Space Science: What's Wrong at NASA

by Robert Bless

In December 1989, after long years of development and delays, the Hubble Space Telescope (HST) is scheduled to be carried into orbit by the space shuttle *Discovery*. The telescope is the most ambitious — and expensive — scientific satellite ever constructed by the National Aeronautics and Space Administration (NASA). Its 2.4-meter-diameter mirror is the world's most nearly perfect astronomical mirror. Above the blurring effect of Earth's atmosphere, the HST will be able to detect celestial objects five times farther away than can be observed by the most powerful ground-based telescopes, and will produce images that are roughly 10 times more detailed than conventional images. In the words of Charles Pellerin, NASA's director of astrophysics, "It's going to blow people's socks off."

Despite the expected rewards, however, the story of the HST is also the story of what's wrong with how NASA conducts space science. Experience with the project has revealed three particular policy areas that render scientific programs less effective and more costly than they ought to be. These are overreliance on the Space Shuttle, a predilection for big projects, and poor management.

The nation is now debating long-term goals for the U.S. space program. Should we send a manned mission to Mars or establish a manned base on the moon? Should we build a space station, and if so, how big should it be and what should it be used for? These are important issues — the government needs a well-planned, coherent strategy to guide future ventures in space. But the problems created for space science by current NASA policies can be addressed immediately, and solving them will do much to advance research even without spending more money.

Getting Off the Bus

Since the *Challenger* accident in January 1986, most people have come to accept what some members of the space science community had been saying all along: that NASA committed a major mistake in making the shuttle the only launch vehicle in its stable. The shuttle can never be a space "bus," as the agency advertised, with the reliability and low cost this implies. Nor is it prudent to risk the lives of astronauts in order to launch satellites that can just as well be lofted into space by unmanned rockets. The recent resumption of shuttle flights should not blind us to these realities.

With the shuttle as the main avenue to space, scientific missions have had to be tailored to its requirements and capabilities. Science has often proved the loser. For one thing, the orbiters can't fly very high, which limits a satellite's altitude. The HST will orbit about 370 miles above the Earth. This is nearly twice as high as most shuttle flights, but our planet still blocks about half of the sky from the telescope's field of vision. Coupled with other operational constraints, this means the telescope can gather data only about one-third of the time — no better than ground-based telescopes. By comparison, the smaller International Ultraviolet Explorer satellite, boosted by a Delta rocket into geosynchronous orbit some 22,000 miles above the Earth, can observe the heavens 85 to 90 percent of the time.

A smaller satellite in a geosynchronous orbit is also likely to require simpler operational systems, since the satellite is directly visible to a single ground station 24 hours a day. This makes control far easier, especially for real-time operations. By contrast, NASA now intends for messages to be relayed to and from satellites in low orbit via the Tracking and Data Relay Satellite System (TDRSS), which has two communications satellites in geosynchronous orbits. In some cases this will work fine, but TDRSS is a very limited resource. The HST and other scientific satellites that must send large amounts of data can expect access to the system only about 15 to 20 percent of the time. This means that real-time operations will be possible only rarely, and that some kinds of celestial observations requiring high data rates will be made more complicated or even compromised. In addition, the Defense Department now has priority for the use of TDRSS, and this may reduce its regular availability to civilian programs.

NASA has tried to make some of the shuttle's capabilities seem like advantages. For example, the agency touted the opportunity to be able to repair or refurbish satellites, either in orbit or by bringing them back to Earth. As it turns out, though, this capability may prove of dubious benefit for the HST, and probably for most other spacecraft as well.

The HST was planned to be the first of a new breed of scientific satellites, with a lifetime of about 15 years, far longer than usual. It was to be built largely of "black boxes" — independently mounted, easily replaceable modules containing equipment that performed individual functions. Every 2 or 3 years the telescope would be brought into the shuttle's cargo bay, where astronauts would replace any ailing boxes, and every 5 years or so astronauts would haul it aboard for a trip back home. After about 6 months of maintenance, the HST would return to orbit via the Shuttle. The HST's longevity, made possible by such regular attention, justified its great cost, estimated in the project's early days to be about $500 million. Or so NASA argued to Congress.

However, when agency engineers took a closer look at plans for refurbishment — which didn't happen until several years into the project — they found that returning the satellite to Earth was prohibitively expensive. Shuttle launches would be more expensive, by roughly a factor of 10, than estimated. It would be necessary to maintain extensive maintenance facilities and a large inventory of electronic, mechanical, and thermal components. And it would take much longer than 6 months to do the job. When it became apparent that the cost of ground-return refurbishment would approach the cost of building a second telescope — and not about $10 million as NASA had told Congress — the idea was abandoned.

Only refurbishment in orbit is now planned, but this won't be as useful or affordable as claimed, either. The HST's original design called for more than 100 replaceable boxes. However, the refurbishment budget fell victim to several raids when the overall program encountered financial difficulties. The number of boxes once dropped to about a dozen, but it has since increased to about 30. These boxes — along with thousands of other items, including spare parts, test equipment, technical drawings, and manufacturing and test records — must be cataloged and stored, and manufacturers must be kept under contract to maintain their knowledge of the subsystems in case they are ever needed.

If a box fails that is critical for the HST's survival — for example, the solar arrays, batteries, or communications receivers — NASA says it will take about a year to be able to mount an emergency shuttle mission to repair the satellite. Failures that reduce the observational capability of the telescope but don't threaten its life will have to wait for a scheduled maintenance flight. NASA now plans such flights every 5 years, though the agency has "reserved" a contingency shuttle flight during the first 5-year period. Of course, most of the support people needed to operate the HST must be kept on the program even when the satellite is inoperative or working at limited capacity.

During refurbishment flights, scheduled or emergency, the shuttle will have to carry enough fuel for two attempts in order to maximize the probability of a successful rendezvous with the telescope. That extra weight, combined with the bulky complement of replacement boxes, will likely mean that no other payload can be carried.

Thus, all of the launch and operational costs should effectively be charged against the HST. Using a conservative price tag of $250 million per shuttle flight, two or three launches would about equal the price of building a second telescope. However, NASA's Office of Space Science and Applications (OSSA), the agency's science arm, has traditionally been little concerned with launch costs. Since the shuttles are handled by another part of the agency, and hence paid for from a different budget, OSSA seems to consider them as essentially "free."

Not to be overlooked, either, is the chance of damage to the telescope during refurbishment. At roughly 12 tons and 15 by 43 feet in size, it is almost as big as the shuttle's cargo bay. Working in space is no easy matter, and docking the satellite in the shuttle will be a complicated and risky endeavor. In mock deployments of the HST at NASA's Johnson Space Center, astronaut Steve Hawley has reported that he achieved "a comfortable amount of clearance between the telescope and the orbiter. When I say comfortable, I mean a few feet or so."

Big Projects, Big Problems

NASA favors large projects for a number of reasons. They are seen to represent a natural evolution in the maturity of a particular scientific field or in the development of technical capability; such arguments were used to justify the shuttle and the space station. Large projects also afford vivid public relations opportunities, and many observers note that the agency usually can sell Congress a billion-dollar project about as easily as a $300 million project.

The HST is undoubtedly a big project. Planning began in earnest in 1971, and construction contracts were awarded in 1977, after Congress finally approved funding. Launch was originally intended for late 1983, but it kept slipping. The date had been set for October 1986 when the *Challenger* exploded. However, the accident probably did not appreciably affect the HST's ultimate launch, since many project participants agree that the telescope was unlikely to have been ready as scheduled. When the HST finally reaches orbit, the project will have cost a little over $2 billion, not including launch costs.

One drawback of large projects is that they generally take longer from conception to the delivery of spacecraft to orbit. This means the technology becomes outdated. Sometimes this isn't a problem: for example, many types of power supplies built 15 years ago are still perfectly adequate. But in areas of rapid technological development, such as computers, the consequences can be great. The two primary computers on the HST are based on technology now considered obsolete — indeed, they are not as powerful as today's low-priced personal computers. The limited computer memory in which to store commands will create significant problems in operating the satellite. Obviously, no spacecraft has ever been launched replete with the very latest technological marvels, but shorter lead times provide the best chance for flying the best equipment.

Long-term projects may also sacrifice scientific flexibility. Science changes rapidly, and the nature of questions that drove the design of a particular instrument might have changed by the time a satellite is ready to launch. Often, payloads can be made sufficiently versatile to avoid such problems. Indeed, this is likely to be true for the HST. But there is little question that some capabilities not now present would be designed into the telescope if it were being built today.

A long development period results in considerable turnover in personnel. Wondering if launch will ever occur, people become discouraged and leave, or are wooed away to more promising programs, or finally retire. This is true at all levels of the project. For example, since 1977 there have been four HST project managers at NASA's Goddard Space Flight Center and five at Marshall Space Flight Center, which developed the HST. NASA's Headquarters has seen about half a dozen HST program managers come and go. Maintaining continuity and project "memories" — vital factors in ensuring smooth, coordinated progress — is difficult under such circumstances.

Long projects are particularly difficult for researchers in universities. Graduate students are able to participate only in small bits of the program, and rarely have the satisfaction of seeing it come to fruition. Young professors, who have only 5 or 6 years to establish their credentials for tenure, are understandably wary of becoming involved in something that promises no scientific return for a decade or more. Even senior professors must ask themselves whether a lengthy and time-consuming commitment as an actively participating investigator is compatible with their responsibilities to teaching, to students, and to departmental and university affairs, not to mention research.

If university faculty and students are to remain involved in space science projects, the environment must be made more attractive. Otherwise, future space scientists may well receive all of their training at NASA Centers or in industry, which will deprive the field of much of the diversity and innovation that nurtures it.

The scientific disciplines served by large projects may also suffer because of long dry spells in data collection. Once a large project has begun, NASA usually feels, not unreasonably, that it cannot afford to put additional money into that branch of astronomy. For example, the HST will carry instruments that analyze ultraviolet light. Therefore, NASA has not committed any other substantial funding to research in this area. Only because of the remarkably long life of the International Ultraviolet Explorer, launched in 1978 and still working, have astronomers had a continuing flow of spectrographic data. By pouring resources into large projects, prospects for the immediate future are mortgaged against ambitious hopes. The gamble may pay off — but it could also jeopardize the health of the science.

Who's in Charge?

NASA once had a reputation for sound management. But if this were ever really true, it is true no more. Indeed, the Rogers Commission identified a host of serious management flaws during its investigation of the *Challenger* disaster. In the case of the HST, a variety of management problems plagued the project from its inception, and contributed to making the satellite cost perhaps two or three times more than originally estimated.

For one thing, the project regularly found itself short of funds toward the end of the fiscal year, which meant that the solution of various problems or the construction of certain equipment had to be delayed. This produced a huge "bow wave" of deferred problems. As a project advances, the options narrow and the right people may no longer be available, and it is almost a fact of scientific life that the longer problems are put off, the more they cost to fix.

Perhaps the greatest management problem, however, arose from the project's organization. In an unusual move, NASA gave two space flight centers — Marshall and Goddard — major management roles. Marshall had overall responsibility and was to oversee construction of the telescope and the spacecraft. The Perkin-Elmer Corporation would build the telescope, and the Lockheed Corporation would build the satellite as a well as assemble all the components into a working observatory and carry out an extensive testing program.

Goddard, reporting to Marshall, was to be responsible for construction of the scientific instruments and the ground system for operating the HST. Goddard contracted work on the ground system to TRW. The center also contracted with a consortium called the Associated Universities for Research in Astronomy (AURA) to form the Space Telescope Science Institute, which would manage the observatory's science programs and serve as the interface between the HST and the international astronomical community. Some of the satellite's equipment was to be built by the European Space Agency, which would be guaranteed at least 15 percent of the telescope's viewing time.

On paper, such fragmented organization may have seemed a reasonable approach, given the project's size and complexity.

But in fact it proved cumbersome and led to significant difficulties. Differences in institutional styles between Goddard and Marshall quickly became apparent. For example, they effectively adopted different approaches to verifying that work was done properly — Goddard usually wanted to conduct performance tests, whereas Marshall was more willing to accept a "paper audit" as evidence — which often left project participants confused when it came to planning their work.

The two centers also engaged in turf battles, and an "us against them" attitude developed that reduced project efficiency even further. For example, Goddard officials tried to make all communications between the groups working on scientific instruments and groups in other parts of the program flow through Goddard, even though its HST staff lacked the manpower or capability to serve as a pipeline.

Because management was so diffuse, the responsibility for systems engineering — that is, making sure that all the HST's components performed together smoothly — was never clear. Not until it became apparent to everyone that the HST project wasn't making serious progress toward completion, and in fact was in jeopardy, did NASA Administrators begin to pay serious attention. In 1983, NASA finally assembled a group of engineers at the agency's headquarters and made them responsible for directing the development program and resolving critical problems. They were also given power of the purse, so the group had real clout.

Communication difficulties contributed to the project's slow progress, especially during the first half-dozen years. Fragmented management and the fortress mentality that developed helped create this problem, but more subtle and pervasive factors made communication across groups and organizations even harder. For example, messengers with bad news were definitely not welcome, particularly at Marshall, and anyone reporting problems was often held responsible for having caused them.

Thus, quarterly reviews presented by project participants to Center Directors and officials from NASA Headquarters were often designed to give the impression that everything was going well, that any problems were well understood and being solved, and that schedules were being met. However, conversations among participants in the hallway or over a beer often revealed drastically different pictures. Not having accurate knowledge about where the project actually stood and what areas needed attention prevented NASA Administrators from intelligently making tradeoffs in allocating development dollars.

Learning from Experience

After the HST reaches orbit and begins sending back exciting new images of the universe, it may be tempting to put aside the problems encountered along the way. That would be a mistake, for only if NASA recognizes the problems caused by its current policies will space science regain its lost vigor. The 20 percent of NASA's budget that historically has gone into space science — now about $4 billion a year — should be sufficient to carry out an exciting program, if it is planned well and carefully executed.

First, the shuttle must be reserved for those missions that absolutely require manned operations. Otherwise, expendable launch vehicles, selected to meet the orbital requirements of the satellite as closely as possible, should be used. NASA does in fact plan to launch some satellites using expendables, but it remains to be seen how vigorously this option will be pursued. For example, the Advanced X-ray Astronomy Facility, a large telescope scheduled for the mid-1990s, is still slated to be launched by shuttle and refurbished in orbit.

NASA should explore ways by which the lifetimes of scientific satellites can be maximized without resorting to extensive orbital refurbishment. There may be a few cases in which simple maintenance by shuttle-borne astronauts would be worthwhile. (Note that this does not mean the satellites themselves should be launched by shuttle.) For example, an instrument with infrared detectors cooled by liquid helium might run out of coolant long before the end of a satellite's useful life. It might be possible to develop a method for replacing the coolant reservoir. Of course, this benefit must be balanced against the orbital limitations imposed upon the satellite by the requirement of a shuttle rendezvous.

A more realistic and generally applicable strategy for adding years to scientific missions is to build a second spacecraft that would be launched when the first one failed. Since it costs less to build two satellites at the same time than it does to build them separately, this could well prove a viable alternative to shuttle refurbishment.

A variation on this approach would have NASA return to its early practice of building a prototype satellite to test before building the final spacecraft. When needed, the prototype could be modified as required and sent on its way.

NASA should also begin to think smaller. Huge space-science projects are justified if they are the only way to obtain crucial scientific data. On the HST, for example, several of the instruments do not actually require the sophistication of the telescope's large mirror in order to fulfill most of their goals, yet their presence has added to its size, complexity, and cost. Launching a series of more modest satellites carrying specialized instruments might well have provided greater rewards. The steady activity would also have kept engineers and scientists productively busy.

Only one NASA space flight center should be given responsibility for the development of any scientific project. (Indeed, one way of judging whether a project is too big is if it requires more than one Center for its development.) Clear lines of authority and responsibility must be established from the start in order to prevent organizational confusion. Systems engineering groups — staffed by engineers and the ultimate users, scientists — must also be organized from the program's outset. Managers must be aggressive in their efforts to learn what is going on in their groups. And officials in NASA headquarters must actively pursue their oversight role in order to better understand budgetary matters as well as to prod the project most effectively.

In planning its scientific project, NASA must assess the real costs of each venture. This means including vehicle and launch costs. In this regard, the agency should begin a long-term effort to reduce costs by developing better ways of building spacecraft, instruments, and ground systems. Too often, practices have continued simply because "that's the way we have always worked."

People with new ideas must be encouraged and rewarded. This is difficult under the best of circumstances. But NASA, like many other federal agencies, has suffered steady manpower reductions, which have forced the agency to farm out more of the construction of instruments and spacecraft to private companies. Not only is this economically questionable; it also means that the expertise developed as a consequence of the job may not be available to NASA in the future. This problem is magnified by the fact that government salary scales have not kept up with the private sector, and the agency is facing increasing difficulty in attracting the most talented and experienced people.

But perhaps the most fundamental issue to be faced is the question of whether NASA should have a space science program at all. Would science be better served if an independent organization took over most of the functions of the agency's Office of Space Science and Applications?

For some space scientists, the answer is yes. An independent space science agency could contract for launch vehicles with NASA or one of the private companies now emerging, and could even arrange with NASA for manned support on the relatively rare occasions that it is needed.

From its earliest days, NASA has been oriented not toward science but toward huge engineering projects, usually involving human activities in space. Its three largest projects — the Apollo program, the shuttle, and now the space station — were undertaken for technological or political reasons, not for their scientific potential. But in selling the shuttle as an all-purpose launch vehicle, NASA forced all space science missions to use it and there is a real danger that the same thing will happen with the space station.

Just this point was made in a report on the space station by the National Academy of Sciences in 1987: "It is important that space science not be conformed, made hostage if you will, to the space station and the shuttle." Indeed, the Academy's Space Science Board concluded in a 1983 report that there would be no scientific need for the space station for at least the next 20 years.

Critics of an independent space science agency often argue that space science would never be funded on its own behalf, and that it exists only because it is a small part of NASA's mission. But this isn't totally convincing. Indeed, it may be that just the reverse is true — that in the minds of many laypeople and perhaps even in the halls of government, science to a considerable degree justifies the larger program. For example, polls conducted during the recent presidential election indicate that space science was of significant interest to a large majority of citizens. In any case, however, a public discussion of the role that space science plays — or should play — in NASA would likely prove useful.

The U.S. space program, now emerging from a period of relative inactivity, is poised for a fresh start. Coupled with the beginning of a new administration, this is an opportune time to reshape NASA's policies. If we proceed with business as usual, we will lose a golden opportunity to inject renewed vitality into the space sciences.

Recommended Reading

Walter A. McDougall, . . .*the Heavens and the Earth: A Political History of the Space Age.* New York: Basic Books, 1985.

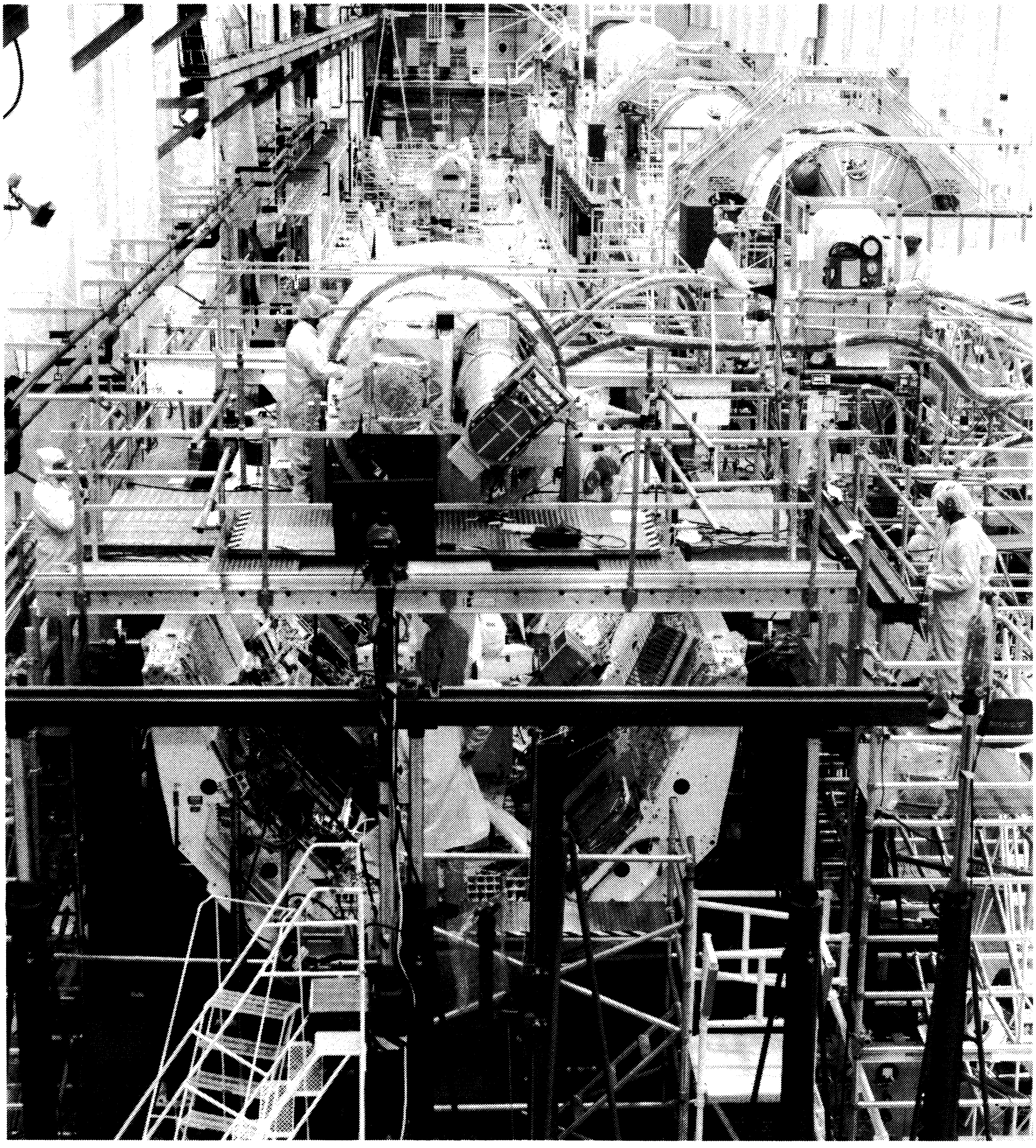
National Commission on Space, *Pioneering the Space Frontier: The Report of the National Commission on Space.* New York: Bantam Books, 1986.

National Research Council, *Report of the Committee on the Space Station of the NRC.* Washington, D.C.: National Academy Press, September 1987.

Robert Smith, *Shaping the Space Telescope: The Interpenetration of Science, Technology, and Politics.* New York: Cambridge University Press, 1989.

National Research Council, "Assessment of the Scientific Value of a Space Station." Report of the Space Science Board, National Academy of Sciences, Washington, D.C., 1983.

This article originally appeared in Issues in Science and Technology (Volume V, Number 2: Winter 1988-89) and is reprinted with permission of the publisher.



Engineers and scientists are shown working in a clean environment on Spacelab-2 during the Mission Sequence Test in the Operations and Checkout Building at Kennedy Space Center in July of 1984. Specialized instruments can be seen on the cruciform structure for the 13 experiments on-board a subsequent Shuttle launch.