# The BIG FIX

## *NASA attempts to repair the Hubble Space Telescope*

By RON COWEN

They've rehearsed for more than a year and choreographed their steps more carefully than the most dazzling Broadway production. And on Dec. 1, if all goes according to schedule, the curtain will go up on the most ambitious shuttle mission NASA has ever attempted.

During the 11-day flight, astronauts will attempt to correct the impaired vision of the Hubble Space Telescope and a laundry list of other troubles plaguing the $2 billion Earth-orbiting observatory. In the process, crew members will take at least five walks in space, a record for any U.S. flight.

To practice, four of the seven crew members have spent hundreds of hours floating in water tanks and gliding weights across "frictionless" floors, practicing such tasks as loosening bolts and replacing fuses on mock-ups of Hubble. Not to mention working with the actual replacement parts.

"We're ready. We've got to the right level in our training at the right time," says astronaut Jeffrey Hoffman. "We could go fly now."

Still, he notes, with so many mechanical and electrical components to contend with, there's a chance that something could go horribly awry, leaving the telescope in worse shape than before the mission.

This may explain why Dennis McCarthy, Hubble deputy project manager for flight systems and servicing, sums up his chief concern about the repair mission in a single word: connectors.

Astronauts must unplug and reattach dozens of electrical connectors during the mission, notes McCarthy of NASA's Goddard Space Flight Center in Greenbelt, Md. Many of the connectors feature sets of pins that must precisely align with a set of holes, much the way cables hook up the components of a personal computer. And even though the shuttle crew will have several tools to straighten pins that become bent, the likelihood is that some of the connectors will prove troublesome, he notes.

"If we don't get surprised, if nothing goes wrong, we know we can do any of these tasks in the water tanks," Hoffman says. "But what I also know is that you can get surprised up there [in space]. It's still a very strange environment and things happen that you don't anticipate. And how well we deal with the surprises will determine the success of the mission."

The larger implications of the repair mission have always been clear: If the astronauts succeed in fixing Hubble, it may help restore NASA's battered reputation. But if the shuttle crew fails to correct Hubble's optical and structural flaws, the space agency's low credibility may plummet even further — along with congressional funding for key space science projects.

The stakes seem even higher now than three years ago when engineers first envisioned the repair mission. Recent setbacks have made this a do-or-die mission for the space agency. NASA recently has suffered the losses of the $1 billion Mars Observer spacecraft, which has not been heard from since Aug. 21 (SN: 8/28/93, p.134), and the NOAA-13 weather satellite, rendered useless by a dead battery.

"There's no question it's life in the fishbowl," Hoffman says. "We knew that when we got assigned to the mission. That's part of the whole gestalt of Hubble."

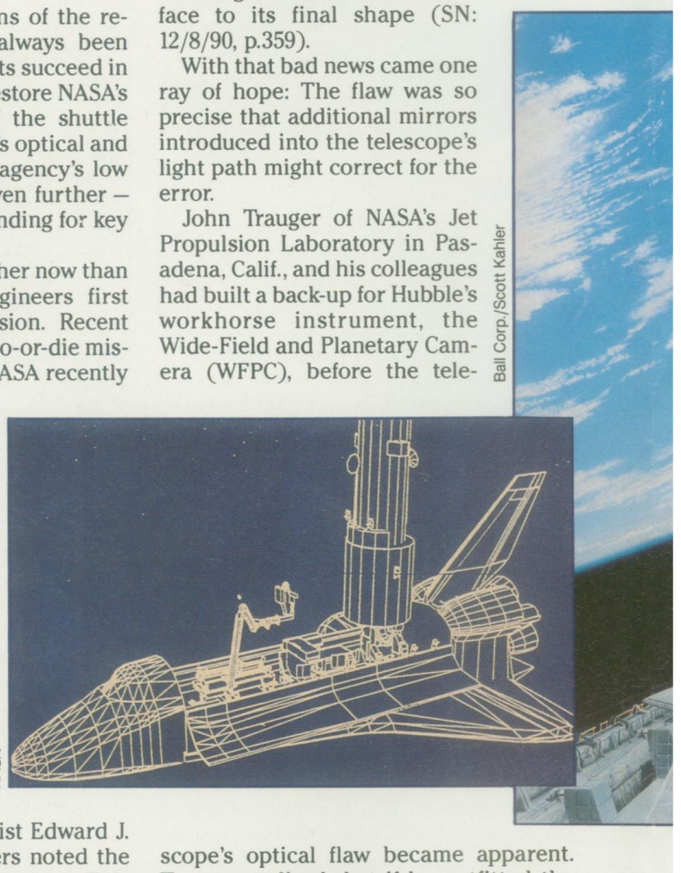
At a press briefing in June, Hubble project scientist Edward J. Weiler of NASA headquarters noted the significance of the repair mission. "This project is going to be in the history books, whether we like it or not, whether as a national disgrace or as a triumph."

The most notorious of Hubble's woes came to light just weeks after its April 1990 launch. Astronomers had long awaited the ultrasharp images that the Hubble Space Telescope seemed poised to offer. But the fuzzy pictures that the craft began radioing back to Earth dashed their hopes. The telescope's primary mirror was hopelessly flawed. Instead of focusing most of the light from faint stars and galaxies into a tight circle with a radius of 0.1 arc second, the mirror spread the concentration of incoming rays. Scientists later discovered that the flaw stemmed from a spherical defect introduced when a contractor ground the mirror's surface to its final shape (SN: 12/8/90, p.359).

With that bad news came one ray of hope: The flaw was so precise that additional mirrors introduced into the telescope's light path might correct for the error.

John Trauger of NASA's Jet Propulsion Laboratory in Pasadena, Calif., and his colleagues had built a back-up for Hubble's workhorse instrument, the Wide-Field and Planetary Camera (WFPC), before the telescope's optical flaw became apparent. Trauger realized that if he outfitted the back-up WFPC with mirrors that had exactly the opposite aberration as Hubble's primary mirror, the camera would still form sharp images.

Other scientists, including the late Murk Bottema of Ball Aerospace and Communications Group in Boulder, Colo., devised a similar fix for three of Hubble's four other instruments. Researchers suggested that if they removed one of the four instruments — phone-booth-size devices that lie parallel to Hubble's optical axis — they could replace it with a similarly shaped compartment mounted with corrective mirrors. These mirrors would intercept the fuzzily focused light



Ball Corp./Scott Kahler



NASA

bounced from the flawed primary mirror before it had a chance to enter any of the detectors. Known as the Corrective Optics Space Telescope Axial Replacement, or COSTAR, this device should sharpen the vision of Hubble's Faint Object Camera, the Faint Object Spectrograph, and the Goddard High-Resolution Spectrograph.

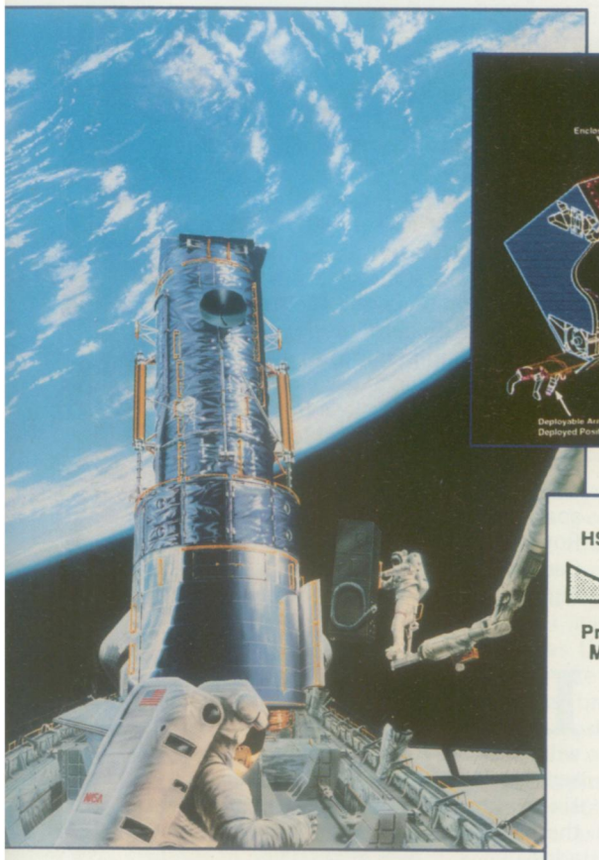
COSTAR, however, has its own downside. The extra mirrors reduce by 20 to 30 percent the light reaching the three instruments, estimates Hubble senior scientist David S. Leckrone of NASA's Goddard Space Flight Center. In addition, COSTAR's presence in the telescope will leave no room for Hubble's fifth instrument, the High-Speed Photometer.

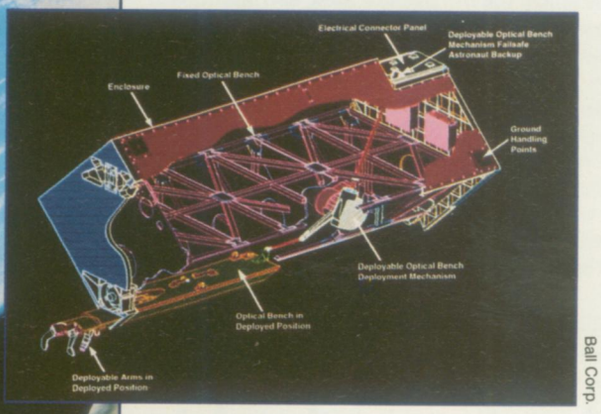
Even without the telescope's highly publicized optical problems, other Hubble troubles now make the repair mission a necessity, Weiler says. Soon after launch, flight controllers discovered that the telescope's pair of wing-like solar arrays that power the craft flutter unacceptably whenever the telescope passes in or out of Earth's shadow. The jitter stems from the rapid heating or cooling that occurs during these times. Although an on-board computer can now direct the orbiting observatory to dampen most of the vibrations, some researchers worry that the solar arrays might eventually snap off (SN: 6/26/93, p.405).

In addition, during the first two years of Hubble's operation, three of the telescope's six gyroscopes, which help point the observatory, failed (SN: 8/10/91, p.86). If one more dies, the telescope won't be able to point accurately enough to do astrophysical observations. In the summer of 1991, a third difficulty arose — problems with a low-voltage power supply in the Goddard High-Resolution Spectrograph (SN: 9/21/91, p.182). Though the device still functions, researchers can't use its highest resolution at short ultraviolet wavelengths.

Altogether, then, four astronauts aboard the space shuttle Endeavour will attempt to repair or replace 11 main components on the telescope. Using a set of some 150 tools, they have logged 368 hours submerged in water tanks simulating repair maneuvers. The team also has rehearsed its moves by pushing model equipment, cushioned by a layer of blowing air, on a frictionless floor that mimics the weightless environment of space. And they have practiced with the actual COSTAR and WFPC instruments they will use in orbit.

"There's no reason to expect that we will get everything done," says Hoffman. "But we're spending a lot of money to go up and rendezvous with the telescope; we shouldn't leave things on the ground that we might be able to do. . . . We'll do the most important things first and, if we have time, we'll do the less important things."





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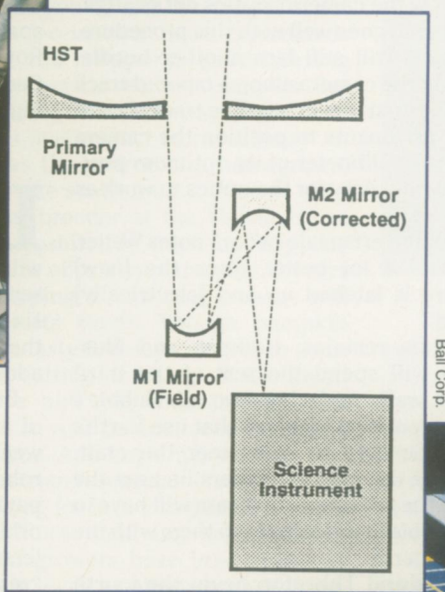

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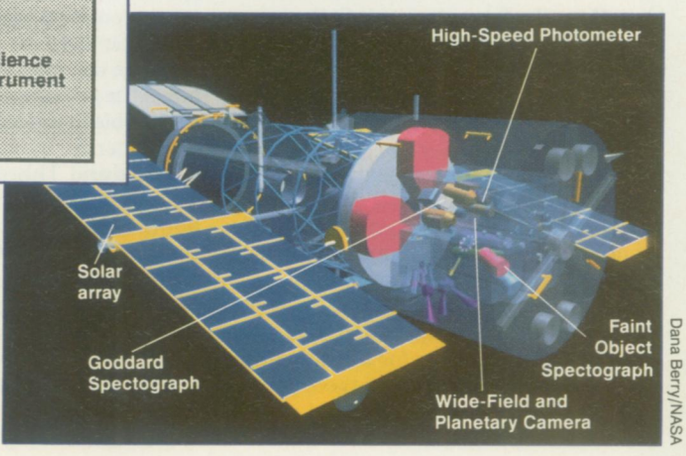
The drama in space will begin in earnest on the third day of the flight, when Endeavour closes in on Hubble and humans get their first detailed look at the telescope in more than three years. The crew will maneuver the shuttle so that the telescope hovers just above its payload bay. Then astronaut Claude Nicollier from the European Space Agency will use the shuttle's 15-meter robotic arm to grab one of Hubble's two grapple fixtures and set the telescope upright onto a ring-shaped support structure in the payload bay. The ring both tilts and rotates to make different parts of the 13-meter-tall telescope accessible for repair.

With Hubble latched securely in place, another astronaut inside the shuttle cabin will use remote control to attach a power cable—an electrical umbilical cord—to the telescope so that Endeavour can



Dana Berry/NASA

*Clockwise from left: Hubble Space Telescope will sit upright in the shuttle's payload bay during repairs. Drawing depicts astronauts installing COSTAR. Cutaway view of COSTAR shows the device's Deployable Optical Bench (DOB), which holds five pairs of mirrors on small mechanical arms. During launch, the arms remain folded; after COSTAR is installed, the DOB will extend into the focal plane of the telescope and deploy its arms to place the mirrors in front of the scientific instruments. Diagram of COSTAR optics shows that mirror M1 intercepts light from the telescope's flawed primary mirror and bounces it to mirror M2, which corrects for the flaw and redirects the light into a scientific instrument. Diagram of Hubble shows some of the devices scheduled for repair or replacement.*

power Hubble throughout its stay in the payload bay.

Then the real work begins. On the fourth day, astronauts will get their first chance to conduct repairs. During each of the mission's five scheduled walks, known as an extravehicular activity (EVA), one of two teams of astronauts – Hoffman and Story Musgrave or Tom Akers and Kathryn Thornton – will float out together into the payload bay. Usually, one astronaut will hold needed tools and other equipment while the other rides the robotic arm up and down like an elevator to reach different parts of the telescope. Each walk is supposed to last six hours, but the teams may stay out an hour or two longer if they find themselves in the middle of a critical repair, Hoffman notes.

The mission has a flexible schedule that could change significantly once the crew sizes up conditions in space. According to the most recent plans, astronauts on the first space walk will attempt to replace two of the telescope's failed gyroscopes. Either Hoffman or Musgrave will ride the robotic arm, using a wrench to loosen bolts on the old gyroscopes and tightening the new ones, while his partner holds the new gyro in place. Gingerly moving inside the telescope's instrument compartment, the partner will also disconnect and reattach electrical connectors for the gyroscopes. Other duties that day may include changing fuses and preparing for the next day's major event – replacing the two solar arrays.

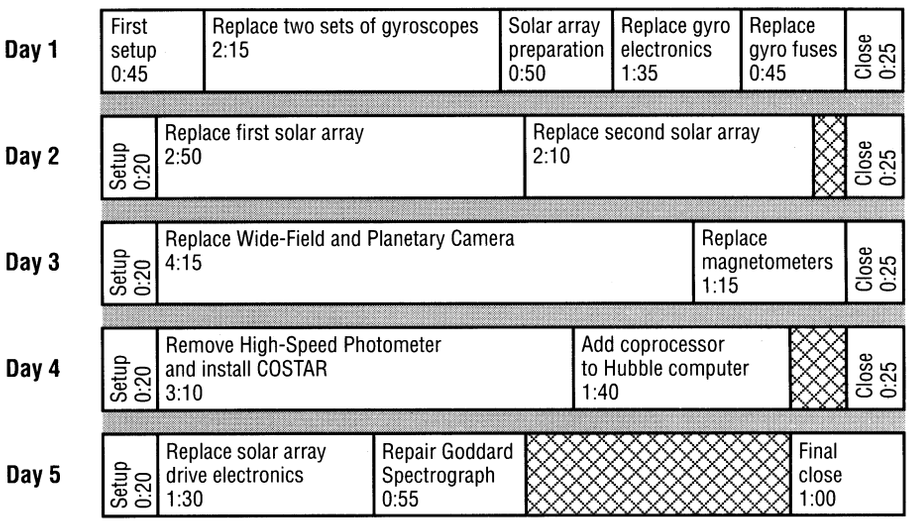
The array replacement should take the most time of any one activity. Astronauts Akers and Thornton will do the honors, tackling one array at a time during the second EVA, on the fifth day of the mission. Riding the robotic arm, one member of this duo will undo electrical connections and latches, freeing one of the bulky, wing-like panels.

Hoffman notes that it isn't easy carrying this 5-meter piece of equipment in the weightless environment of space, where a little push goes a long way. But thanks to simulations on the ground, moving each array "is going to take time, but we know how to do it," Hoffman asserts.

After stowing the old array, either Akers or Thornton will install the new unit. Once the two astronauts fit the array in place, one of them must carefully attach electrical connectors from the panel to a socket on the telescope. "This operation is not difficult, but it's delicate," comments Hoffman. "You have a bolt that's pulling your connector together and it's a blind mate. So if it doesn't go in easily and you insist on [forcing it], you could strip the thread and do major damage."

Should such damage occur, he adds, "You wouldn't be able to get the connectors together, either for the new solar array or the old one. And then you've basically lost a solar array – and you've lost a telescope."

## Tentative Space-Walk Schedule




On the third space walk, astronauts will begin fixing Hubble's flawed optics. The first order of business: replacing the present Wide-Field and Planetary Camera with a model that has built-in corrective optics. Hoffman and Musgrave will work together to slide the old, wedge-shaped camera out of the telescope and hang it over the side of the payload bay. Just before they slide the new camera in, the astronauts will perform a simple but crucial task. They must remove a protective cover from a key mirror on the camera, which directs light from the main beam of the telescope into the WFPC.

Accidentally touching the exposed mirror could contaminate its pristine surface or throw the camera's optics out of alignment. If all goes well with this procedure, the team will still face another hurdle, guiding the camera along a tapered track into the instrument bay. The track should allow astronauts to position the camera within a millimeter of its optimum position, a necessity for the optics to work as planned.

"Human errors do occur," notes Weiler. "I'll feel a lot better when the [new] camera is latched up and [electrically] tested."

If time remains, Hoffman and Musgrave will spend the rest of the third space walk replacing two of Hubble's magnetometers, devices that use Earth's magnetic field to help steer the craft. Because the magnetometers lie near the top of the telescope, the team will have to tilt Hubble in order to reach them with the robotic arm.

Akers and Thornton begin the fourth walk in space by sliding out the phone-booth-size High-Speed Photometer and replacing it with COSTAR, which should dramatically improve the resolution of three Hubble detectors. "There's a very tight clearance getting it [COSTAR] into the cavity, about a quarter inch or so," says Hoffman. "If a little bit of thermal insulation from the telescope bunches up or a bolt wasn't tightened up as much as we think it should be, things could come to a screeching halt."

After installing COSTAR, the major activity of this space walk, Akers and Thornton will upgrade Hubble's impaired computer memory by adding a new and more efficient coprocessor.

On the fifth and possibly final walk, astronauts will install electronics that will enable the solar panels to rotate and track the sun. Alas, the electronics have connectors thought to be particularly difficult to manipulate in space. The same team will also add a new electronics box to the Goddard High-Resolution Spectrograph, which should enable the spectrograph to function at its full capacity. NASA may approve one or two extra days for space walks if needed, says Joseph H. Rothenberg of the Goddard Space Flight Center, Hubble's associate director of flight projects.

If both WFPC and COSTAR fail to operate, or if major structural or electronic problems remain, NASA will consider a second repair mission, says NASA's Weiler. The mission might fly six months to a year later, depending on the nature of the additional repairs, he adds.

But scientists won't know the outcome of this December's repair flight until weeks after astronaut Nicollier uses the robotic arm to lift Hubble out of the payload bay and return it to its proper orbit. Leckrone notes that flight controllers will need some seven to nine weeks to "restart" the Hubble instruments and slowly check out the optics before they can tell if the telescope has the sharper vision astronomers seek.

It remains to be seen whether the upcoming mission will provide NASA with a great start to the new year or heap another disaster on the beleaguered space agency.

In either case, the world will be watching. □