

Space Telescope: 2 years late, \$1.2 billion and still counting

As the National Aeronautics and Space Administration set off on its 25th year on 1 October, it faces what many consider its severest test: whether it can manage to correct the course of its Space Telescope. Hailed as "the single greatest advance in optical astronomy since Galileo's telescope" and "the most important astronomical happening for the 20th century," Space Telescope has been haunted from the outset by technical flaws and managerial foul-ups. Even if all goes according to NASA's much-revised plan, this unique observatory, once scheduled for launch in 1984, will be at least 2 years late and cost as much as \$450 million to \$500 million more than expected. At NASA's new estimate of \$1.2 billion, the Space Telescope, when it is at last placed in orbit sometime between June and December of 1986, will be one of the most expensive pieces of scientific equipment in US history.

The schedule delays and cost overruns were explained in agonizing detail last June before the House Subcommittee on Space Science and Applications by officials of NASA and the two main contractors, Lockheed Missiles and Space Co. and Perkin-Elmer Corp. In a remarkable *mea culpa*, NASA administrator James M. Beggs admitted that the agency and its contractors "seriously underestimated" the technical complexities of the job and adopted a "success-oriented" construction plan that virtually guaranteed there would be few or no spare parts, acceptance tests and design changes. Neither NASA nor the contractors had the funds or the staff to dig into the roots of the problems, said Beggs. Moreover, communications among the contractors, their subcontractors, NASA headquarters and the two space-flight centers involved in the program, Marshall and Goddard, were sporadic and often guarded to avoid revealing any embarrassing technical glitches or, as the Pentagon would have it, any sensitive optical technologies. As a consequence, almost everything that could go wrong invariably went wrong.

Space Telescope, Beggs informed members of Congress, is "the toughest

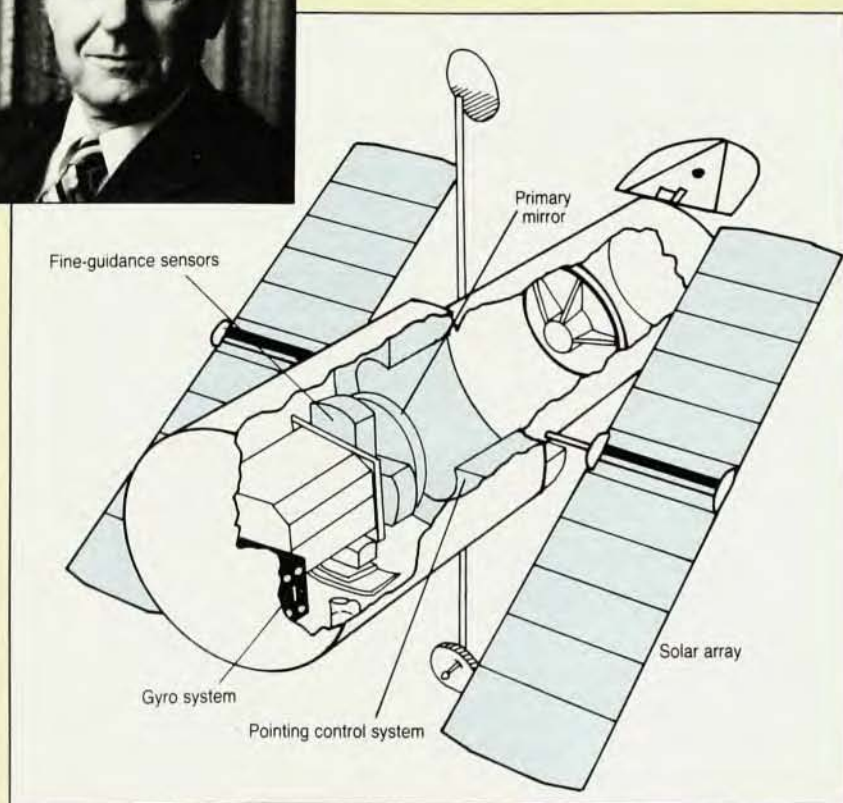
job NASA has ever tried to do." The crown jewel of NASA's astrophysics program, it was recognized from its start in 1977 as an exciting scientific and technical challenge that would extend the state of the art in optics, electronics and aeronautical engineering. First suggested by Hermann Oberth in the 1920s, it was advanced in 1946 by Princeton's Lyman Spitzer, whose voice carried great weight among astronomers during the National Academy of Sciences survey that called for such a facility in 1972. In that report, astronomers ordained that it should not be just another satellite telescope but an ultramodern observa-

tory, capable of a quantum leap in star gazing over even the 200-inch Hale telescope atop Palomar Mountain.

Orbiting 320 miles above the Earth, unaffected by the absorption and scattering of the atmosphere, Space Telescope would have a "seeing" capability of point sources 50 times fainter and 7 times further away, increasing the volume of space now visible by a factor of 350. Its 2.4-meter fused-silica mirror, though modest by terrestrial standards, will be able to achieve an angular resolution of 0.1 arcsecond, about 10 times better than observatories on Earth, and will eventually stretch the observable spectrum from roughly



Of all NASA projects, says the agency's administrator, James M. Beggs, Space Telescope is perhaps the most difficult and demanding. Some of the technical troubles are identified in the accompanying diagram.



1000 angstroms in the ultraviolet to 1000 microns in the infrared, a range that is mostly absorbed by the atmosphere. Photons will feed into five newly devised instruments—a photometer, two spectrographs, a wide-field planetary camera and a faint-object camera, each with its own science team and principal investigator (PHYSICS TODAY, April 1982, page 46).

To realize this, Space Telescope needs unprecedented accuracy of its optics, stability of its structure and precision of its pointing mechanism. Not content with such requirements, NASA wants Space Telescope to work for 15 to 20 years and has designed it so that the instruments and other parts can be repaired or replaced in orbit by astronauts or brought back to Earth by shuttle for major work.

Accessible for change. In addition, Space Telescope will be linked to the ground at Goddard by NASA's two new Tracking and Data Relay Satellites in geosynchronous orbit, where they are visible about 85% of the time. But because the satellite will be engaged in other missions as well, it will be available for communication on Space Telescope business only 20 minutes on each orbit. Even so, this is an improvement. Instead of sending data home in spurts to a scattering of ground stations as previous astronomical satellites have done, Space Telescope will store the data on board for relay in a nearly continuous stream through the satellites. The real-time, interactive capability and the option to change instruments make Space Telescope enormously attractive to astronomers. It also suggests to the astronomy community that it serve as the prototype for a series of future space observatories.

Right now, though, NASA is chagrined about its handling of the Space Telescope. While no single event caused the development delays and cost run-ups, Beggs told Congressmen, "we should have seen them coming. Good management recognizes troubles early and takes appropriate actions. We underestimated the time, money and people it would take to deal with the difficulties and uncertainties, which were inherent in the program from the beginning but went unrecognized."

The management problems are in part the legacy of the 1970s, when NASA's budget stringencies led to skimping on parts and people for the shuttle, Landsat D and space science programs. Not surprisingly, massive overruns occurred when troubles developed and schedules slipped. In the case of Space Telescope, Beggs explained, "in addition to the technical challenge, we introduced an unusual management structure," with responsibility for developing scientific instruments and post-launch operations given to

Goddard and responsibility for spacecraft engineering to Marshall, which also served as "prime contractor." This division led to an abundance of territorial rivalries and virtually no end-to-end systems integration. At NASA headquarters in Washington, the Office of Space Sciences and Applications had five directors in six years. "With so many people going through revolving doors," C. Robert O'Dell of Rice, project scientist for Space Telescope for most of its development cycle, said in an interview, "it was inevitable that they never got a proper education about the program."

When Beggs was informed in November 1982 that Space Telescope was falling way behind schedule at the rate of one week every month, that designs were being changed and that Congress would have to provide more money, he ordered Samuel W. Keller, NASA's deputy associate administrator, to organize a "Tiger Team" to conduct an independent review of the program. Not only was the management set-up at Marshall and Goddard "deplorable," Keller reported, the situation at Lockheed and Perkin-Elmer also needed "immediate attention." Says Keller: "Nobody had a tight grip on the whole project or, for that matter, any of its parts."

Trouble shooting. Shortly thereafter, Congressional investigators were informing the House Appropriations Committee that NASA headquarters and the telescope's lead center, Marshall, had failed to keep close watch on the contractors. Officials at both places admitted to the Congressional team that they assumed Lockheed and Perkin-Elmer would perform the way NASA had usually worked with large aerospace companies—without detailed supervision. NASA and Congressional investigators agree on the technical problems that have caused long delays, increased costs and in some cases still threaten to impair the most effective operation of Space Telescope. The components of concern:

► The optical telescope assembly, with its 96-inch primary mirror, Koesters' prisms, fine-guidance sensors and alignment latches. The centerpiece of Space Telescope, this assembly has been the most troublesome. Fabricating and polishing the primary mirror by Perkin-Elmer was considered so difficult that the company and NASA called on Eastman-Kodak to develop a backup mirror in the event the original one suffered a mishap. The mirror must be accurate to less than a millionth of a centimeter over its entire expanse, and the associated optics have to be stable despite the stresses of launching and the wide range of temperatures in space so that it is kept aligned within 0.007 arc second while

locked on a 14.5-magnitude star for up to 24 hours—a precision that could enable it to "see" a row of dimes on Michigan Avenue in Chicago from the White House. While this unprecedented mirror took longer than expected to prepare, O'Dell and other astronomers now consider it "superb," actually exceeding the original specifications for visual and ultraviolet images. But after 15 months in a "clean room" at Perkin-Elmer, dust settled on the mirror, covering about half of 1% of the surface, which is considered "acceptable" by the standards of telescopes on Earth and, if it does not increase, should not significantly affect the search for faint objects near bright stars, according to O'Dell. To safeguard the mirror against further dust accumulations, Perkin-Elmer proposes to blow an inert gas such as molecular nitrogen across it and vacuum the residue. A potential problem of molecular contamination of the mirror's coating should be correctable by vacuum baking of the spacecraft's components. The first of four fine-guidance sensors—interferometric devices that are essential to aiming the telescope by way of two known guide stars—is an engineering model that is to be subjected to proof testing in November. If those tests show the sensors to be faulty, NASA officials are likely to assign the job to Lockheed and use Perkin-Elmer as a subcontractor, though NASA also is considering whether to accept a reduction in the pointing accuracy to 0.012 arc second—at least until an improved fine-guidance system can be installed later when Space Telescope is brought home for servicing. Another problem with the assembly involves 27 latches that maintain the alignment of sensors and scientific instruments. In tests, the latches tended to chafe, preventing an exact fit. But when the coating was changed from aluminum oxide to tungsten carbide cobalt, the latches worked well. Later, when imperfections appeared in the Koesters' prisms, essential for gathering interferometric data, NASA became alarmed once again. Now the prisms have been corrected for greater precision, but a backup system is being studied at Johns Hopkins University Applied Physics Laboratory.

► The pointing control system, with its reaction wheels that are used to maneuver the telescope, the five scientific instruments and the high-gain antenna. When the reaction wheels showed signs of vibrating, which could disturb the stability of the whole 25 000-pound Space Telescope, new bearings were installed by Lockheed. To provide for greater stability, the gyro system underwent improvements at Holloman Air Force Base.

► The solar arrays, which are specified

to yield 4000 watts of electrical power. After some delays, caused in welding the solar cells and fabricating the electronics, the arrays are now undergoing final tests by the builders, the European Space Agency. Another hitch involving ESA concerned the photon detector tube on the faint-object camera, which was unable to withstand vibrations in a stimulated launch test, and had to be redesigned and rebuilt.

Since testifying before Congress in June, Beggs is more confident that NASA and its contractors have gone a long way toward correcting the problems, especially the management troubles. At both Perkin-Elmer and Lockheed, top executives are now responsible for making sure everything comes in on time and within budget. "It will be embarrassing to have to ask Congress for more funds," says Keller.

Costs to science. All systems are not Go yet. A number of critical components need to be developed and integrated into Space Telescope. Among these are the high-gain antenna, in-flight and ground computers and mission operations system that will link Space Telescope with the Space Tele-

scope Science Institute, officially dedicated on 15 June in a spacious brick building in a leafy corner of The Johns Hopkins University campus in Baltimore. The institute, which is administered by the 16-member Association of University for Research in Astronomy, is organized to process proposals by astronomers to use Space Telescope, allocate time for research on it and gather and analyze data beamed back from space (PHYSICS TODAY, March 1981, page 59). The institute already has attracted a few detractors who complain about its growth in staff and its tendency to take on more functions.

Space Telescope itself has been a source of criticism from astronomers. By its lateness, it will miss the voyage around the sun of Halley's Comet, which will begin approaching Earth in November 1985 for the first time in 76 years and come closest in February 1986. By its astronomical cost, Space Telescope has forced NASA to cut back on the Solar Optical Telescope (PHYSICS TODAY, September 1982, page 17) and to raise questions about the starting time of the Advanced X-ray Astronomical Facility. —IG

children with the intellectual tools needed for the 21st century." After a 17-month study of the situation, the commission, which was organized by NSB, the policy-making body of the National Science Foundation, put together an ambitious plan it claims is designed to make science and math education in US schools the best in the world by 1995.

In September's second examination of the problem, *High School: A Report on Secondary Education in America* (published by Harper & Row), Ernest L. Boyer, president of the Carnegie Foundation for the Advancement of Teaching, recommends a somewhat different strategy—a two-year science sequence that includes basic courses in the biological and physical sciences "taught in a way that gives students an understanding of the principles of science that transcends the disciplines." In addition, advanced science should be available as part of an elective cluster for students who want to prepare for college and careers. "Not all students are budding scientists," Boyer writes, "but becoming a responsible citizen in the last decade of the 20th century means that everyone must become scientifically literate. Having a substantial knowledge of scientific facts and processes, and understanding more about the interdependent world in which we live, are essential parts of the core of common learning."

Sad but true, a 1980 survey by the Carnegie Foundation found that 75% of public high-school seniors reported taking two years of science or less. For most this meant ninth-grade general science or environmental science and tenth-grade biology. Chemistry and physics attract only 37% and 22% of high-school students, respectively.

Better courses and teachers. The NSB Commission admits that promoting the

Will school reforms follow the reports?

What more can there be to say about the sorry state of US public education? Since April, when the government's National Commission on Excellence in Education warned of a "rising tide of mediocrity," the public has been deluged with schemes for reform from educators, politicians and business leaders. Rounding up the usual suspects in the learning crisis is easy enough: the shortage of competent and committed teachers, the decline and breakup of the family that once instilled respect for authority and learning, the distractions of television and pop culture, the conflicting demands on public school systems that are now expected not only to teach but to make up for past and present racial and economic injustice. Coming up with properly financed, acceptable solutions to the complex problems can be far more difficult indeed.

What has been proposed in two new reports issued within two days of each other in September underscores the situation. In *Educating Americans for the 21st Century*, the National Science Board Commission on Precollege Education in Mathematics, Science and Technology gets behind the National Commission on Excellence in Education to push in the direction of rigid prescriptions. Both urge that more classroom time be spent on mathematics and science—at least an hour of math and half hour of science each day

for every child from first through sixth grades, says the NSB Commission, and as soon as 1985 the national requirement for high-school graduation should be a minimum of 3 years of math, including a year of algebra, and 3 years of science and technology, with a term of computer science.

This is essential for updating the old "basics," the NSB Commission argues, because "the nation that dramatically and boldly led the world into the age of technology is failing to provide its own

Percentage of high-school students taking 3 years of science and mathematics

