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A Building Block Approach for Crashworthiness Testing of Composites

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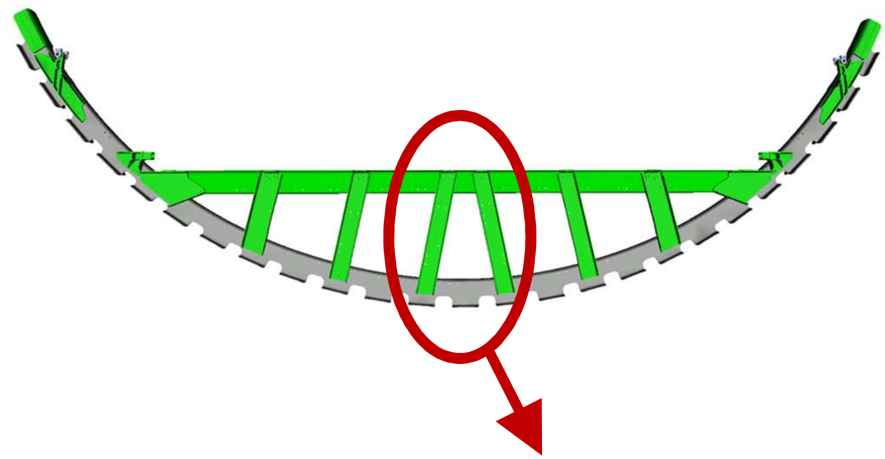
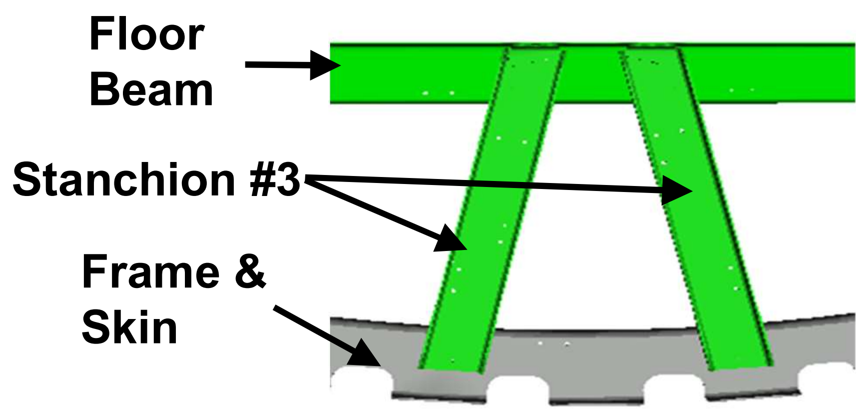
FAA Sponsored Project Information

- **Principal Investigator:**
  - Dr. Dan Adams
- **Graduate Student Researchers:**
  - Erin Blessing
  - Dalton Ostler
  - Mark Perl
- **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

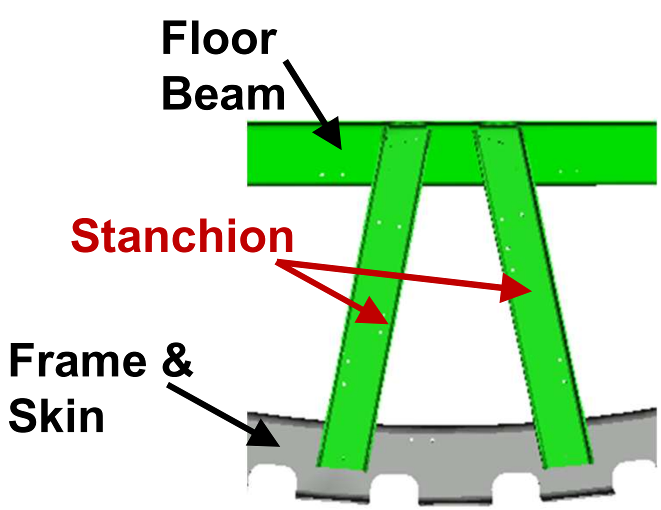
Traditional Design: Use of 0°, ±45°, and 90° plies

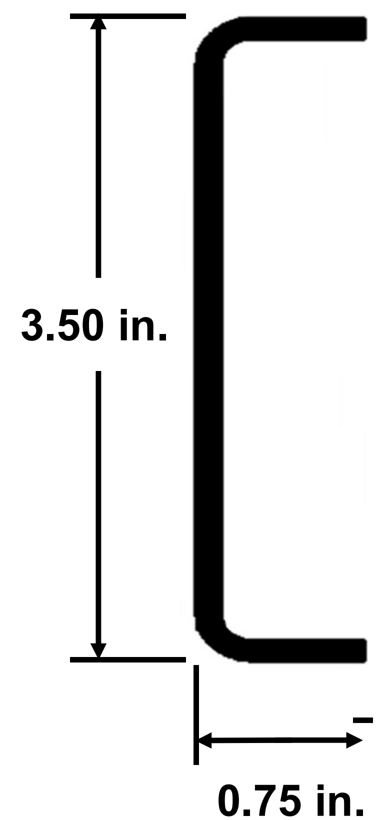
Material: IM7/8552 unitape prepreg

Geometry: C-channel

Laminate: "Hard" laminate

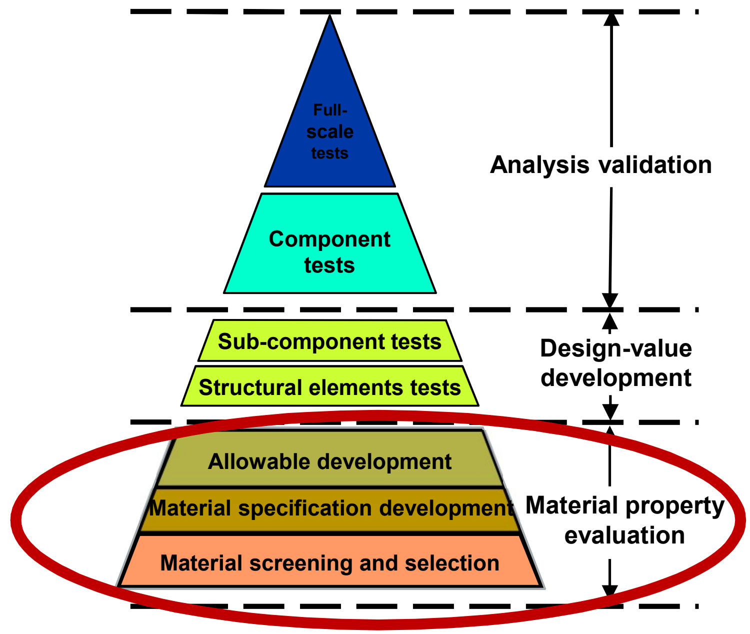
- 50% 0°, 25% ±45°, 25% 90° (50/25/25)
- 16 plies (@ 0.0072 in.), 0.115 in. thickness

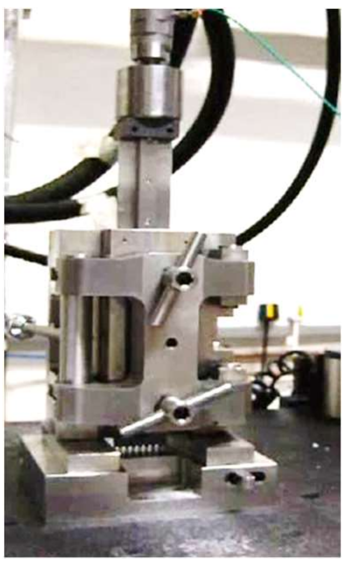


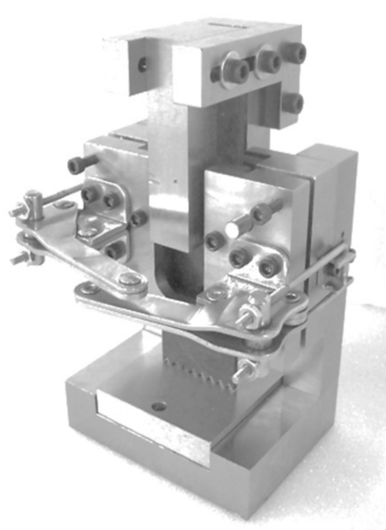


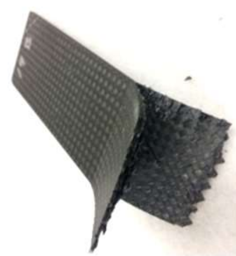
Initial Testing Activities:
Laminate Design for Crashworthiness

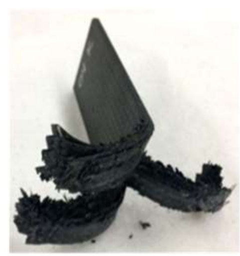
- Flat-coupon crush testing
- Tailor laminate to achieve stable crush, high energy absorption
- Mini round-robin to evaluate proposed crush test fixtures and draft standard







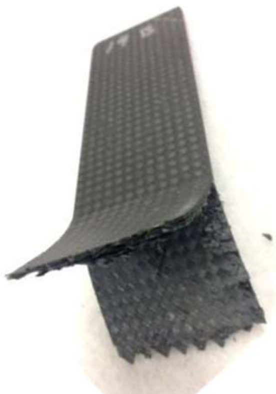


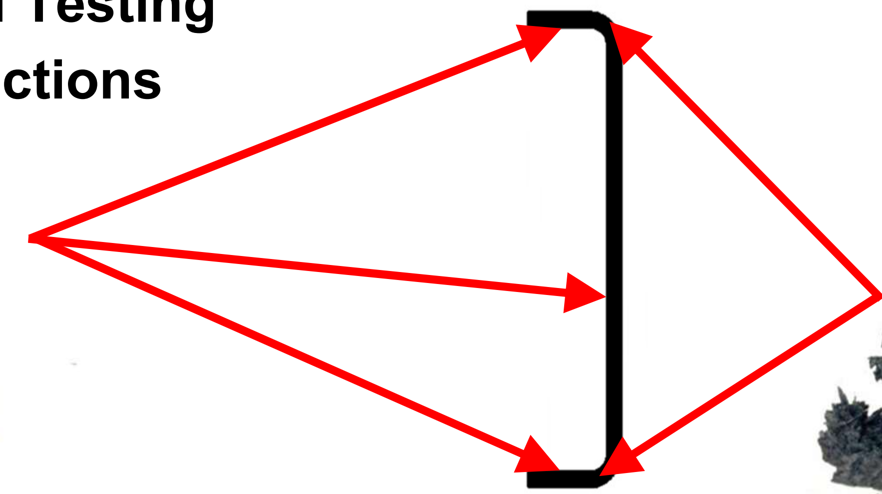


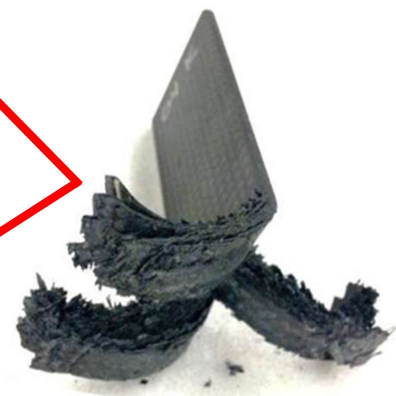
Flat Coupon Crush Testing:
Unsupported and Pin-Supported

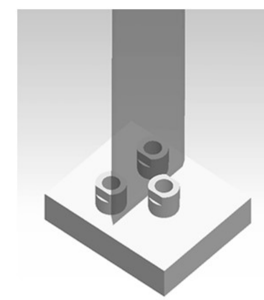
Unsupported Testing
For Flat Sections

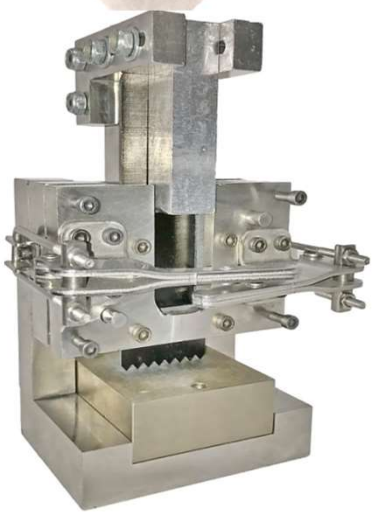
Pin-Supported Testing
For Curved Sections





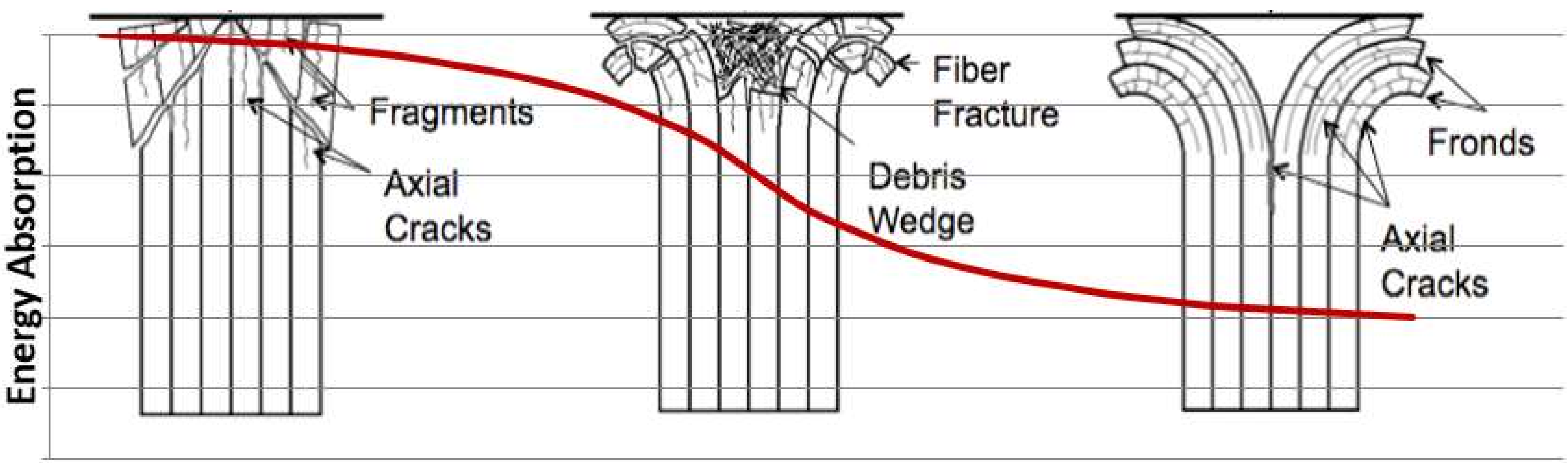






- **Measure SEA and Crush Stress for both support conditions**
- **For use in crush predictions of structural members**

Previous Research Results:
Crush Modes Affect Energy Absorption



Fragmentation

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

Brittle Fracture

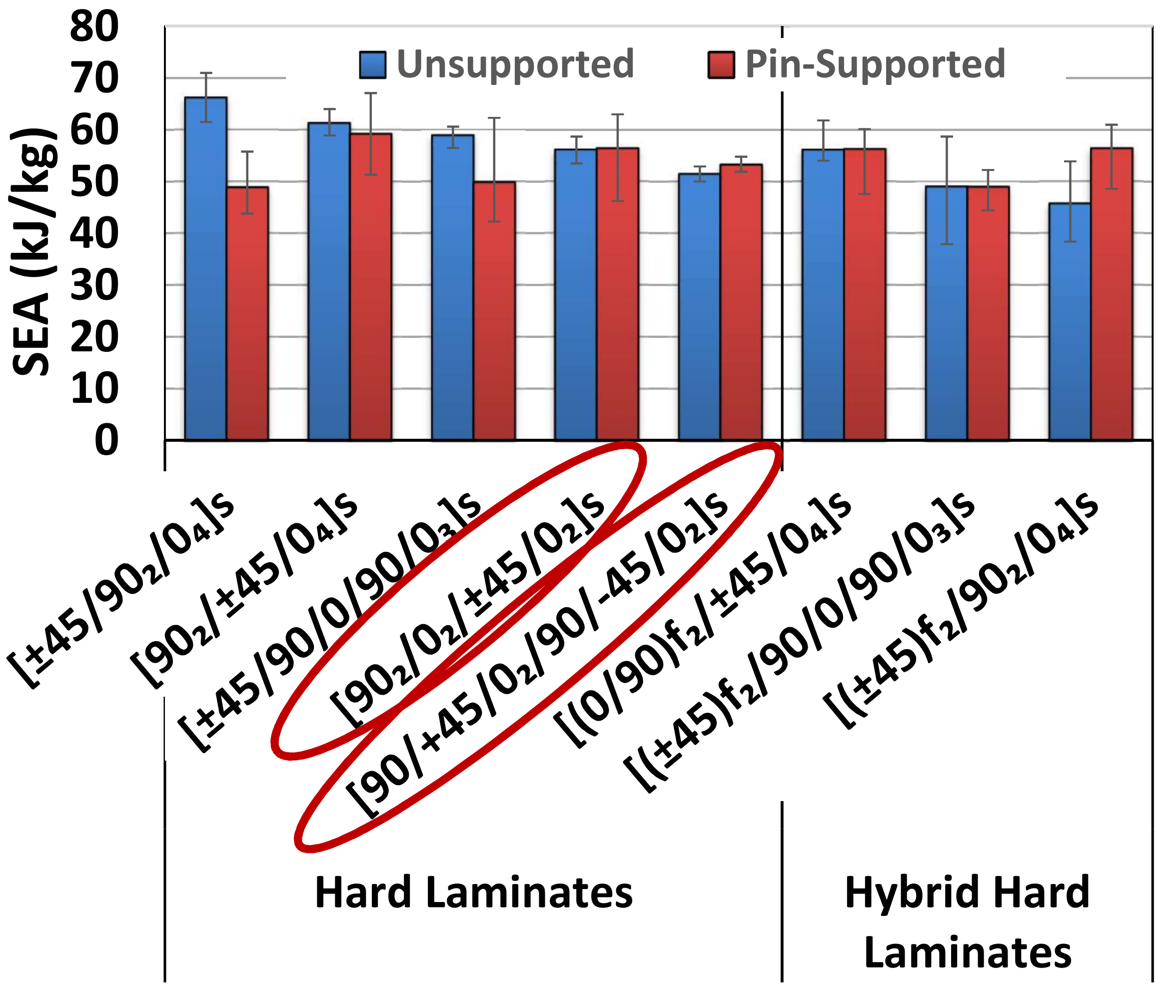
- Intermediate axial cracks
- Combines characteristics from other failure modes

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**

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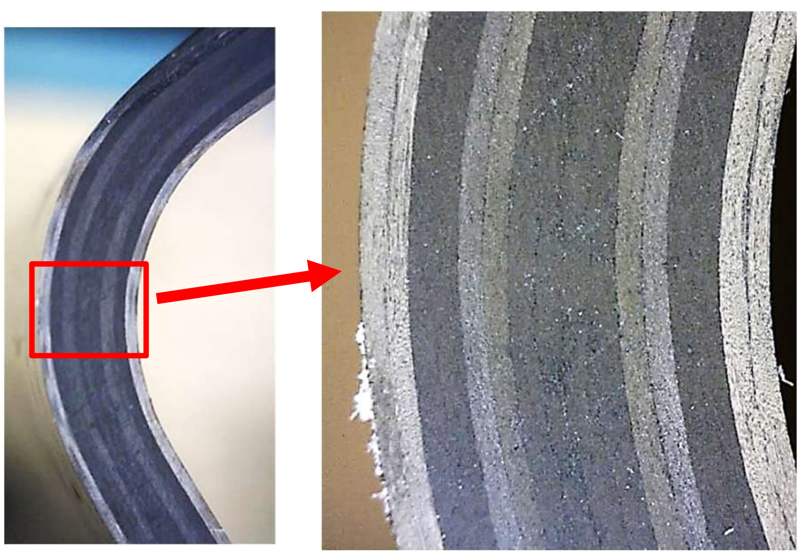
C-Channel Stanchion Crush Testing:
Specimen Manufacturing



- 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
- $[90_2/0_2/\pm45/0_2]_s$ 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
- High-speed video of crush process
- Results used to assess numerical modeling capabilities

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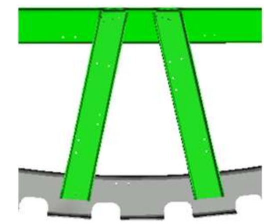
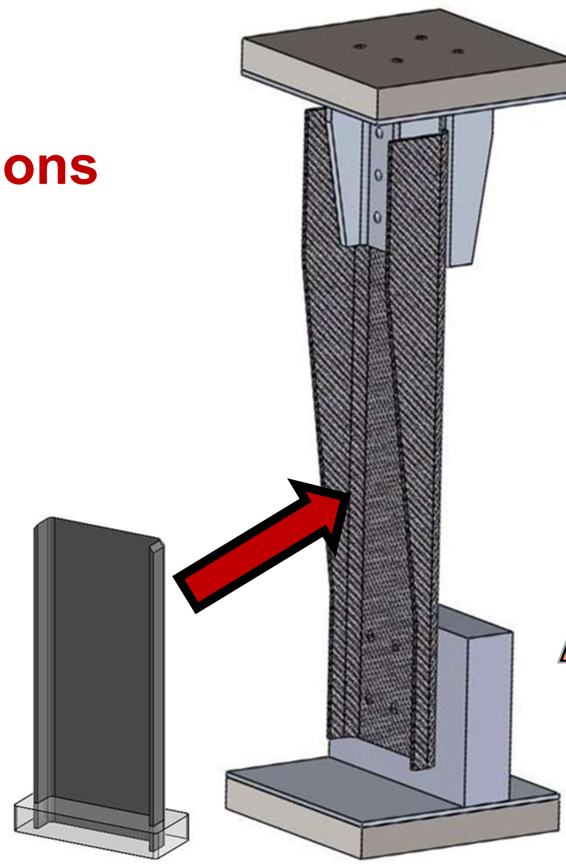
C-Channel Crush Testing:
High-Speed Video of Crush Process

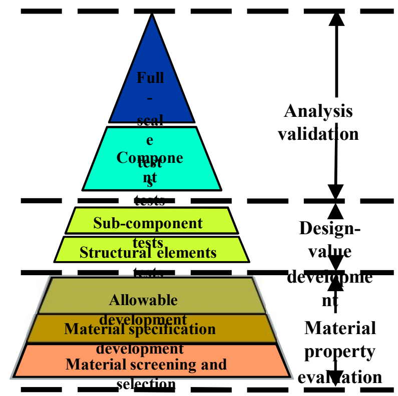
Current Focus:
Crush Testing of Single Stanchion Assembly

<u>Additional considerations include</u>:

- 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

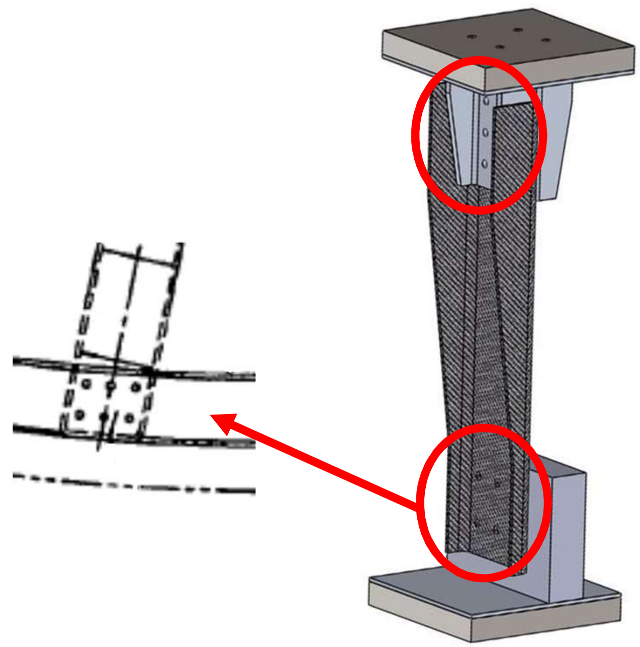






Design of Bolted Attachments:
Dynamic Bearing Testing

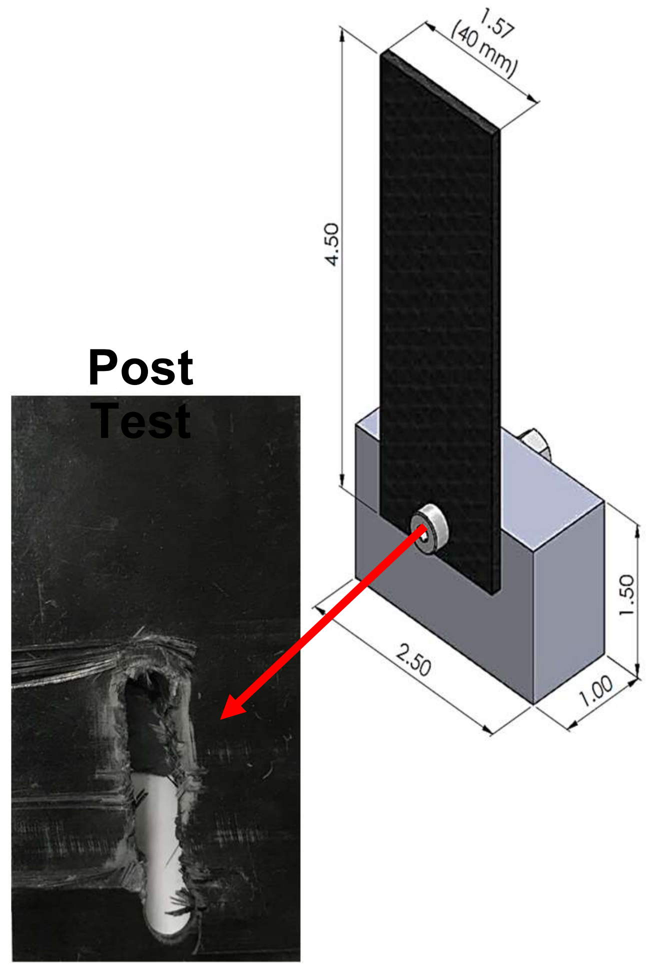
- **Stanchion bolted to the upper floor and lower frame**
- **Bearing failure possible at bolted connections**
- **Investigate dynamic bearing strength and bearing crush behavior**
  - **Single fastener tests to establish dynamic bearing strength**
  - **Bolted C-channel tests to establish joint load 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



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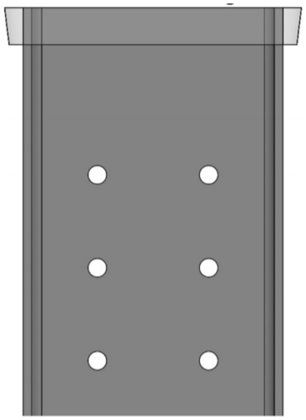
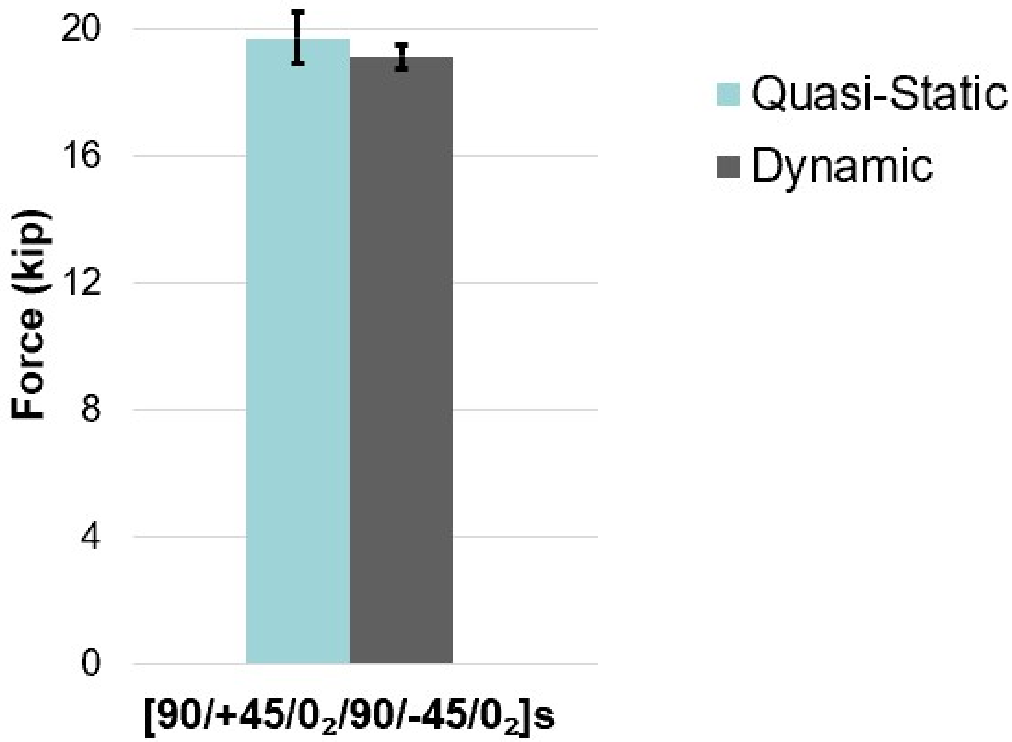
Dynamic Bearing Testing:
Bolted C-Channel Test

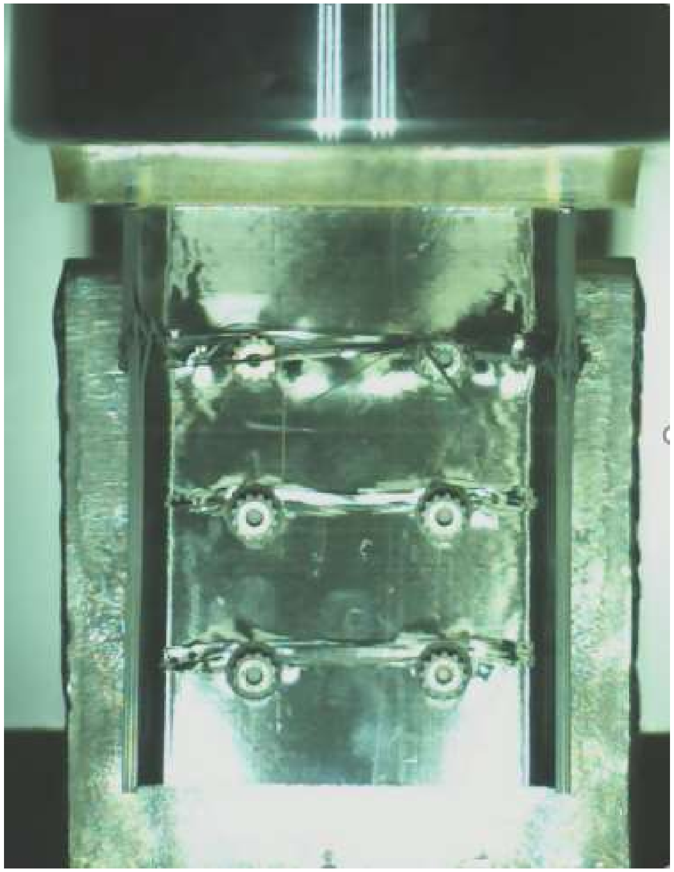
- Single-shear testing of bolted joint design
- Six 0.25 in. diameter bolts, three rows two columns
- Top of channel potted to prevent end crushing
- Establishment of dynamic and quasi-static joint performance
  - Initial failure load
  - Failure mode and location
- Testing of selected “hard” laminate
- 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 ±45° layers for increased bearing strength**
  - **Maintain 0 ° plies to maintain laminate axial strength**
  - **Replace all 90° plies with ±45° plies**

C Channel Ply Stacking Sequence														
Hard Laminate							Bolted Region							
90	90	90	90	90	90	90	90	-45	-45	-45	-45	-45	-45	-45
45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	90	90	90	90	90	90	90	90	45	45	45	45	45	45
-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45	-45
90	90	90	90	90	90	90	45	45	45	45	45	45	45	45
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
90	90	90	90	90	90	90	90	90	90	-45	-45	-45	-45	-45
Tool Side	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**			
Tool Side	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**	**Tool Side**			

Current Focus:
Crush Testing of Single Stanchion Assembly

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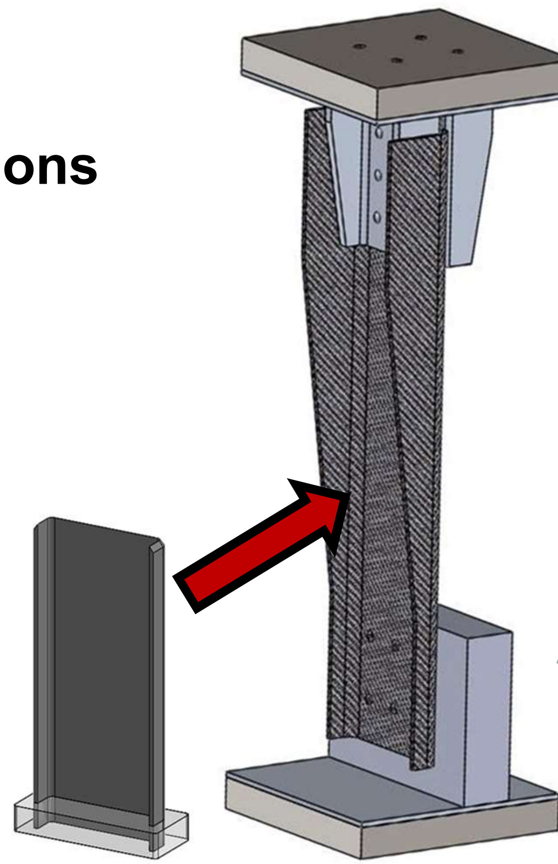
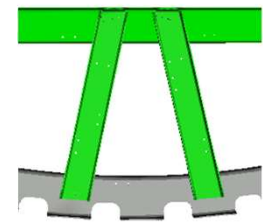
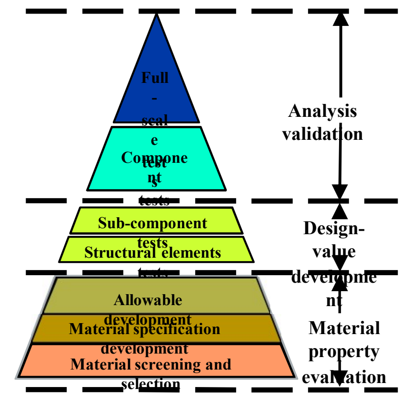
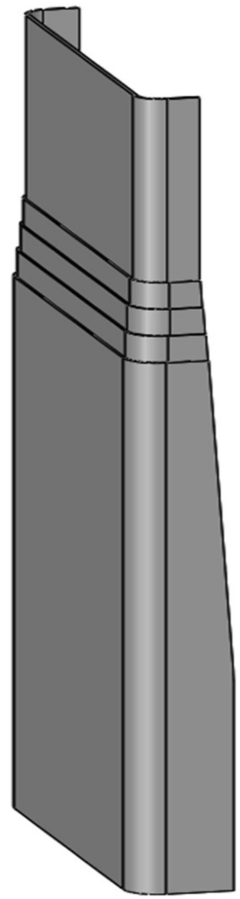


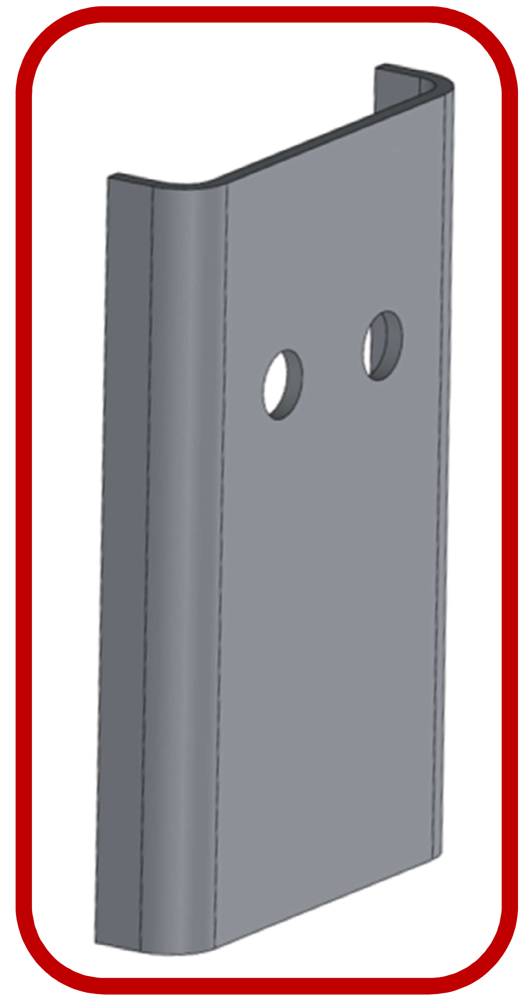




C-Channel Stanchion Crush Initiator: Use of Laminate Ply-Drops & Machined Holes

- **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**



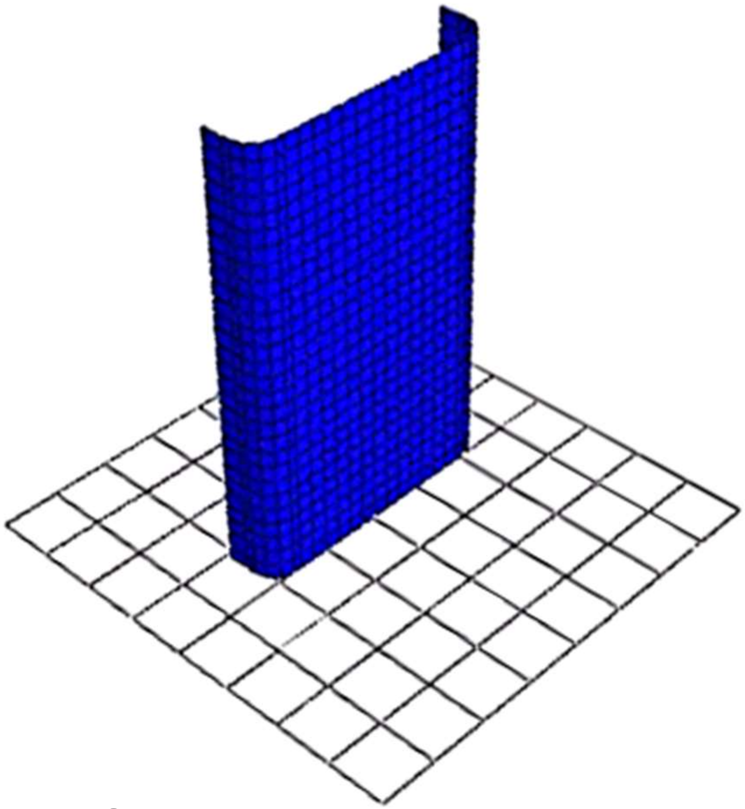


Upcoming Testing: C-Channel with Reduced Cross-Section

- 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

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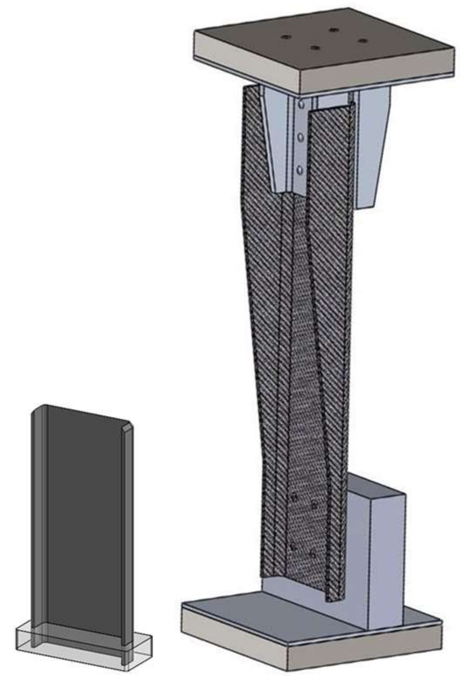
Primary CMH-17 Emphasis:
Numerical Prediction of Crush Behavior

CMH-17 COMPOSITE MATERIALS HANDBOOK

- **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

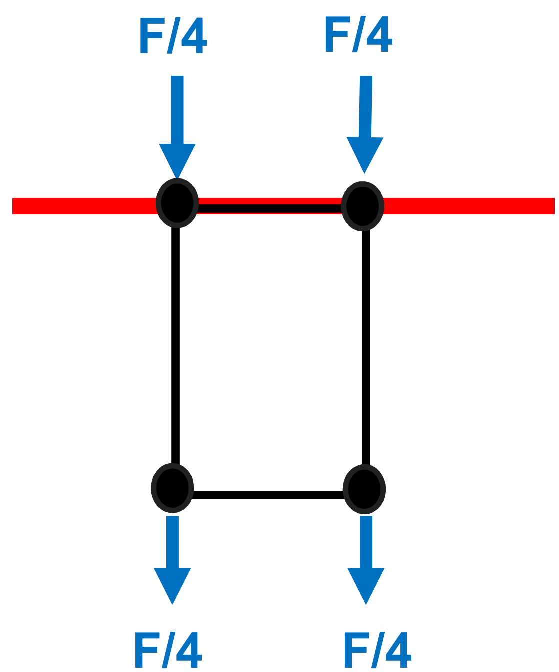
1) Crushing stress applied at Master/ Slave Contact

- 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



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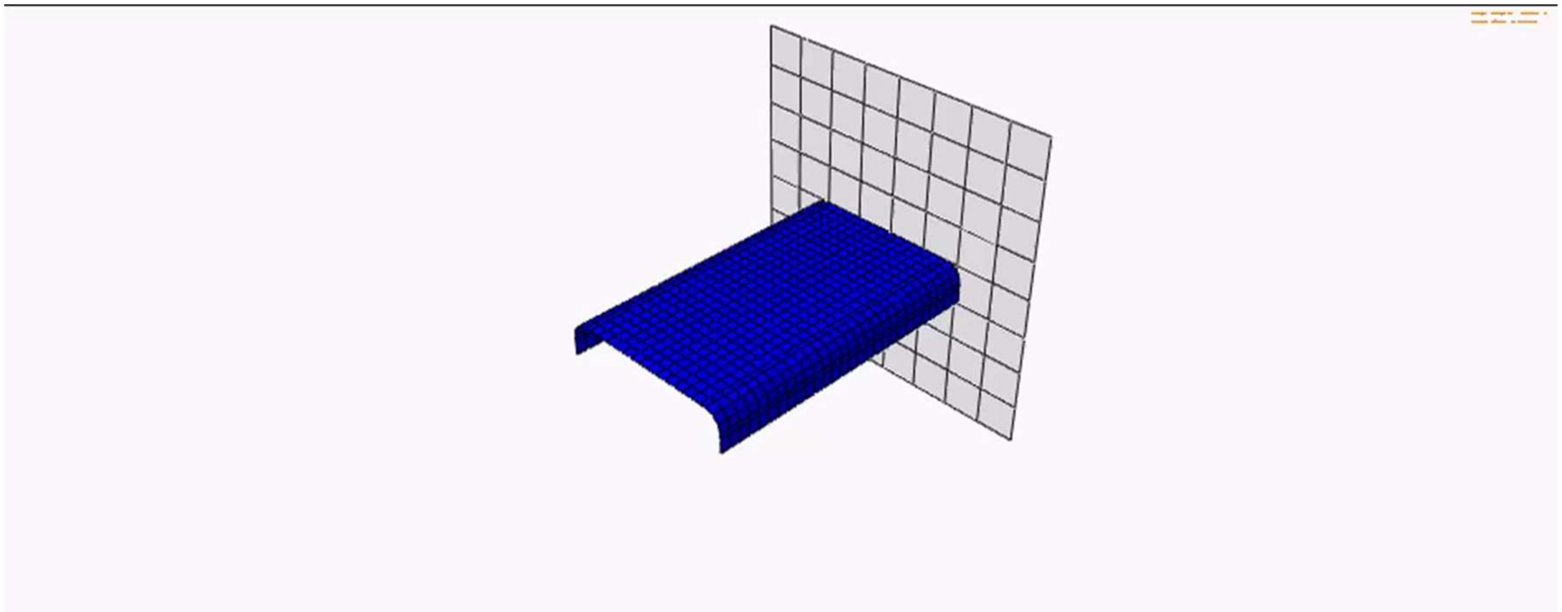
CZone Modeling:
Model of Base C-Channel

- **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.

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