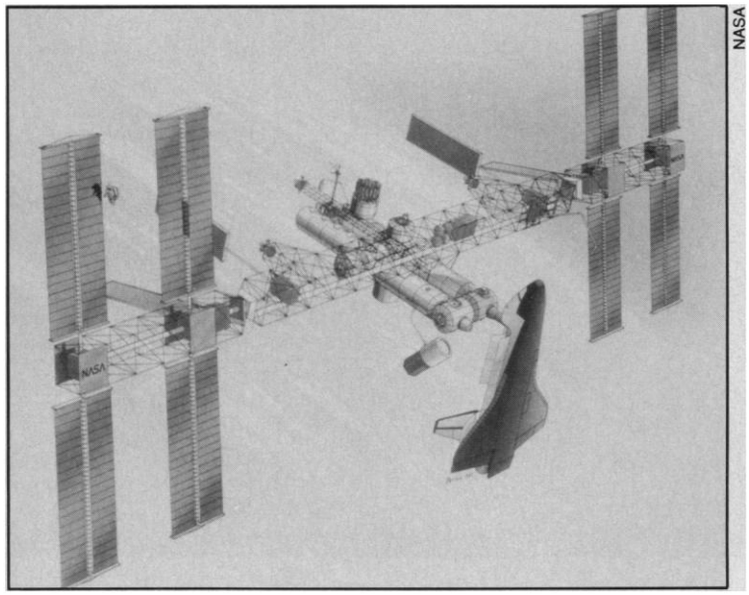
The Space Station Is Losing Friends

Even ardent space enthusiasts are low on patience: the ungainly structure NASA wants to build seems too big, too bureaucratic, and too risky. Is it time to start over?



Good engineering? *On a viewgraph the station looks great—but there's no way to test it before launch.*

WITH ITS ESTIMATED COST NOW standing at some $37 billion, and its purpose as a "permanently manned" orbital laboratory still as vaguely defined as ever, NASA's proposed space station *Freedom* is no stranger to political controversy. Lately, however, the proposal has begun to draw some scathing reviews for its alleged technical shortcomings as well: "The work that's been done to date is crap," says one particularly frustrated space station insider, who asked not to be quoted by name. "It's not even good engineering."

While other critics aren't quite so vehement on the subject, there is nonetheless a widespread perception in the space community that the space station program is rapidly sinking of its own weight. Increasingly, even the space enthusiasts who would like to see it used as a stepping stone to the moon and Mars won't support it. Take Thomas Paine, administrator of NASA during the Apollo moon landings, chairman of the 1986 National Commission on Space, and now a member of a White House committee on the goals and purposes of the space program: "The current space station program is no longer endorsed by most scientists," he declared in a 9 September letter to Martin Marietta chief Norman Augustine, who chairs the committee, "and is delaying, not advancing, the President's goals [for the exploration of the moon and Mars]."

Like many of the other critics that *Science* interviewed for this article, Paine thinks NASA would be far better off if it scrapped its current plan and found some simpler, cheaper, more evolutionary approach to working in space.

What bothers these critics is not just that the station will have to be launched in at least 28 separate payloads aboard the notoriously balky space shuttle, nor that it will have to be assembled and maintained in orbit by astronauts making hundreds of sorties per year in clumsy spacesuits—an issue that only became a top priority at NASA last spring after it was revealed in the *New York Times*. Nor, for that matter, are the critics concerned so much about technical flaws that might turn up in this piece or that piece of the station.

Instead, say the critics, their concern is with the totality of the station: what's going to happen when all the individual systems are finally assembled in orbit. The space station is going to be so big, so complex, and such an enormous leap beyond anything ever done before in space that nasty surprises are almost inevitable, they say. With no space station experience other than the long-fallen Skylab, last visited in 1974, NASA is trying to jump straight to a football field–sized facility that will reliably support human habitation for 30 years—with little chance for the engineers to experiment and learn along the way. "[The space station] has no period as a child. It immediately becomes an adult," says John McElroy, a former deputy director of NASA's Goddard Space Flight Center and now dean of engineering at the University of Texas in Arlington.

Worse yet, say the skeptics, there seems to be no feasible way to assemble and test the station on the ground before launch. Its first end-to-end test will be in orbit—an approach that is all too reminiscent of the fiasco of the fuzzy-eyed Hubble Space Telescope. Former Air Force Secretary and NASA Advisory Council chairman John McLucas put it bluntly: "What can't be tested, can't be trusted."

NASA officials, for their part, stoutly maintain that their space station design is the *right* design. "Early on in the decade we looked at more than a dozen structures" before settling on this one, says William Raney, special assistant to NASA's space station program manager Richard Kohrs. Moreover, he says, the basic design concept has been reviewed and endorsed many times since then by outside groups such as the National Research Council.

"Right" or not, however, the current space station design is now headed for its most thoroughgoing technical examination ever. Starting in November and continuing until the end of December, NASA's own space station design team is planning to conduct the first station-wide "preliminary design review," in which they finally get to put all the subsystems designs together and look for overall problems. Whether the official report will actually admit to any serious problems remains to be seen. But space station insiders speaking to *Science* off the record have pointed out several examples of the "Great Leap Forward" approach that they find worrisome.

■ **Vibrations in the truss.** The truss is the backbone of the station, the 120-meter spar that anchors the four crew modules in the center and that carries the 75-kilowatt solar panels out at the ends. It will be a fairly rigid object, being made as a latticework of stiff, graphite-epoxy rods. But nothing is ever perfectly rigid. The truss can therefore be expected to twist and oscillate in any number of subtle ways, all the while transferring potentially dangerous vibrations into the modules, the solar arrays, and anything else attached to it. So what will happen when the station's 90-minute orbit carries it from

the nightside of the earth to the dayside and the sunlit portion of the structure suddenly starts heating up and expanding ever so slightly? Then there's atmospheric drag, not a trivial matter for something as large as the station orbiting at the relatively low altitude of 400 kilometers: what kind of forces will drag exert on the truss and the sail-like solar arrays? And what kind of vibrations will be set up in the structure when drag brings the station into lower orbit, as it will, and the crew has to fire the built-in thrusters to regain altitude?

Since there is no way to reproduce the free-floating environment of space on the ground, the only way to answer such questions is to simulate the station on computers. Very large computers. And since the station will actually have to be assembled in at least 28 stages, with each partial structure flying on its own for a time, that analysis will have to be repeated at least 28 times.

Of course, there's nothing wrong with computer simulations in principle. The problem is that in this case, there's no way to know for sure how accurate the simulations might be because there's no way to test them against reality. No one has ever built a graphite-epoxy structure in space that's remotely the size of this one. Moreover, it's worth remembering that the Hubblespace telescope, quite aside from its optical problems, is plagued by a "jitter" in its solar arrays that all the elaborate analyses done before launch failed to identify.

■ **Thermal control.** Space is often thought of as cold. But in fact, the space station modules are going to be accumulating quite a bit of heat from experimental equipment, people, and sunlight. The trick will be to get rid of it.

The designers' current plan for thermal management calls for air-conditioners and heat exchangers inside the modules to dump the excess heat into pipes full of water, which will then circulate out of the modules and transfer the heat to a second set of pipes carrying a mixture of liquid and gaseous ammonia—a fluid that happens to be extremely efficient at moving heat around, but so toxic that no one wants it anywhere near the crew compartments. This second set of pipes will circulate the ammonia through a pair of fins out on the truss, where the heat will be radiated into space.

The ammonia system is a good example of off-the-shelf design, say those familiar with the program, since a similar thermal management system has long been used on the shuttle. But therein lies the problem. The shuttle system is not only an order of magnitude smaller than what's being proposed for the station, but it can be flushed out and refurbished if necessary every time the shuttle

Engineers Stymied by Chaos

Engineers at the working level of NASA's space station project say they would feel a lot better about their ability to make the station function properly if they thought that the agency's management structure were capable of dealing with large-scale issues coherently. Experience, however, suggests otherwise.

For example, says one project insider speaking off the record, "You can't point to X and say that's a bad design decision, because project managers don't even know what the design *is*." It keeps changing. In the years since the basic configuration was first laid out in the mid-1980s, budgetary reality and the post-Challenger limits on shuttle capacity have forced the station through several major redesigns and a host of minor ones. At any given time there may be dozens of change orders for engineers to keep track of—a situation that might as well have been created to help things fall through the cracks.

Take the issue of weight. The target weight for the completed station is 512,000 pounds, a figure dictated by constraints on the flight rate and lifting capacity of the shuttle. But this summer, when the station team finally started adding up the weight of all the individual pieces, in preparation for the preliminary design review the station is to undergo in November, the answer came up some 150,000 pounds over that target—enough to require at least another four shuttle trips. The result has been a fierce effort to "scrub" the design, to find everything that can be left off or pared down to save weight. The effort has been so fierce, in fact, that some engineers are beginning to wonder if this weight-loss regimen isn't beginning to compromise safety, reliability, and performance.

Exacerbating the chaos of constant retrofitting is the overweight structure of space station management: "The space station is a nightmarishly large, complex project," explains a station engineer, "not because it has to be, but because of history and politics." Former NASA administrator James M. Beggs, who started lobbying for a space station almost as soon as he was nominated for the post in 1981, has freely admitted that the project was largely intended to give the agency's research centers something to do after they got the space shuttle flying. After President Reagan endorsed the station in 1984, the project was accordingly divided among four major centers (Johnson, Marshall, Goddard, and Lewis), each of which then subcontracted most of the actual work to an aerospace company. The estimated cost of the station immediately began to soar. And by 1986, intercenter bickering had fragmented and stalled the project so badly that NASA headquarters was forced to add a whole new layer of centralized authority: the space station management office in the Washington, D.C., suburb of Reston, Virginia.

But then the Reston office developed its own instability. Managers deputized from the field centers would come in, stay a year or two, and go back home. Few of them have wanted to make a permanent move and pay Washington-area housing prices.

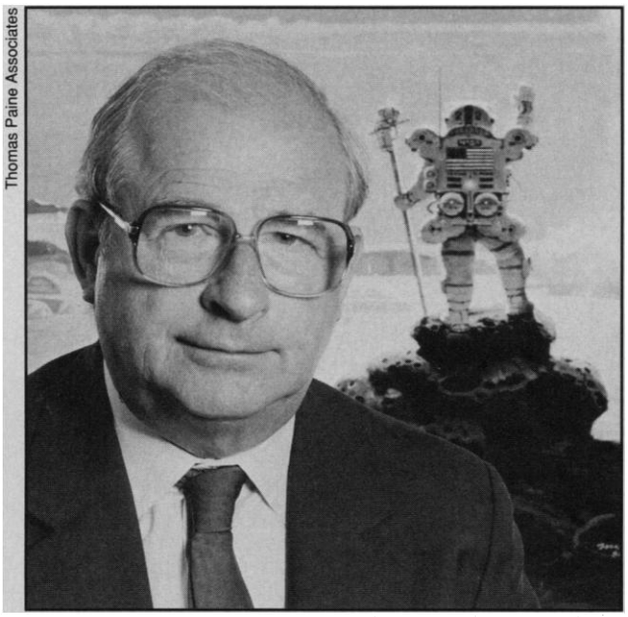
One consequence: Reston is only just now putting together an overall "verification" plan for the space station—the schedule laying out precisely how all the components and subsystems of the station will be tested or simulated before launch to make sure they work as required. Verification is hardly a new concern. Engineers working at the individual subsystem level have been thinking and worrying about it for years. Last year, a National Research Council panel singled verification out as a critical unresolved issue for the station as a whole.* And just this past summer, NASA's own space station advisory committee delivered a stinging critique of the central management's "continuing weakness" and underfunding of this area: "The baseline Verification Plan for Space Station requires considerable corrective action to correct significant deficiencies," wrote the panel, chaired by Martin Marietta president Tom Young.

In fairness, of course, Young's panel also said that the program's new station verification plan does look promising. Moreover, even some of the more skeptical insiders admit that NASA's leadership is trying hard to get issues such as weight and verification under control. But then, says one, the agency has already spent 6 years and $4 billion on this project. "It's amazing to me that the program got this far without understanding issues like weight and testing," he says. "They're only seriously addressing them now." ■ **M.M.W.**

* "Space Station Engineering Design Issues" (National Academy Press, Washington, D.C., 1989).

comes back to the ground. The space station version will have to operate 24 hours a day for 30 years, with no chance of having the station brought into drydock for an overhaul.

What makes this especially worrisome is that ammonia is not only toxic but corrosive, with a nasty habit of eating into valves and seals. So how are the astronauts going to do on-orbit maintenance if and when the system springs a leak? A careful design might eliminate that problem—but then, careful design was also supposed to eliminate the possibility of hydrogen leaks in the shuttle. Or what happens if the ammonia starts seeping into the water loop, and from there into the modules themselves? At 400 kilometers up, there's no stepping out for a breath of fresh air.



Eyes on Mars. *The space station is delaying solar system exploration, says former NASA chief Paine.*

■ **On-orbit housekeeping.** The current design calls for the crew to occupy four modules on the station: one habitat module built by NASA for sleeping, eating, and relaxation; and one laboratory module apiece from NASA, Japan, and the European Space Agency. According to the mockups built so far, these modules will be bright, spacious, and engineered with painstaking attention to such "human factors" as comfort, ease, and privacy. But they are also supposed to remain in space for 30 years. So, even leaving aside the possibility of ammonia leaks, how is the crew supposed to prevent all the thousands of nooks and crannies from accumulating dirt, molds, bacteria, and ever increasing levels of subtle toxins? Imagine a submarine that's been continuously at sea since 1960, says one project engineer, and you'll know what those modules will be like after awhile.

The lesson of all this is not that such problems can't be solved, say project engineers, nor that NASA should never try anything new in space. It's that, when the agency does try something new, it should walk before it runs. After all, the Apollo 11 moon landing in 1969 was a Great Leap Forward, too—but it was preceded by nearly a decade of experimentation in the Mercury and Gemini programs and in Apollos 1 through 10.

This argument seems to be resonating with a good many critics of the station—including a surprising number of NASA veterans and other space afficianados who make no secret of their enthusiasm for President Bush's year-old "Space Exploration Initiative" for exploring the moon and Mars. On 19 September, for example, at a meeting on space station alternatives convened by a nationwide space interest group known as the Planetary Society, participants heard alternative plans discussed by such figures as Buzz Aldrin, the second man to walk on the moon; Maxime Faget, one of NASA's chief engineers on Mercury, Gemini, Apollo, and the shuttle; and Owen Garriott, a crew member on both Skylab and the shuttle. And shortly before that, on 9 September, members of the Augustine committee on the future of space exploration heard yet another alternative plan from Paine.

The specific details of these suggestions varied considerably. But their philosophy was basically the same: break the space station up into smaller, simpler, more self-contained components. One piece might be an orbital fuel depot for deep space probes, for example, while another might be a "man-tended" module full of automated materials science experiments, which would be visited and serviced by space shuttle astronauts only once or twice per year. The European Space Agency already has such a module under development, as does Faget's own start-up company, the Houston-based Space Industries (*Science*, 21 April 1989, p. 282). But in any case, say the critics, NASA should build up its capabilities step by step, so that it can learn as it goes, and so that mistakes and surprises won't be so devastating. And most important, the agency should get something up there quickly, so that it can start getting some real work done in space and so that the country can see something happening.

Without some such restructuring, says Caltech planetary scientist Bruce Murray, president of the Planetary Society and a former director of NASA's Jet Propulsion Laboratory, "a progressively less interesting, more costly, and more delayed U.S. space station program will become irrelevant to the United States...[and] there will be no future space program for the United States of importance."

When confronted with such suggestions, NASA officials quickly point to the serious political obstacles that prevent any real changes to the space station program. For one thing, they say, the agency is now enmeshed in a web of international agreements with Japan and the European Space Agency for their laboratory modules, and with Canada, which will provide a remotely controlled manipulator arm for servicing the station. In this country, moreover, the agency is embedded in a web of legal agreements with its space station contractors.

Nevertheless, the looming deficit may soon force NASA to take a more evolutionary course with the space station. Desperate to meet its deficit reduction targets, the Senate's VA–HUD–Independent Agencies subcommittee recently hacked out $864 million from NASA's $2.451-billion space station budget request; if that cut is upheld in conference with the House, NASA's 1991 space station budget will actually be lower than it was in fiscal 1990. With NASA itself estimating that the completed station will cost some $37 billion by the year 2000—a figure that includes not just hardware, but salaries, facility costs, and launch expenses—it's clear that something has to give.

William Lenoir, the astronaut who is now NASA's associate administrator for both the shuttle and space station programs, admitted as much in recent testimony before House space authorization subcommittee under Representative William Nelson (D–FL): If space station budgets are kept as tight as they now seem to be, said Lenoir, "We would have to go into what I would call architectural redesign"—a major rethinking of the space station.

Another strong push for change could come from the Augustine commission, created by the White House's National Space Council to reexamine the U.S. space program's overall direction and fundamental assumptions. The commission is scheduled to report on 15 December. And members say the space station question is clearly one they cannot ignore.

"If the Space Station Program is in good shape, our independent committee should establish this fact and endorse it," wrote Paine in a 9 September letter to Augustine. "If not, we must say so and recommend timely action."

■ M. MITCHELL WALDROP