3.7 CAIB Recommendation 4.2-1 – Solid Rocket Booster Bolt Catcher

Test and qualify the flight hardware bolt catchers.

3.7.1 RTF TG Interpretation

The meaning of the CAIB recommendation is clear.

3.7.2 Background

A fault tree review conducted for the Columbia Accident Investigation Board (CAIB) uncovered a significant problem with the Solid Rocket Booster (SRB) bolt catchers. Each SRB is connected to the External Tank (ET) by four separation bolts: three at the bottom plus a larger one at the top that weighs approximately 65 pounds. These larger upper (or "forward") separation bolts (one on each SRB) and their associated bolt catchers on the External Tank were the subject of a great deal of scrutiny by the CAIB.

About two minutes after launch, pyrotechnic charges break each forward separation bolt into two pieces, allowing the spent SRBs to separate from the External Tank. Two "bolt catchers" on the ET each trap the upper half of a fired separation bolt, while the lower half stays attached to the Solid Rocket Booster. As a result, both halves are kept from flying free of the assembly and potentially hitting the Orbiter. Bolt catchers have a domed aluminum cover containing an aluminum honeycomb matrix that absorbs the energy of the fired bolt. The two upper bolt halves and their respective catchers subsequently remain connected to the External Tank, which burns up during reentry, while the lower halves stay with the Solid Rocket Boosters that are recovered from the ocean.

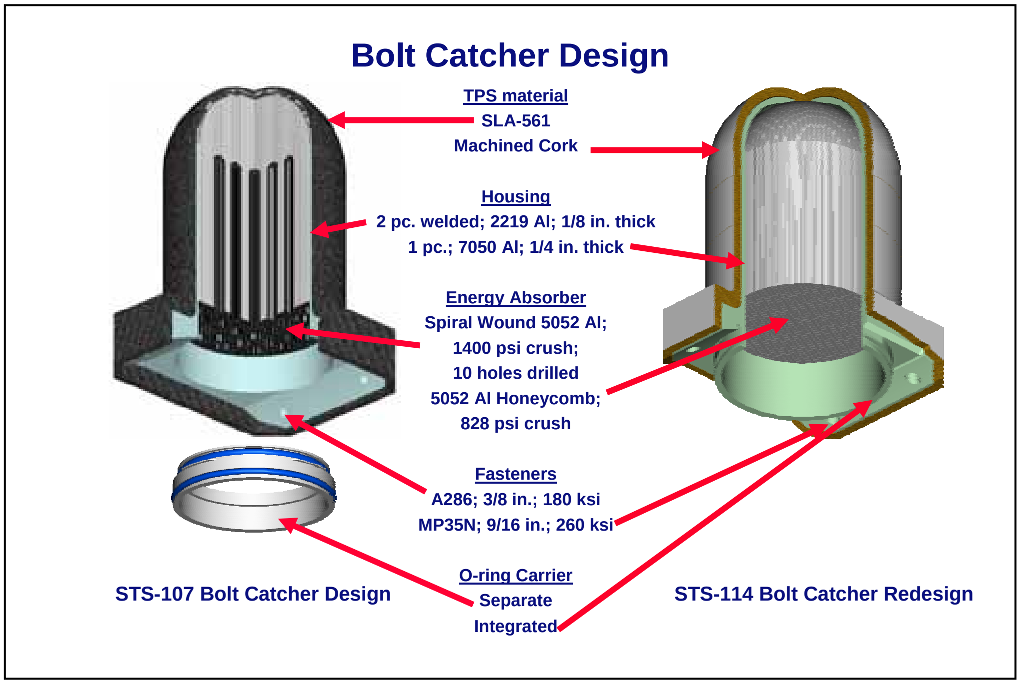
If one of the bolt catchers had failed during STS-107, the resulting debris could have damaged the wing leading edge of *Columbia*. Concerns that the bolt catchers may have failed, causing metal debris to ricochet toward the Orbiter, arose because the configuration of the bolt catchers used on Space Shuttle missions differed in important ways from the design used for the initial qualification tests. Despite the extensive CAIB analyses, the accident board also was not able to determine that the SRB bolt catchers, while an unlikely cause, could be definitively excluded as a potential cause the damage that doomed *Columbia*.

Static and dynamic testing, conducted as a result of the CAIB inquiries, demonstrated that the bolt catchers flown on STS-107 had a factor of safety of 0.956, rather than 1.4 as required by specification. The CAIB and NASA also identified additional reasons to be concerned about the bolt catchers. The bolt catchers did not meet their established requirements; specifically, the thermal protection system for the assembly was not qualified for the separation shock environment; failures of the bolt catcher attach fasteners or inserts could lead to debris; and the ejection effects of the NASA standard initiator (NSI) from its pressure cartridge during bolt firing were not included in the original bolt catcher qualification.

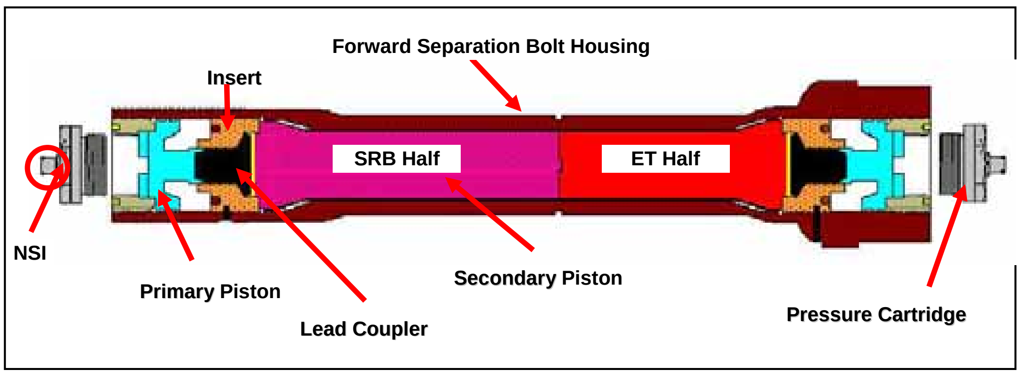
3.7.3 NASA Implementation

The bolt catcher assembly and related hardware has been redesigned. The bolt catcher housing is now fabricated from a single-piece aluminum forging that removes the weak point at the weld from the original design. The strength of the housing has been increased by doubling the thickness and using a stronger aluminum. Further, NASA has redesigned and resized the bolts and inserts that attach the bolt catcher to the ET, using larger and stronger fasteners. The housing design was enhanced with an integral O-ring carrier design that eliminated a separate carrier and one O-ring. The assembly's thermal protection system is replaced by machined cork with enhanced adhesion properties to reduce the potential for debris, and a new honeycomb energy absorber was introduced to reduce the loads. Mandatory government inspection points have been added for the thermal protection system, structure, and energy absorber with 100-percent surveillance of all manufacturing processes during final assembly. This new assembly was qualified by testing as a complete system to demonstrate compliance with NASA factor-of-safety and debris requirements.

The bolt catchers were extensively redesigned after STS-107, and subjected to a full-range of qualification testing.



The forward ET-SRB separation bolt is broken in half when the SRBs are jettisoned. It is the ET half of this bolt that the bolt catchers are intended to capture.



NASA has completed the redesign of the bolt catcher assembly and its associated hardware. Critical Design Reviews were completed for both the bolt catcher and the NSI pressure cartridge in May 2004. Development testing completed to date includes: energy absorber characterization; bolt catcher system drop and firing test; bolt catcher structural tests; bolt catcher attachment fastener prying and bending test; separation bolt velocity determination; NSI pressure cartridge and retention device quick look margin tests; NSI pressure cartridge burst tests; and NSI pin ejection simulations. Thermal protection system qualification testing was completed in August 2004.

Qualification testing of the bolt catcher assembly, to the original specifications, was begun in July 2004. During the final qualification test simulating NSI pin ejection firing, results showed that the actual crush depth was less than the predicted crush depth. (Crush depth is the measurement of the distance the bolt travels into the energy absorber inside the bolt catcher.) The difference between actual and predicted crush depth was determined to be caused by

Polymer Development Laboratories (PDL) foam and the energy absorber counterbore. In order to improve crush depth prediction accuracy, the PDL foam and energy absorber counterbore were eliminated by reducing the length of the energy absorber. Testing shows this reduction in length is acceptable because the longer energy absorber was added before the maximum bolt velocity was established. Subsequent testing proved that the bolts have a lower maximum velocity than the design allows; therefore shortening the energy absorber does not alter the effectiveness of the bolt catcher. However, it does allow for greater predictability of crush depth. Qualification testing was completed in October 2004.

The bolt catchers for ET-120, originally intended for use on STS-114, during their installation at the Kennedy Space Center. The bolt catchers used on ET-121, the tank actually used for STS-114, were identical.

3.7.4 RTF TG Assessment

The RTF TG conducted multiple fact-finding trips in support of the bolt catcher recommendation. The Task Group also supported several design reviews, including the Delta Critical Design Review (CDR) on April 28-30, 2004, and the Design Certification Review on November 22, 2004.

The bolt catcher for the SRB to ET separation bolt has been modified to provide an adequate safety factor, per the original specification. The STS-107 design was a two-piece welded assembly and the new design is based on a one-piece forging. The energy absorber used to attenuate the bolt impact load has been redesigned as well. Additionally, the thermal protection system has been changed from a sprayed-on material to bonded cork. The NASA standard initiator in the pressure cartridge had exhibited an ejection failure mode during several tests which could damage the energy absorber prior to bolt impact. This issue has been addressed by the incorporation of a locking ring assembly to aid in retention of the NSI.

The SRB bolt catcher has successfully completed qualification testing and has demonstrated a minimum structural factor of safety of 1.86. The new assembly was qualified by testing as a complete system to demonstrate compliance with NASA factor-of-safety and debris requirements. Additionally, the NSI retention device has been determined to exhibit a minimum factor of safety of 2.3. The redesigned bolt catcher has successfully completed Level IV DCR.

The RTF TG assessment of NASA's actions was completed at the December 16, 2004 meeting. The intent of CAIB Recommendation 4.2-1 has been met.

Discovery being lifted onto the stack originally intended for use during STS-114. Anomalies with this External Tank forced the eventually switch to the stack planned for use on STS-121.

3.8 CAIB Recommendation 4.2-3 – Two-Person Closeout Inspections

Require that at least two employees attend all final closeouts and intertank area hand-spraying procedures.

3.8.1 RTF TG Interpretation

The Columbia Accident Investigation Board (CAIB) subsequently clarified that this recommendation was intended to apply across the entire Space Shuttle Program for all types of closeouts; although the External Tank (ET) intertank was specifically called out, the recommendation was not intended to be limited to this area. The RTF TG therefore interpreted this recommendation to mean that NASA should review and update all of their process controls to ensure that at least two people observe all final closeout activities in critical areas.

3.8.2 Background

In its report, the CAIB remarked on the Agency's overall success in improving security following September 11, 2001. At that time, NASA embarked upon a comprehensive review of all security procedures in place and all Space Shuttle Program projects and elements cooperated with their host Centers and NASA Headquarters, Office of Security Management and Safeguards, to review NASA and contractor security procedures and implementing a wide array of improvements. This review encompassed the entire scope of security-oriented activities, including hiring procedures, personnel reliability assurance programs, physical site security, specific anti-terrorism measures, and manufacturing and processing procedures.

The CAIB report (pp. 93-94) provides additional detail into the possibility that willful damage contributed to the STS-107 accident. The accident board's investigation determined that this was not a credible potential cause of intertank foam debris.

During this security review, however, the CAIB identified several processes that did not require two people to be present when an area on the flight vehicle was closed-out. Although unlikely, this could allow an individual to sabotage the vehicle without being observed. Equally as important, this was counter to the general policy of "two sets of eyes are better than one" that provides additional technical and safety checks during closeouts.

3.8.3 NASA Implementation

The External Tank Project amended all manufacturing processes and procedures to ensure that at least two employees, and in most cases several more, are present at all manufacturing steps. This includes manual foam applications and all other closeouts, both at Michoud Assembly Facility and the Kennedy Space Center. Furthermore, NASA implemented more-stringent quality assurance requirements and provided additional employee training, certification, and work documentation of inspections and imagery.

In response to additional guidance provided by the RTF TG in April 2004, NASA widened the scope of its corrective measures by issuing additional direction for all major flight hardware and ground processing elements to conduct an audit of their final closeout procedures and protocols. The audit included a review of quality assurance closeout protocols and the protection they offer against willful damage. This audit was completed on April 30, 2004 and the results forwarded to the Task Group shortly afterward.

In the back of the Orbiter Processing Facility bay 3, workers check one of the thermal protection system blanket ground wires to ensure a proper ground between the blanket and the Orbiter Boom Sensor System (OBSS). The installation will conclude TPS closeout prior to installation of the boom in *Discovery*. At least two workers are present for all closeout activities.

3.8.4 RTF TG Assessment

The Task Group conducted several fact-finding activities during early 2004. A closure package was received by the RTF TG in time for this recommendation to be considered at the April 2004 plenary meeting. The Task Group assessed the Agency's implementation of this recommendation and determined that NASA was defining the accident board's intent too narrowly. The Task Group's fact-finding site visits, review of the CAIB report, and correspondence with members of the CAIB, led them to suggest that NASA should widen its perspective to include *all* flight hardware elements, rather than just the External Tank. Nevertheless, sufficient progress had been made for the Task Group to conditionally close their assessment at the April 16, 2004, public meeting.

Accordingly, NASA widened the scope of its corrective effort to conduct a program-wide audit of all final closeouts for major flight hardware elements, both at the manufacturing sites and at the Kennedy Space Center. This audit was completed on April 30, 2004, and all revised requirements were incorporated into the appropriate documentation by January 2005.

The results from this audit were received by the RTF TG on December 8, 2004, and the results presented in the closure package were considered satisfactory. NASA provided data on the documentation that had been updated, also to the Task Group's satisfaction.

The RTF TG assessment of NASA's actions was completed at the December 16, 2004 meeting. The intent of CAIB Recommendation 4.2-3 has been met.