Technical Report

Team 3

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COSTAR, Corrective Optics Space Telescope Axial Replacement installed, replacing High Speed Photometer (HSP)

1. Problem Description

The Hubble Space Telescope (HST), when it was first launched in 1990, was equipped with a High-Speed Photometer (HSP), which was used to make "rapid light measurements of astronomical objects at a variety of wavelengths from the near ultraviolet to the visible." While this part was very special for the operation of the telescope, it was also simple with it not having any moving parts to function properly.

The primary mirror of the Hubble space telescope was compromised from the beginning of the launch. The HSP also had very little space and weight capacity to incorporate an additional instrument.

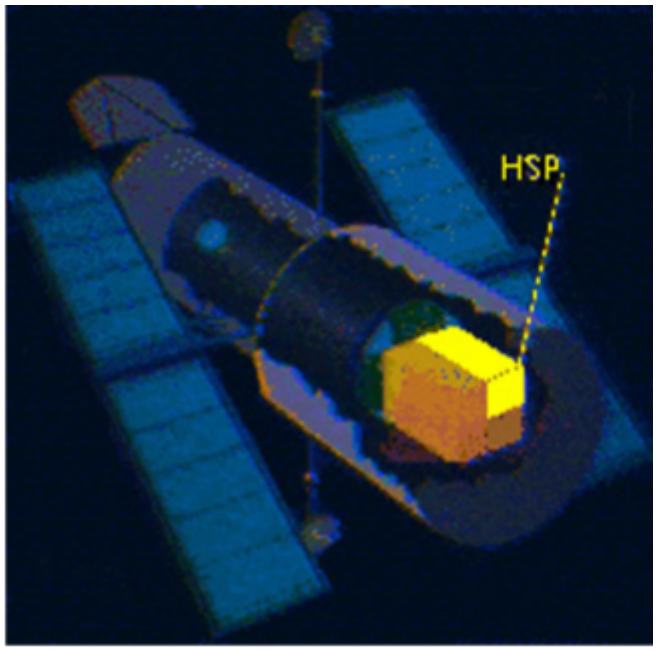

Figure 1. The image shows the Hubble telescope and where the High Speed Photometer is located.

The HSP, as shown in Figure 1, took up a relatively large amount of room, requiring it to be replaced by the COSTAR. Although the HSP specifically was not flawed, the main issue stemming from this was a defective mirror installed before the launch. This mirror suffered from "spherical aberration" which means that not all portions of the mirror focused on the same point. The defective mirror caused blurry vision from the telescope, resulting in lower-quality images than what was initially expected.

Ultimately, this problem needed to be corrected as soon as possible, as it resulted in the telescope working at fractions of its peak efficiency. Another over-encompassing problem of the mirror being flawed that needed to be solved was how the corrections of the mirror would be made. Although the telescope was designed to be worked on throughout its life, many options were discussed, including the option of bringing the telescope back to Earth to have the primary mirror replaced by a backup.

2. Problem Analysis

To fix the poor picture quality of the Hubble Space Telescope (HST), a group of engineers decided to place mirrors in front of the instruments. The engineers found out that there was an issue that caused the light from different parts of the primary mirror to focus at different places. By adding mirrors, the engineers believed the issue would be corrected. The instrument, which was named the Corrective Optics Space Telescope Axial Replacement (COSTAR), had to be installed in space. As seen in figure 2, the COSTAR was a large package at thirteen meters in length. The HST was designed to provide parts to be installed in space, which allowed for the mission to be possible.

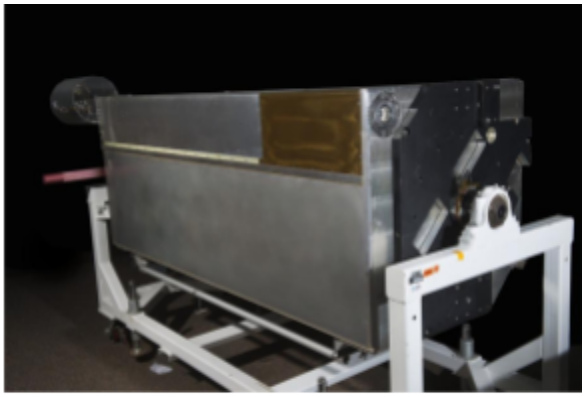

Figure 2. Image of the COSTAR before the first hubble mission.

There was also a weight capacity for the telescope, so a part from the telescope would have to be removed to install the COSTAR. The team of engineers decided they would replace the high-speed photometer with the COSTAR package. Since the high-speed photometer was not used often on the telescope, that was the best instrument to be removed.

Seven astronauts were sent to the HST to fix the issue. The COSTAR was carried to orbit in the bay of the spaceship in an enclosed instrument. The enclosure was called the science instrument protective instrument (SIPE), which kept COSTAR warm with vibrations for a safe launch. As shown in figure 3, the spaceship's robotic arm was used to gently dock the Hubble in the shuttle's cargo bay. Once the HST docked to the flight support system in space, the astronauts disconnected the electrical connectors on the high-speed photometer. The astronauts then slid the photometer out and placed it in a holding instrument. The COSTAR was then removed from the SIPE and moved toward the HST. Once the instrument was installed, the electrical connectors were connected. The astronauts ran tests for a day after the mission was complete, and once they were assured everything worked properly, the astronauts returned to Earth.

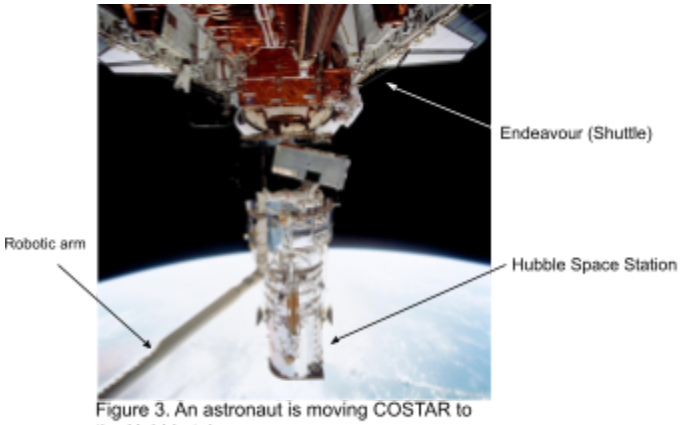

Figure 3. An astronaut is moving COSTAR to the Hubble telescope.

3. Solution Plan

As stated in the problem analysis, the issue with the Hubble Space Telescope was a distortion on the primary mirror that needed to be corrected. The solution was to identify the error by evaluating the pictures that the HST took and it was determined that the error was made during the manufacturing of the HST. The issue was determining which optics would work.

To find the solution, the optics went through trials. COSTAR is what made up the optics. COSTAR was placed on CAS(COSTAR Alignment System) ensuring the placement of mirrors and stabilizing the proper shape. The Engineers knew they had to prevent the error from happening. They had to make sure that CAS was operating well so COSTAR could operate or else it would go unnoticed. The trials it went through were verified by multiple groups including Ball Aerospace and the European Space Agency(ESA).

Figure 4. This shows the before and after of the COSTAR attachment.

To prevent errors in CAS, COSTAR underwent testing by attaching to HOMS(Hubble Opto-Mechanical Simulator). This verified that COSTAR would work for HST once they would attach and had the proper prescription needed when they connected. This was essentially a simulator that matched the HST optical system. COSTAR had been set to have the proper calibration, optics, and alignment at the time. Figure 4 shows the difference that the attachment of the COSTAR system made compared to the old HST system. The sheer difference in quality of the picture proves the necessity of the COSTAR system.

Due to limited space in the HST hub area; miniature motors were used to deploy and adjust the position of each mirror. COSTAR contains 10 optical elements along with 12 motors allowing for the 5 optical channels to be aligned. This system is used to ensure that each image that is captured correctly even with the small packaging volume available for the optics.

Needless to say, the construction of COSTAR was challenging as it demanded a tight schedule (26 months), had a small availability for the optics, and found the proper optics needed. It has to be tight because of how little HST could carry.

4. Pros and cons, possible alternate solution, and conclusion.

Pros:

Following the successful installation of the Corrective Optics Space Telescope Axial Replacement (COSTAR), the Hubble Space Telescope has regained its ability to focus accurately. This crucial enhancement ensures precise readings for the remaining instruments, the Faint Object Camera (FOC), Goddard High Resolution Spectrograph (GHRS), and Faint Object Spectrograph (FOS), thereby optimizing the telescope's overall observational capabilities for scientific research and discovery.

Learning from this issue every instrument installed after HST's deployment has been designed with built-in corrective optics.(esahubble.org)

Cons:

To accommodate the installation of the Corrective Optics Space Telescope Axial Replacement (COSTAR), a decision was made to remove the High Speed Photometer (HSP) from its position within the Hubble Space Telescope. This was decided as it was the least used instrument on board the Hubble compared to the others.

The COSTAR was built to seamlessly integrate into where the HSP was located. This meant that the COSTAR had very strict dimensions and tolerances making it difficult and costly to design and manufacture. The budget for the COSTAR’s development was around $50 million.(asd.gsfc.nasa.gov)

To facilitate this replacement astronauts had to get to the Hubble and then do a spacewalk to begin to work on the telescope and return to Earth after they were done. Every step has a chance of something going wrong and endangering the crew.

Possible Alternatives

There were a few possible solutions that were being considered. One of them was replacing the distorted primary mirror itself. This would fix the root of the problem and there would be no need for a corrective lens. However, it was deemed impractical considering the mirror’s size and weight being 1,825 pounds and with a 7.8-foot diameter.

Another solution that was considered was a software-based correction. There were some attempts, but none were successful to fully compensate for the distortion. The results had a loss in image clarity and what was desired was the best image quality possible.

Conclusion

In conclusion, the Corrective Optics Space Telescope Axial Replacement (COSTAR) successfully corrected the distorted primary mirror on the Hubble space telescope. The installation was completed, and the High-Speed Photometer (HSP) was replaced. The COSTAR was difficult and costly to create with its 50 million-dollar budget. The mission to get to and replace the Corrective Optics Space Telescope Axial Replacement was hazardous and costly. Ultimately, the COSTAR replaced the HPS and did its job improving the image quality of the Hubble to how it was supposed to be.

Cite

https://asd.gsfc.nasa.gov/archive/hubble/a_pdf/news/facts/COSTAR.pdf

https://www.nasa.gov/history/SP-4219/Chapter16.html

https://esahubble.org/about/general/instruments/costar/

https://en.wikipedia.org/wiki/Corrective_Optics_Space_Telescope_Axial_Replacement
(figure 2 image)

https://www.dvidshub.net/image/716110/astronauts-thornton-and-akers-during-installation-costar-hst (figure 3 image)

https://esahubble.org/about/general/instruments/hsp/ (figure 1)

https://esahubble.org/static/archives/images/screen/opo9407a.jpg (figure 4 image)