A Building Block Approach for Crashworthiness Testing of Composites

Dalton Ostler
Erin Blessing
Mark Perl
Dan Adams
University of Utah

JAMS 2019 Technical Review
May 22-23, 2019
FAA Sponsored Project Information

- Principal Investigators:
  Dr. Dan Adams

- Graduate Student Researchers:
  Dalton Ostler
  Erin Blessing
  Mark Perl

- FAA Technical Monitor:
  Allan Abramowitz

- Collaborators:
  Boeing: Mostafa Rassaian, Kevin Davis
  Engenuity, LTD: Graham Barnes
  Hexcel: Audrey Medford
Current CMH-17 Challenge Problem: Composite Cargo Floor Stanchion

- Central assembly consisting of four primary members
  - Stanchion #3 (primary crush member)
  - Floor beam
  - Frame
  - Skin
- Initial sizing based on 6g vertical loading condition (Altair Engineering)
  - Cross section geometry
  - Laminate ply orientations
  - Laminate thickness
Primary Crush Member: C-Channel Stanchion

Traditional Design: Use of 0°, ±45°, and 90° plies

Material: IM7/8552 unitape prepreg

Geometry: C-channel

Laminate: "Hard" laminate

- 50% 0°, 25% ±45°, 25% 90° (50/25/25)
- 16 plies (@ 0.0072 in.), 0.115 in. thickness
Initial Testing Activities: Laminate Design for Crashworthiness

- Flat-coupon crush testing
- Tailor laminate to achieve stable crush, high energy absorption
- Mini round-robin to evaluate proposed crush test fixtures and draft standard
Flat Coupon Crush Testing: **Unsupported and Pin-Supported**

- **Unsupported Testing**
  - For Flat Sections
  - Measure SEA and Crush Stress for both support conditions
  - For use in crush predictions of structural members

- **Pin-Supported Testing**
  - For Curved Sections & Corners
Previous Research Results: Crush Modes Affect Energy Absorption

**Fragmentation**
- Short axial cracks
- Shear failure from compressive stresses
- Extensive fiber fracture

**Brittle Fracture**
- Intermediate axial cracks
- Combines characteristics from other failure modes

**Fiber Splaying**
- Long axial cracks
- Frond formation
- Delamination dominated
Flat Coupon Crush Test Results: Hard Laminates

All laminates produced good energy absorption

- 50% 0°, 25% ±45°, 25% 90°
- No significant difference due to fabric layers in Hybrid laminates
- Minimal variation between laminates investigated
- Two laminates selected for further investigation
C-Channel Stanchion Crush Testing: Specimen Manufacturing

- IM7/8552 carbon/epoxy unitape prepreg, 190 gsm
- \([90_2/0_2/\pm45/0_2]_s\) and \([90/+45/0_2/90/-45/0_2]_s\) “Hard” laminates
- 0.25 in. corner radius, 0.114 in. average thickness
- Layup and cure in accordance with NCAMP specifications
- \(~1.5\%\) thickness difference between flat and corner sections (corner thickness slightly lower)
Validation of Numerical Crush Modeling Methods: C-Channel Crush Testing

- University of Utah instrumented drop-weight impact tower
- \([90_2/0_2/\pm45/0_2]_s\) and \([90/+45/0_2/90/-45/0_2]_s\) “hard” laminates
- Three crush velocities
  - 300 in/sec (~10 ft. drop height)
  - 150 in/sec (~2.5 ft. drop height)
  - Quasi-static
- Results to be used to assess numerical analysis capabilities
- High-speed video of crush process
C-Channel Crush Testing:
High-Speed Video of Crush Process
Current Focus: Crush Testing of Single Stanchion Assembly

Additional considerations include:

- Bolted attachments (top and bottom)
  - Design of bolted connections
  - Design of laminate in bolted regions
- Crush initiator
  - Internal ply-drops
  - Reduced cross-sectional area
  - Produced failure at prescribed location, load level, and failure mode
- Subsequent stable crush of stanchion

Additional considerations include:
- Design-value development
- Material property evaluation
- Component tests
- Sub-component tests
- Structural elements tests
- Allowable development
- Material specification development
- Material screening and selection
- Full-scale tests
- Analysis validation
- Design-value development
- Material property evaluation

Current Focus: Crush Testing of Single Stanchion Assembly
Design of Bolted Attachments: Dynamic Bearing Testing

- Stanchion bolted to the upper floor and lower frame
- Bearing failure possible at bolted connections
- Investigate dynamic bearing strength and bearing crush behavior
  - Single fastener tests to establish dynamic bearing strength
  - Bolted C-channel tests to establish joint load capacity
Dynamic Bearing Testing:
Single Fastener/Single Shear Testing

- Use of Univ. of Utah flat coupon crush test fixture
- 0.25 in. diameter steel fastener
- Test specimen bolted to steel block
- Compression loaded
  - Quasi-static: 0.4 in/min
  - Dynamic: 144 in/sec (drop-weight impact)
Dynamic Bearing Testing: Single Fastener/Single Shear Testing

- Failure of single fastener
  - Quasi-static: 3.5 kip
  - Dynamic: 4.1 kip
- Failure by fastener tearing through the laminate
- No visible degradation to the fastener
- Stanchion will consist of six fasteners. Therefore, the desired dynamic peak load would be 24.3 kip
Dynamic Bearing Testing:
Bolted C-Channel Test

- Single-shear testing of bolted joint design
- Six 0.25 in. diameter bolts, two rows three columns
- Top of channel potted to prevent end crushing
- Establishment of dynamic and quasi-static joint performance
  - Initial failure load
  - Failure mode and location
- Testing of two selected “hard” laminates
- Of use for assessing numerical modeling methods
Bolted Joint Dynamic Testing: Summary of Results To Date

- Similar failure mode in all tests
- Similar max. bearing loads for two hard laminates tested quasi-statically and dynamically
Bolted Joint Dynamic Testing: Summary of Results To Date

- Bearing design with 3 rows and 2 columns
- Similar failure as previous bolted design
- Slight increase in peak failure loading
- Similar failure modes in all tests
Bolted Joint Dynamic Testing: Summary of Results

- By changing the bearing configuration
  - Quasi-static peak increased by 10.5%
  - Dynamic peak increased by 5%
  - Below the theoretical 6 bearings value by 4.9 kip
  - Not a significant peak load increase
    - Proposing a bearing parameter change to increase the dynamic peak value
- Again, of use in assessing modeling capabilities
Current Focus:
Bolted Joint Design and Validation

- Investigate use of quasi-isotropic laminate in bolted region of stanchion
- Additional ±45° layers for increased bearing strength
- Desire to continue all 0° layers throughout stanchion into bolted region to retain compression strength
- Options under investigation:
  - Replace 90° plies with ±45° plies
  - Additional ±45° plies added to laminate
Current Focus:
Crush Testing of Single Stanchion Assembly

Additional considerations include:

- Bolted attachments (top and bottom)
  - Design of bolted connection
  - Design of laminate in bolted region

Crush initiator

- Internal ply-drops
- Reduced cross-sectional area
- Produced failure at prescribed location, load level, and failure mode
- Subsequent stable crush of stanchion
C-Channel Stanchion Crush Initiator: Use of Laminate Ply-Drops

- Ply-drop regions in stanchion laminate
- Produces laminate failure under dynamic compression loading
- Serves as a crush front for subsequent stanchion crushing
- $[90_2/0_2/\pm 45/0_2]_s$ laminate
C-Channel Stanchion: Ply-Drop Crush Initiator Design

- Investigated dropping outermost 4, 6, and 8 plies of 16 ply “hard” laminate
- Multiple ply drop configurations
  - Different thicknesses at either ends
  - Same thicknesses at both ends and a ply-drop region in the center
  - Full thickness change (90° step) vs. staggered ply drops
  - Variable length ply drop regions
Ply-Drop Crush Testing:
90° Ply-Drop and Tapering

- 90° ply-drop used at desired failure location
- Tapered thickness region for laminate build-up
  - 1/16 in. spacing between ply drops in taper region
- Of use for predicting the location, mode, and load level at failure

![Image of ply-drop crush testing with labels for 90°, 0°, +45°, and -45° orientations.]
Example Ply-Drop Crush Test: Double-Side 90° Ply-Drop

- Initial failure occurs at lower ply-drop
- Peak load: 14.5 kip
Current Focus:
Crush Testing of Single Stanchion Assembly

Additional considerations include:

- Bolted attachments (top and bottom)
  - Design of bolted connection
  - Design of laminate in bolted region
- Crush initiator
  - Internal ply-drops
  - Reduced cross-sectional area
  - Produced failure at prescribed location, load level, and failure mode

Subsequent stable crush of stanchion
Pre-Stanchion Assembly Testing:
Bolted Joint with Ply-Drop

- Failure at prescribed location.
- Subsequent stable crushing.
- Minimal deflection of bolted region.

<table>
<thead>
<tr>
<th></th>
<th>Avg. Peak Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing (dynamic)</td>
<td>20.0 kip</td>
</tr>
<tr>
<td>Ply-drop (8 plies)</td>
<td>15.4 kip</td>
</tr>
</tbody>
</table>
Upcoming Testing:
C-Channel with Reduced Cross-Section

- Configuration of bearing stacking sequence to be quasi-isotropic or addition of ±45’s
- Use of ply-drop configuration selected from previous testing
- Reduction in flange height in region of crush initiation
- Tapered flange height to promote stable crush behavior
- Designed to fail at ply drop region and display stable crush in region with increasing cross sectional area
- Test results to be used to assess numerical modeling capabilities
BENEFITS TO AVIATION

- Building block approach for developing composite crush structures for crashworthiness
- Coupon-level test methods for use in initial crashworthiness assessment of candidate composite materials and laminates
- Documentation of building block approach for crashworthiness design and experimental validation in CMH-17
- Dissemination of research results through FAA technical reports and conference/journal publications
Questions?

Don’t forget to fill out the feedback form in your packet or online at www.surveymonkey.com/r/jamsfeedback

Thank you.