

How Hubble Space Telescope failed

--Synopsis of Hubble Space Telescope Optical Systems Failure Report

OPTI 521 synopsis by Tianquan Su

Introduction: The Hubble Space Telescope (HST) was launched on April 24, 1990. During checkout on orbit, it was discovered that the primary mirror was misshaped, leading to 0.4-wave rms wavefront error at 632.8nm. This fabrication flaw was caused by an assembling mistake on the testing instrument, Reflective Null Corrector (RNC), which was used to test the surface of the mirror. Through the investigation of the course for the flaw, engineers and researchers should learn how to avoid similar situations happening again.

HST OPTICAL DESIGN

The Optical Telescope Assembly (OTA) in The Hubble Space Telescope is a two-mirror reflecting telescope with a focal ratio of $f/24$. This kind of telescope is generally referred to as Cassegrain telescope, but the mirrors in the OTA are slightly more aspheric than in the normal Cassegrain type. The primary mirror in the OTA (the one in which the error exists) is a 2.4-m diameter concave hyperboloid. The 0.3-m diameter secondary mirror is a convex hyperboloid.

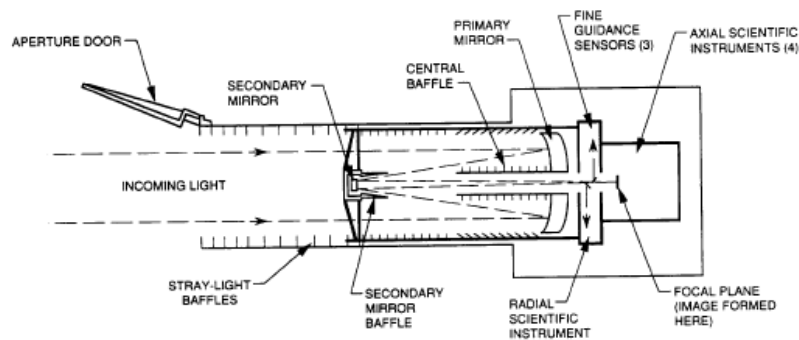


Figure 1: Optical Telescope Assembly

REFLECTIVE NULL CORRECTOR USED IN HST TESTING

Aspheric mirrors produce better quality images than spherical mirrors, but the shape makes them more difficult to test. When testing sphere surface, the center of curvature of the test part is putted coincident with the focus position of the transmission sphere, the test wave of the interferometer makes a normal incidence angle with the surface under test and is retroreflected. This test configuration, known as a null test, shows the deviations of the measured surface from the reference sphere. The standard way applying this method on a general asphere is to introduce some sort of correction optics in order to adapt the incoming test wavefront to the

surface under test. This null corrector (or null compensator) generates from the incoming spherical wave a wavefront that impinges normally to the test surface and is thus retroreflected, forming a null interferogram. Null correctors may be implemented with refractive, reflective or diffractive optics. The primary mirror of OTA was measured with a coaxial reference interferometer in conjunction with a novel reflective null corrector (RNC) designed by Perkin-Elmer Corporation (P-E). The company planned to certify the RNC with great care and not to do any independent testing of the mirror.

As shown in Figure 2 and Figure 3, the RNC consists of two spherical mirrors, the larger of which has a clear aperture of < 10 in. (25.4 cm), and a small refraction field lens whose clear aperture is < 1 in. (2.54 cm).

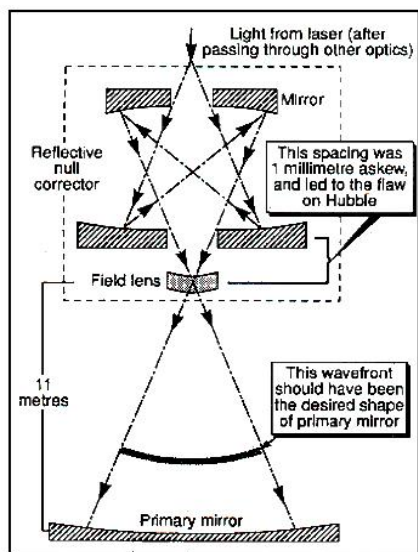


Figure 2: Reflective Null Corrector

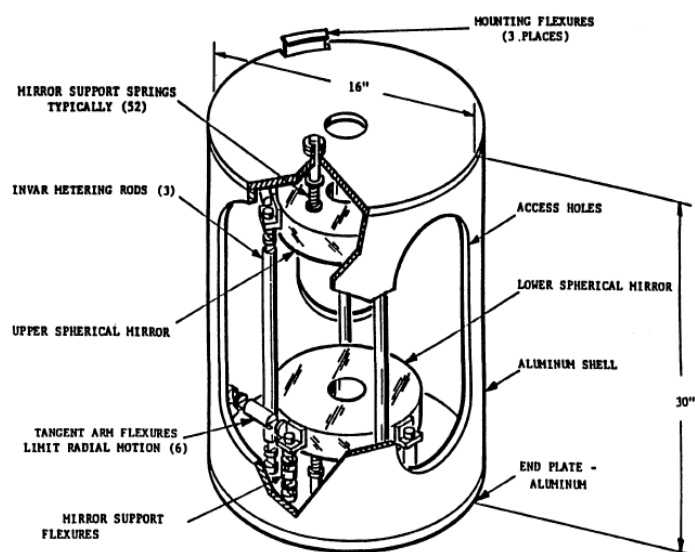


Figure 3: Structure of RNC

ERRORS IN PRIMARY MIRROR AND RNC

After the HST was put into orbit and the first light images were taken, computer simulation of these images indicated that 0.5-wave rms wavefront spherical aberration at 547 nm existed in the OTA. Through analyzing the aberrations of the image, the doubt was centered on the primary mirrors.

The testing results of the primary mirror differed between RNC and a refractive null corrector – the former one showed no error while the latter one give the opposite result. The refractive null corrector was used to measure the curvature of the primary. Its result was right to explain the image error. Thus, the RNC was doubted. And after other possible courses were excluded, the spacing of the RNC elements became the suspect.

The optical element spacing of the RNC was measured by shining collimated light up through the field lens using an interferometer as the source, and by placing a flat mirror at the focus of the

field lens. This measurement showed that the field lens was about 1.3 mm too far from the lower mirror. When the field lens position error is taken into account and applied in correcting the data taken with the RNC, it results in a mirror shape that would account for most of the error observed in the HST images.

HOW THIS ERROR OCCURRED

(As the necessary records to reproduce what actually happened were missed, the following analysis is a conjecture.)

The RNC used to measure the HST primary mirror was modified from the one used on a smaller mirror prototype. This modification required adding a new field lens and respacing the optical elements. Figure 4 shows the positions of the metering rods used to set the optics.

The metering rods were made of Invar (a metal with a small temperature expansion coefficient). The ends of the metering rods were rounded and polished for using an interferometer to measure the position. This procedure involved auto-reflecting a focused beam of light off the end of a rod and observing an interference pattern from the beam that came back on itself. Centering the light beam on the rod end was essential for the measurement. To prevent the metering rod from being misaligned laterally with respect to the interferometer axis, P-E decided to attach "field caps" to one end of the rod (Figure 5). The field caps were fitted over the rod ends and had a small aperture in the center to ensure centering of the rod on the beam.

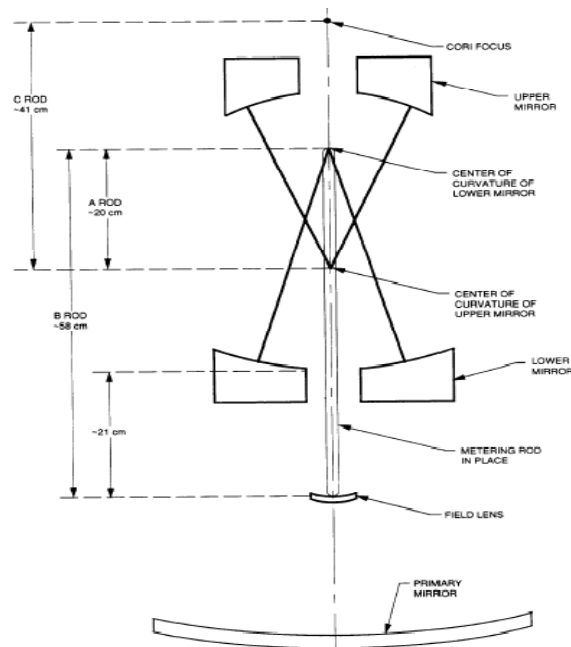


Figure 4: Position of metering rod used to spacing optical elements in RNC

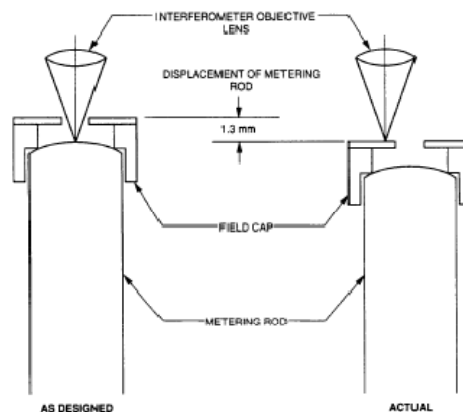


Figure 5: Displacement due to the interferometer focusing on the field cap instead of the metering rod

The top surface of the field cap was covered with nonreflecting material; however, some of this material had broken away from a small area around the field cap aperture. It appears that the operator obtained reflection from the field cap where the nonreflecting material was absent, rather than the rod end, causing the 1.3 mm misspacing. A test with the equipment showed that it was quite easy, even probable, to make this error with the configuration used. The final location of the field lens was then set with the addition of the spacers. As a result, the field lens was about 1.3 mm too far from its correct position relative to the lower mirror.

CONCLUSION

Large projects usually have considerable quantities of procedure steps. Errors in early step can cause huge damage to the whole project. The investigation clearly showed that the method used to spacing the RNC could be improved. Reliance on a single test method is a process which is clearly vulnerable to simple error. Errors were shown during the fabrication and testing procedure, but were ridiculously ignored by P-E. This indicates that efficient communication within the group is needed. Moreover, tight budget, both timely and economically, prevented the system from being tested fully and independently. After all, competitive, organizational, cost, and schedule pressures were all factors in limiting full exposure of all the test information to qualified reviewers.

Reference

1. "The Hubble Space Telescope Optical Systems Failure Report", NASA, November 1990;
2. L. Furey, T. Dubos, D. Hansen, and J. Samuels-Schwartz, "Hubble Space Telescope primary-mirror characterization by measurement of the reflective null corrector", *Applied Optics*, Vol. 32, Issue 10, pp. 1703-1714;
3. Christof Pruss, Eugenio Garbusi, and Wolfgang Osten, "Testing Aspheres", *Optics and Photonics News*, Vol. 19, Issue 4, pp. 24-29