



Volume II

Appendix D.4

Fault Tree Elements Not Closed

This appendix contains fault tree elements that were not closed or could not be completely closed by the Board by the end of the *Columbia* investigation. In some cases, a fault tree element may never be closed since neither analysis nor data is available to rule that element out as a potential cause. In some cases, the lower-level fault trees contained in this appendix will cause a higher-level fault tree in Appendix D.3 to remain open as well (annotated as “Open due to lower element” in Appendix D.3).

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Fault Tree Elements Not Closed

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Fault tree analysis is a deductive, top-down method of analyzing an undesirable event (e.g., the loss of crew and vehicle during re-entry) to determine all the ways that the event can happen, based on the behavior of the components, lower-level assemblies, and interfaces. Fault trees are visual representations of all the events that can occur in a system to cause a system to fail.

As noted in Chapter 4, NASA chartered six teams to develop fault trees for each of the Shuttle’s major components: the Orbiter, Space Shuttle Main Engine (SSME), Reusable Solid Rocket Motor (RSRM), Solid Rocket Booster (SRB), External Tank (ET), and Payload. In addition, a seventh Systems Integration fault tree team analyzed failures involving two or more Shuttle components.

Some of the element closures will extend beyond the writing of this report. In addition, there will be some elements that can never be closed as neither data nor analysis can unambiguously rule out a contribution to the *Columbia* accident. Below are listed fault tree elements that were not closed by the Board as of the writing of the report. The elements are grouped by their potential for contributing either directly or indirectly to the accident. The first group contains elements that are believed to have contributed to the accident. Here, contributed means that the element was an initiating event or a likely cause of the accident. The second group contains elements that could not be closed and may or may not have contributed to the accident. These elements are potential causes or factors in this accident. The third group contains elements that could not be closed, but are unlikely to have contributed to the accident. Appendix D.3 lists all the elements that were closed and thus eliminated from consideration as a cause or factor of this accident.

Table 1: Fault Tree Elements Not Closed, and Likely Contributed to the Accident.

BRANCH	ELEMENT NUMBER	DESCRIPTION OF FAULT TREE ELEMENT
Orbiter	SFOML-WING-11-5	ET Debris Impact on Ascent. Launch photography and onboard sensors indicated that bipod foam struck the underside of the left wing leading edge.
Orbiter	SFOML-WING-11-66	Loss of RCC Panel Due to T-Seal Failure. The T-seals between RCC panels 7 and 8 and 8 and 9 could have been the initial location of the breach.
Orbiter	SFOML-WING-12-9	RCC Damage Due to Impact Caused Sneak Flow Causing Loss of Panel. Damage could have been initiated at the RCC panel or an adjoining T-seal.
ET	1.1.1.4.1.1.1.1	BX-250/Forward Bipod Fittings/Inadequate Design Methodology. Forward bipod fitting assembly debris due to an inadequate design methodology.
ET	1.1.1.5.1.1.1.1	SLA-561/Forward Bipod Fittings/Inadequate Design Methodology. Forward bipod assembly Super Light Ablator application with inadequate design methodology causes debris.

BRANCH	ELEMENT NUMBER	DESCRIPTION OF FAULT TREE ELEMENT
ET	1.1.1.5.1.2.1.1	SLA-561/Plate Connector-Bipod Fitting/ Inadequate Design Methodology. Forward bipod fitting plate connector Super Light Ablator application with inadequate design methodology causes debris.
ET	1.1.1.4.1.1.3.2.1	BX-250/Forward Bipod Fittings/Debris Due to Inadequate Manufacturing Process Plan. Forward bipod fitting assembly debris due to an inadequate manufacturing process plan.
ET	1.1.1.4.1.1.3.3.6	BX-250/Forward Bipod Fittings/Debris Due to MAF Material Processing. Forward bipod fitting assembly debris due to inadequately defined acceptance testing during Machoud Assembly Facility Processing.
ET	1.1.1.4.1.1.3.7	BX-250/Forward Bipod Fittings/Undetected Anomaly. Forward bipod fitting assembly debris due to undetected anomaly during Machoud Assembly Facility processing.
Integration	B561	Transport Mechanism. There are transport mechanisms to facilitate debris striking the orbiter left wing area from viable debris sources (ET, orbiter, and SRB).

The “likely contributed to the accident” entries address the release of debris from the ET and the impact of this debris on the orbiter wing RCC panels or T-seals. Although the Super Light Ablator has not been implicated in the foam release, it cannot be ruled out.

Table 2: Fault Tree Elements Not Closed, and Possibly Contributed to the Accident.

BRANCH	ELEMENT NUMBER	DESCRIPTION OF FAULT TREE ELEMENT
Orbiter	SFOML-WING-8-51	RCC Panel Improper Installation. Addresses improper installation of the wing leading edge RCC as an initiating cause.
Orbiter	SFOML-WING-8-54	RCC Processing/Material Defect. Addresses the possibility that an initial manufacturing or material defect was present in the RCC from the original manufacturing that led to failure.
Orbiter	SFOML-WING-8-57	RCC Substrate Failure Due to Mission Cycles. The lack of NDE inspection leaves this possibility suspect.
Orbiter	SFOML-WING-8-58	RCC Substrate Failure Due to Ground Cycles. The lack of NDE inspection leaves this possibility suspect.
Orbiter	SFOML-WING-8-59	RCC Failure Due to Aging. Investigates the question of RCC aging over time versus mission cycles.
Orbiter	SFOML-WING-12-3	Micrometeoroid Impact on Orbit. Based on the orbiter orientations, the chance of a micrometeorite or orbital debris hitting the RCC leading edge is 1 in 13,800.
Orbiter	SFOML-WING-12-4	Orbital Debris Impact on Orbit. Based on the orbiter orientations, the chance of a micrometeorite or orbital debris hitting the RCC leading edge is 1 in 13,800.
Orbiter	SFOML-WING-11-8	SRB Debris Impact on Ascent. The SRB bolt catcher and the SRB separation motors are possible sources of debris.
SRB	B.1.3.4.4.3.1	Debris Due to Failure of Attach Fasteners, LMC Supplied.
SRB	B.1.3.4.4.3.2	Debris Due to Failure of Bolt Catcher Structure.
SRB	B.1.3.4.4.3.3	Debris Due to Failure of LMC ET Thrust Fitting or Inserts.
SRB	B.1.3.4.4.3.4	Debris Due to Failure of Insulation (SRB/LMC).

The “possibly contributed to the accident” include a number of different means to cause damage to the wing leading edge. The effect of ageing (both operational and calendar) of the RCC is uncertain at best. Certain debris sources are listed here as they could lead to relatively heavy objects hitting the wing leading edge. Micrometeoroids and space debris can also cause a large enough hole in the RCC to allow superheated air to enter the wing.

Table 3: Fault Tree Elements Not Closed, and Unlikely to have Contributed to the Accident.

BRANCH	ELEMENT NUMBER	DESCRIPTION OF FAULT TREE ELEMENT
Orbiter	SFOML-WING-8-60	RCC Failure Due to Test Cycles. Stress testing was done on the RCC T-seal located between panels 9 and 10, inspected, and returned to OV-102.
Orbiter	SFOML-WING-9-20	Loss of RCC Panel due to RCC Panel Fastener Failure. Portions of all the panels were found in the debris field in Texas.
Orbiter	SFOML-WING-10-5	Prelaunch Unidentified Impact While on the Launch Pad. There is high confidence that pad inspections should detect any RCC damage.
Orbiter	SFOML-WING-11-6	Orbiter Caused In-flight Impact on Ascent. All the access panels have been accounted for and the other materials (e.g., tile) are of low mass.
Orbiter	SFOML-WING-11-18	Lift Off (Pad Debris) Impact. There is good foreign object debris discipline maintained at the launch pad.
Orbiter	SFOML-WING-12-94	Orbiter Debris Source from Loss of Tile During Entry. Tiles are low-density material and there are no indications in the debris and other data of a large tile malfunction.
Integration	SFOML-WING-11-9	Orbiter Bird Strike on Ascent. Photo and video evidence did not record a bird strike.
ET	1.1.1.1.1.2.5	NCFI 24-124 LO2 Tank Acreage Undetected Anomaly. NCFI 24-124 undetected LO2 tank acreage anomaly during vendor manufacturing or processing causing TPS debris.
ET	1.1.1.1.1.3.9	NCFI 24-124 LO2 Tank Acreage Undetected Anomaly. NCFI 24-124 undetected LO2 tank acreage Machoud Assembly Facility processing anomaly causing TPS debris.
ET	1.1.1.1.1.4	NCFI 24-124 LO2 Tank Acreage Debris. NCFI 24-124 LO2 tank acreage debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.1.2.1.2.8	NCFI 24-124 Intertank Acreage Undetected Anomaly. NCFI 24-124 undetected intertank acreage outside surface vendor manufacturing or processing anomaly causing TPS debris.
ET	1.1.1.1.2.1.3.7	NCFI 24-124 Intertank Acreage Undetected Anomaly. NCFI 24-124 undetected intertank acreage outside surface anomaly during Machoud Assembly Facility processing causing TPS debris.
ET	1.1.1.1.2.1.4	NCFI 24-124 Intertank Acreage Debris Due to KSC Processing. NCFI 24-124 intertank acreage debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.1.2.2.2.5	NCFI 24-124 Intertank Acreage Undetected Anomaly. NCFI 24-124 undetected intertank acreage I/T foam machining, cell "L" and +Z stringer panels and thrust panel anomaly during Machoud Assembly Facility processing causing TPS debris.
ET	1.1.1.1.2.2.3	NCFI 24-124 Intertank Acreage Debris. NCFI 24-124 intertank acreage debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.1.2.3.2.5	NCFI 24-124 Intertank Acreage Undetected Anomaly. NCFI 24-124 undetected intertank acreage foam venting anomaly during Machoud Assembly Facility processing causing TPS debris.
ET	1.1.1.1.2.3.3	NCFI 24-124 Intertank Acreage Debris. NCFI 24-124 intertank acreage debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.1.3.1.2.5	NCFI 24-124 LH2 Tank Acreage Undetected Anomaly. NCFI 24-124 undetected LH2 tank acreage, barrel foam spray anomaly during vendor manufacturing or processing causing TPS debris.
ET	1.1.1.1.3.1.3.9	NCFI 24-124 LH2 Tank Acreage Undetected Anomaly. NCFI 24-124 undetected LH2 tank acreage, barrel foam spray anomaly during Machoud Assembly Facility processing causing TPS debris.

BRANCH	ELEMENT NUMBER	DESCRIPTION OF FAULT TREE ELEMENT
ET	1.1.1.1.3.1.4	NCFI 24-124 LH2 Tank Acreage Debris. NCFI 24-124 LH2 tank acreage debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.1.4	NCFI 24-124 LH2 Tank Acreage Debris. External impacts to ET TPS produce NCFI 24-124 debris.
ET	1.1.1.3.1.1	PDL-1034 Bipod Debris. PDL-1034 bipod closeout/final assembly of the forward bipod fittings PDL application resulting in TPS debris.
ET	1.1.1.3.2.1	PDL-1034 LH2 and I/T Splice Debris. PDL-1034 LH2 and I/T splice TPS – I/T to LH2 tank, cell “A” stack and LH2 aft dome apex application causing TPS debris.
ET	1.1.1.3.3.1.3.3	PDL-1034 LO2 and I/T Splice, P/L Bracket 861, and Aero Vents Debris. PDL-1034 LO2 and I/T splice, P/L bracket 861, and aero vents debris due to Machoud Assembly Facility PDL-1034 material processing.
ET	1.1.1.3.3.1.3.7	PDL-1034 LO2 and I/T Splice, P/L Bracket 861, and Aero Vents Undetected Anomaly. PDL-1034 LO2 and I/T splice, P/L bracket 861, and aero vents undetected Machoud Assembly Facility processing anomaly causes TPS debris.
ET	1.1.1.3.4.1.3.3	PDL-1034 LO2 P/L and C/T Brackets Debris. PDL-1034 LO2 P/L and C/T brackets, LO2 tank ice frost ramp debris due to Machoud Assembly Facility PDL-1034 material processing.
ET	1.1.1.3.4.1.3.7	PDL-1034 LO2 P/L and C/T Brackets Undetected Anomaly. PDL-1034 LO2 P/L and C/T brackets, LO2 tank ice frost ramp undetected Machoud Assembly Facility processing anomaly causes TPS debris.
ET	1.1.1.3.4.1.4	PDL-1034 LO2 P/L and C/T Brackets Debris. PDL-1034 LO2 P/L and C/T brackets, LO2 tank ice frost ramp debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.3.4.2.4	PDL-1034 LO2 P/L and C/T Brackets Debris. PDL-1034 LO2 P/L and C/T brackets, Sta.371 fairing bracket, Sta.371 pressline hard mount, and I/T por Sta.1075, -Z application causes debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.3.5	PDL-1034 LO2 Tank Debris. PDL-1034 LO2 tank foam, LO2 tank ogive and barrel application causes TPS debris.
ET	1.1.1.3.6.1.3.3	PDL-1034 I/T Wedges Debris. PDL-1034 I/T wedges debris due to Machoud Assembly Facility PDL-1034 material processing.
ET	1.1.1.3.6.1.3.6	PDL-1034 I/T Wedges Undetected Anomaly. PDL-1034 I/T wedges undetected Machoud Assembly Facility processing anomaly causes TPS debris.
ET	1.1.1.3.7.1.3.3	PDL-1034 I/T and C/T Brackets and Fairings Debris. PDL-1034 GO2 P/L and C/T I/T support bracket foam debris due to Machoud Assembly Facility PDL-1034 material processing.
ET	1.1.1.3.7.1.3.7	PDL-1034 I/T and C/T Brackets and Fairings Undetected Anomaly. PDL-1034 GO2 P/L and C/T I/T support bracket foam undetected Machoud Assembly Facility processing anomaly causes TPS Debris.
ET	1.1.1.3.7.1.4	PDL-1034 I/T and C/T Brackets and Fairings Debris. PDL-1034 GO2 P/L and C/T I/T support bracket foam debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.3.7.2.3.3	PDL-1034 I/T and C/T Brackets and Fairings Debris. PDL-1034 I/T fairings, RSS antennas and Xt 1082.8 P/L C/T support debris due to Machoud Assembly Facility PDL-1034 material processing.
ET	1.1.1.3.7.2.3.7	PDL-1034 I/T and C/T Brackets and Fairings Undetected Anomaly. PDL-1034 I/T fairings, RSS antennas and Xt 1082.8 P/L C/T support undetected Machoud Assembly Facility processing anomaly causes TPS debris.
ET	1.1.1.3.7.2.4	PDL-1034 I/T and C/T Brackets and Fairings Debris. PDL-1034 I/T fairings, RSS antennas and Xt 1082.8 P/L C/T support debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.

BRANCH	ELEMENT NUMBER	DESCRIPTION OF FAULT TREE ELEMENT
ET	1.1.1.3.7.3.3.3	PDL-1034 I/T and C/T Brackets and Fairings Debris. PDL-1034 I/T press line and cable tray support bracket foam debris due to Machoud Assembly Facility PDL-1034 material processing.
ET	1.1.1.3.7.3.3.7	PDL-1034 I/T and C/T Brackets and Fairings Undetected Anomaly. PDL-1034 I/T press line and cable tray support bracket foam undetected Machoud Assembly Facility processing anomaly causes TPS debris.
ET	1.1.1.3.7.3.4	PDL-1034 I/T and C/T Brackets and Fairings Debris. PDL-1034 I/T press line and cable tray support bracket foam debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.3.8.1.3.3	PDL-1034 LO2 Feed Line and Supports (External) Debris. PDL-1034 LO2 feedline yokes and base fitting assembly causes debris due to Machoud Assembly Facility PDL-1034 material processing.
ET	1.1.1.3.8.1.3.7	PDL-1034 LO2 Feed Line and Supports (External) Undetected Anomaly. PDL-1034 undetected LO2 feedline yoke and base fitting assembly anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.3.8.1.4	PDL-1034 LO2 Feed Line and Supports (External) Debris. PDL-1034 LO2 feedline yokes and base fitting assembly debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.3.8.2.3.3	PDL-1034 LO2 Feed Line and Supports (External) Debris. PDL-1034 LO2 F/L flanges and elbow tie, Xt1115-2053, and LH2 F/L base debris due to Machoud Assembly Facility PDL-1034 material processing.
ET	1.1.1.3.8.2.3.7	PDL-1034 LO2 Feed Line and Supports (External) Undetected Anomaly. PDL-1034 undetected LO2 F/L flanges and elbow tie, Xt1115-2053, and LH2 F/L base anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.3.8.2.4	PDL-1034 LO2 Feed Line and Supports (External) Debris. PDL-1034 LO2 F/L flanges and elbow tie, Xt1115-2053, and LH2 F/L base debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.3.8.3.3.2	PDL-1034 LO2 Feed Line and Supports (External) Debris. PDL-1034 LO2 Aluminum straight section foam debris due to manufacturing process plan.
ET	1.1.1.3.8.3.3.3	PDL-1034 LO2 Feed Line and Supports (External) Debris. PDL-1034 LO2 Aluminum straight section foam debris due to Machoud Assembly Facility PDL-1034 material processing.
ET	1.1.1.3.8.3.3.6	PDL-1034 LO2 Feed Line and Supports (External) Undetected Anomaly. PDL-1034 undetected LO2 Aluminum straight section foam anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.3.8.4.3.3	PDL-1034 LO2 Feed Line and Supports (External) Debris. PDL-1034 LO2 feed line strut foam debris due to Machoud Assembly Facility PDL-1034 material processing.
ET	1.1.1.3.8.4.3.6	PDL-1034 LO2 Feed Line and Supports (External) Undetected Anomaly. PDL-1034 undetected LO2 feed line strut foam anomaly during Machoud Assembly Facility processing causes debris.
ET	1.1.1.3.8.4.4	PDL-1034 LO2 Feed Line and Supports (External) Debris. PDL-1034 LO2 feed line strut foam debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.3.9.1	PDL-1034 LO2 PAL Ramp Debris. PDL-1034 LO2 PAL ramp foam application – LO2 tank/intertank PAL ramp causes TPS debris.
ET	1.1.1.3.22	PDL-1034 External Impacts Causes Debris. External impacts to the ET TPS produces PDL-1034 debris.
ET	1.1.1.4.1.1.3.1.1	BX-250 Bipod Inadequately Trained Operator. BX-250 bipod, forward bipod fitting assembly debris due to inadequately trained operator during Machoud Assembly Facility processing.

BRANCH	ELEMENT NUMBER	DESCRIPTION OF FAULT TREE ELEMENT
ET	1.1.1.4.1.1.3.3.2	BX-250 Bipod Debris. BX-250 bipod, forward bipod fitting assembly debris due to improper storage during Machoud Assembly Facility processing.
ET	1.1.1.4.1.1.3.3.5	BX-250 Bipod Improper Application Process. BX-250 bipod, forward bipod fitting assembly debris due to improper application process during Machoud Assembly Facility processing.
ET	1.1.1.4.1.1.4	BX-250 Bipod Debris. BX-250 bipod, forward bipod fitting assembly debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.4.2.1.1.1	BX-250 LH2 and I/T Splice Inadequate Design Methodology. BX-250 LH2 and I/T splice inadequate design methodology causes TPS debris.
ET	1.1.1.4.2.1.3.1.1	BX-250 LH2 and I/T Splice Inadequately Trained Operator. BX-250 LH2 and I/T splice causes TPS debris due to inadequately trained operator during Machoud Assembly Facility processing.
ET	1.1.1.4.2.1.3.3.2	BX-250 LH2 and I/T Splice Improper Storage. BX-250 LH2 and I/T splice causes TPS debris due to improper storage.
ET	1.1.1.4.2.1.3.3.5	BX-250 LH2 and I/T Splice Improper Application Process. BX-250 LH2 and I/T splice causes TPS debris due to improper application process.
ET	1.1.1.4.2.1.3.3.6	BX-250 LH2 and I/T Splice Inadequately Defined Acceptance Testing. BX-250 LH2 and I/T splice causes TPS debris due to inadequately defined acceptance testing.
ET	1.1.1.4.2.1.3.8	BX-250 LH2 and I/T Splice Inadequate Resolution of Identified Anomaly. BX-250 undetected LH2 and I/T splice anomaly during Machoud Assembly Facility material processing causes TPS debris.
ET	1.1.1.4.2.1.4	BX-250 LH2 and I/T Splice Debris. BX-250 LH2 and I/T splice debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.4.3.1.3.1.1	BX-250 LO2 and IT Splice, P/L Bracket 861, and Aero Vents Debris. BX-250 LO2 and IT splice, P/L bracket 861, and aero vents causes TPS debris due to inadequately trained operator.
ET	1.1.1.4.3.1.3.3.2	BX-250 LO2 and IT Splice, P/L Bracket 861, and Aero Vents Debris. BX-250 LO2 and IT splice, P/L bracket 861, and aero vents causes TPS debris due to improper storage.
ET	1.1.1.4.3.1.3.3.5	BX-250 LO2 and IT Splice, P/L Bracket 861, and Aero Vents Debris. BX-250 LO2 and IT splice, P/L bracket 861, and aero vents causes TPS debris due to improper application process.
ET	1.1.1.4.3.1.3.8	BX-250 LO2 and IT Splice, P/L Bracket 861, and Aero Vents Debris. BX-250 LO2 and IT splice, P/L bracket 861, and aero vents causes TPS debris due to an anomaly during Machoud Assembly Facility processing.
ET	1.1.1.4.3.1.4	BX-250 LO2 and IT Splice, P/L Bracket 861, and Aero Vents Debris. BX-250 LO2 and IT splice, P/L bracket 861, and aero vents causes TPS debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.4.4.1.3.3.2	BX-250 I/T Wedges. BX-250 I/T wedges causes TPS debris due to improper storage.
ET	1.1.1.4.4.1.3.3.5	BX-250 I/T Wedges. BX-250 I/T wedges causes TPS debris due to improper application process during material processing.
ET	1.1.1.4.4.1.3.6	BX-250 I/T Wedges. BX-250 undetected I/T wedge anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.4.5.1.3.3.2	BX-250 LO2 Feed Line Supports (External). BX-250 LO2 feed line supports (external) causes TPS debris due to improper storage.
ET	1.1.1.4.5.1.3.3.5	BX-250 LO2 Feed Line Supports (External). BX-250 LO2 feed line supports (external) causes TPS debris due to improper application process of the Machoud Assembly Facility BX-250 material processing.

BRANCH	ELEMENT NUMBER	DESCRIPTION OF FAULT TREE ELEMENT
ET	1.1.1.4.5.1.3.4.5	BX-250 LO2 Feed Line Supports (External). BX-250 LO2 feed line supports (external) causes TPS debris due to improper application process of the Machoud Assembly Facility DPTU adhesive processing.
ET	1.1.1.4.5.1.3.7	BX-250 LO2 Feed Line Supports (External). BX-250 LO2 feed line supports (external) causes TPS debris due to an anomaly during Machoud Assembly Facility BX-250 materials processing.
ET	1.1.1.4.5.1.4	BX-250 LO2 Feed Line Supports (External). BX-250 LO2 feed line supports (external) causes TPS debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.4.6.1.3.1.1	BX-250 LO2 PAL Ramp. BX-250 LO2 PAL ramp causes TPS debris due to inadequately trained operator.
ET	1.1.1.4.6.1.3.3.2	BX-250 LO2 PAL Ramp. BX-250 LO2 PAL ramp causes TPS debris due to improper storage.
ET	1.1.1.4.6.1.3.3.5	BX-250 LO2 PAL Ramp. BX-250 LO2 PAL ramp causes TPS debris due to improper application process.
ET	1.1.1.4.6.1.3.3.6	BX-250 LO2 PAL Ramp. BX-250 LO2 PAL ramp causes TPS debris due to inadequately defined acceptance testing.
ET	1.1.1.4.6.1.3.7	BX-250 LO2 PAL Ramp. BX-250 undetected LO2 PAL ramp anomaly during Machoud Assembly Facility processing causes debris.
ET	1.1.1.4.6.1.4	BX-250 LO2 PAL Ramp. BX-250 LO2 PAL ramp debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.4.18	BX-250 External Impacts. BX-250 external impacts to the ET TPS produces debris.
ET	1.1.1.5.1.1.3.7	SLA-561 Bipod. SLA-561 undetected bipod, forward bipod fitting assembly SLA application anomaly during Machoud Assembly Facility processing causes debris.
ET	1.1.1.5.1.2.3.7	SLA-561 Bipod. SLA-561 undetected bipod, forward bipod fitting plate connector SLA application anomaly during Machoud Assembly Facility processing causes debris.
ET	1.1.1.5.1.3.3.7	SLA-561 Bipod. SLA-561 undetected bipod, forward bipod fitting strut SLA application anomaly during Machoud Assembly Facility processing causes debris.
ET	1.1.1.5.2.1.3.7	SLA-561 LO2 C/Ts and Fairings. SLA-561 undetected LO2 GO2 P/L Barry mounts on tank, Sta. 371.0 C/T bracket, and foam trims for P/L flange anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.5.2.1.4	SLA-561 LO2 C/Ts and Fairings. SLA-561 undetected LO2 GO2 P/L Barry mounts on tank, Sta. 371.0 C/T bracket, and foam trims for P/L flange TPS debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.2.2.3.7	SLA-561 LO2 C/Ts and Fairings. SLA-561 undetected LO2 P/L brackets Sta. 404.34 thru Sta. 718.04 SLA application anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.5.2.2.4	SLA-561 LO2 C/Ts and Fairings. SLA-561 LO2 LO2 P/L brackets Sta. 404.34 thru Sta. 718.04 debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.2.3.3.7	SLA-561 LO2 C/Ts and Fairings. SLA-561 undetected LO2 tank cable tray SLA application anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.5.2.3.4	SLA-561 LO2 C/Ts and Fairings. SLA-561 LO2 tank cable tray TPS debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.2.4.3.7	SLA-561 LO2 C/Ts and Fairings. SLA-561 undetected LO2 tank P/L and C/T support Sta. 371.0 SLA application anomaly during Machoud Assembly Facility processing causes TPS debris.

BRANCH	ELEMENT NUMBER	DESCRIPTION OF FAULT TREE ELEMENT
ET	1.1.1.5.2.4.4	SLA-561 LO2 C/Ts and Fairings. SLA-561 LO2 tank P/L and C/T support Sta. 371.0 debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.2.5.3.7	SLA-561 LO2 C/Ts and Fairings. SLA-561 undetected LO2 cable tray cover SLA application anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.5.2.5.4	SLA-561 LO2 C/Ts and Fairings. SLA-561 LO2 cable tray cover TPS debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.2.6.3.7	SLA-561 LO2 C/Ts and Fairings. SLA-561 undetected LO2 tank C/T covers and C/T fairing cover SLA application anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.5.2.6.4	SLA-561 LO2 C/Ts and Fairings. SLA-561 LO2 tank C/T covers and C/T fairing cover TPS debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.2.7.3.7	SLA-561 LO2 C/Ts and Fairings. SLA-561 undetected LO2 tank C/T gap closure SLA application anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.5.2.7.4	SLA-561 LO2 C/Ts and Fairings. SLA-561 LO2 tank C/T gap closure TPS debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.2.8.3.7	SLA-561 LO2 C/Ts and Fairings. SLA-561 undetected LO2 tank P/L and C/T support bracket SLA application anomaly during Machoud Assembly Facility processing causes debris.
ET	1.1.1.5.2.8.4	SLA-561 LO2 C/Ts and Fairings. SLA-561 LO2 tank P/L and C/T support bracket TPS debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.2.9.3.7	SLA-561 LO2 C/Ts and Fairings. SLA-561 undetected LO2 composite nose cone seal SLA application anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.5.2.9.4	SLA-561 LO2 C/Ts and Fairings. SLA-561 LO2 composite nose cone seal TPS debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.3.1.3.7	SLA-561 Press Line Barry Mounts. SLA-561 undetected press line Barry mounts SLA application anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.5.3.1.4	SLA-561 Press Line Barry Mounts. SLA-561 press line Barry mounts debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.4.1.2.7	SLA-561 ET/SRB Forward Bolt Catcher. SLA-561 undetected ET/SRB forward bolt catcher SLA application anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.5.4.1.3	SLA-561 ET/SRB Forward Bolt Catcher. SLA-561 ET/SRB forward bolt catcher debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.5.2.3.7	SLA-561 I/T Fairings. SLA-561 undetected I/T fairing LO2 feedline SLA application anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.5.5.2.4	SLA-561 I/T Fairings. SLA-561 I/T fairing LO2 feedline debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.5.3.3.7	SLA-561 I/T Fairings. SLA-561 undetected I/T fairing LO2 tank cable tray SLA application anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.5.5.3.4	SLA-561 I/T Fairings. SLA-561 I/T fairing LO2 tank cable tray debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.6.1.3.7	SLA-561 LO2 Feed Line Supports. SLA-561 undetected LO2 yoke feed line supports SLA application anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.5.6.1.4	SLA-561 LO2 Feed Line Supports. SLA-561 LO2 yoke feed line supports debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.5.13	SLA-561 External Impacts to ET TPS. External impacts to ET TPS produces SLA-561 debris.

BRANCH	ELEMENT NUMBER	DESCRIPTION OF FAULT TREE ELEMENT
ET	1.1.1.6.1.1.3.9	MA-25S Bipod Undetected Anomaly. MA-25S undetected bipod strut MA-25S application anomaly during Machoud Assembly Facility processing causes TPS debris.
ET	1.1.1.6.1.1.4	MA-25S Bipod Debris Due to Processing. MA-25S bipod strut TPS debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.6.3	MA-25S External Impacts to ET TPS. External impacts to ET TPS produces MA-25S bipod debris.
ET	1.1.1.7.1.1.3.3.2	SS-1171 LO2 Feed Line and Supports (External). SS-1171 LO2 feed line aluminum straight section foam application causes TPS debris due to improper storage.
ET	1.1.1.7.1.1.3.3.5	SS-1171 LO2 Feed Line and Supports (External). SS-1171 LO2 feed line aluminum straight section foam application causes TPS debris due to improper application.
ET	1.1.1.7.1.1.3.6	SS-1171 LO2 Feed Line and Supports (External). SS-1171 undetected LO2 feed line aluminum straight section foam application anomaly during Machoud Assembly Facility processing causes debris.
ET	1.1.1.7.1.1.4	SS-1171 LO2 Feed Line and Supports (External). SS-1171 LO2 feed line aluminum straight section foam debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.7.1.2.3.3.2	SS-1171 LO2 Feed Line and Supports (External). SS-1171 LO2 feed line flex section foam application causes TPS debris due to improper storage.
ET	1.1.1.7.1.2.3.3.5	SS-1171 LO2 Feed Line and Supports (External). SS-1171 LO2 feed line flex section foam application causes TPS debris due to improper application.
ET	1.1.1.7.1.2.3.6	SS-1171 LO2 Feed Line and Supports (External). SS-1171 undetected LO2 feed line flex section foam application anomaly during Machoud assembly Facility processing causes debris.
ET	1.1.1.7.1.2.4	SS-1171 LO2 Feed Line and Supports (External). SS-1171 LO2 feed line flex section foam debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.7.1.3.3.3.2	SS-1171 LO2 Feed Line and Supports (External). SS-1171 LO2 feed line yoke application causes TPS debris due to improper storage.
ET	1.1.1.7.1.3.3.3.5	SS-1171 LO2 Feed Line and Supports (External). SS-1171 LO2 feed line yoke application causes TPS debris due to improper application.
ET	1.1.1.7.1.3.3.6	SS-1171 LO2 Feed Line and Supports (External). SS-1171 undetected LO2 feed line yoke application anomaly during Machoud Assembly Facility processing causes debris.
ET	1.1.1.7.1.3.4	SS-1171 LO2 Feed Line and Supports (External). SS-1171 LO2 feed line yoke foam debris due to KSC processing resulting in a cohesive, shear, delamination, or crack failure of the TPS.
ET	1.1.1.7.6	SS-1171 LO2 Feed Line and Supports (External). External impacts to ET TPS produces SS-1171 debris.
ET	1.1.2.13.2	Non-TPS Debris. Ice - There is no indication from the final inspection results or Ice monitoring activity of STS-107/ET-93 to indicate external ice was a contributor but it cannot be 100% ruled out.
ET	1.1.2.13.5	Non-TPS Debris From Interface. This element investigated debris potential due to design deficiencies, inadequate processing, or mission problems, and found no evidence of non-TPS debris striking the left wing of STS-107 during lift-off and ascent but it cannot be 100% ruled out.
ET	1.2.1.1.3.5	Structural I/Fs EO-1 Forward Attach I/F. Structural I/Fs EO-1 forward bipod attach interface incorrect parts assembly, lack of torque sequencing requirements on strut/fitting assembly bolts could lead to inadequate preloads resulting in one or more bolts/nuts loosening and being released as debris.

BRANCH	ELEMENT NUMBER	DESCRIPTION OF FAULT TREE ELEMENT
ET	1.2.1.1.3.6	Structural I/Fs EO-1 Forward Attach I/F. Structural I/Fs EO-1 forward bipod attach interface incorrect parts installation, lack of torque requirement on spindle fitting safety wired bolts could cause local TPS debris due to vibration effects.
ET	1.2.1.1.5.4	Structural I/Fs EO-1 Forward Attach I/F. Structural I/Fs EO-1 forward bipod attach interface bipod hardware/components under foam are exposed during ascent and becomes debris, investigated bipod heater connector plate becoming debris.
ET	1.2.1.7.3.1	Structural I/Fs EB-1 Forward SRB Attach -Y and EB-2 Forward SRB Attach +Y. EB-1 forward SRB attach -Y and EB-2 forward SRB attach +Y incorrect part materials usage, investigation found Loctite fastener compound used in the assembly of the SRB fitting did not have recorded traceability. Shelf life could have been exceeded possibly reducing capabilities and allowed associated hardware debris.
ET	1.2.1.7.4.1.1.4	EB-1 Forward SRB Attach -Y & EB-2 Forward SRB Attach +Y Incorrect Parts Installation / SRB Mate. One finding was related to failure of the OMI to call out performance and verification of break away torque on the RSS fairing installation which could potentially result in the loss of a fastener.
SRB	B.1.3.1	Nose Cap Assembly Damage/Malfunction Causes Debris. By design, the SRB nose cap assemblies are ejected from the SRBs during the parachute deployment sequence and are not recovered. There is no evidence (film review and post-flight inspection) of any anomalous behavior.
SRB	B.1.3.1.1	Loss of TPS Causes Debris. Film review confirmed both nose caps were attached during ascent and nominal separation from the external tank and postflight photos and retrieval video review confirmed no loss of MCC-1 from the SRB retrieved hardware other than from splashdown or retrieval and tow back operations. Post flight inspection of the nose cap interface plane on the recovered frustums showed no evidence of abnormalities.
SRB	B.1.3.2.4.1	Debris from BSM Plume. Non-propellants have been identified that ablate during motor firing and generated debris. This debris includes Room Temperature Vulcanizing (RTV) sealant, Conoco grease, ink stamp ID numbers. In addition, contamination / foreign materials have been noted during manufacturing to include RTV, neoprene, lead shot, and paint chips.
SRB	B.1.3.2.4.2	Debris Ejection from Motor (Forward BSM). Standing water in the BSM has occurred in the past and can lead to unburned propellant being a debris source. Enhanced leak tests have been introduced before STS 107 to avoid this problem. During STS 107 pad stay, 8.68 inches of rain was recorded.

There are many ways that the space shuttle can be damaged. Debris sources and manufacturing quality control make up most of the items in the above table. Although “unlikely” in the *Columbia* accident, they must be examined and diligently reviewed so that they do not become contributors in the future.