from first principles the soccer-ball structure of the carbon 60, or buckyball, molecule. Since then, they have developed more algorithms to reconstruct other nanoscale structures.

Although ingenious algorithms are indispensable, Streiffer says that imaging techniques must also continue to improve. "The holy grail of x-ray microscopy right now," he observes, "is to be able to put a single nano-object into an x-ray beam and know not only the nanoscopic shape but the position and chemical identity of every atom that makes up that nanoscopic structure." Matthias Bode, also at Argonne's center, notes that spectroscopic methods—the study of materials based on the light they absorb or emit—will be another weapon in the imaging arsenal. "Usually what you want to do in nanoscience is correlate structure with some kind of property that acts on the nanoscale," he explains, adding that spectroscopy would enable investigators "to correlate, say, the size or shape of the particle to specific electronic or magnetic properties."

Taming the nanostructure problem will be the key to achieving the ultimate goal of nanotechnology: custom-designing nanomaterials for specific functions. "We're obviously very far away from that," Billinge admits. Still, he insists, "it's a rich and exciting problem, and I'm kind of glad it's not solved. It gives me something exciting to do."

Mark Wolverton, based in Bryn Mawr, Pa., described upgrades to radio telescopes in the November 2008 issue.

POLICY

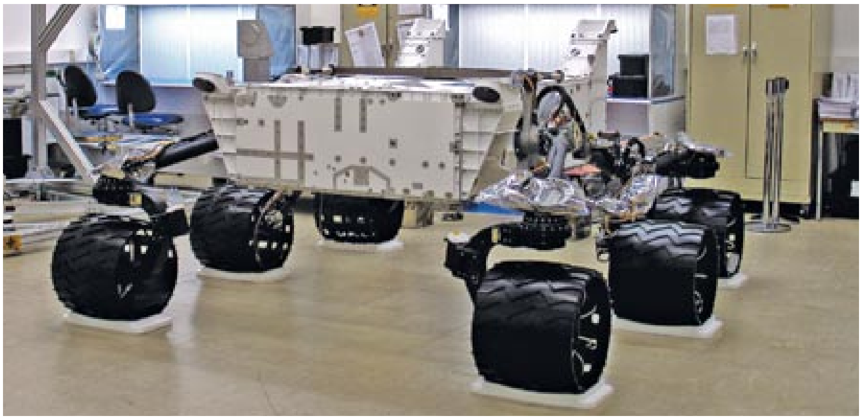
Space Sticker Shock

The laws of physics are easy; it's economics that vexes NASA BY GEORGE MUSSER

In October, NASA announced that the $1.5-billion Mars Science Laboratory (MSL), a car-size rover planned for launch this fall, had become the $2-billion Mars Science Laboratory. When first conceived, it was the $650-million Mars Science Laboratory. Even more egregious is the $1-billion-make-that-$4.5-billion James Webb Space Telescope, successor to Hubble. Complex projects of any kind—not only in the space program—always cost more than anticipated. But experts say the agency could—and needs to—do better.

"We have to accept the fact that there will be some cost overruns, but I think a lot of it could be mitigated if we managed things differently," insists Sushil K. Atreya of the University of Michigan, a member of the MSL team and of a National Research Council (NRC) panel that evaluated NASA's planetary exploration program last year.

The panel's prognosis was bad. Between ballooning costs and shrinking budgets, NASA has had to delay or cancel many projects. Some worry that Congress may never trust it with ambitious future projects, such as bringing samples of Mars back to Earth for analysis, which scientists feel is ultimately the only way to tell whether the Red Planet was once inhabited. "As a result of the disregard for cost control, I'm now pessimistic that Mars sample return can ever happen," says Alan Stern, who was NASA associate administrator for science until resigning last March in protest at the agency's handling of MSL overruns.



PRICEY PROBLEMS: **Mars Science Laboratory rover has had troubles with actuator motors for its wheels and other systems. Fixing them is one reason project costs have skyrocketed.**

COURTESY OF NASA/JPL

It is not as if agency officials are unaware of the problem. Every project goes through independent evaluations and sets aside about a third of its budget as "reserves" for contingencies. But this is never quite enough to hold the line. "In an organization run almost exclusively by engineers and scientists, the technical will always supersede the financial," says Humbolt Mandell of the University of Texas at Austin, a former high-level manager for the space shuttle and space station. The competition among project proposals reinforces this inclination; to get funded, projects have to promise the moon (sometimes literally).

Many experts argue that NASA should invest more in technology development. The agency used to have a stand-alone program to invent rockets, power supplies and communications systems that science missions could then pull off the shelf—making it easier to price them out. That program is now gone, and some scientists argue that MSL is one victim. "I think the cost of everything was severely underestimated because they didn't have enough good information, because not enough investment had been made in the technology," concludes Wesley Huntress of the Carnegie Institution of Washington, co-chair of the NRC panel.

Longer lead times could also mitigate overruns. Right now designing a spacecraft takes about a year and a half and 15 to 20 percent of the mission's total budget. "It's rather short," Atreya says. An extra year or more would give engineers more time to nip problems in the bud.

To plug gaps, NASA headquarters should also maintain its own reserves, amounting to maybe 5 percent of the agency's science budget, says the University of Michigan's Lennard Fisk, until recently chair of the NRC Space Studies Board. Otherwise, when a project comes up short, NASA either cancels it (which can be expensive, if a new effort has to start from scratch) or raids another project for the money (which disrupts it, so it will probably end up overrunning, too).

Stern, though, argues that none of the above would have saved MSL. He says that the initial cost guesstimate was unrealistic and that managers failed to scale back the project once they realized it was going to break the bank. "No one ever made any compromises to try to keep it on cost," he maintains. In extreme cases, NASA should hit the abort button, Mandell says: "Putting the absolute kill levels on a program ahead of time and sticking with them will force people to be less optimistic and to build in more reserves."

Some finances, though, are beyond NASA's control. Five years ago President George W. Bush ordered NASA to replace the shuttle but failed to pay the transition costs, forcing NASA to make internal cuts, such as eliminating technology development and delaying projects that were ready to go, which ultimately raised costs. If those who foot the bill expect NASA to make the best use of their money, then it would help if they, too, set expectations in line with resources.