Composites Damage Tolerance

MSFC Engineering
Damage Tolerance
Assessment Branch
Wayne Gregg/EM20
September, 2008
Composites Damage Tolerance

- Constellation Requirements for Fracture Control
- MSFC-RQMT-3479
  - Background & Development Approach
  - Examples of Criteria & Implementation
How does damage tolerance of composites fit within the framework of Constellation requirements?

Constellation Program
Level II Requirements

Fracture Control

Materials
(NASA-STD-6016)

Structures
(SDVR)

Pressure Vessels

Fasteners

Composite/Bonded Structure

Batteries

Mechanisms

Etc…

NASA-STD-5019

MSFC-RQMT-3479
MSFC- RQMT-3479 Background & Development Approach

• Began development of composite fracture control requirements to address shortcomings of prior requirements
  • Prior requirements were limited in scope to proof testing, manufacturing history, and NDE
• Developed in conjunction with members of the NASA Fracture Control Methodology Panel during 2004 – 2006
  • Significant fracture community involvement (~115 comments addressed) prior to final version publication
  • Adopted Agency effort into a MSFC Requirements Document, June 2006
  • NASA Fracture Control Methodology Panel agreed in 2006 that NASA-STD-5019 would refer to MSFC-RQMT-3479 for fracture control of composites
• Cast requirements in the framework and language of existing NASA fracture control requirements.
• Review other requirements in addition to NASA requirements:
  • Aircraft – Civil – FARs/MIL-HDBK-17F
  • General literature
• Rely on ANSI/AIAA S-081 for COPVs.
• Refer to MIL-HDBK-17F (now CMH-17) for specific methodologies.

• Further Development
  • Efforts to revise NASA-STD-5019(A) are underway to include MSFC-RQMT-3479 requirements and to update with lessons learned from Orion and Ares efforts
Composites Damage Tolerance

Classification of Composite Parts and Bonds for Fracture Control

A part (or bond) is fracture critical if its failure due to the presence of a flaw would result in a catastrophic hazard. All composite parts and bonds shall be classified according to the following:

**Exempt**
- Non-structural and no safety critical function

**Non-Fracture Critical**
- Low released mass
- Fail safe
- Contained
- Low risk
- Non-hazardous leak before burst (NHLEB)

**Fracture Critical**
- Proofed
- Damage tolerant

**Damage Tolerant Approach**
- 1. Damage Threat Assessment (DTA)
- 2. Impact Damage Protection Plan (IDPP)
- 3. Damage Tolerance Coupon Tests
- 4. Damage Tolerance Development Tests
- 5. Analytical Support
- 6. Damage Tolerance Full-Scale Component Tests
- 7. Implement IDPP
- 8. NDE Parts
- 9. Proof Test to 1.05 Minimum
- 10. Post-Proof NDE
- 11. In-Service Inspection
Examples of MSFC-RQMT-3479 Criteria & Implementation
# Composites Damage Tolerance

## Summary Sheet - Composite Fracture Control Classifications and Requirements

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Non-Fracture Critical</th>
<th>Fracture Critical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low Released Mass</td>
<td>Fall Safe</td>
</tr>
<tr>
<td>Reference Section</td>
<td>5.2.1</td>
<td>x</td>
</tr>
<tr>
<td>No catastrophic hazard/loss of SCF</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Part must be larger than open holes</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Enclosure/container not FC</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Not a pressure vessel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No hazardous fluid</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>FOS on containment</td>
<td>1.0 Fly, analysis or test</td>
<td>1.15 p/thin test, or 1.15 p/thin analysis or test</td>
</tr>
<tr>
<td>DUL capability</td>
<td>NFC impacted parts - ver by test</td>
<td>w/impact damage &gt; NDE, from loose part, DTA, or imposed - ver by test</td>
</tr>
<tr>
<td>Inspections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Visual</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Walkaround</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Special Visual</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. NDE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proof tested (&lt;80% UFL)¹</td>
<td>Foot Note 1</td>
<td>x</td>
</tr>
<tr>
<td>DTA Task 1</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>DTA Task 2</td>
<td>x²</td>
<td>x²</td>
</tr>
<tr>
<td>DTA Task 3</td>
<td>x²</td>
<td></td>
</tr>
<tr>
<td>IDPP</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

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¹ MSFC DT/EM20
## Composites Damage Tolerance

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<td>Fall Safe</td>
</tr>
<tr>
<td>Reference Section</td>
<td>5.2.1</td>
<td>5.2.2</td>
</tr>
<tr>
<td>Damage tolerant coupon tests</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damage tolerant development tests</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damage tolerant full scale component tests</td>
<td>FC impacted parts</td>
<td>FC impacted parts</td>
</tr>
<tr>
<td>Traceability (Section 5.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unique Requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressurized enclosures shall have the characteristic of being NHLLB3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walls shall leak ≤ MDP, Verif. by test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall shall not burst @ Ult x MDP, Verif. by test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow shall not grow @ Ult x MDP, Verif. by test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No repressurization as pressure leaks down</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generally limited to payloads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal to payload vehicle, module</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Debris shall meet low mass</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Below no-growth threshold strain</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

**Foot Notes:**
1. NASA-STD-8001 requires proof test of all composite parts/structures to 1.05/1.20
2. Required to the extent needed to establish impact damage size for DUL capability test (Line 11)
3. Required to the extent needed to determine no-growth threshold strain (Line 35)
Composites Damage Tolerance

Steps in Establishing Damage Tolerance

- Design Concept and Requirements
- Damage Threat Assessment
- Impact Damage Protection Plan
  - Flight Hardware
    - Implement Damage Protection Plan
    - NDE Flight Parts
    - Proof Test Flight Article
    - Post Proof NDE of Flight Article
    - In-Service Inspections
  - NDE Flight Parts
  - Damage Tolerant Development Test
  - Damage Tolerant Coupon Tests
  - Analytical Support
  - Hardware Design

Damage Tolerant Approach

- 1. Damage Threat Assessment (DTA)
- 2. Impact Damage Protection Plan (IDPP)
- 3. Damage Tolerance Coupon Tests
- 4. Damage Tolerance Development Tests
- 5. Analytical Support
- 6. Damage Tolerant Full-Scale Component Tests
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- 9. Proof Test to 1.05 Minimum
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Damage Tolerant Full-Scale Component Test

- Induce Flaws per Section 5.3.2.6
- Design Ultimate Load Test
- Design Limit Load Test
- 1 Lifetime Test
- No flaw initiation allowed
- No flaw growth allowed
- Full NDE
- Full NDE
- Full NDE
- 1 Lifetime Test
- No flaw initiation allowed
- MSFC DT/EM20

Demonstrate by test(s) that there is no catastrophic failure due to flaws during (or following if appropriate) the design limit load test, and that the component performs as structurally and mechanically intended:
- > no structural failure, burst, etc.
- > no catastrophic leak due to flaws
- > no catastrophic mechanical malfunction
- > structurally and mechanically performs design function
Composites Damage Tolerance

• Certification Examples:
  Fatigue & Strength Tests with Damage

Application/Examples - MIL-HDBK-17-3F – Section 7.9.2
Commercial Aircraft – Boeing 777 Empennage Torque Boxes
Preproduction Horizontal Stabilizer Test Sequence – Demonstrate “No Growth”
Composites Damage Tolerance

Implementation Example: Ares I Upper Stage Composites Interstage

♦ Carbon Fiber Facesheets, Aluminum Honeycomb Core
- IM7/8552-1 Carbon/Epoxy Facesheets
- A15052 1/16 inch cell – 3.1 #/0.3 Core
- FM300k Adhesive Bondline

Coupon Tests

<table>
<thead>
<tr>
<th>Damage Tolerance</th>
<th>Purpose</th>
<th>Test Requester</th>
<th>Test Sizes</th>
<th>Quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test #</td>
<td>Description</td>
<td>Priority</td>
<td>Layup</td>
<td>Specification</td>
</tr>
<tr>
<td>61</td>
<td>Environmental Effects (E/F)</td>
<td>1</td>
<td>[500, 450, 300, 250]</td>
<td>NA</td>
</tr>
<tr>
<td>62</td>
<td>Residual Strength (E/F)</td>
<td>1</td>
<td>[500, 450, 300, 250]</td>
<td>NA</td>
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<tr>
<td>63</td>
<td>No-Growth Threshold (E/F)</td>
<td>1</td>
<td>[500, 450, 300, 250]</td>
<td>NA</td>
</tr>
<tr>
<td>64</td>
<td>Fatigue at Limit (E/F)</td>
<td>1</td>
<td>[500, 450, 300, 250]</td>
<td>NA</td>
</tr>
<tr>
<td>65</td>
<td>Validation of Preps (E/F)</td>
<td>1</td>
<td>[500, 450, 300, 250]</td>
<td>NA</td>
</tr>
</tbody>
</table>

Medium Density Core Sandwich

<table>
<thead>
<tr>
<th>Test #</th>
<th>Description</th>
<th>Priority</th>
<th>Layup</th>
<th>Specification</th>
<th>Purpose</th>
<th>Test Requester</th>
<th>Test Sizes</th>
<th>Quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>67</td>
<td>Environmental Effects (E/F)</td>
<td>1</td>
<td>[500, 450, 300, 250]</td>
<td>NA</td>
<td>Variable environmental boundary in test, develop residual strength curve</td>
<td>A. Notesc</td>
<td>0'' x 4''</td>
<td>2</td>
</tr>
<tr>
<td>68</td>
<td>Residual Strength (E/F)</td>
<td>1</td>
<td>[500, 450, 300, 250]</td>
<td>NA</td>
<td>Variable environmental boundary in test, develop residual strength curve</td>
<td>A. Notesc</td>
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<td>24</td>
</tr>
<tr>
<td>69</td>
<td>No-Growth Threshold (E/F)</td>
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<td>[500, 450, 300, 250]</td>
<td>NA</td>
<td>Variable environmental boundary in test, develop residual strength curve</td>
<td>A. Notesc</td>
<td>0'' x 4''</td>
<td>4</td>
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<tr>
<td>70</td>
<td>Fatigue at Limit (E/F)</td>
<td>1</td>
<td>[500, 450, 300, 250]</td>
<td>NA</td>
<td>Variable environmental boundary in test, develop residual strength curve</td>
<td>A. Notesc</td>
<td>0'' x 4''</td>
<td>2</td>
</tr>
<tr>
<td>71</td>
<td>Validation of Preps (E/F)</td>
<td>1</td>
<td>[500, 450, 300, 250]</td>
<td>NA</td>
<td>Variable environmental boundary in test, develop residual strength curve</td>
<td>A. Notesc</td>
<td>0'' x 4''</td>
<td>3</td>
</tr>
</tbody>
</table>

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Implementation Example: Ares I Upper Stage Composites Interstage

- Test Based Approach

**Diagram:**
- Full-Scale Qualification Test
- MSFC-ROMT-3479
- Figure 5 with Qualification Damage
- All damage threats larger than the qualification size must be mitigated by a protection plan

**Graphs:**
- Determine NDE Sizes vs. Impact Energy (or defect size)
- Coupon Tests: Residual Strength vs. NDE (or defect) size

**Analysis Support:**
- Development Tests

**Figure:**
- MSFC-DT/EM20