The Space Shuttle Columbia Accident Investigation: Forensic Tools, Techniques, and Results

Steve McDanel
Chief, Failure Analysis and Materials Evaluation Branch
NASA, Kennedy Space Center
steve.mcdanel@nasa.gov

Principals: Dr. Brian M. Mayeaux (NASA-Johnson Space Center)
Thomas E. Collins (Boeing-Huntington Beach)
Dr. Gregory A. Jerman (NASA-Marshall Space Flight Center)
Steven J. McDanel (NASA-Kennedy Space Center)
Dr. Robert S. Piascik (NASA-Langley Research Center)
Richard W. Russell (Boeing-Kennedy Space Center)
Dr. Sandeep R. Shah (NASA-Marshall Space Flight Center)
Shuttle Columbia: April 12, 1981
Shuttle Columbia: January 16, 2003
Shuttle Columbia: STS-107

• Launch – January 16, 2003
Shuttle Columbia: STS-107

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- Launch + 81.9 seconds, External Tank left bipod foam strikes Columbia's left wing
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- Approximately 1 minute 24 seconds into peak heating region of re-entry interface, 8:52:17, an off-nominal temperature in the left main landing gear brake line sensor
- Over California first signs of debris shedding observed at 8:53:46 am
- First sign of trouble reported in mission control at 8:54:24 when four hydraulic sensors were indicating "off-scale low"
- Loss of signal from Columbia recorded at 8:59:32 am.
Shuttle Columbia: STS-107

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- Loss of signal from Columbia recorded at 8:59:32 am.
- Videos made by observers on the ground at 9:00:18 am revealed that the Orbiter was disintegrating
Recovery

- Mach 18 at an altitude of 208,000 feet at time of break-up
- The size of the debris field was 645 miles long and 10 miles wide
- Each piece of debris was photographed, analyzed for potential hazards, given a unique identification
- Each piece’s location was noted and a preliminary identification was attempted
- Debris sent to one of several staging locations, then to the Kennedy Space Center
Recovery
Recovery
Reconstruction
Reconstruction
Nemotodes (round worms) Experiment
Columbia Recovery and Reconstruction Statistics

- Over 16,000 people at recovery sites
- 1.5 million hours expended in search and recovery effort
- 150,000 hours expended in reconstruction phase
- Approximately 84,000 pieces retrieved
- Approximately 85,000 lbs of debris retrieved, representing approximately 38% of the Orbiter’s dry weight
- Debris Reconstruction Team at KSC - 150 people
M&P Engineering Team

M&P Team
NASA
Unites Space Alliance
Boeing

Support Laboratories:
NASA JSC  USA
NASA KSC  Boeing FL
NASA MSFC  Boeing H. B.
NASA LaRC
NASA GRC

Reconstruction Engineering

Hardware Forensics Team (HFT)

Debris Assessment Working Group (DAWG)

Orbiter Vehicle Engineering Working Group (OVEWG)

Columbia Accident Investigation Board (CAIB)
The M&P Team gratefully acknowledges the talents and contributions of the following individuals:

**NASA-GRC**
- Herb Garlick
- Leslie Greenbauer-Seng
- David Hull
- Nathan Jacobson
- Elizabeth Opila
- James Smialek

**NASA-JSC**
- Jay Bennett
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- John Figert
- Julie Henkener
- Julie Kramer-White

**NASA-KSC**
- Larry Batterson
- Virginia Cummings
- Dionne Jackson
- Thad Johnson
- Hae Soo Kim
- Sandra Loucks
- Peter Marciniak
- Wayne Marshall
- Orlando Melendez
- Scott H. Murray
- Jaime Palou
- Donald Parker
- Victoria Salazar
- Eric Thaxton
- Stan Young

**NASA-LaRC**
- Robert BERRY
- Stephen Smith
- William Winfree

**NASA-MSFC**
- James Coston
- Greg Steele

**Boeing**
- Rodger Capps
- Tab Crooks
- Jeff Hauser
- Stephanie Hopper
- Mark Hudson
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- Robert Pavel
- Keith Pope
- Janet Ruberto
- Keith Pope
- Jim Stewart

**USA**
- Cathy Clayton
- Stanley Schultz
- Bryan Tucker

**CAIB**
- Dr. Gregory T. A. Kovacs
- G. Mark Tanner
Reconstruction Hangar: 2-04-03
Reconstruction Hangar: 2-14-03
Reconstruction Hangar: 2-20-03
Reconstruction Hangar: 03-12-03
Reconstruction Hangar: 03-20-03
Reconstruction Hangar: 03-26-03
Reconstruction Hangar: 04-17-03
Reconstruction Hangar: 05-22-03
Reconstruction
Reconstruction: From Left Wing
Reconstruction: Tiles
Reconstruction: Tiles
Left Outboard Main Tire
LH Landing Gear Trunnion
Debris

Main Landing Gear Uplock Roller

Heaviest splatter on inboard side

Main Landing Gear – Corner Tile

INBD

Forward
Debris

Midbody Panel - Erosion and tile damage
Carrier Panel Tiles
Leading Edge Representation

Left Wing Leading Edge

RCC Panel Numbers

T-Seals

RCC panel

RCC rib

Upper Access Panel

Lower Access Panel

Dynaflex insulation - In601 foil with borachrome fibers inside

- RCC
- Inconel
- Dynaflex

1. Aluminum
2. LL2000
3. Inconel 71B
Initially, analysis was restricted to visual and macroscopic examination of debris in the hangar.
# Analytical Techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Purpose</th>
<th>Benefit</th>
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</thead>
<tbody>
<tr>
<td>Photography</td>
<td>Photo documentation</td>
<td>Documentation to maintain traceability</td>
</tr>
<tr>
<td>Scanning Electron Microscopy - SEM/EDS</td>
<td>Semi-quantitative elemental composition</td>
<td>Elements present, identify difference between top and bottom of sample</td>
</tr>
<tr>
<td>X-ray Diffraction XRD</td>
<td>Identify compounds</td>
<td>Identify compounds of crystalline structure</td>
</tr>
<tr>
<td>Electron Microprobe</td>
<td>Identify elements</td>
<td>Determine exact composition</td>
</tr>
<tr>
<td>Fourier Transform Infra-Red – FTIR</td>
<td>Qualitative organic composition</td>
<td>If organic, aid in identification</td>
</tr>
<tr>
<td>ESCA/XPS</td>
<td>Identify inorganic &amp; organic compounds</td>
<td>Aid in tracking of oxidation states, such as oxide; compound identification</td>
</tr>
<tr>
<td>Metallography + SEM</td>
<td>Layering of material</td>
<td>Composition through deposit layers</td>
</tr>
<tr>
<td>Inductively coupled plasma - ICAP</td>
<td>Quantitative elemental composition</td>
<td>Elements present, Quantify bulk composition of sample</td>
</tr>
<tr>
<td>NDE Inspections- Radiography, CT, Ultrasonics</td>
<td>Non-destructive Inspection and identification</td>
<td>See through the materials, identify differences in materials, identify defects</td>
</tr>
</tbody>
</table>
Typical EDS, XPS, and XRD results:

**XRD**

**ESCA/XPS**

Pressure: $1 \times 10^4$ Torr
Conditions: Magnesium X-rays at 15 KV and 12 mA

<table>
<thead>
<tr>
<th>Element</th>
<th>Position, Binding Energy (eV)</th>
<th>Possible Compound(s)</th>
<th>Mass Concentration (weight %)</th>
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<td>O 1s</td>
<td>532.050</td>
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<tr>
<td>Al 2p</td>
<td>75.050</td>
<td>$\text{Al}_2\text{O}_3$, minor Aluminum silicate</td>
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<td>Fe 2p</td>
<td>710.050</td>
<td>FeO and Fe$_2$O$_3$</td>
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<tr>
<td>Cr 2p</td>
<td>575.750</td>
<td>CrO$_2$</td>
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<td>Cu 2p</td>
<td>932.850</td>
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<tr>
<td>Si 2p</td>
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<td>Al silicate</td>
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<td>N 1s</td>
<td>399.150</td>
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<td>1.91</td>
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**EDS**

Elements Detected (Approximate Weight %) via SEM/EDS

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<th>Al</th>
<th>Si</th>
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<td>7</td>
<td>6</td>
<td>22</td>
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</tbody>
</table>
Deposit types via Micro-Probe

Cerachrome + Aluminum + Inconel + Alumina
Aluminum + Inconel + Cerachrome + Type A Coating
SiC
Carbon-Carbon
Typical

Spherical
Type A Coating
Alumina
Aluminum + Alumina + Inconel
SiC
Carbon-Carbon

Cerachrome + Type A Coating
SiC

Carbon-Carbon
Globular

Tubular

Cerachrome + Type A Coating
SiC
Carbon-Carbon
3D Reconstruction of Left WLE
3D Reconstruction: Panels 8, 9, 10
3D Reconstruction

Port Wing RCC Panels 5-10
3D Reconstruction
3D Reconstruction Left Wing
Failure Sequence

- Melting and vaporization of the Inconel 601 foil-covered cerachrome insulation blankets
- Slumping of the wing carrier panel tile immediately aft of the breach
- Erosion of the RCC adjacent to, and downstream of, the breach
- Melting and/or weakening of the Inconel 718 and A286 leading edge attach hardware
- Destruction of adjacent instrumentation and wire bundles
- Penetration of the aluminum wing leading edge spar
Proposed Breach Path and Directionality of Flow
Found September, 2004