Fastener Capture Plate Technology to Contain On-Orbit Debris

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Abstract

The Fastener Capture Plate technology was developed to solve the problem of capturing loose hardware and small fasteners, items that were not originally intended to be disengaged in microgravity, thus preventing them from becoming space debris. This technology was incorporated into astronaut tools designed and successfully used on NASA's Hubble Space Telescope Servicing Mission #4. The technology's ultimate benefit is that it allows a very time-efficient method for disengaging fasteners and removing hardware while minimizing the chances of losing parts or generating debris. The technology aims to simplify the manual labor required of the operator. It does so by optimizing visibility and access to the work site and minimizing the operator's need to be concerned with debris while performing the operations. It has a range of unique features that were developed to minimize task time, as well as maximize the ease and confidence of the astronaut operator. This paper describes the technology and the astronaut tools developed specifically for a complicated on-orbit repair, and it includes photographs of the hardware being used in outer space.

Introduction

Background of Problem

Confronted with the unique challenge of fixing a failed electronics board inside the Hubble Space Telescope (HST), NASA got the job done thanks to astronauts equipped with new tools and technologies. Servicing Mission #4 (SM4) occurred in May of 2009 and was a complete success. The failed electronics board was inside one of HST's many instruments, the Space Telescope Imaging Spectrograph (STIS). Accessing the board meant getting behind an aluminum Front Panel that was held in place with 111 fasteners, ranging from #4 countersunk to #4 and #8 socket head caps screws, with many having washers. It also meant worksite preparation by removing parts such as a handrail that blocked access to the Front Panel. To make things even more challenging, during the late stages of mission planning another instrument, the Advanced Camera for Surveys (ACS), had an electrical failure requiring four more electronics boards be removed.

Replacing entire instruments was not an option in this case, so NASA set off to replace just the failed electronics boards. This meant performing on-orbit surgery, but if any one of those fasteners had come free inside the telescope it could have been very detrimental to the telescope's functionality. Technologies, tools, and techniques had to be developed to avoid such a situation and ensure the mission would be successful.

Problem Solution – Tools

Four tool designs were developed and fabricated for HST SM4, each incorporating the same general fastener capture technology but for distinctly different work sites. These tools are the STIS Fastener Capture Plate (Figure 1), the ACS Fastener Capture Plate (Figure 2), the Handrail Removal Tool (Figure 3), and the Clamp Removal Tool (Figure 4).

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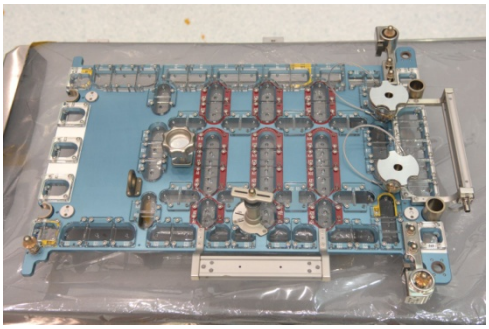

Figure 1 – STIS Fastener Capture Plate

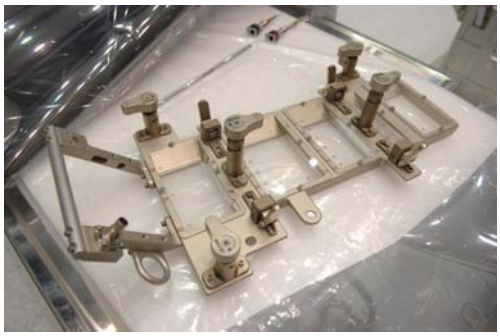

Figure 2 – ACS Fastener Capture Plate

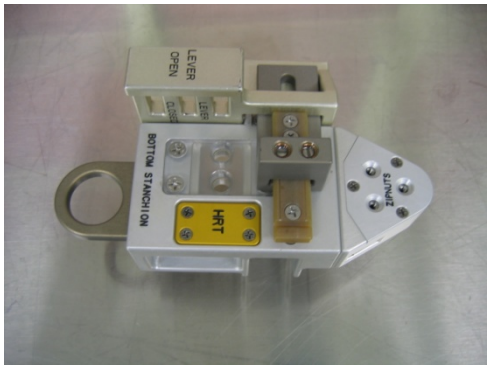

Figure 3 – Handrail Removal Tool

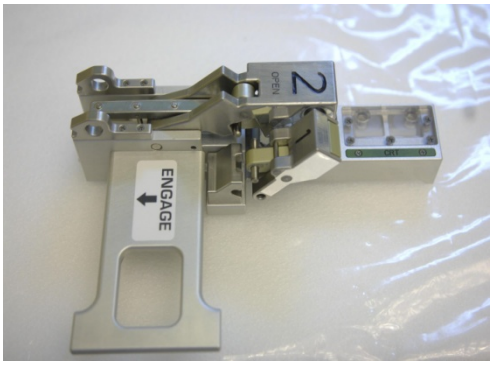

Figure 4 – Clamp Removal Tool

General Tool Description

A typical solution to the loose fastener problem would be to disengage, remove, and discard each fastener one-by-one. This would involve multiple tools used in concert, for example, grabbing the fastener with one tool while it is being disengaged with a second tool and then disposing of it into a trash bag or third tool. Stowing the released fastener is another complicated operation during which there is risk of losing the fastener. The tools invented simplify the problem by reducing the number of tools operated simultaneously and by removing the risky operation of stowing the fastener.

With the new tools, each tool is permanently attached to its worksite by the operator. This allows the operator to have both hands free. Each tool has clear windows with holes that line up with the fasteners that are to be removed. These holes allow the operator to insert a screwdriver-type bit through the window to unscrew each fastener. Behind each window is a gap, which creates a pocket or cavity for the fastener to fall in to after it is unscrewed. In some cases, a compliant gel material fills in the gap to grab the head of the released fastener. The holes in the window are small enough that the fastener cannot escape, but large enough for the bit to pass through. This concept is pictured with the Handrail Removal Tool in Figure 5.

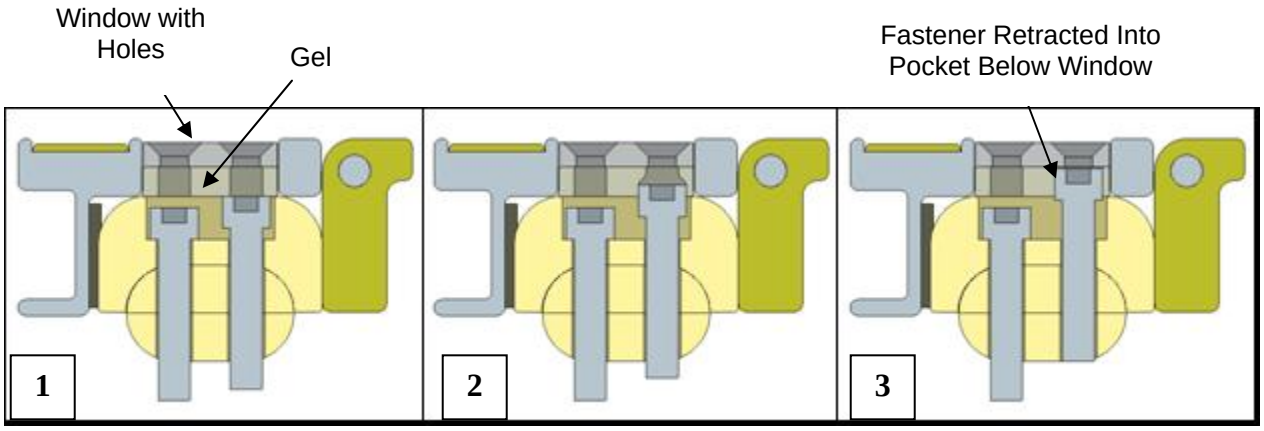

Figure 5 – Profile View of Fastener Capture Windows Concept

Figure 6 – Photograph from an Evaluation of the Fastener Capture Windows Concept

Unique Tool Features

Some unique features of the technology that give it advantages over prior fastener removal methods are listed below. All the listed features were intended and developed to minimize task time, as well as maximize the ease and confidence of the astronaut operator.

1) The action of disengaging fasteners is not automated but rather allows the operator full control and feedback.
2) The fasteners can be completely disregarded after they are disengaged. They do not need to be grabbed, stowed or cleaned up.
3) The tool can be attached in place just once and does not need to be handled or moved around the work site. It then can be used as the handling interface for the removed hardware.
4) The loosened fasteners are positively captured at all times and cannot come free without ultimate structural failure.
5) The tool minimizes particulate debris, even if a fastener were to be drilled out.
6) The tool can prevent a loosened fastener from incidental thread re-engagement with its mating part.
7) The tool can keep the loosened fastener positioned for easy re-engagement if necessary.

Tool Design

Tool Design Overview

The STIS Fastener Capture Plate tool is shown with labeled components in Figure 7. The other fastener capture tools created for the HST SM4 mission have similar features but differing geometries and capture different amounts of fasteners.

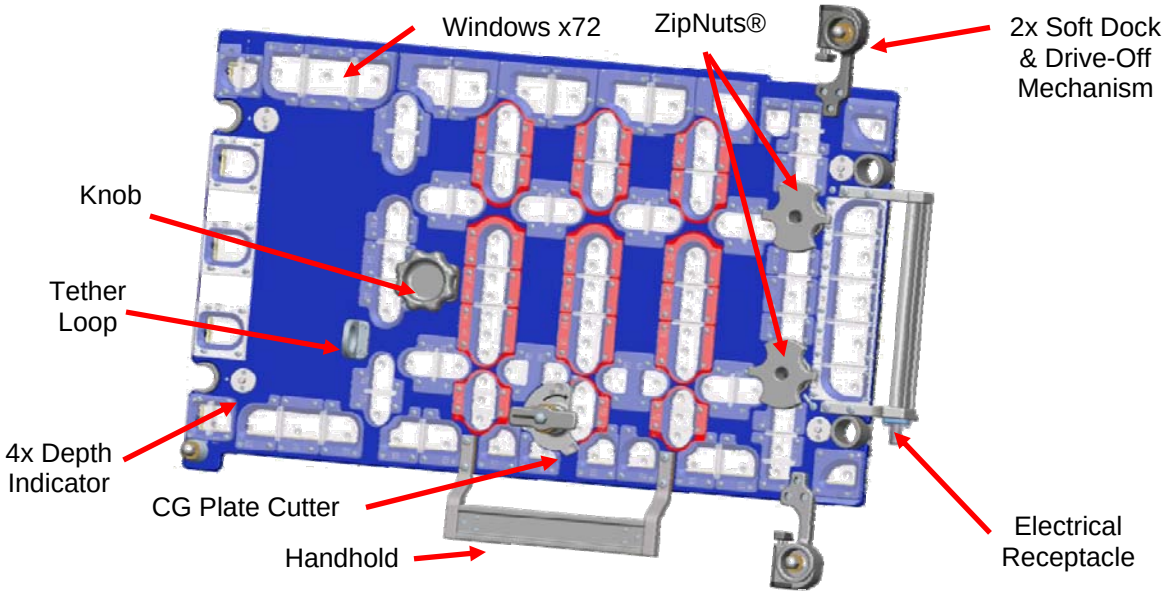

Figure 7 – STIS Fastener Capture Plate Overview

The STIS Fastener Capture Plate attaches to the front side of the STIS instrument, shown in Figure 8. The attachment mechanism is not detailed here, but the Fastener Capture Plate is essentially anchored at its four corners to the STIS Front Panel. The Front Panel, detailed in Figure 9, needs to be removed to gain access to the failed electronics board.

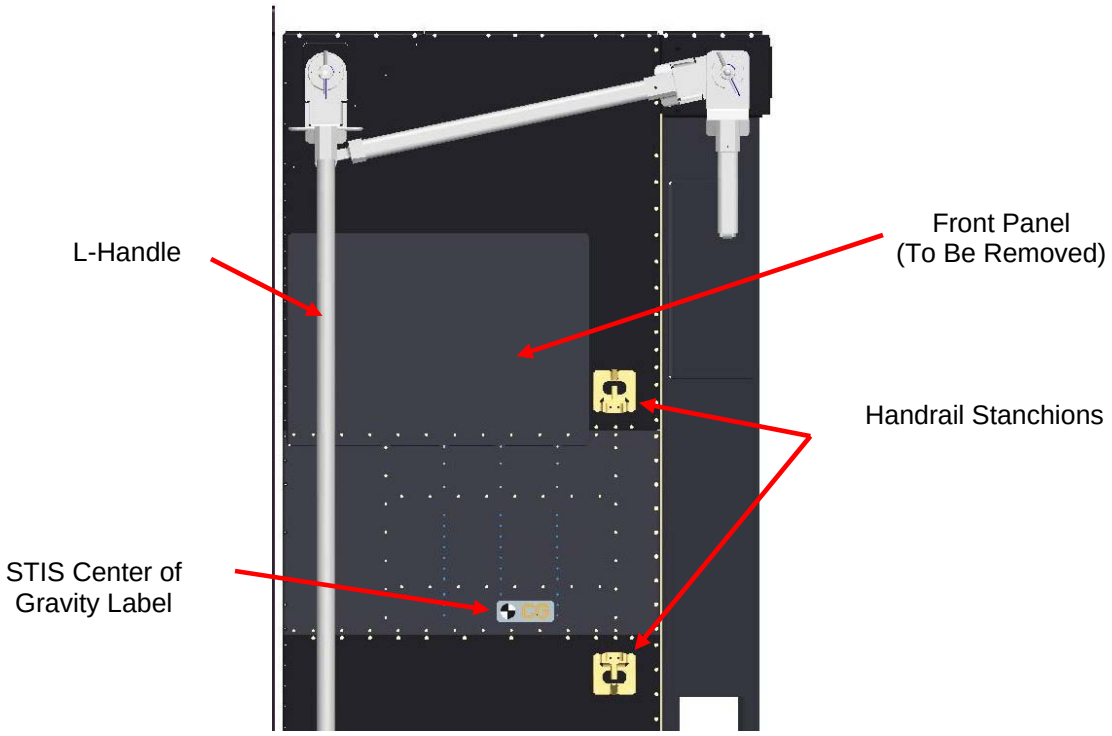

Figure 8 – STIS Fastener Capture Plate Worksite – STIS Front Panel

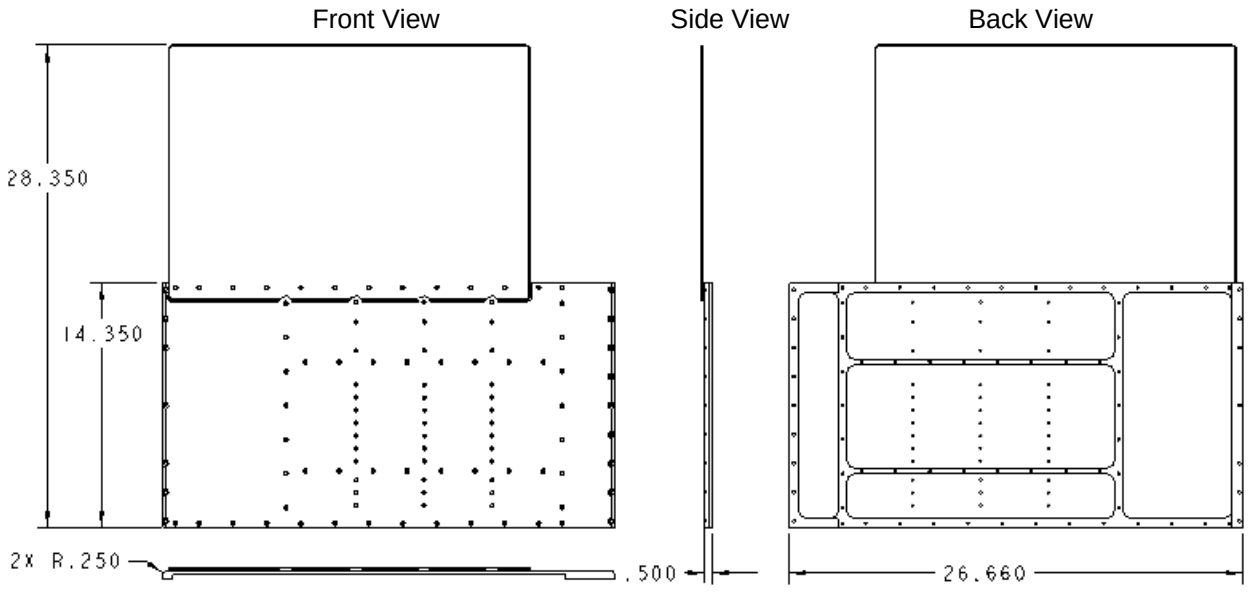

Figure 9 – STIS Front Panel Details (dimensions are in inches)

The layout of the 111 fasteners holding the Front Panel on can be seen in Figure 10. There are three types of fasteners, two having washers, the details of which can be found in Table 1.

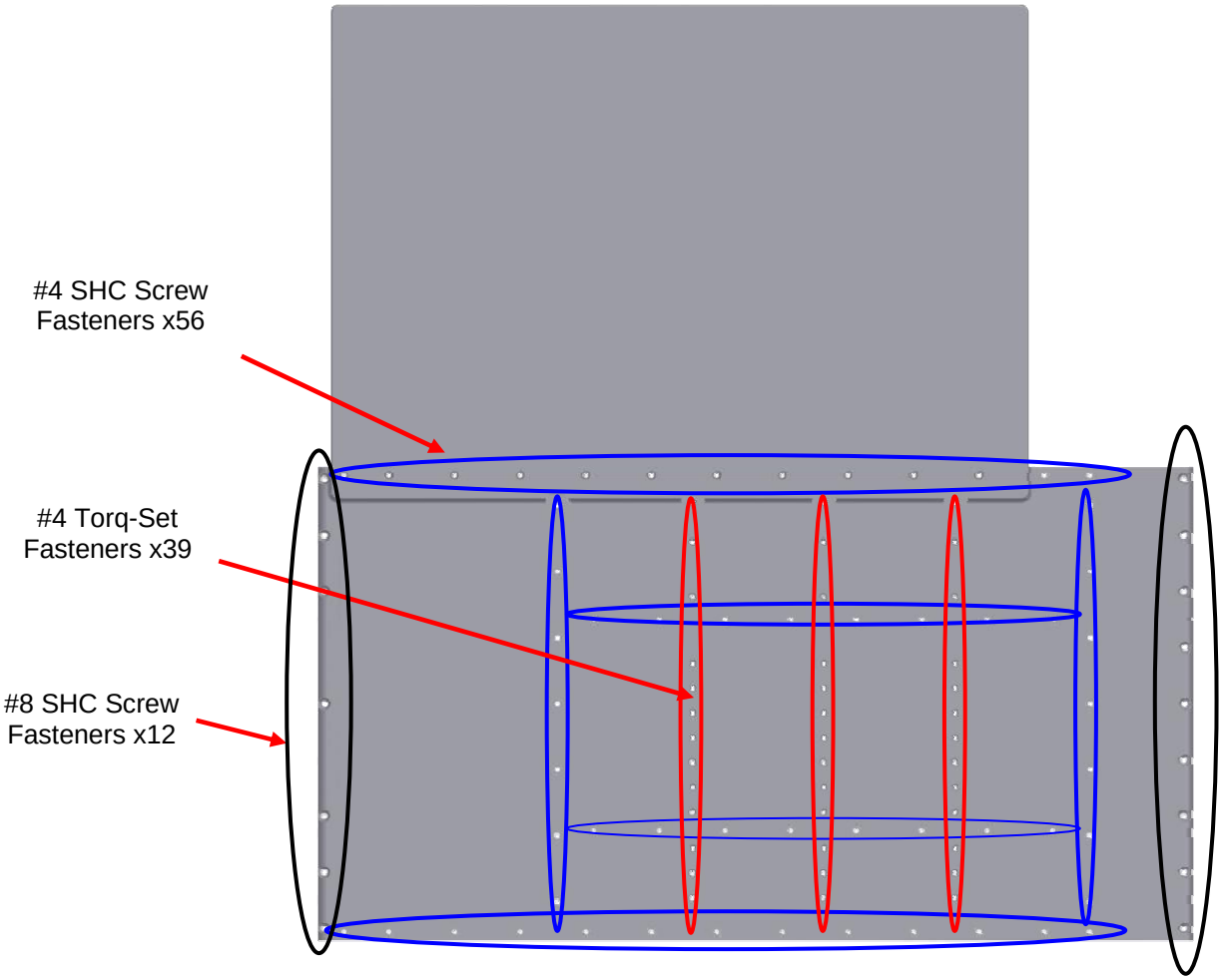

Figure 10 – STIS Front Panel Fastener Layout

Table 1 – STIS Front Panel Fastener Details

Fastener Type	Qty	Size (inches)	Specification / Part Number
#4 Torq-Set Screw	39	0.112-40, 3/8 inch long	NAS 1189E04T6K
#4 Socket Head Cap Screw	56	0.112-40, 7/16 inch long	NAS 1352E04LE7
#4 Reduced Diameter Washer	56	0.125 ID	NAS 620C4
#8 Socket Head Cap Screw	12	0.164-32, 1/2 inch long	NAS 1352N08LL8
#8 Reduced Diameter Washer	12	0.179 ID	NAS 620C8

When attached in place on STIS, the default position of the Fastener Capture Plate aligns its clear windows and holes with the Front Panel fastener locations. The colors on the tool (red, white and blue) help the operator differentiate between the different types of fasteners. Each fastener also has an alpha-numeric label. This allows an operations monitor to take note of what fasteners have and have not yet been removed, so as to make sure none get omitted. These colors and labels can be seen in Figure 11.

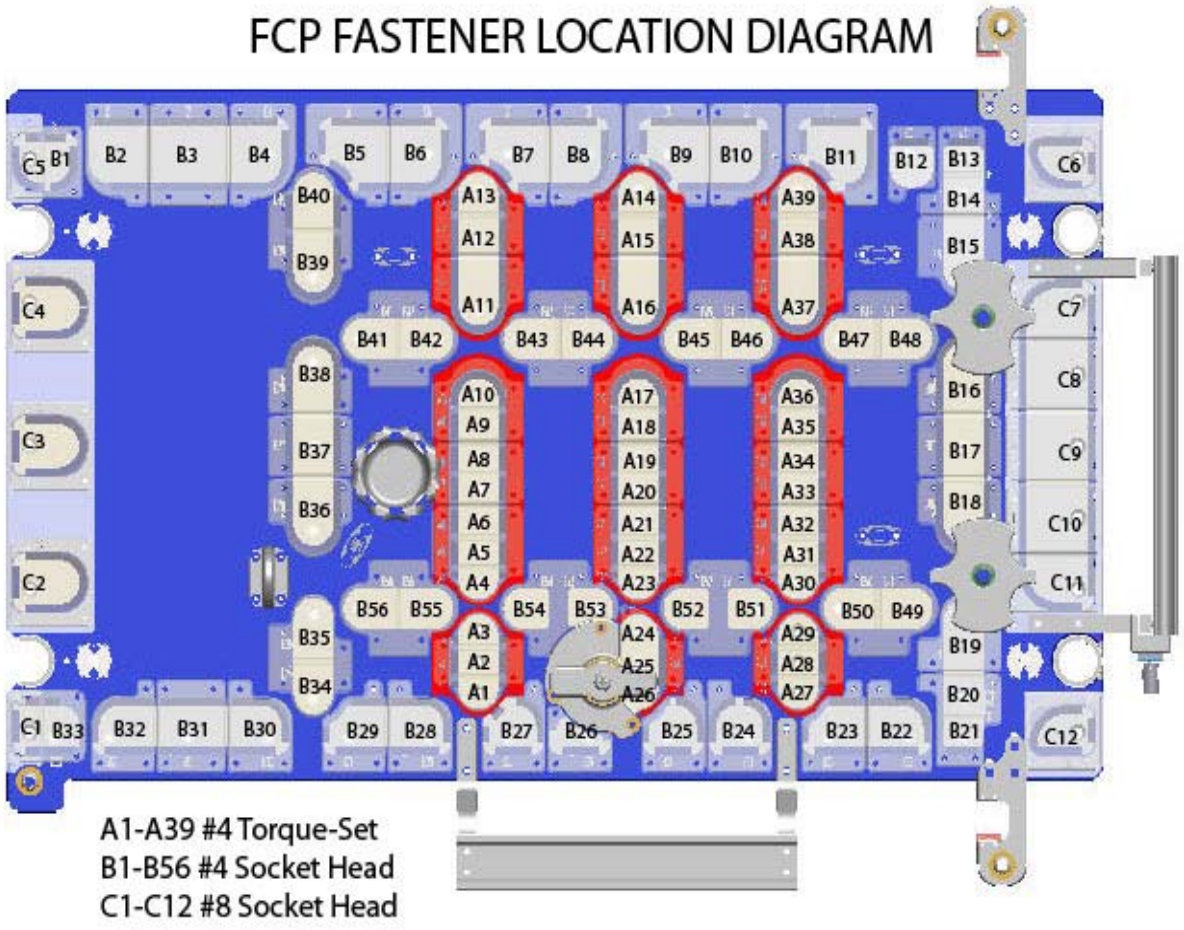

Figure 11 – STIS Fastener Capture Plate Fastener Labels

Tool Operation

Before the STIS FCP can be installed, the worksite needs to be prepared. This involves removing a handrail and a radiator clamp that block access to the Front Panel. Both of these items are held in place with fasteners, which must also be disengaged, captured, and removed. This is accomplished with the Handrail Removal Tool and the Clamp Removal Tool. These tools function with similar fastener capturing technology as the Fastener Capture Plate. Removing the handrail leaves behind the handrail's stanchions, seen in Figure 8. The handrail and clamp are removed and stowed in trash bags. Then anchor points must be installed onto the worksite for attaching the FCP.

These anchor points are created by removing four fasteners from the Front Panel, one at each corner, and replacing them with custom studs. Once they are in place, the FCP can be installed. Figure 12 shows

FCP installation. First, the FCP is positioned in place and the left side is lowered beneath the L-Handle. Second, the right side can be lowered such that the studs align with their mating holes in the FCP. Then third, the four corresponding nuts can be tightened onto the four studs, essentially fastening the FCP in place on top of the Front Panel.

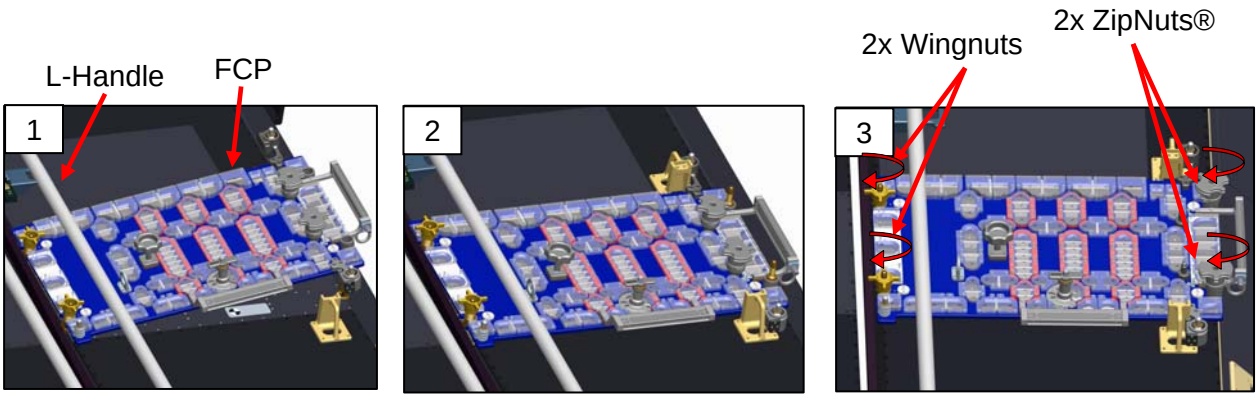

Figure 12 – STIS FCP Installation

In order to tighten the four nuts, the operator may need to let go of the FCP. In microgravity, this could allow the FCP to float freely and become misaligned. To prevent this, the FCP has a "soft dock" mechanism that holds it in place temporarily. This mechanism is essentially two spring-loaded plungers that interface with the handrail stanchions at the worksite, shown in Figure 13.

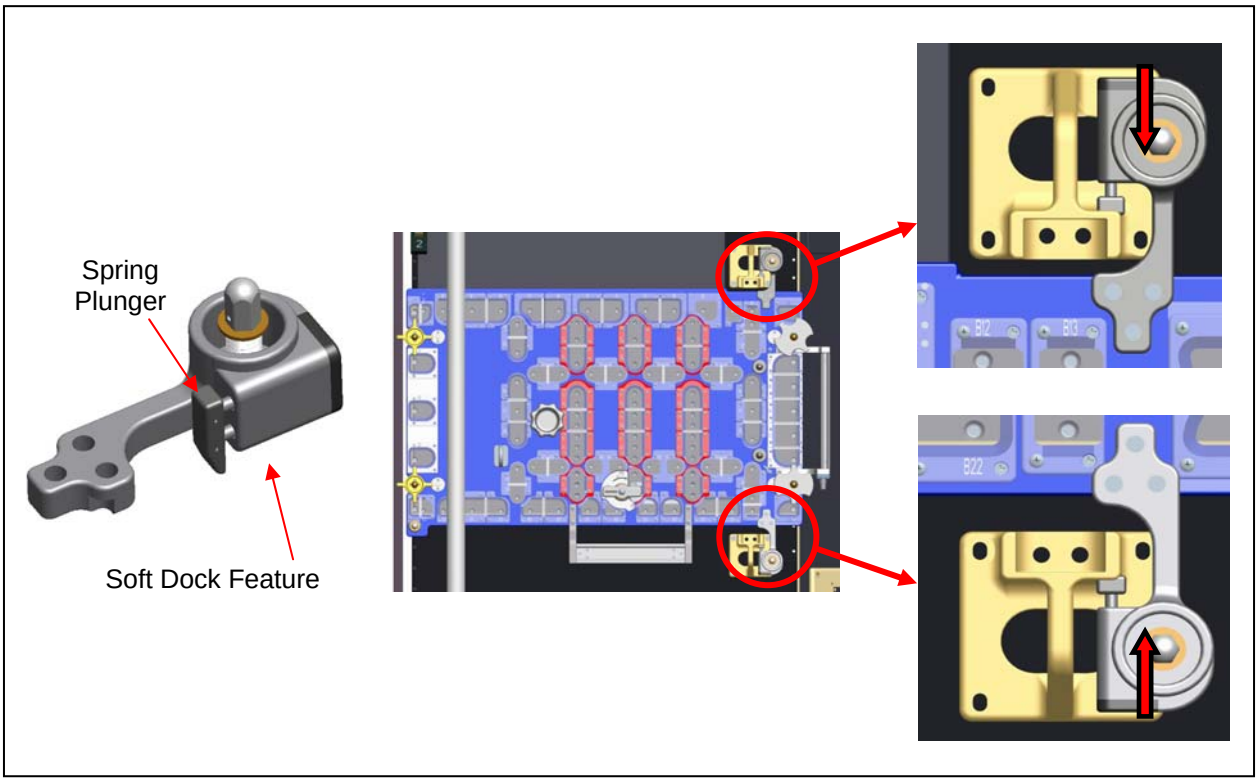

Figure 13 – STIS FCP Soft Dock Details

Once the FCP is fully installed, the task of removing the remaining 107 fasteners and the Front Panel can begin. Each fastener can be disengaged by a bit through an Access Hole in the windows in the FCP. The Access Hole will assist alignment within specified tolerances of the screw heads once the FCP is installed properly. Figure 14 shows a detailed view of the window design. Some windows may have multiple Access Holes, and some Access Holes may have countersinks to help guide the bit into place.

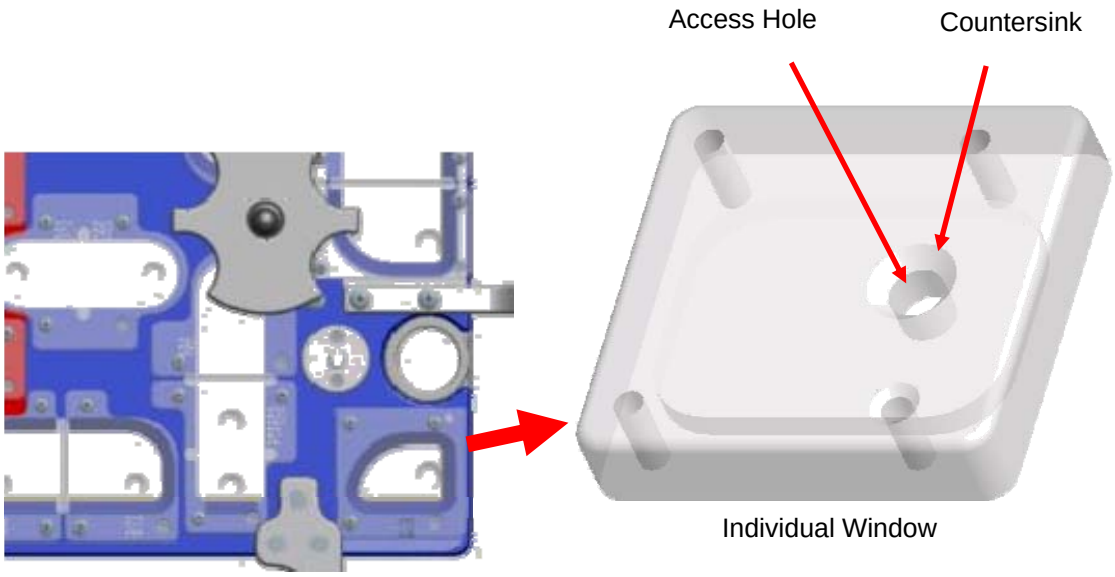

Figure 14 – Close-Up View of an FCP Window Component

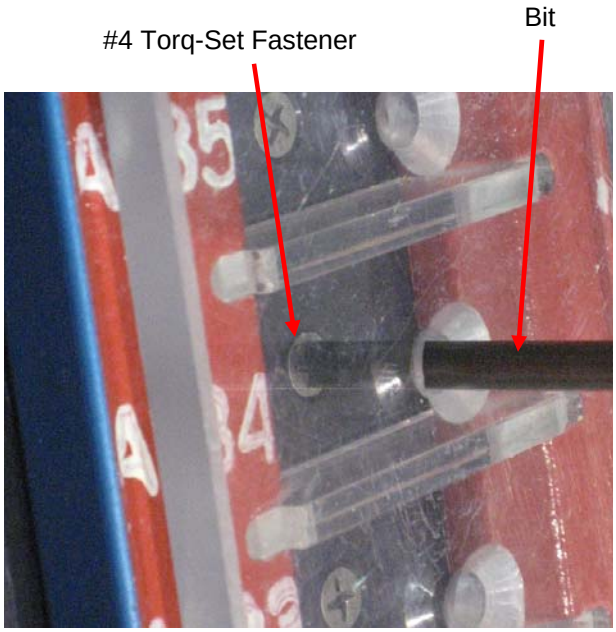

Figure 15 – Close-Up View of a Fastener Being Disengaged Through a Window

Once all 111 fasteners have been disengaged, the Front Panel is disconnected from the STIS instrument but still directly attached to the FCP tool via the four studs. Since the FCP is still “soft docked” to the handrail stanchions, it will not float away. The operator can use both hands to move the tool / Front Panel assembly away from the worksite.

Tool Design Considerations

Design of the fastener capture technology involved many tests, prototype iterations, and trade-offs. Many design considerations involved deciding how to deal with possible anomalies and common fastener problems, such as stripped head recesses. A problem encountered often on Earth is when, after a fastener is fully disengaged, its last thread incidentally re-engages with its mating female thread. One solution implemented was having a soft, compliant material within the fastener cavity that holds the fastener in place after it is disengaged. This is illustrated in Figure 16 in a cross-section view of the Handrail Removal Tool. This concept can also be utilized if the design needs to allow the fasteners to be re-engaged, because the fastener is held fairly stationary for bit re-engagement. Design details that must be taken into consideration include particle contamination, optimal geometries, and adequate compliant material durometer.

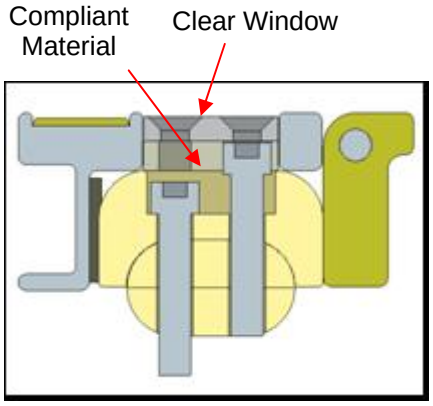

Figure 16 – Illustration of Fastener Cavity Compliant Material Concept

Accessibility and operator visibility of the worksite are major design considerations. The fastener capture technology works best when the operator can see the fastener heads clearly and closely without obstruction. This makes it easier to determine if the screwdriver bit is properly engaged, recognize if a fastener is turning properly, and realizing the fastener is all the way out. The geometry necessary for implementing this does not always align with other essential design features, leading to important trade-off decisions.

Whether or not the screwdriver bits already exist or still are in design stage must factor into the tool design. Reach and access evaluations may deem the bit must engage a fastener at a slight angle. Also material strength analysis may influence the bit’s diameter and other geometries. The Access Holes in the tools must accommodate these types of variables.

In order to ensure the fasteners and washers are properly contained, the tool’s geometry is important but also its position relative to the fasteners and mating surfaces. For the STIS Fastener Capture Plate, this is dependent upon the four anchor points and proper installation. The operator must be given some sort of feedback that the tool is installed properly, meaning sufficient enough to guarantee successful functionality. This feedback is provided by Depth Indicators on the FCP that tell the operator that the tool is seated flush enough to its mating surface such that there are no gaps to allow fasteners to escape.

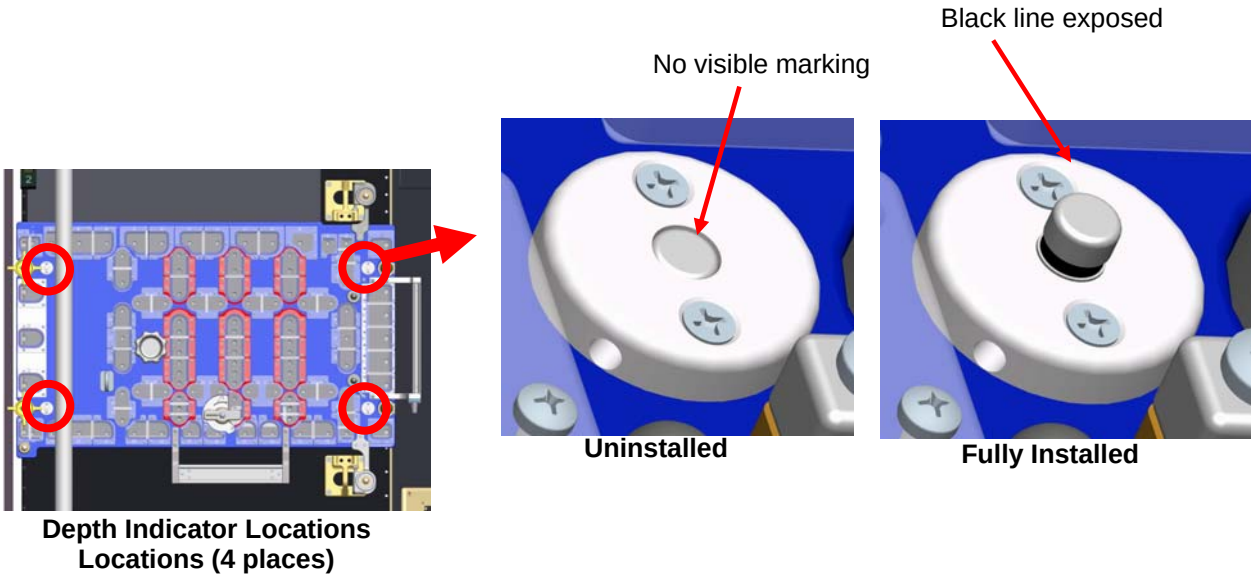

Figure 17 – Illustration of Depth Indicators

Due to tolerance stack-ups and anomalies, it would be impossible to guarantee that the FCP is installed exactly flush with its mating surface. Therefore, some compliance must be built into the system. This is accomplished with a gasket barrier around the perimeter of the underside of the tool. The compliant gasket creates a seal at the mating interface, providing containment to prevent disengaged fasteners or washers from getting free.

A potential problem of significant concern early on in the design phase was the presence of a Center of Gravity label on the Front Panel that covered up some of the fasteners that needed to be removed. The label is a sticker made of sheet metal and is not simply removable by hand. A lot of testing was employed to come up with a solution. Drilling through the label was evaluated, as well as a mechanism for pealing it off. In the end, included in the STIS FCP is a mechanism for cutting the label in a manner that removed just enough label material to reveal the fasteners it covered up.

Another design requirement of the STIS FCP involved providing the operator a means of prying the Front Panel off with enough force to overcome a sticky gasket that is holding it in place underneath. This was accomplished by including a power tool driven Drive-Off Mechanism that could be actuated if the force was too much to overcome by hand.

Tool Development and Evaluation

The fastener capture technology was developed through many tool design reviews as well as evaluation and testing of prototypes. Many of these evaluations occurred at the NASA Neutral Buoyancy Lab, where astronauts train and practice for EVA's underwater to help simulate zero-gravity. Early prototypes of the tools allowed the operators to make the following deductions:

- Removal of the Front Panel and fasteners should be done by an EVA crewmember and not an automated tool.
- Each fastener at the worksite is accessible to be removed individually.
- Use of the fastener capture technology of the FCP was preferable to removing and stowing each fastener individually.
- Disengaging the fasteners would require a clear line-of-sight to each fastener.
- An astronaut in a spacesuit could accomplish removal of all fasteners without being over-fatigued.
- Operators demonstrated the ability to diagnose and remove a stuck fastener.
- Demonstrated reliable operation of the Center of Gravity Label Cutter.

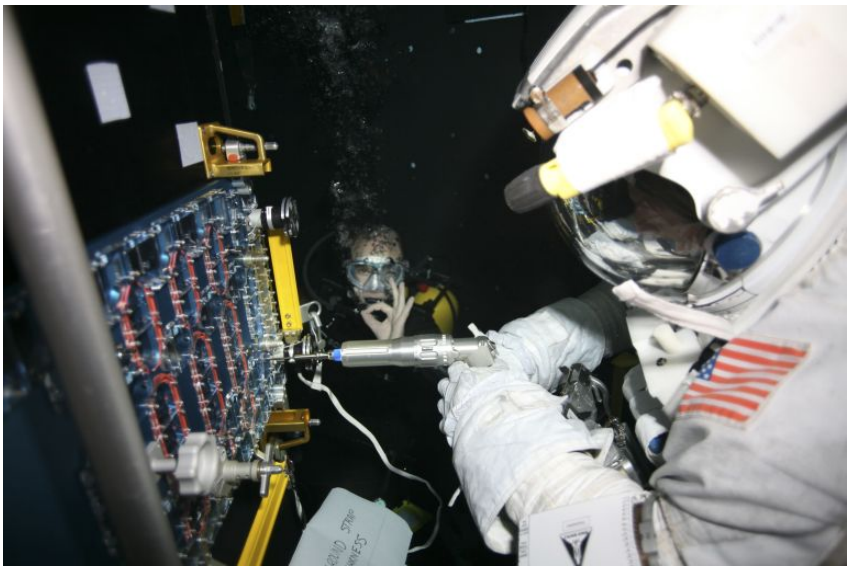

Figure 18 – STIS FCP Being Evaluated Underwater at the Neutral Buoyancy Lab

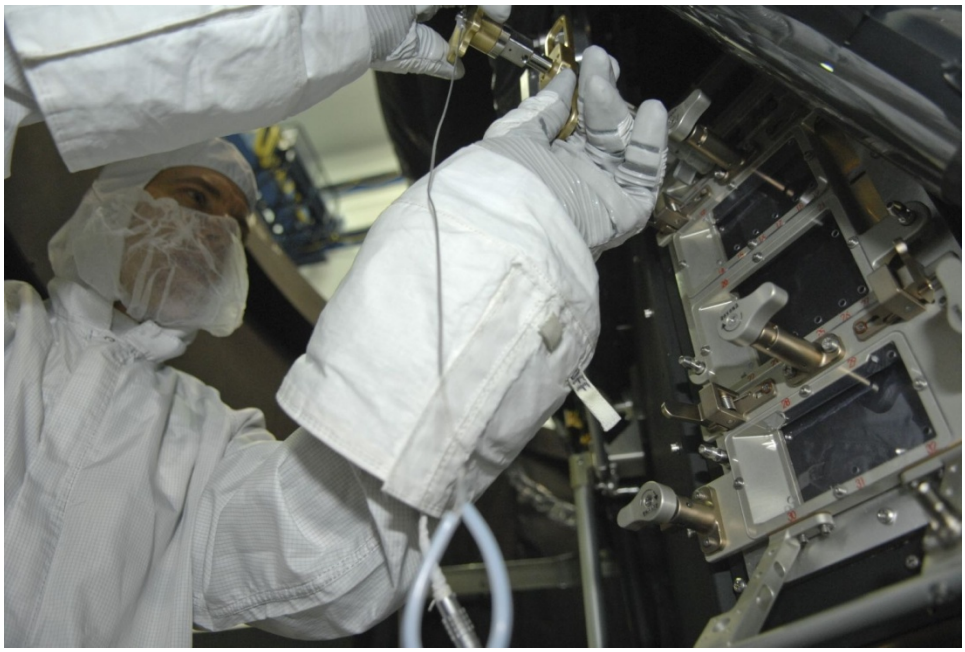

Figure 19 – ACS FCP Being Evaluated on a Mockup

On-Orbit Tool Performance

HST SM4 occurred in May of 2009 and was a complete success. The failed electronics boards inside both STIS and ACS instruments were replaced on-orbit. The fastener capture tools contained all removed fasteners as designed. Images of the tools on-orbit can be seen in Figures 20, 21, and 22.

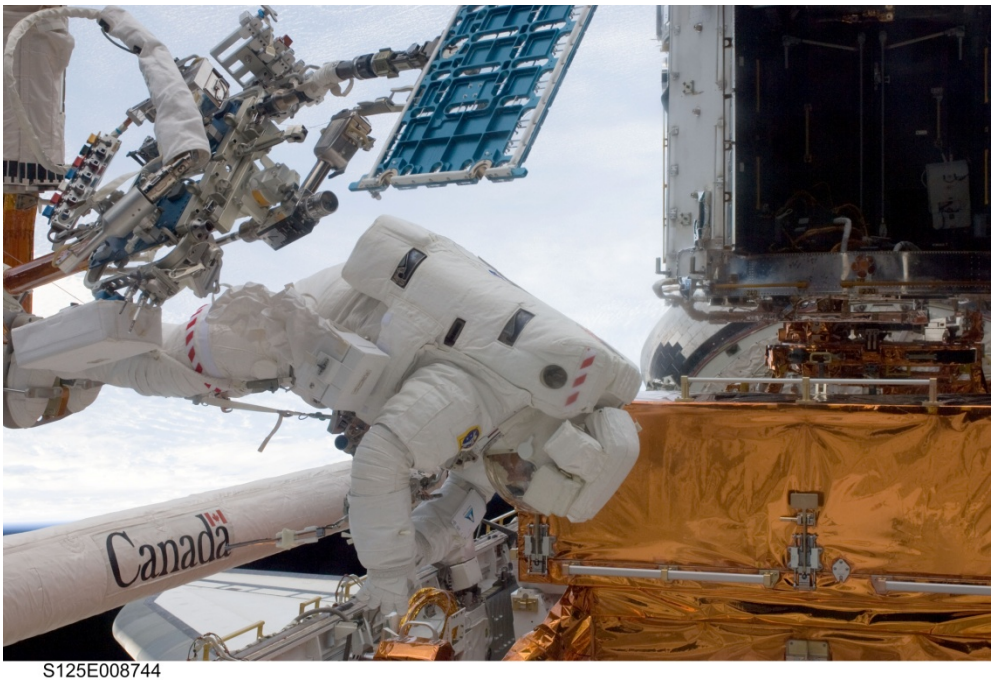

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Figure 20 – STIS FCP Being Translated to the Worksite On-Orbit

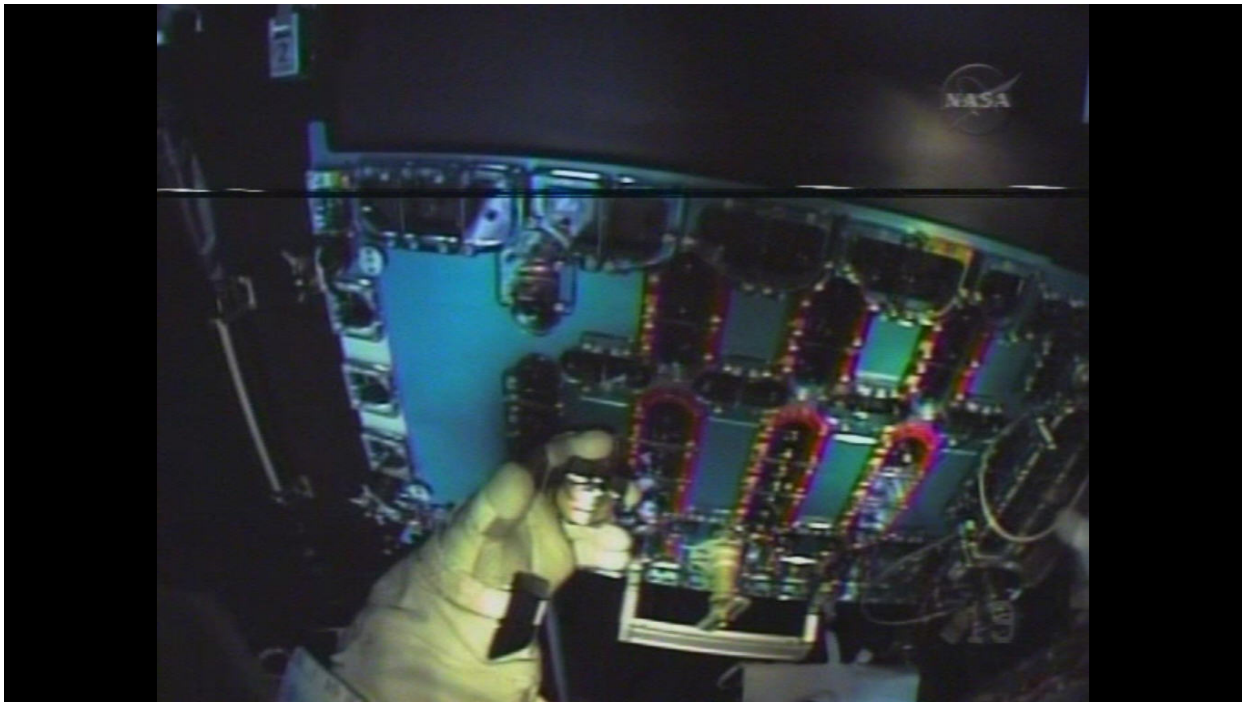

Figure 21 – STIS FCP Being Installed On-Orbit

Figure 22 – Handrail Removal Tool Installed on Handrail On-Orbit

Summary

The Fastener Capture Plate technology proved that it could solve the problem of capturing fasteners that were not originally intended to be disengaged on-orbit in microgravity, specifically for NASA's Hubble Space Telescope Servicing Mission #4. The technology demonstrated a very time-efficient method for disengaging fasteners and removing hardware while minimizing the chances of losing parts or generating debris. The four astronaut tools that implement this concept were used successfully on-orbit. There were many design variables determined for overcoming anomalies, maximizing operator efficiency, and minimizing space debris. This technology and the research put into developing the tools could be utilized in any future need for on-orbit repairs where space debris and contamination is a concern.

Acknowledgements

The development of the Fastener Capture Plate technology, related EVA tools, and STIS Repair engineering would not have been possible without the thoughtful work of Jon Penn, Tim Horner, Matt Ashmore, Torrie Kelly, Hans Raven, Kristoff Paulson, Mike Cortina, Jill McGuire, and Justin Cassidy. Thank you for your help and insight.

References

1. NASA Human Spaceflight: Gallery. <http://spaceflight.nasa.gov/gallery>
2. NASA: Hubble Space Telescope. <http://www.nasa.gov/mission_pages/hubble/main/index.html>