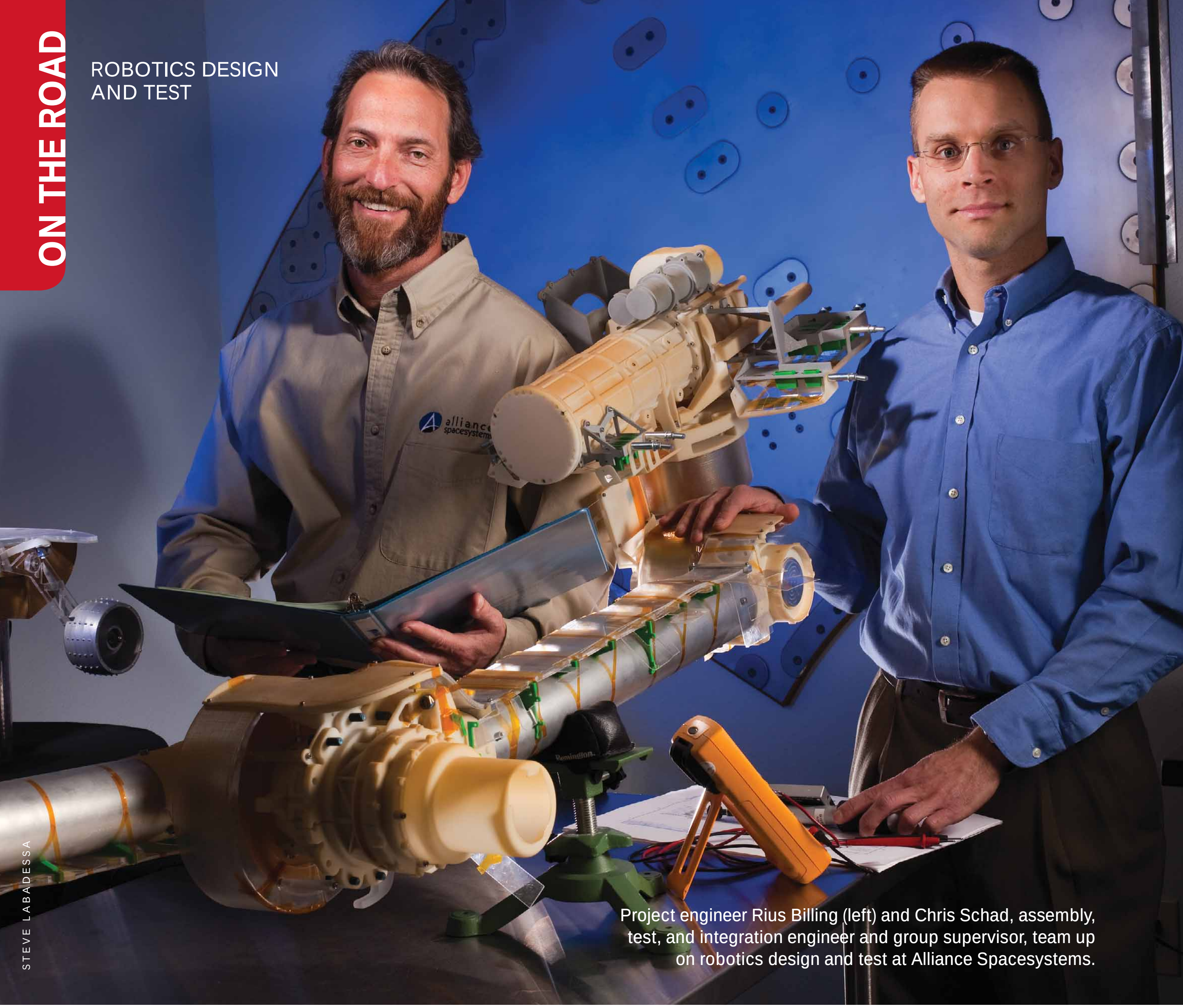
ROBOTICS DESIGN AND TEST



STEVE LABADESSA

Project engineer Rius Billing (left) and Chris Schad, assembly, test, and integration engineer and group supervisor, team up on robotics design and test at Alliance Spacesystems.

REACHING OUT

FROM UNDERGROUND TO OTHER WORLDS, ENGINEERS AT ALLIANCE SPACESYSTEMS GET A GRIP ON ESOTERIC APPLICATIONS FOR THEIR ROBOTIC ARMS.

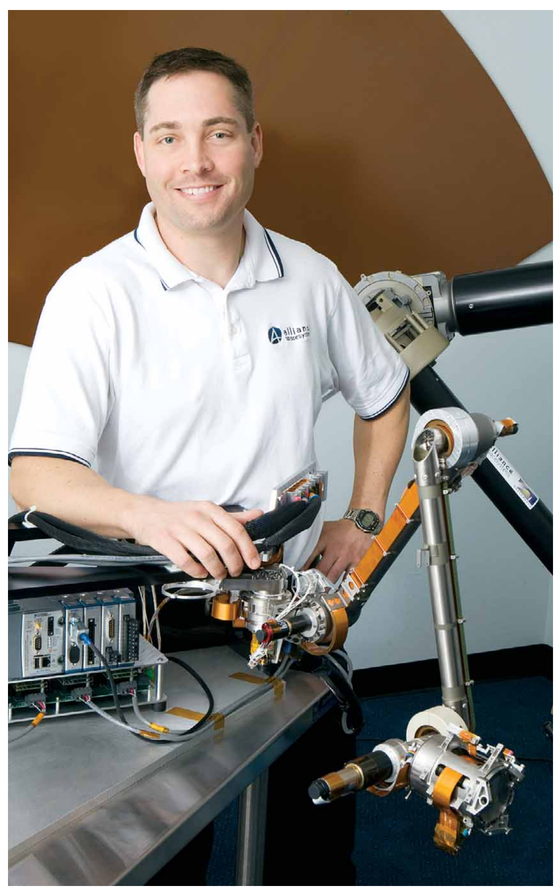
BY RICK NELSON, EDITOR IN CHIEF

PASADENA, CA—Robotics applications at Alliance Spacesystems tie together mechanical and electrical engineering disciplines in ways that can create significant challenges for system design and test. The engineering team has met those challenges for applications including underground gas-pipe exploration and camera-boom mechanisms that mount on a car roof to facilitate the filming of Hollywood chase scenes. But as the company's name suggests, its primary focus is on aerospace applications, including robotic arms for Mars explorers.

"We're considered mostly an aerospace company, but I like the fact that we work with terrestrial robotics and other areas, too," said Sean Dougherty, mechatronics technical advisor at Alliance Spacesystems. "It's a neat mix. For aerospace, reliability is everything, and it's nice that we can apply that to the terrestrial world, too." Shorter-term terrestrial projects, he said, allow the team to remain productive and to hone their expertise during gaps in the longer-term aerospace projects.

Dougherty outlined some of the projects in which Alliance Spacesystems has been involved:

- End effectors—tools at the end of robotic appendages that perform specific tasks such as drilling, trenching, or grasping. Alliance's LSAS (Low-force Sample Acquisition System) can drill into rocks and frozen soils on Mars' surface using a percussive hammer action. LSAS has been successfully tested in a thermal-vacuum chamber that mimics Mars' pressure and temperatures, and in the Mars Yard at NASA's JPL (Jet Propulsion Laboratory) while mounted to the robotic arm of the Rocky 8 rover. In addition, the MIDAS (Mars Integrated Drilling And Sampling) System meets NASA's need for drilling, coring, and abrading tools using low-mass, mobile, robotic platforms.
- Gas-pipe explorers—a series of self-propelled prototype robots that inspect 4- and 6-in. underground gas pipes by moving inchworm-like through them. The first cylindrical model propelled itself using a lead screw and the sequential inflation and deflation of airbags that gripped the pipe wall. The latest design contains deployable wheels and can access pipelines via a hole as small as 1 in. in diameter.
- A robotic arm for the Mars Surveyor 2001 spacecraft. Under contract to JPL, Alliance Spacesystems modified the design of the robotic arm from the Mars Polar Lander to adapt it to the Surveyor spacecraft and its lander mission. Following redesign, Alliance Spacesystems fabricated, assembled, and tested the robotic arm prior to its on-time delivery to NASA.
- Robotic arms for Spirit and Opportunity, NASA's Mars exploration rovers. Called the Instrument Deployment Device, or IDD, each robotic arm brings a rover's scientific instruments into contact with Mars' rocks and soils. Each arm is equipped with numerous Alliance-developed mechanisms, including actuators that position scientific instruments, contact sensors that detect proximity to targets of interest, and an interconnect system that traverses the rotating joints to conduct power and signals to the electromechanical devices and instruments.
- A robotic arm for NASA's Phoenix Mars Lander, which landed on Mars on May 25, 2008, and operated successfully about two months longer than its planned three-month mission near the Martian north polar region. As this article goes to print, the NASA Mars Odyssey orbiter is listening for the Phoenix Mars Lander in the unlikely event that Phoenix survived Martian arctic winter conditions.
- A robotic prototype for the Hubble Space Telescope mission to repair the STIS (Space Telescope Imaging Spectrograph), an instrument on the Hubble that suffered electronic board failures. Never intended to be serviced in orbit, the STIS interior is accessible only after removing a cover attached by more than 100

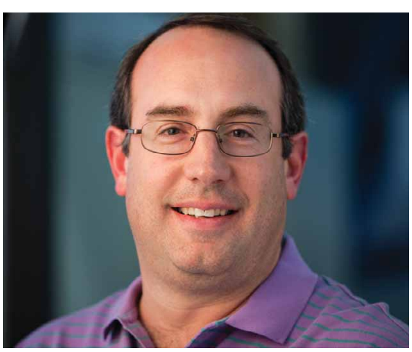


Sean Dougherty employs National Instruments hardware and software when developing prototypes of robotic arms. Courtesy of National Instruments.

screws of three different head types, some of which are covered by a nameplate. Alliance developed a fully functional conceptual prototype in only three months to prove the feasibility of a robotically assisted repair.

- Robotics for DARPA's FREND (Front-end Robotics Enabling Near-term Demonstration) program (originally called Spacecraft for the Universal Modification of Orbits, or SUMO). The NRL (Naval Research Laboratory) contracted with Alliance Spacesystems to design and build the robotics that would allow a servicing spacecraft to dock with satellites not originally designed for servicing. The 2-m-long FREND arm offers the potential for spacecraft salvage, repair, rescue, repositioning, de-orbit and retirement, and debris removal.

In process now, said Dougherty, are robotic arms for the MSL (Mars Science Laboratory) rover, which must be able to lift almost 75 lb of instruments to reach out and test Martian rocks and soil. The arm also must provide support for a sampling drill, which must be held steady during operation. Engineers at Alliance Spacesystems working in conjunction with engineers at JPL are building two identical arms, one of which, already completed, will remain on Earth to help in planning mission requirements. The other will go to Mars on the rover.



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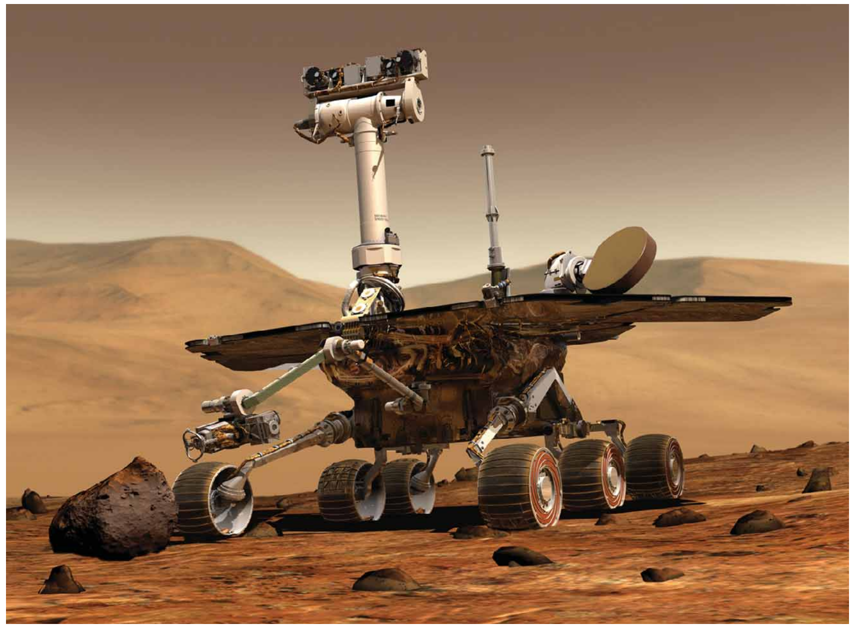
Richard Fleischner, group supervisor for mechanical engineering at Alliance Spacesystems, said he focuses on the nuts and bolts of mechanisms and structures, adding, "When it comes to pumping electrons, that's where I stop."

Putting all these projects together requires a multidisciplinary approach. Referring to an article in *EDN* (Ref. 1), Dougherty said, "Your article described



The Instrument Deployment Device, or IDD, is an Alliance Spacesystems robotic arm that brings the scientific instruments on NASA's Mars rovers into contact with rocks and soils on the planet. Courtesy of Alliance Spacesystems.

us as domain experts, and that's a good description. We do have some very detail-oriented mechanical designers and electrical designers, but for the most part, we try to focus on the end-to-end solution." To be able to focus on the end solution, he said, the engineers use high-level software and rapid prototyping hardware to quickly evaluate designs.

Dougherty himself has degrees in mechanical engineering and aerospace engineering. "As an undergrad, I wasn't very interested in electrical engineering," he said, "but when I went back to grad school at Stanford, I took a mechatronics class, and that piqued my interest. I was already interested in robotics, and the instructor was really good at explaining electronics and its role in controlling physical motion. I was in the aerospace department there, and aerospace engineering tends to be more of a system-engineering discipline, where you combine electrical and controls knowledge along with an understanding of structures and mechanisms." He said tools like LabView, which he first used in college for test and data-acquisition applications, enable him to handle electronics design tasks involving sensors, actuators, and motors without having to do detailed printed-circuit-board-level development work.

After getting his undergraduate degree, Dougherty worked at Johnson Space Center in Houston on the International Space Station program, training astronauts on robotics. After grad school, he came in contact with Alliance Spacesystems at a conference and joined the then-two-year-old company in 2000.

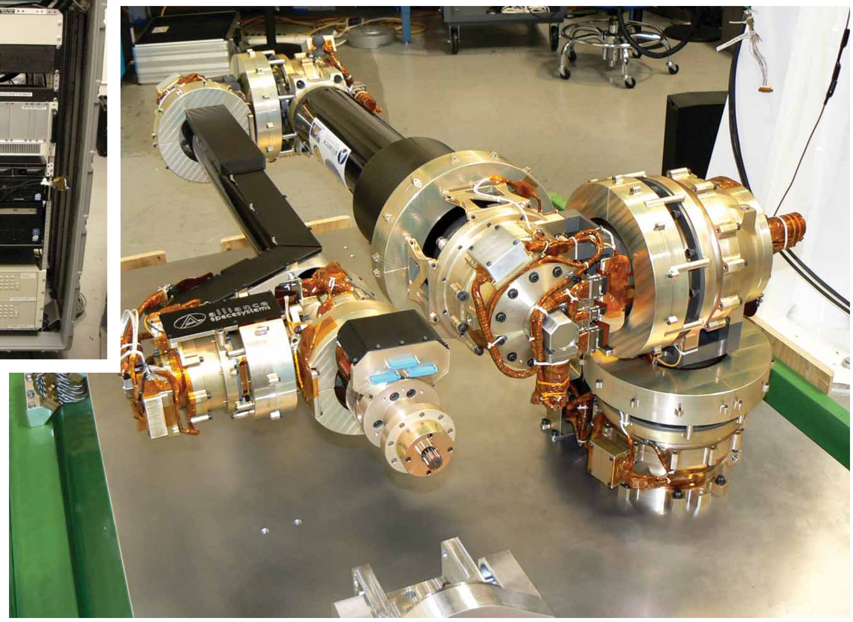
Four engineering groups

Alliance has four main engineering groups, explained Dougherty. The mechanical design group's members perform CAD (computer-aided design) but also do their own calculations and finite-element analysis. That group includes Richard Fleischner, group supervisor for mechanical engineering, who said he focuses on the nuts and bolts of mechanisms and structures, adding, "When it comes to pumping electrons, that's where I stop." Illustrating the multidisciplinary nature of the team, Rius Billing, project engineer for the MSL robotic arm, was educated in electrical engineering and worked as an electrical engineer at JPL, but now focuses on mechanical design at Alliance.

A second group, called the analysts, solves the most complex analysis problems, according to Dougherty. "Both groups are multidisciplinary in that they have to understand a lot of different software," he said. "Almost everyone at the company knows SolidWorks [CAD software], a lot know Nastran [finite element analysis software from NEi Software], and all have to understand motors and electronics."

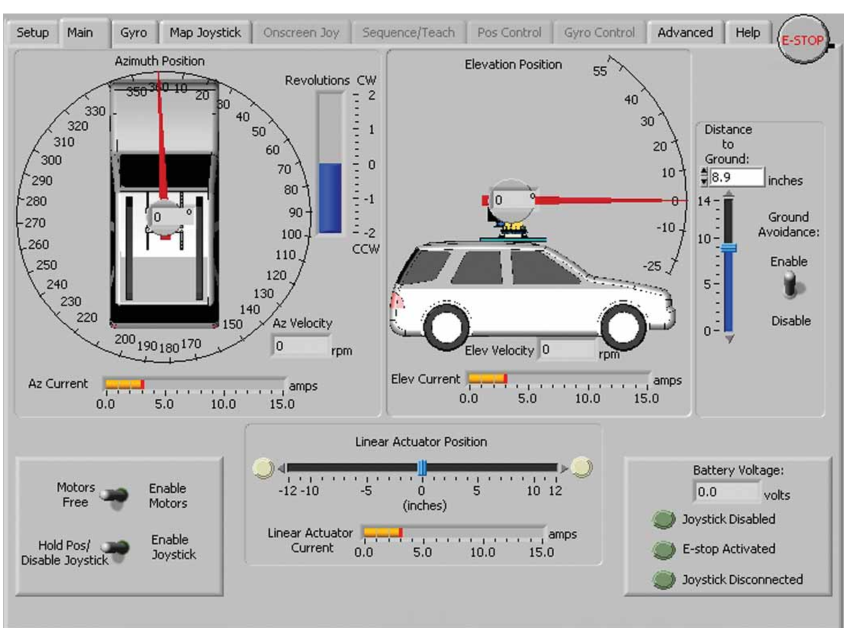
His own group is the mechatronics group, which is probably the most multidisciplinary. "We have to know SolidWorks and do some mechanical design, but we focus mostly on how we control the mechanisms. We do software and controls work, and also need to understand stiffness and the torques and forces and dynamics."

The final group is the assembly, integration, and test group. Members of that group are also multidisciplinary, Dougherty said. "They have to understand how the whole project works and how it goes together. They also do a lot of LabView work, because a lot of our test equipment uses LabView to do data acquisition and to control various mechanisms used in the life testing. Our two groups intermingle, and often you can't really distinguish between the two. It just depends on the phase of the program." He added, "Because we are a small company, we encourage everyone to have skills in every area. Our work is just so diverse that you don't know exactly what you might be working on, so if you have multiple skills it really helps out the company, and it makes the job really interesting."



Alliance Spacesystems built a prototype robotic arm for the Naval Research Laboratory in support of DARPA's FREND (Front-end Robotics Enabling Near-term Demonstration) program. Alliance Spacesystems is providing the robotics and associated control electronics (inset) to enable FREND to autonomously grapple satellites, including those that are not outfitted with custom interfaces. Courtesy of Alliance Spacesystems.

Chris Schad, assembly, test, and integration engineer and group supervisor, stressed that the multidisciplinary nature of the job extends beyond engineering disciplines. "There are days when I do my own shipping and receiving and act as my own purchasing agent and facilities manager," he said. The day we spoke, he said, was more rewarding. "This morning I worked a little bit of the MSL arm, handling some high-level wiring. Then, I got into some detail work on a precision hinge we are working on. We need to find a solenoid that will work in a thermal vac chamber, so later I'll be calling some solenoid vendors and doing some static analysis to figure out how much force and how much stroke I need."



Shown modeled in LabView, a joystick-controlled camera boom assists with filming car chases and other movie scenes. Courtesy of Alliance Spacesystems.

Testing the MSL arm

Schad outlined some of the test challenges his group faces. "For the MSL flight arm," he said, "we have to plan thermal-vac testing as well as some pretty intensive vibe testing. The vibration testing will pose particular challenges, because of stringent requirements on contamination control and planetary protection" to avoid introducing Earthly microbes into the Martian environment. He explained, "We are going to shake [the robotic arm] in a bag, and we have to figure out how to do that. There is the potential that we are going to have to partially take the arm out of its launch locks to perform one of the vibration tests to simulate the rover traversing Mars. So, that's going to present some pretty significant challenges associated with keeping it clean, getting it out of its locks, and getting it back into the locks for the ride home."

But despite the testing challenges, Schad said, "The greatest challenge we face on an almost daily basis is balancing work. We have a couple of jobs right now, MSL being one, that are all going to hit at the same time. I really have to stay plugged in and do the best I can anticipating problems and delegating and fighting the fires as they come up." He added, "Because we are a small group, we have very much a matrix-management style. Now I'm working with some analysts doing structural proof testing. Normally, they wouldn't come in until the end of the project, but I've got them involved in preplanning and ordering nuts and bolts for the test." His goal, he said, "is to make sure that I've anticipated things far out enough so I can have the right people available for each program," managing technician loading and having sufficient engineers available for testing.

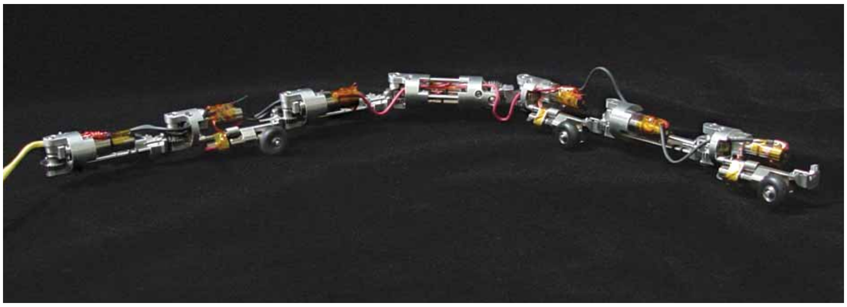
Hardware and software for prototyping

Alliance Spacesystems has been working with National Instruments tools since the days of SCSI hardware and is now using NI PXI and USB data-acquisition tools, among others. Dougherty also cited NI CompactRIO, saying that platform was valuable in building a robotics test bed for Spirit and Opportunity. "Obviously, the arms on Mars don't use CompactRIO, but it is a great platform for building a customizable test bed" that let the team quickly evaluate and optimize control algorithms. What flies, he said, is specialized hardware with code written in C.

He said that as tools like LabView increasingly work with aerospace mainstays such as Wind River's VxWorks (Ref. 2), the high-level tools may be used more. He noted that reliable software is critical during test. "We don't want to damage the hardware. We don't have that many copies, and it's not like we can go buy one if we break it. For Mars, every two years you have a launch window, and if you miss it, you are waiting another two years. Damage could have a huge impact, but we have few concerns about interfacing our hardware with LabView."

Dougherty said rapid prototyping capability was particularly important in designing a camera boom for use in the movie industry. Unlike in the aerospace industry, movie makers don't tend to spend a lot of time developing detailed requirements documents. One group of filmmakers, for example, just knew they wanted a camera boom that could be mounted on the roof of a Porsche Cayenne SUV, for example, and that could be controlled by a camera operator inside the vehicle while the vehicle traveled at speeds up to 100 mph. Using LabView to complete several iterative designs of a camera crane, the Alliance Spacesystems team was able to determine that a velocity-con-

The Mars Science Laboratory flight arm will require thermal-vac testing as well as some pretty intensive vibe testing while meeting stringent requirements on contamination control and planetary protection.



The GPEX gas-pipe explorers are a series of self-propelled prototype robots. Where the first GPEX model moved like an inchworm to inspect 4- and 6-in. underground natural gas pipes, the latest design contains deployable wheels and can access pipelines via a hole as small as 1 in. in diameter. Courtesy of Alliance Spacesystems.

trolled-joystick approach, rather than a position-controlled approach, provided optimum performance, and it enabled the team to smoothly implement range sensors and gyro control to avoid contact of the camera with the vehicle or ground even when the camera operator had an obstructed view. The gyro and sensors also kept the boom level when the vehicle climbed or descended a hill.

Dougherty said Alliance uses LabView mostly for test, but added that it's also involved in the design process—for projects like the camera boom as well as for aerospace projects. "With our prototype flight arm," he explained, "LabView allows us to rapidly try new things. One experiment we want to do is called compliance control, where we have a force-torque sensor on the end of the arm, and we try to minimize the forces imparted to a spacecraft. With such experiments, there are a lot of different approaches we want to try, and a lot of iterations. We use LabView because we can change the code really easily, and it has interfaces to all the drivers and hardware we use, so we don't have to worry too much about the low-level programming and can directly address the engineering problem right away."

Dougherty cited other tools Alliance engineers use, including Quanser software for controls work, noting that Quanser has LabView plug-ins, as do the MathWorks' Matlab and Simulink, other tools the Alliance engineers use. If there is one thing Dougherty would like to see vendors provide, it is an end-to-end solution that would support models from all the software the company uses. He noted that LabView will work with SolidWorks, for example, but the simulations don't run in real time. He added that Energid has really efficient solvers for robotics, but that there is still some interfacing work to do. What happens, he said, is that often the engineers will build one model in SolidWorks, then another in Nastran to do dynamics analysis, and then yet another in Simulink to do controls work. "Getting to where you can use the same model in all those different tools would be nice. It feels like we are close, but it's not seamless yet." T&MW

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FOR FURTHER READING

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