This appendix contains – reproduced at smaller than normal size – the study of radar returns from past Space Shuttle launches to determine whether the Solid Rocket Booster bolt catchers may have failed during the flight of STS-107. The report concluded that there was the possibility that one of the debris items seen on radar during that flight could have been part of a bolt catcher.

This appendix has no recommendations, but the Board did make recommendations related to the bolt catcher issue in Volume I. The conclusions drawn in this report do not necessarily reflect the conclusions of the Board; when there is a conflict, the statements in Volume I of the Columbia Accident Investigation Board Report take precedence.
25 June 2003

Department of the Air Force
45<sup>th</sup> Space Wing
Patrick Air Force Base, FL 32925

ATTN: 45<sup>th</sup> Range Management Squadron (45 RMS/RMSS)

SUBJECT: CONTRACT F08650-00-C-0005: TECHNICAL NOTE – BOLT CATCHER DEBRIS ANALYSIS FOR SHUTTLE STS-107 (CDR A205)

The attached Technical Note presents an analysis of the STS-107 vehicle debris detected by Eastern Range radar following Solid Rocket Booster separation. The analysis was specifically conducted to determine if any debris detected following Solid Rocket Booster separation was characteristic of an External Tank Bolt Catcher.

If additional information is required, please contact Michael Ignacek at (321) 494-9740.

Original signed by

Susan J. Vaughn
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SJV/II

Attachment: As stated

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INTRODUCTION
Shuttle STS-107 was launched from Space Launch Complex (SLC) 39A, located at the Kennedy Space Center (KSC), on 16 January 2003. During the ascent phase of this launch, the Orbiter Vehicle, Columbia, was impacted by debris emitted from the External Tank (ET) at approximately T+81 seconds (s). At the request of Mr. William H. Hease, National Aeronautics and Space Administration (NASA) Shuttle Flight Safety Manager, CSR Systems Analysis performed a debris analysis of radar data, optical video, and optical film images collected during the launch.

The analysis was conducted in two parts. The original report, distributed on 14 February 2003 [ref. 1], consisted of analyses of debris detected at T+110 s to T+140 s (near the time of internal ET separation and partial ET breakup), and T+150 s to T+230 s. The time frame around Solid Rocket Booster (SRB) separation is typically characterized by abundant plume effects and expulsion of solid fuel debris and was, therefore, not analyzed in the original report. At the request of Mr. Hease, the time period from T+110 s to T+140 s was analyzed for debris, and the results were distributed in a revision to the original report on 4 April 2003 [ref. 2].

BOLT CATCHER DEBRIS ANALYSIS FOR SHUTTLE STS-107
Chuck Cook, Karen Beauchamp, Michael VonNiederhausern

An analysis of debris detected following Solid Rocket Booster separation indicates that one debris item, Item #33, is a good candidate to be an External Tank Bolt Catcher. Peak amplitudes of the debris returns are consistent with those of an External Tank Bolt Catcher. Range Time Intensity data from previous missions indicates that debris items have been detected at or near Solid Rocket Booster separation on 19 past missions. Seven items from five missions exhibited similarities to Item #33.

Additional examples of candidate debris were identified within the original report, but those items were not conducted in time to include in the publication of the revised report. At the request of Mr. W. Wayne Hols, Jr., NASA Shuttle Launch Integration Manager, an analysis of debris detected following SRB separation was conducted to determine if any of the debris items were characteristic of an ET Bolt Catcher.

For additional information, contact the author at (321) 494-9720 or through e-mail at <karen.beauchamp@patrick.af.mil>
An ET Bolt Catcher is composed of an aluminum casing, covered with a Super Light Ablative (SLA) coating. In the opening at the base of a Bolt Catcher, a honeycombed aluminum disk exists to absorb the explosive energy of the bolt as it separates the SRB from the ET (Fig. 3). Bolt Catcher dimensions are shown in Fig. 3.

A Bolt Catcher’s radar return signature characteristics, as well as its mean and maximum RCS, were established in controlled testing at the AFRL, WPAFB. The testing was conducted within the ER radar operating parameters of 5690 MHz frequency and linear vertical polarization. These signatures and measurements were used as an approximation of the signal that may be returned from a Bolt Catcher if captured by the ER tracking radar. Fig. 4 and Fig. 5 present the results of the AFRL C-Band tests. Note that all measurements and all the AFRL were taken from a Bolt Catcher without SLA coating. All comparisons made in this report use these numbers. Although no RCS information is available for a Bolt Catcher with an SLA coating, the maximum RCS magnitudes are not expected to be significantly different from that of an uncovered Bolt Catcher due to the thickness of the coating (1.52 cm) relative to the radar’s wavelength (λ), which is 5.27 cm or 0.29λ, and the low radar reflectivity of SLA. A 230 cm² plate with SLA coating has an RCS of -32 dBsm versus 3.9 dBsm for a similarly sized metal plate without SLA coating [ref. 4].

The command for SRB separation was issued at T+127 s. Radar 0.14 detected no items around the time of SRB separation. Radar 19.14 detected five items, and Radar 28.14 detected one item. The maximum RCS of the detected items during that time ranged from -15 dBsm to +1 dBsm.

Examination of the RTI charts for Radar 19.14 and Radar 28.14 shows a large cloud of debris particles after SRB separation with some distinct particles discernable from the cloud (Fig. 6 and Fig. 7). The possibility exists that more debris was present than was detected, as the separating SRB and/or its plume may have masked signals from separating objects.

**Fig. 3. ET Bolt Catcher Dimensions**

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Bolt Catcher Debris Analysis for Shuttle STS-107

The digitized data from T+110s to T+140s was analyzed in an attempt to determine the basic shape (e.g., flat plate, cone, cylinder, sphere) of the debris. Radar signatures were examined for all objects. For all but a single item, Item #33, the signal returns from the debris could not effectively be distinguished from the radar noise. The signal specular analysis, the majority of the debris is assumed to be irregular in shape. As a result, all debris items during this time period were excluded as possible Bolt Catcher candidates, with the exception of debris Item #33. The speculars from Item #33 were well defined, and a detailed analysis of debris Item #33 is provided in the following section.

Debris Item #33

Debris Item #33 (Fig. 8) is first observed at T+128 s, one second after the SRB separation command was issued. The item has a range separation rate of 520 m/s (with a 130 m/s uncertainty), and is visible for two seconds. The signal return of this item is significantly stronger than any of the debris detected by any radar from SRB separation through the remainder of the mission, indicating a larger or a more highly reflective item than any of the other detected debris items. An RTI contour plot depicting debris item #33 separating from the Orbiter/ET stack is shown in Fig. 8.

The maximum RCS of Item #33 returns is consistent with the peak amplitudes for the nose, broadside, and base of an ET Bolt Catcher as determined at proximity to SRB separation. Radar 28.14 detected five debris items in this analysis. Analysis of the specular data demonstrates that the RCS peak amplitudes of Item #33 returns are within the uncertainty ranges established in Revision 1 of the original Technical Report [Ref. 3] to be matched to the RCS of the individual facets of a Bolt Catcher: nose, broadside, and base. The AFRL tests indicate that the rounded nose of a Bolt Catcher has a maximum RCS of -3.0±1 dBsm. The broadside and the end of a Bolt Catcher have a maximum RCS of -3.0±1 and -2.4±0.1 dBsm, respectively. The peak specular measured at Radar 28.14 ranged from -2 to 2 dBsm with a 3-dBms uncertainty.

If Item #33 were a metallic cylinder, its theoretical dimensions would be similar to the dimensions of an ET Bolt Catcher. The peak specular amplitudes indicate that the item has a maximum reflective surface of 170±60 cm². This reflective area would be produced by a cylinder with a 20.0 cm diameter and a length of 32.0 cm. These tolerances on the Item #33 dimension estimates make it well within the possibility to be the dimensions of an ET Bolt Catcher.
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Bolt Catcher Debris Analysis for Shuttle STS-107

Historical Review
CSR Systems Analyst reviewed 46 previous Shuttle missions for which RTI charts are available, dating back to November 1994. On 19 of these missions, a debris item was detected at a time similar to that of Item #33, specifically, at or near the time of SRB separation. Additionally, on five of these 19 missions, the debris items exhibit a very strong similarity to Item #33 in that they were singular, distinct items, and had similar returns. These five missions were F1642 (STS-110), F1076 (STS-105), F4289 (STS-100), A4651 (STS-95), and A3839 (STS-90). It cannot be determined if these items are identical to Item #33, since all data required to perform a complete analysis may not exist.

CONCLUSIONS
Debris Item #33 was determined to be the only possible candidate for an ET Bolt Catcher. Analysis of speculars from the item shows that the peak amplitudes of the returns are characteristic of the peak amplitudes for the nose, broadside, and bottom of an ET Bolt Catcher as determined by RCS measurements by the AFRL at WPAFB. Additionally, the peak return observed by Radar 28.14 would, theoretically, be indicative of a metal cylinder with similar dimensions of an ET Bolt Catcher.

Full characterization of the signature pattern could not be accomplished due to PRF limitations, and the exact shape of the debris item could not be determined. As a result, this analysis cannot definitively determine if this item is, or is not, an ET Bolt Catcher. However, due to the detection of the item in close proximity to SRB separation, the similar peak amplitudes, and similar theoretical size, this item is considered a reasonable candidate to be an ET Bolt Catcher.

Debris Item #33 was evaluated to determine if it could be any part of the Forward Separation Bolt assembly. The ET Bolt Catcher attachment bolts, Bolt Catcher honeycomb panel, and ET separation bolt were eliminated as possible candidates, since none of these items would produce a return of the magnitude observed by Radar 28.14. Additionally, the signal returns from Item #33 were determined to be too large to be a Booster Separation Motor (ISM) cover.

RTI data from previous missions indicate that debris items have been detected at or near SRB separation on 19 past missions. Seven items from five missions exhibit strong similarities to Item #33.

REFERENCES