National Aeronautics and Space Administration

Communication Aberration:

HST Optical Systems Failure

Leadership ViTS Meeting

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THE MISHAP

After Hubble Space Telescope (HST) launched on April 24, 1990, the photographs it recorded indicated a flaw in the primary mirror known as a spherical aberration. This meant the mirror directed incoming light rays to many focal points instead of just one, causing the images it recorded to blur. Investigators later determined that the aberration existed because HST's primary mirror had been polished into the wrong shape.

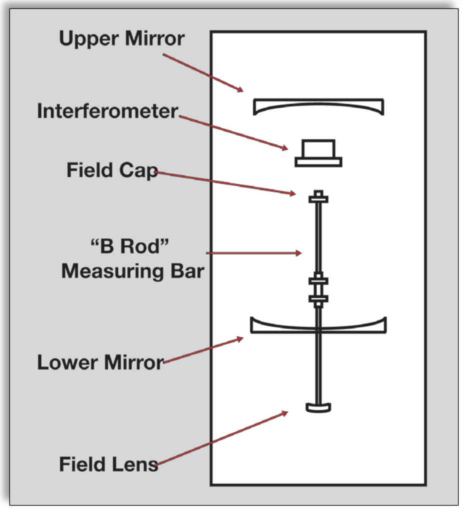
Mirror Fabrication and Null Testing

•Aspheric mirrors, such as the one used in HST, are fabricated by placing glass discs through repetitive polishing cycles that gradually wear away material until the disc conforms to the desired shape.

•At several intervals during the polishing procedure, technicians check the mirror for proper curvature by conducting a null test, which requires a null corrector and an interferometer.

•Null correctors are lenses that create an optical template which allows technicians to compare the mirror with a projection of its desired shape.

•Interferometers produce wave patterns (interferograms) that show discrepancies between the mirror being tested and the projected optical template.



RNC side view. The "B Rod" measuring bar ensured accurate spacing between the components.

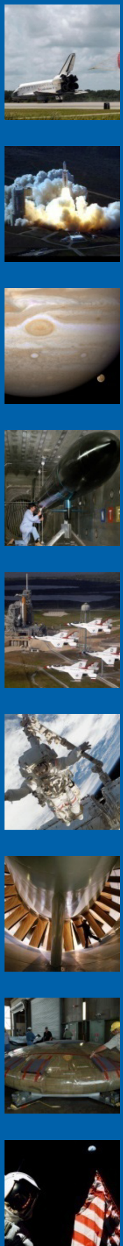
Reflective Null Corrector

•Most null correctors use large lenses to project the optical template, but it is difficult to perform unambiguous tests to determine that the lenses are producing the correct image, and imperfections in the glass can limit lens accuracy.

•To solve these problems, Perkin-Elmer, the prime contractor for HST mirror fabrication, developed a reflective null corrector (RNC) that replaced the large lenses with two mirrors and a small field lens.

•Using the RNC, Perkin-Elmer would be able to predict the shape of the optical template simply by knowing the dimensions of the mirrors, the dimensions of the field lens, and the spacing between the components.

•Perkin-Elmer did not plan to test the RNC independently. Instead, it would rely on certification of individual components and precise assembly of the apparatus.



WHAT HAPPENED?

Null Corrector Adjustments

•Perkin-Elmer demonstrated the RNC's accuracy by using it to test a small replica of HST's primary mirror. The RNC was a major factor in NASA's decision to award Perkin-Elmer with the prime contract for mirror fabrication.

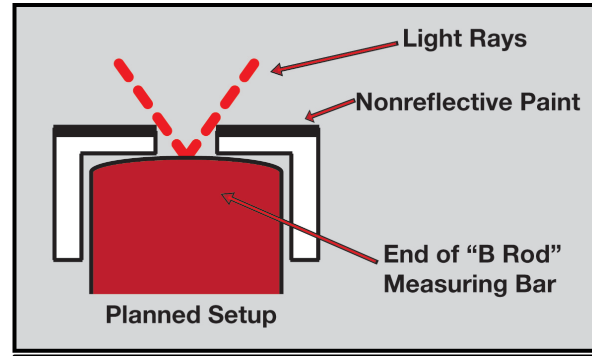
•After the demonstration, Perkin-Elmer needed to re-space the elements in the RNC to project the correct optical template for the large primary mirror.

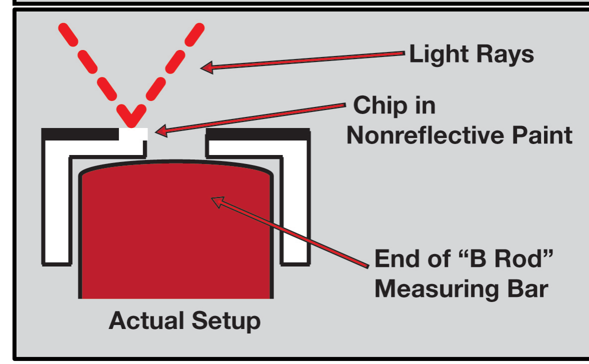
•To ensure proper spacing between the elements, the technician used a "B Rod" measuring bar fitted with an end cap that prevented the bar from moving laterally.

•The interferometer would emit a light beam meant to pass through a hole in the end cap. The light would reflect off of the end of the B Rod and back into the interferometer, creating a measurement that would verify that lens placement matched calculations.

•Some of the non-reflective coating chipped away from the end cap, and the light beam reflected off of the end cap instead of the measuring bar, resulting in an erroneous reading. When the technician attempted to position the field lens based on the reading, it would not fit.

•Without informing anyone, the technician added washers to each of three bolts that held the field lens retainer in place, allowing the lens to fit, but altering the spacing by 1.3 mm.





Diagrams depict field cap detail.
Top: planned setup showing light rays reflecting off of measuring bar. Bottom: actual setup showing light rays reflecting off of field cap.

Vertex Tests and Discrepant Data

•In 1981, late in the polishing process, Perkin-Elmer measured the primary mirror's center of curvature using a refractive null corrector and an inverse null corrector.

•The resulting interferograms had wavy lines – outcomes that contradicted interferograms from the RNC and indicated a flaw in the mirror.

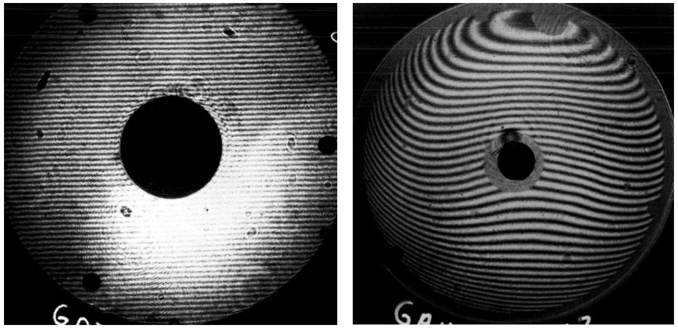
•The optics fabrication group at Perkin-Elmer considered the refractive and inverse null correctors to be less accurate than the RNC, so they assumed the flaw was in the refractive and inverse null correctors, not the mirror or the RNC. No one attempted to resolve the discrepancy.

•The flaw in the primary mirror's shape was not discovered until after HST entered orbit in 1990.

PROXIMATE CAUSE

NASA established the Allen Commission to investigate, and the findings implicated the 1.3 mm misplacement of the field lens. The misplacement caused the RNC to project the wrong optical template. Then, the computerized polisher, which shaped the mirror based on the RNC's output, polished the mirror into a hyperbola that was slightly too flat near the edges. The incorrectly shaped mirror failed to direct incoming light to a single focal point, blurring each image before it reached the camera.

UNDERLYING ISSUES



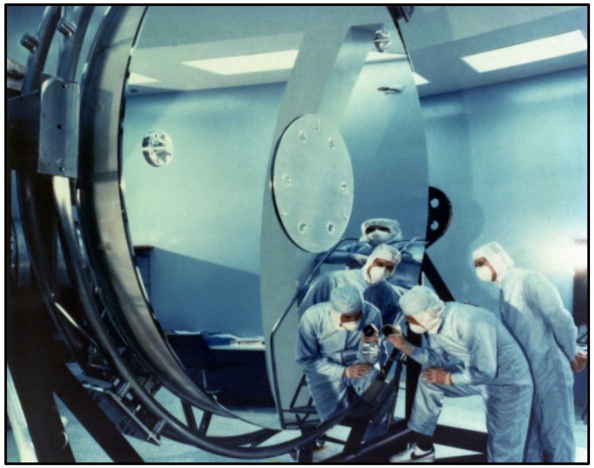
Left: Interferogram from RNC indicating a perfectly shaped mirror Right: Interferogram from inverse null corrector indicating spherical aberration.

Inadequate Communication

- The technician should have filled out a non-conformance report to document the addition of the washers to the RNC, but investigators could find no evidence that such a report had ever existed.
- When Perkin-Elmer performed vertex tests using refractive and inverse null correctors, it did not share the results with NASA because the results contradicted interferograms from the RNC, and they assumed the RNC was infallible.
- At the time, the culture at Perkin-Elmer made it easy to forego communication protocols. Perkin-Elmer allowed the division where the mirror was fabricated to operate in a closed-door environment, restricting communication and preventing problems from being reviewed.
- This situation existed because of the fact that while Perkin-Elmer was shaping HST's primary mirror, it was also fabricating spy satellites for the DoD. DoD only allowed 15 people to obtain appropriate security clearance and USAF permission to enter the facility.
- Therefore, few NASA SMA personnel were stationed on-site, and of those, none had enough technical background in optics to realize the depth of the problems occurring with Hubble's mirror.

Distraction: Perkin-Elmer was also wrestling with the design and development of HST's fine guidance sensor (FGS) while it struggled to complete the primary mirror on time. Because developing the FGS was thought to be more of a challenge than shaping the primary mirror, NASA managers, rather than pressing for problems related to the mirror, focused efforts, questions, and analyses at the FGS. NASA managers paid little attention to the mirror, making it easy for Perkin-Elmer to rationalize discrepant test results and gloss over other concerns.

FOR FUTURE NASA MISSIONS



Engineers examine HST's primary mirror at Perkin-Elmer's optical fabrication facility

- NASA committed leadership errors that played significant roles in the Hubble mishap. As per Dr. Charles Pellerin, former director of Astrophysics at NASA, "NASA created an environment so hostile that the contractor only told us of problems they were sure were real and threatening."

- NASA's leaders must possess "soft skills" to enhance team-building and better identify managerial shortcomings before they result in broken team interfaces and technical mistakes.

In 20 years, HST has completed more than 110,000 revolutions around Earth.

- Project managers must identify equipment that critically impacts flight hardware quality and reliability.
- Ensure that documentation covering design, development, fabrication, and testing is properly prepared, indexed, and maintained.
- Ensure clear assignment of responsibility to QA and engineering, and give QA an independent reporting path to top management.
- Under schedule and budget pressure, managers may disregard evidence of threats to mission success in the name of efficiency. NASA must not allow these distractions to inhibit sound reasoning, judgment, and decision-making.