the Availability Digest

Hubble Trouble

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The Hubble Space Telescope

Named for Edwin Hubble, an American astronomer, the Hubble Space Telescope is perhaps one of NASA's most successful missions since the Apollo project put men on the moon. Carried aboard the Discovery Space Shuttle from Florida's Kennedy Space Center on May 12, 1990, as a joint effort by NASA and the European Space Agency, Hubble has helped to pin down the age of the universe. It has pointed to the existence of dark energy that apparently makes up the bulk of the mass of the universe.

The length of a school bus and weighing some twelve tons, Hubble has made over 100,000 revolutions 360 miles above the Earth since it was launched. It has been used by 4,000 astronomers around the world to capture images of planets in our solar system as well as images of far-off stars and galaxies.

Hubble was designed for long life. It was the first space telescope designed to be serviced in space by astronauts. All of its control and communications electronics are backed up by redundant systems so that it can survive the failure of any electronic component. The backup systems are kept turned off so that they will last longer in the high radiation and low temperatures of space. It has been discovered that little aging occurs in an unpowered component.

However, with all of the care taken, Hubble was initially declared a massive failure. When it took its first pictures in 1990, the pictures were fuzzy. It turned out that the problem was caused by a major error in the telescope's optics. Although the telescope's main mirror had been ground to great precision within 1/96 of the wave length of visible light, it was, nevertheless, ground wrong. After months of analysis, it was determined that the problem could be corrected by new optical components for the telescope's instruments with the same error in the opposite sense to compensate for the mirror's error – in effect, a set of spectacles for Hubble to correct the optical aberration. These corrections were installed on Hubble during the first servicing mission in 1993, and Hubble's sight was made near-perfect.

Since then, Hubble has captured some of the most beautiful high-resolution images of deep space ever seen, transmitting back 66 gigabytes of information a day to the Goddard Space Flight Center in Maryland.

The Final Servicing Mission That Wasn't

Over the years, three more missions were flown to service the telescope. They were made in 1997, 1999, and 2002. Worn components were replaced. Optical instruments were upgraded. But never did a computer component have to be replaced. Not for eighteen years.

The final mission to service Hubble was scheduled for October 14, 2008. After that, no more servicing missions could be scheduled because of the phasing out of the Space Shuttle program. In effect, Hubble would be on its own.

However, just two weeks before that final mission, on September 27th, Hubble went dead. Scrambling to find the cause, NASA postponed indefinitely the last servicing mission so that the problem could be repaired by a space walk if at all possible.

In hindsight, this problem couldn't have occurred at a better time. If it had happened three weeks later, there would have been no opportunity to visit Hubble to make any necessary repairs. Hubble might have become just another piece of space junk.

The Failure

Fortunately, the failure only prevented image data from being transmitted; but Hubble could still receive commands from Goddard. This allowed the problem to be analyzed by the scientists and engineers on the ground.

They determined that the Science Data Formatter (SDF) had failed. This is an 80486-based processor designed by IBM in the 1970s and built by Fairchild Camera and Instruments in the 1980s. It is responsible for formatting the image data from Hubble's five main instruments into packets and sending them to Earth.

The SDF is part of a larger system, the Science and Instrument Control and Data Handling system (SIC&DH), which controls all of Hubble's instruments. The SIC&DH comprises seven components, including the failed SDF, the group of which are treated as a single system for redundancy purposes. The SIC&DH system that failed is known as "Side A." The dormant, unpowered backup system is "Side B."

When Side A failed, all of Hubble's instruments went into "safe mode" to protect themselves. Thus, with the instruments turned off, and with the transmission of image data interrupted, Hubble appeared dead.

The Solution

The obvious solution was to fail over to the backup Side B SIC&DH. Having been unpowered for eighteen years, Side B should have been as good as new. However, the last time it was exercised was in 1990, before the launch. Was it still good?

There was only one way to find out – put it into service. Provisions existed to switch the redundant Side B SIC&DH into service, replacing the failed Side A, via commands from the ground. This procedure understandably required significant planning since it had never been done except in a test environment prior to launch. On October 16th, 20 days after the SDF failure, NASA was ready to try.

The first step was to remotely command the backup SIC&DH to power up and take over control, a procedure that took about ten hours. Data was uploaded to it, and this data was transmitted back to Goddard to verify that it had uploaded properly. Several of Hubble's instruments were then brought out of safe mode to verify that each had a working interface with Side B. To the relief of all, these steps were successful; and the instruments were returned to safe mode to await commands later in the day.

The next step was to send commands to switch Hubble's science instruments from their safe mode and to take internal exposures as a baseline test of the telescope's instruments. This baseline would be sent to Goddard, where it would be compared to an old Side A baseline to verify proper operation of the instruments. Baseline checking was expected to be completed by noontime, October 17th, and NASA announced that they expected science observations to restart sometime the morning of October 18th, two days later.

The Failover Fault

SIC&DH failover is complex. First, commands had to be sent to Hubble to command Side B to take over. This had been successfully completed. Next, the instruments had to be recalibrated, and baseline data had to be sent to Goddard to ensure that the instruments were working properly. At this point, the telescope would be ready to be returned to service.

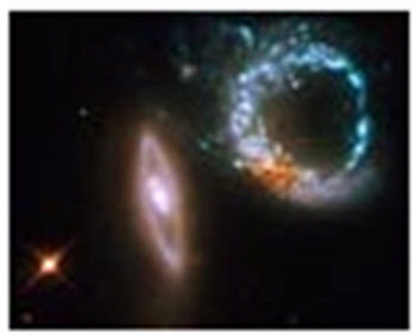
However, Hubble did not return to service the next day, as NASA had anticipated. When NASA attempted to bring Hubble to life for the baseline tests, the SIC&DH unit shut down shortly thereafter; and the instruments went back into safe mode. Hubble had just experienced a failover fault.

Fortunately, the Hubble team was able to get a memory dump from the SIC&DH so it could analyze what had gone wrong. It turned out that the SIC&DH had stopped receiving "I'm alive" messages from the instruments and had shut them down by placing them into safe mode.

The Hubble team had updated the data-handling protocols when they first brought Side B online. Was it possible that these new protocols were flawed? Or was there some more fundamental hardware failure that might prevent Hubble from coming back to life?

The Success

As it turned out, the problem was with a power supply that caused the instruments to misbehave. The ground crew studied this problem for several days as they did not want to harm the instruments. Finally, they were able to correct the low-voltage problem; and Hubble went online on October 25th. The SDF failure had left Hubble inoperative for four weeks, but it was now returning spectacular images.



A pair of gravitationally interacting galaxies called Arp 147, taken just after Hubble was restored to operation in October, 2008.

At this point, NASA decided to replace the failed SDF with a spare unit that fortunately had been built with the other two units and had been stored at Goddard for safekeeping. In this way, full redundancy would be restored to the telescope's instrument control system, which would be accomplished on the delayed service mission. This was the first computer problem to require the replacement of a component since Hubble was launched.

The Future

The final shuttle mission is now rescheduled to launch on May 12, 2009. Atlantis will take the replacement SDF to Hubble, where it will be installed during a space walk by the astronauts. The currently operational Side B will continue to control Hubble's instruments, and the repaired Side A will act as its backup. The astronauts also will install upgraded and new instruments – the tasks that had been planned for the now-delayed October mission.

Until the replacement unit is installed, Hubble is running without a spare instrument controller. If any unit should fail, the entire SIC&DH will fail. There is no Side C to which to fail over. Why is there such a long delay from the decision in October to replace the SDF and the May mission? It turns out that there is a lot of work to do beforehand.

First, the SDF replacement unit must be exhaustively tested to ensure that it can withstand the vibration of launch and the ravages of high radiation and low temperatures in space. In addition, the astronauts must be trained in the replacement of the unit; and the mission must be totally replanned.

NASA estimates that this should give Hubble another five to ten years of life, enough to carry it past the launch of the next space telescope, the James Webb Space Telescope. However, the Webb telescope will not be a direct replacement for Hubble. It will focus on the infrared spectrum. When Hubble finally dies, its visible and ultraviolet view of the universe will be gone.

As a final note, an IMAX camera will be carried on Atlantis to record the repair. This footage will be added to footage taken by another IMAX camera when Hubble was launched in 1990 and again on the Endeavour servicing mission in 1993. The Hubble IMAX documentary is scheduled for release in early 2010.

A "Lessons Learned" Vacuum

There is not much in the way of lessons that can be learned by us Earth-bound IT technicians from Hubble's experience. Space computing simply has challenges that we not in NASA may never understand.

The fact that the instrument control computer had an MTBF (mean time before failure) of 18 years is phenomenal, especially given the fact that it was designed and built over thirty years ago!

The long failover of three weeks (plus an additional week due to the failover fault) was due in part to the fact that the backup Side B had to remain in an unpowered state so that it would not deteriorate in the hostile space radiation and temperature environment. Furthermore, it had to be thoroughly tested from the ground before it could be put into service.

An MTR (mean time to repair) of eight months for the SDF failed unit is certainly troublesome but understandable given that the SDF failure was an unscheduled event and that a Shuttle mission had to be planned around it

In today's technology, one improvement that perhaps could be made (and probably is being made) in future space systems is in failover time. If failover could be performed automatically and controlled by onboard logic, it perhaps could be fairly rapid. Of course, one probably cannot periodically test failover – that might be too dangerous. We just have to take our chances when a fault occurs and have built in the monitoring and command procedures to overcome a failover fault – a capability well-exhibited by Hubble.

Another improvement would be to implement triple redundancy. If a module should fail, it can be replaced and still have a backup. This is, in fact, the practice in the International Space Station.[1]

[1] Triple Redundancy Failure on the Space Station, *Availability Digest*; November, 2007.

References

Information for this article was taken from the September and October, 2008, issues of Computerworld, Scientific American, The Register, Florida Today, Space Ref, freep.com, Space Daily, Eflux Median, Ars Technica, CNN News, and the NASA Hubble Telescope Status Update.

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The Wikipedia Hubble entry contributed to this article.