A Building Block Approach for Crashworthiness Testing of Composites

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FAA Sponsored Project Information

- **Principal Investigator:**
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- **Graduate Student Researchers:**
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  Dalton Ostler
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- **FAA Technical Monitor:**
  Allan Abramowitz

- **Collaborators:**
  Boeing: 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

Frame & Skin

Floor Beam

Stanchion

3.50 in.

0.75 in.
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

- Measure SEA and Crush Stress for both support conditions
- For use in crush predictions of structural members
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
- “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)
C-Channel Crush Testing:
Crush Test Parameters

- University of Utah instrumented drop-weight impact tower
- \([90_2/0_2/\pm 45/0_2]_S\) 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
- High-speed video of crush process
- Results used to assess numerical modeling capabilities
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
  - Localized stress concentration
  - Reduced cross-sectional area
  - Produced failure at prescribed location, load level, and failure mode

- Subsequent stable crush of stanchion
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**

- Compression loaded
  - Quasi-static: 0.4 in/min
  - Dynamic: 144 in/sec (drop-weight impact)
- Failure of single fastener
  - Quasi-static: 3.5 kip
  - Dynamic: 4.1 kip

Stanchion will consist of six fasteners. Therefore, the desired dynamic peak load would be 24.6 kip.
Dynamic Bearing Testing:
Bolted C-Channel Test

- Single-shear testing of bolted joint design
- Six 0.25 in. diameter bolts, three rows two 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 selected “hard” laminate
- Of use for assessing numerical modeling methods
Bolted Joint Testing:
High Speed Video of Dynamic Bearing Test

- Similar failure modes in all tests
Current Focus: Bolted Joint Design

- Laminate transition for improved bolted joint strength
  - Additional $\pm 45^\circ$ layers for increased bearing strength
  - Maintain $0^\circ$ plies to maintain laminate axial strength
  - Replace all $90^\circ$ plies with $\pm 45^\circ$ plies

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<tr>
<th>C Channel Ply Stacking Sequence</th>
<th>Hard Laminate</th>
<th>Bolted Region</th>
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C-Channel Stanchion Crush Initiator: Use of Laminate Ply-Drops & Machined Holes

- Two crush initiators investigated
  - Ply drops
  - Machined holes
- Laminate failure in desired region under dynamic compression loading
- Fracture surface serves as crush front for further stanchion crushing
- Machined holes selected for use
Upcoming Testing:
C-Channel with Reduced Cross-Section

• Quasi-isotropic “like” laminate in joint regions through ply substitution
• Use of machined holes in web for crush initiator
• Tapered flange height to promote stable crush behavior
• Test results to be used to assess numerical modeling capabilities
University of Utah Modeling Approach: ABAQUS Explicit with CZone

- **CZone: Crush Modeling**
  - An Abaqus Explicit Add-on
  - Developed by Engenuity LTD
  - Developed to model crush in composites
  - Uses measured crush stress of laminate as an input property

- **Abaqus Explicit**
  - Runs simultaneously
  - Allows failure away from the crush front
Primary CMH-17 Emphasis: Numerical Prediction of Crush Behavior

- Total of 14 analysis teams
- Different codes, approaches, and material models
- Common set of material properties
- Provided with crush test results from flat coupon tests
- Blind predictions to be submitted
  - C-channel crush tests
  - Stanchion crush tests
CZone Numerical Approach: How Crush Stress is Applied as a Laminate Material Property

1) Crushing stress applied at Master/Slave Contact
   - Master Surface (red plate)
   - Slave Surface (crushing element)

2) Crushing force is calculated and distributed to nodes

3) Crushing elements move through rigid surface

4) Elements delete past the rigid surface
CZone Modeling:
Model of Base C-Channel

- Two Parts Modeled
  - Discrete Rigid Plate
  - Crushing Specimen (C-Channel)
- Crush stress applied at contact interface
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?

Thank you.