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Development of a Building Block Approach for Crashworthiness Testing of Composites

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THE UNIVERSITY OF UTAH

FAA Sponsored Project Information

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  Allan Abramowitz

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  Hexcel: Audrey Medford

  Engenuity, LTD: Graham Barnes

Outline

- Overview: CMH-17 Crashworthiness Working Group activities
- Current focus: Phase III Crashworthiness building block exercise
- Flat coupon crush testing for laminate evaluation
- Plans for upcoming research

Overview:
CMH-17 Crashworthiness Working Group

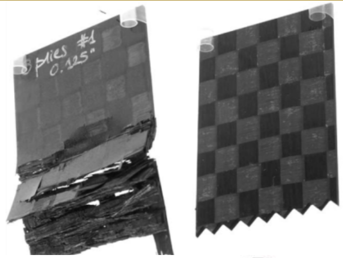
- Founded in 2005
- Original focus on automotive composites
- Recent focus on aviation applications
- Testing, Analysis, and Certification subgroups
- Two previous activities in testing and analysis
- Current focus: Phase III crashworthiness building block exercise

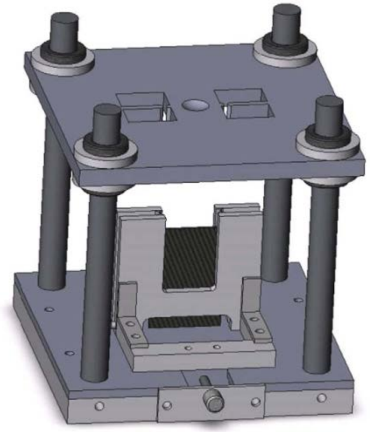
Meeting: Wednesday 8:00-12:15, Officer's Club North

Previous Initiatives:
CMH-17 Crashworthiness Working Group

<u>Phase I: Coupon-level crush testing</u>

- Flat and sinusoidal specimens
  - T700/2510 flat-woven carbon/epoxy woven prepreg (Toray)
  - $[0/90]_{ns}$ cross-ply laminates
- Quasi-static testing
- Focus on test development and evaluation
- Initial crush test results for numerical model calibration



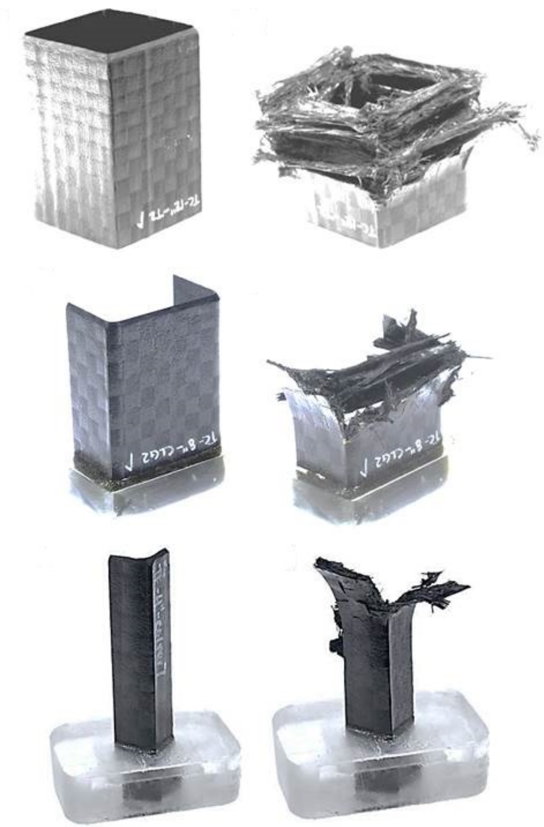


Feraboli et al., <u>Composites: Part A</u>, 40 (2009) 1248–1256

Previous Initiatives:
CMH-17 Crashworthiness Working Group

Phase II: Tube crush testing and simulation

- Same material & laminate as Phase I
- Square tube and tube section specimens
  - Channel and corner shapes (5)
  - Tube section bases mounted in epoxy
  - 45 degree chamfer crush trigger
- Quasi-static testing
- Numerical simulation using commercial finite element codes
- Results to be published in Handbook

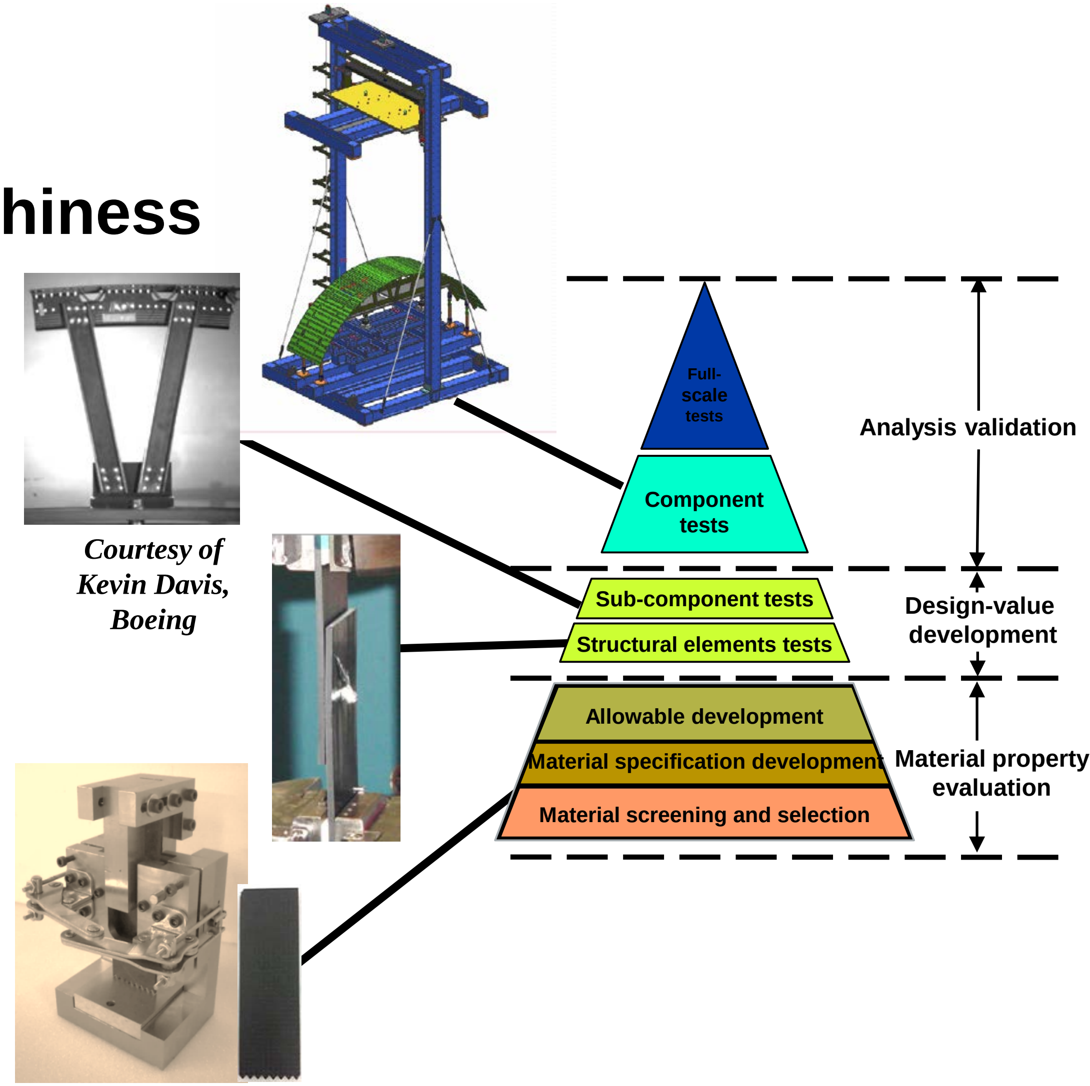


Feraboli et al., Composites: Part A, 40 (2009) 1248–1256

Current Focus:
Crashworthiness Building Block Development

Phase III Activity

- Focus on FAA Crashworthiness Certification
- Building on Phase I & II activities
- Testing to support analysis development and evaluation
- Currently underway



Courtesy of Kevin Davis, Boeing

Proposed Phase III Testing Activities: Building Block Process

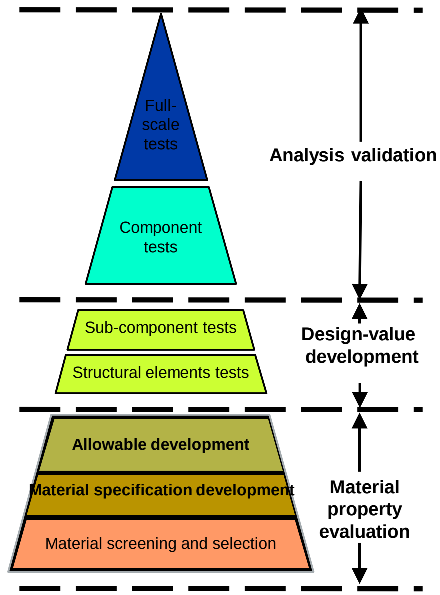
Concurrent "Top-Down" and "Bottom-Up" efforts

Initial Top-Down Effort

- Challenge problem definition & initial design
  - Stiffness and strength requirements, 6g loading
  - Element geometries
  - Laminate definition
- Identification of structural element tests

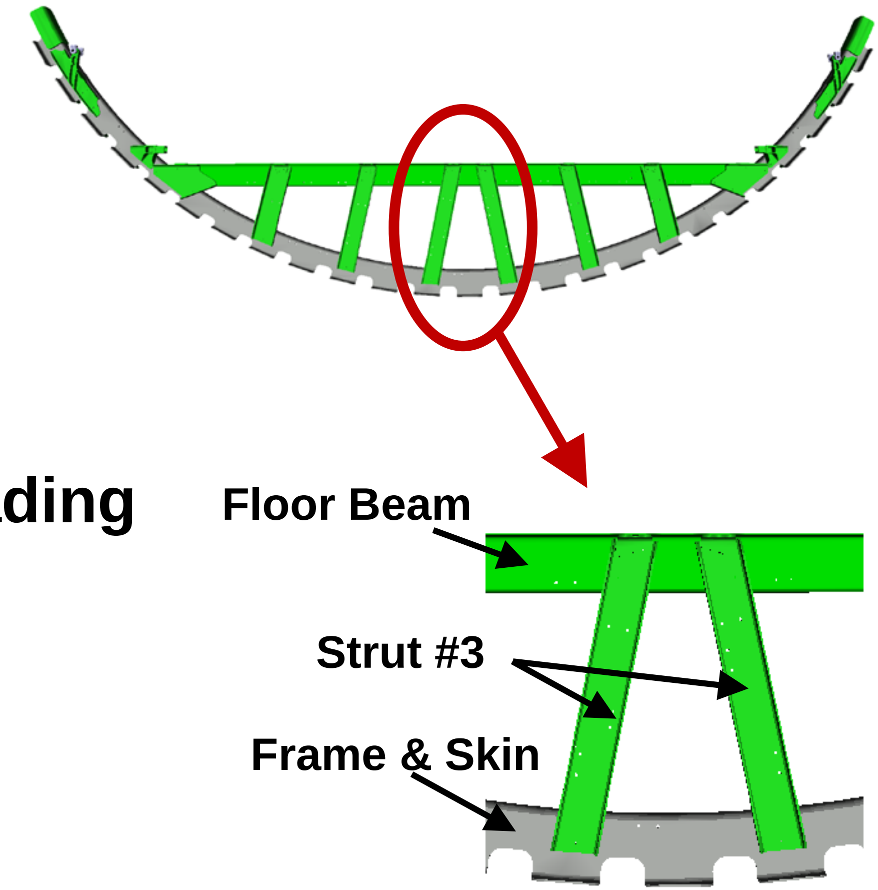
Initial Bottom-Up Effort

- Material selection: IM7/8552 unitape & fabric
- Laminate design for crashworthiness
- Identification of specialized coupon-level tests required for simulation codes



Phase III Challenge Problem:
Composite Cargo Floor Stanchion

- **Central stanchion consisting of four primary members**
  - **Strut #3 (primary crush member)**
  - **Floor beam**
  - **Frame**
  - **Skin**
- **Sizing based on 6g vertical loading condition (Altair Engineering)**
  - **Cross section geometry**
  - **Laminate ply orientations**
  - **Laminate thickness**
- ***Traditional* and *non-traditional* laminate design**



Stanchion Definition: Strut #3

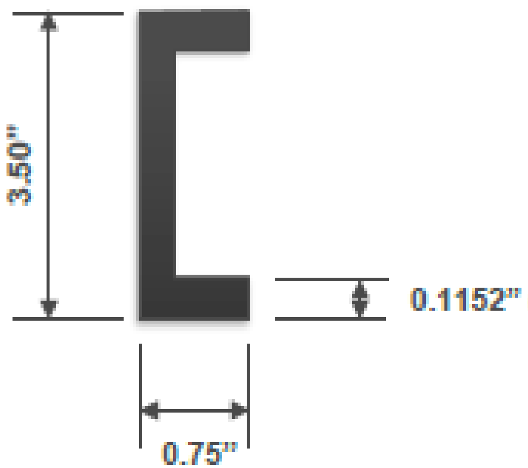
Traditional Design: Use of 0°, ±45°, and 90° plies

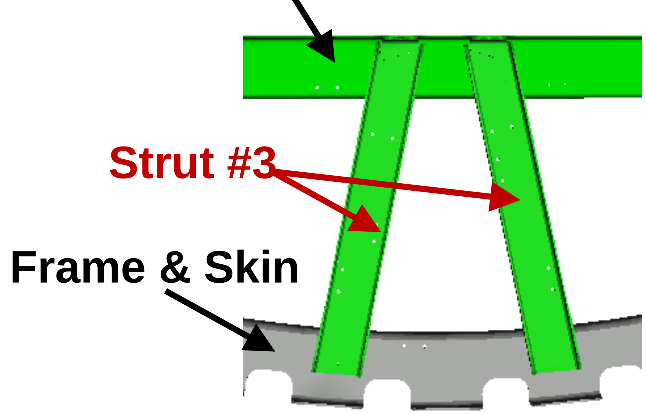
Material: IM7/8552 unitape prepreg

Geometry: C-channel

Laminate: "Hard" laminate

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





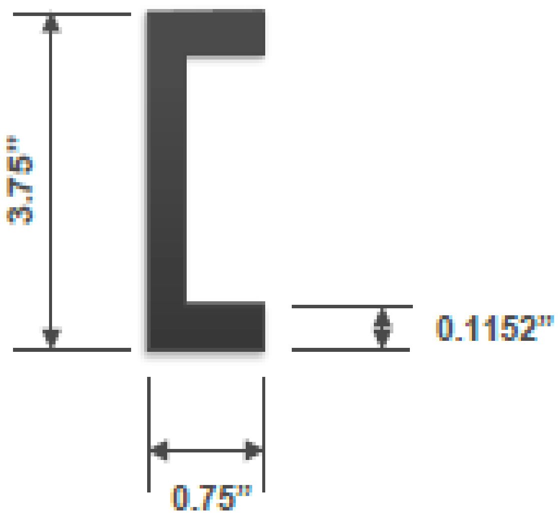
Traditional Design: Floor Beam

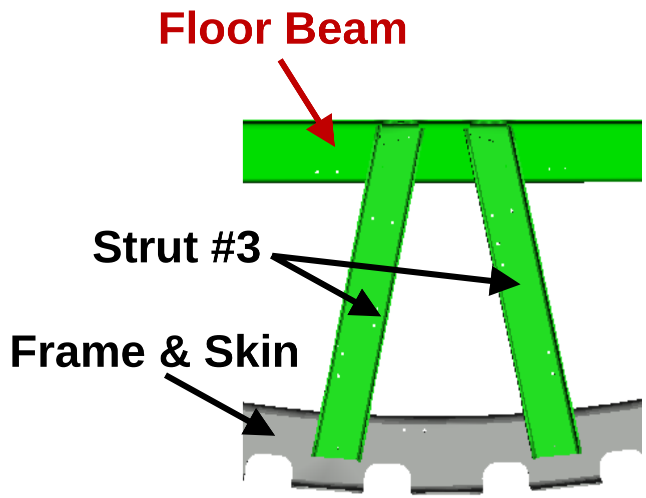
Material: IM7/8552 unitape prepreg

Geometry: C-channel

Laminate: "Hard" laminate

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





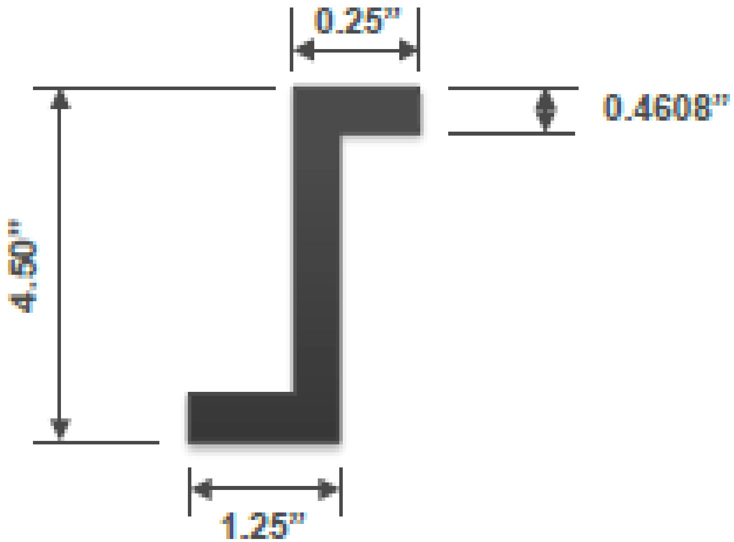
Traditional Design: Frame

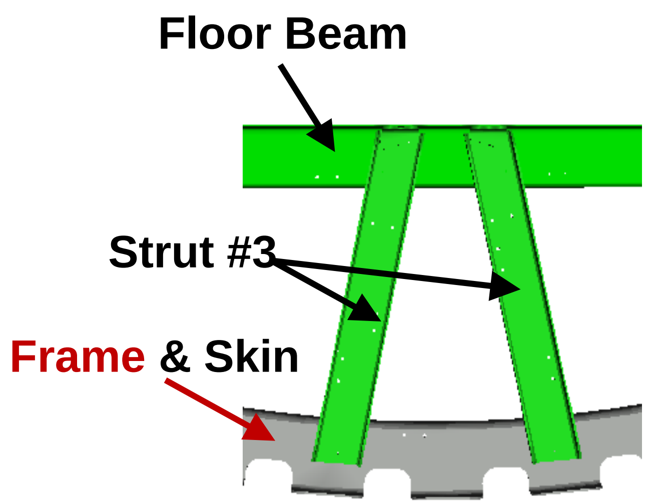
Material: IM7/8552 unitape prepreg

Geometry: Z-channel

Laminate: Quasi-isotropic laminate

- 25% 0°, 50% ±45°, 25% 90° (25/50/25)
- 64 plies (@ 0.0072 in.), 0.461 in. thickness



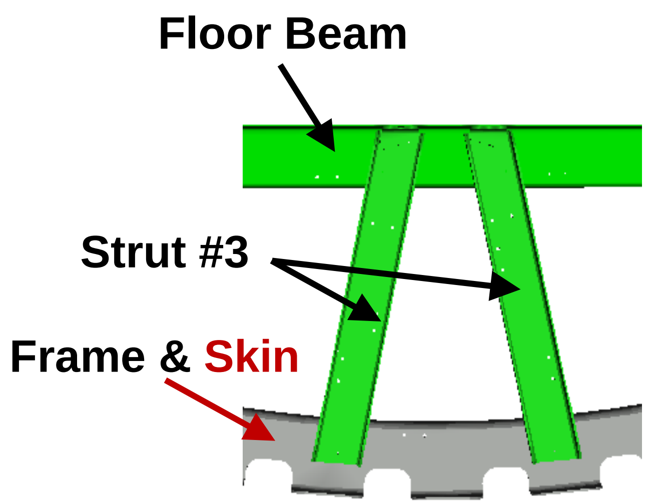


Traditional Design: Skin

Material: IM7/8552 unitape prepreg

Laminate: Quasi-isotropic laminate

- 25% 0°, 50% ±45°, 25% 90° (25/50/25)
- 24 plies (@ 0.0072 in.), 0.173 in. thickness



Laminate Summary:
Altair Traditional Design:

Two laminates of interest:

1) (50/25/25) 50% 0°, 25% ±45°, 25% 90°

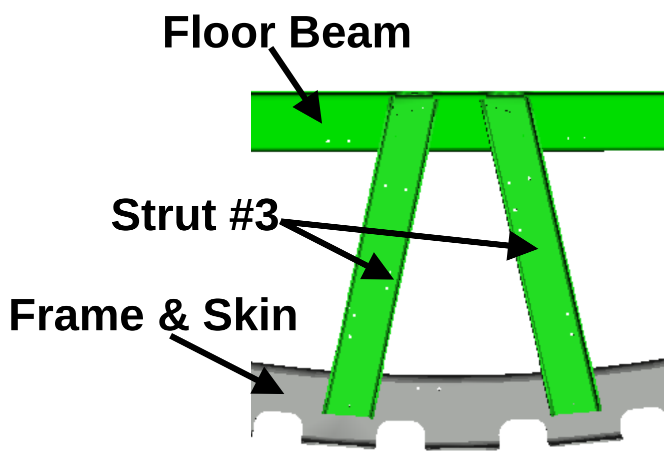
16 ply thickness: 8 0's 4 ±45's 4 90's

- Strut #3 (primary crush member)
- Floor Beam

2) (25/50/25) 25% 0°, 50% ±45°, 25% 90°

24 and 64 ply thickness

- Frame (64 plies)
- Skin (24 plies)



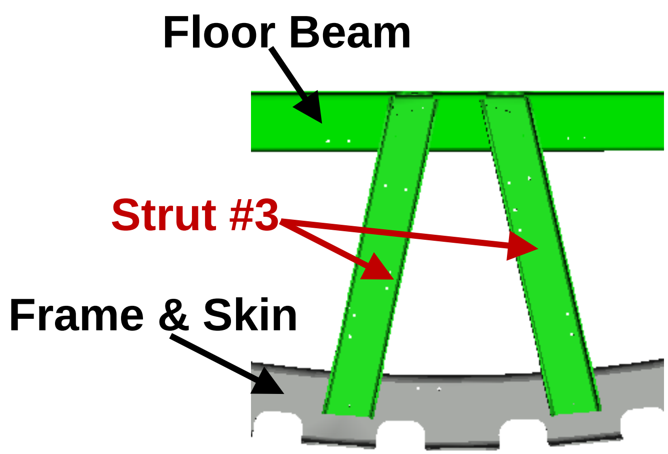
Proposed Laminate For Testing: Altair Non-Traditional Design:

- **Use of 0°, ±ϴ°, and 90° ply orientations**
- **Primary component of interest:**

  Strut #3 (primary crush member):

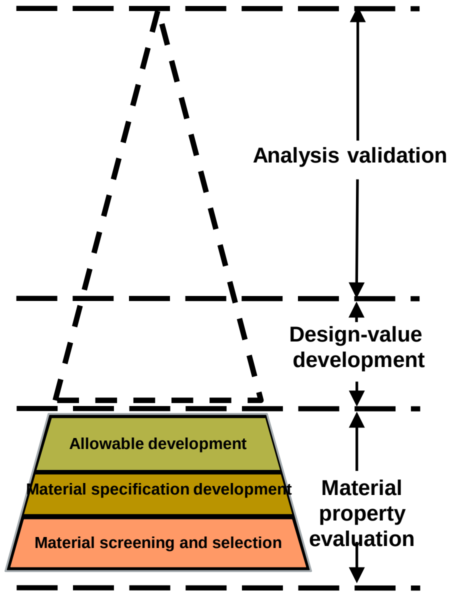
  25% 0°, 50% ±22.5°, 25% 90°

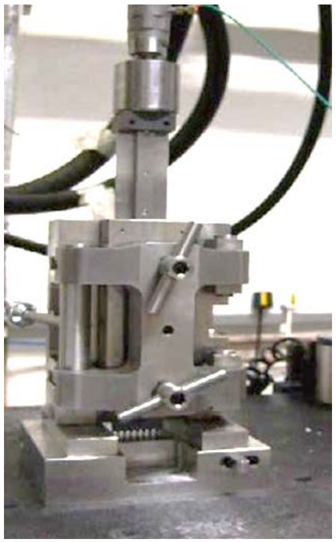
  - **16 plies (@ 0.0072 in.), 0. 0.115 in. thickness**

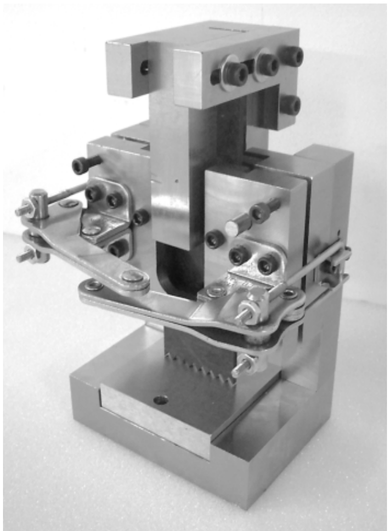


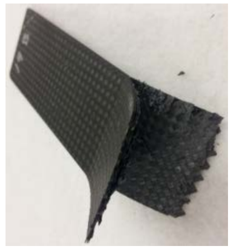
Proposed Testing Activities: Flat Coupon Crush Testing

- Laminate design for crashworthiness
- Tailor laminate to achieve stable crush, high energy absorption
- Mini round-robin to evaluate proposed crush test fixtures and draft standard





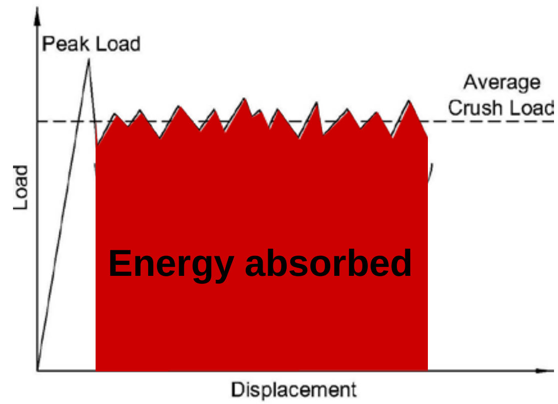




Flat Coupon Crashworthiness Testing: *What will these tests provide?*

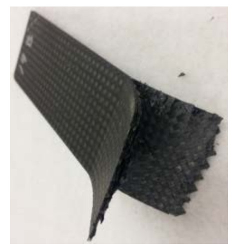
Specific Energy Absorption (SEA): **Energy absorbed per unit mass of crushed material**

- **Usefulness typically limited to material/laminate screening and ranking purposes**



Sustained Crush Stress: **Average crush load divided by the specimen cross sectional area**

- **A measure of the crashworthiness of a composite material/laminate**
- **Useful in the design of crush structures**

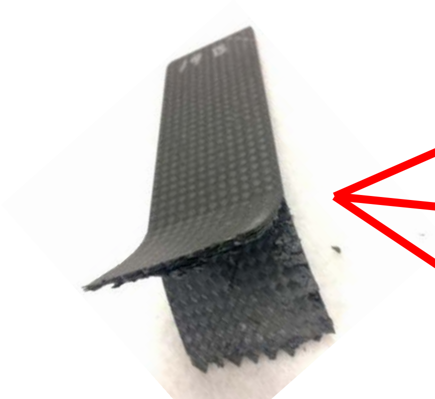


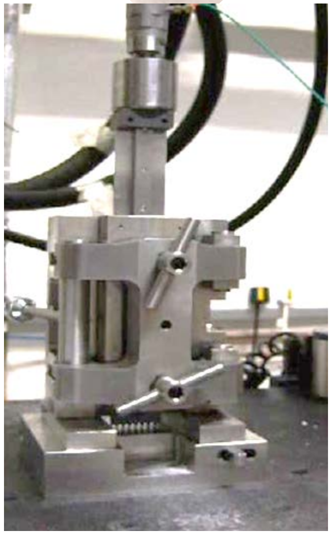
Compression Crush Ratio: **Ratio of compression strength to the sustained crush stress**

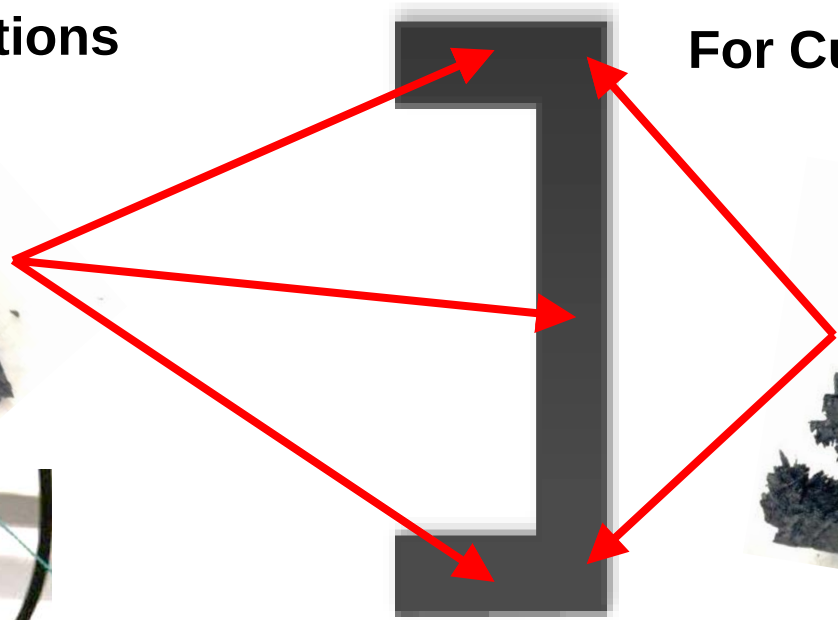
- **An indicator of the likelihood of the composite material crushing in a stable manner**

Flat Coupon Crush Testing:
Unsupported and Pin-Supported

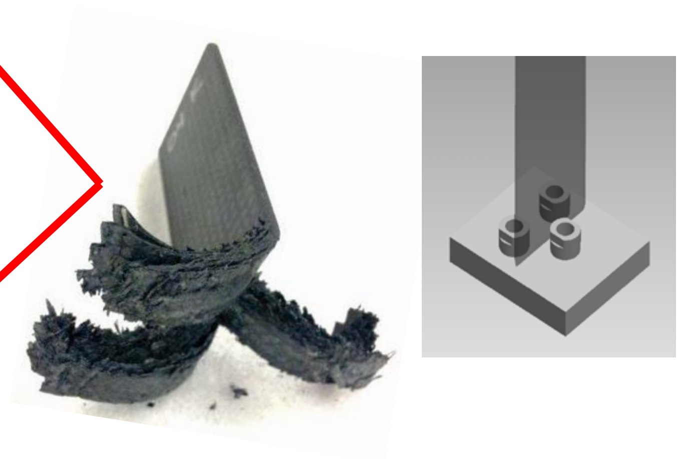
Unsupported Testing
For Flat Sections







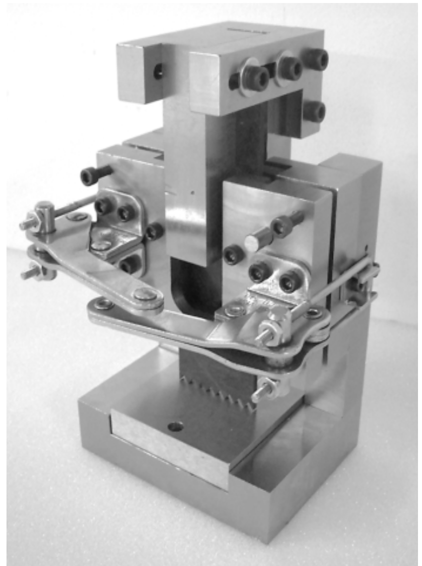
Pin-Supported Testing
For Curved Sections & Corners



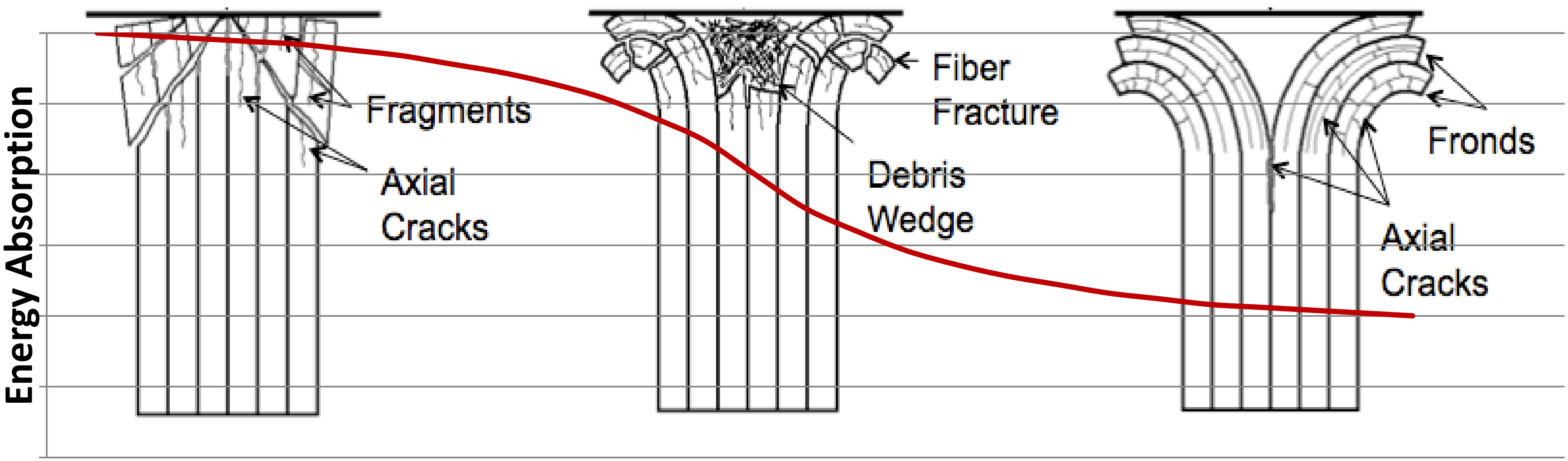
- **Measure SEA and Crush Stress for both support conditions**
- **For use in crush predictions of structural members**

Flat Coupon Crush Testing:
Laminate Design for Crashworthiness

- **Materials:**
  - **IM7/8552 Unitape (190 gsm)**
  - **IM7/8552 Woven fabric prepreg (193 gms)**
- **Laminate Design**
  - **Ply stacking sequence**
  - **Ply blocking (blocked vs. dispersed)**
  - **Hybrid unitape & woven fabric**



Previous Research Results: Crush Modes Affect Energy Absorption



Fragmentation [F]

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

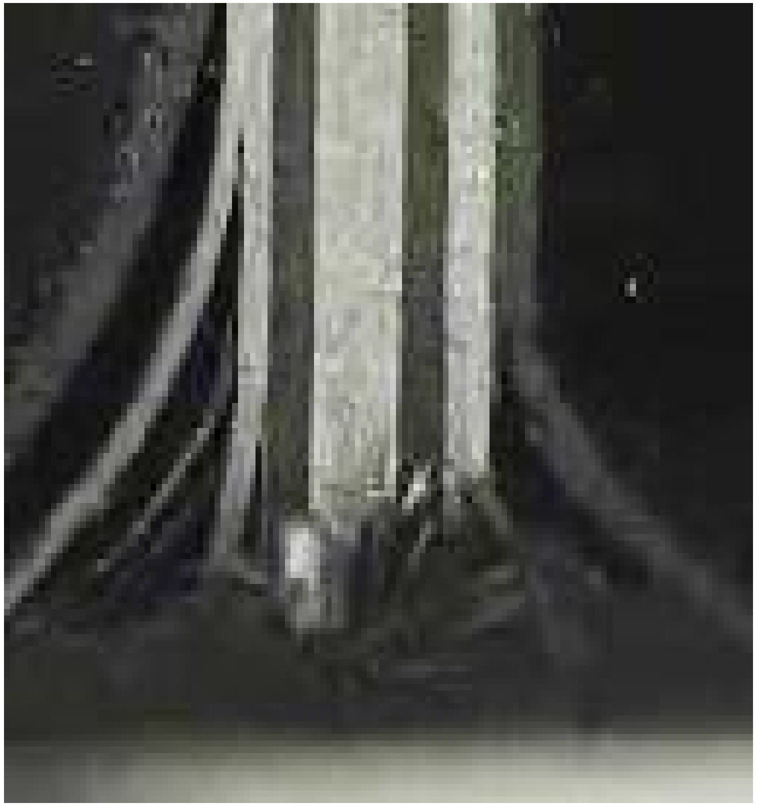
Brittle Fracture [B]

- Intermediate length cracks
- Combines characteristics from other failure modes

Fiber Splaying [S]

- Long axial cracks
- Frond formation
- Delamination dominated

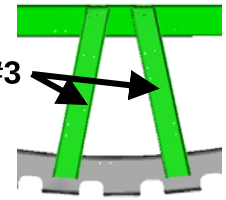
High Speed Video Results: Identification of Crush Failure Modes



- Fragmentation of inner layers
- Splaying of outer layers

Laminate Design for Crashworthiness: Strut #3 Traditional Design

"Hard" Laminates (50/25/25) to be tested:

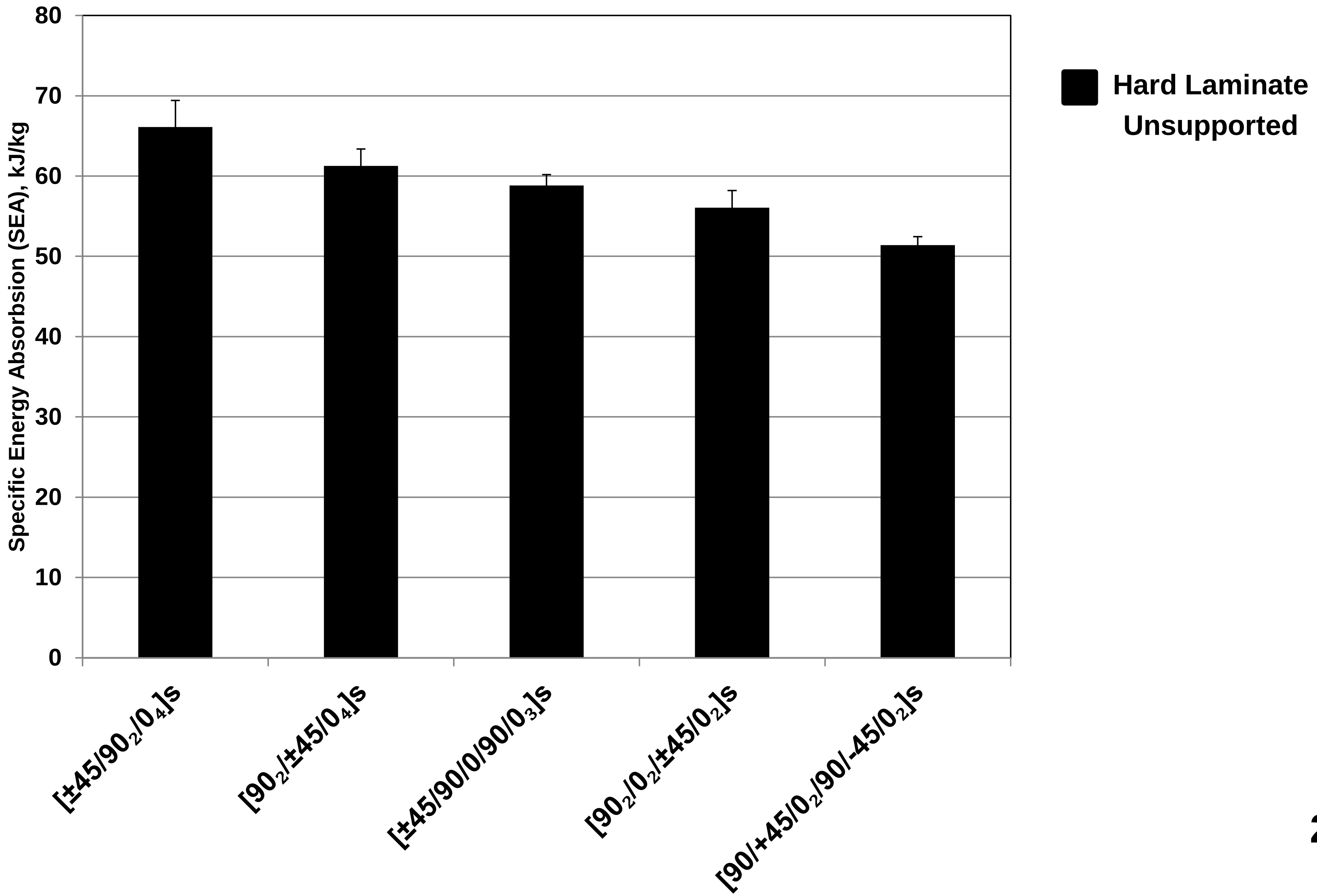


- $[90_2/\pm45/0_4]_S$ — *Stiffest plies at midplane*
- $[90_2/0_2/\pm45/0_2]_S$ — *High SEA in previous study*
- $[90/+45/0_2/90/-45/0_2]_S$ — *Ply dispersion while maintaining SEA*
- $[\pm45/90_2/0_4]_S$ — *45's on outside, high SEA previous study*
- $[\pm45/90/0/90/0_3]_S$ — *45's on outside, greater ply dispersion*

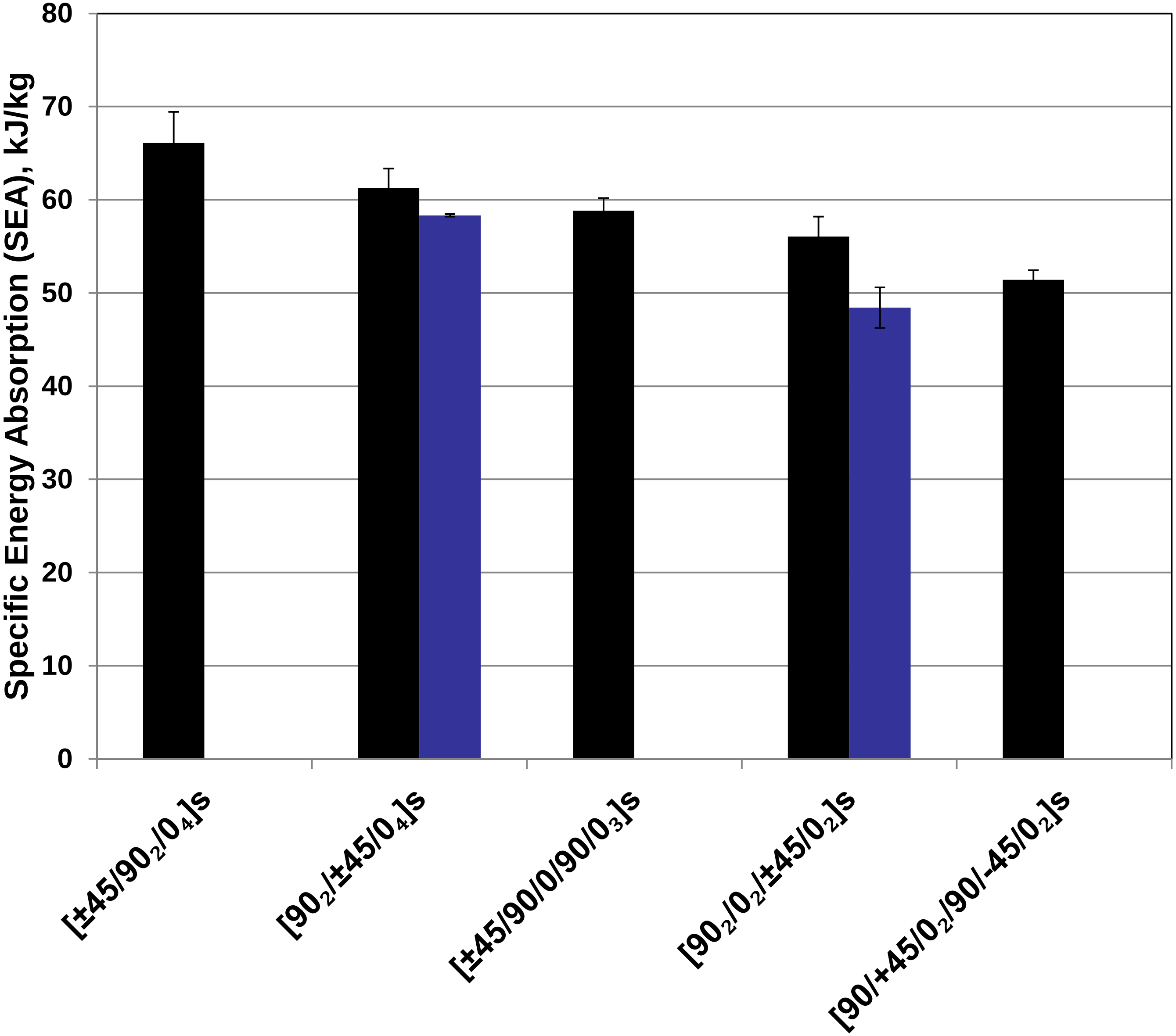
<u>Hybrid laminates</u> – with fabric layers

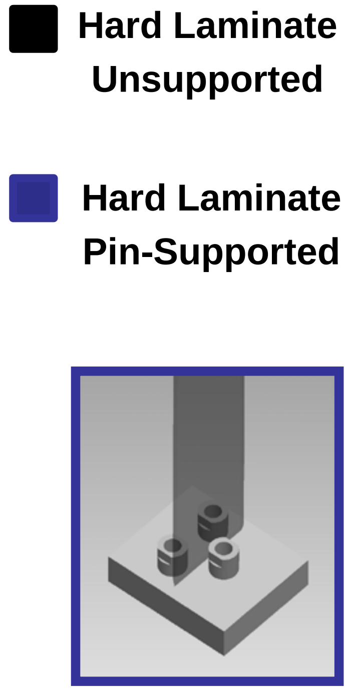
- $[(0/90)_f/\pm45/0_2]_S$ — *0/90 Fabric layer on outside*
- $[(\pm45)_f/90_2/0_4]_S$ — *±45 fabric layer on outside*
- $[(\pm45)_f/90/0/90/0_3]$ — *Outer fabric layer, greater ply dispersion*

Strut #3 Traditional Design:
Initial Crush Test Results



Strut #3 Traditional Design:
Initial Crush Test Results

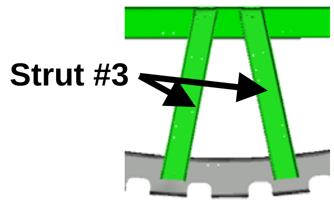




Laminate Design for Crashworthiness: Strut #3 Non-Traditional Design

25% 0° 50% ±22.5° 25% 90° laminates to test:

- $[90/\pm22.5/0]_{2S}$ — Dispersed plies, stiffest plies at midplane
- $[90_2/(\pm22.5)_2/0_2]_S$ — Blocked plies, stiffest plies at midplane
- $[(\pm22.5)_2/90_2/0_2]_S$ — 22.5's on outside
- $[\pm22.5/90/0]_{2S}$ — 22.5's on outside, greater ply dispersion



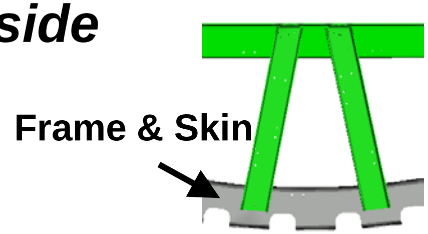
Laminate Design for Crashworthiness: (25 50 25) Quasi-Isotropic Laminate

Quasi-isotropic laminates (25/50/25) to be tested:

- $[90/\pm45/0]_{2S}$ — *Dispersed plies, stiffest plies at midplane*
- $[90_2/(\pm45)_2/0_2]_S$ — *Blocked plies, stiffest plies at midplane*
- $[(\pm45)_2/90_2/0_2]_S$ — *45's on outside*
- $[\pm45/90/0]_{2S}$ — *45's on outside, greater ply dispersion*

Hybrid laminates – with fabric layers

- $[(0/90)_f/\pm45/90/\pm45/0]_S$ — *0/90 fabric layer on outside*
- $[(\pm45)_f/(\pm45)_f/90_2/02]_S$ — *±45 fabric layer on outside*



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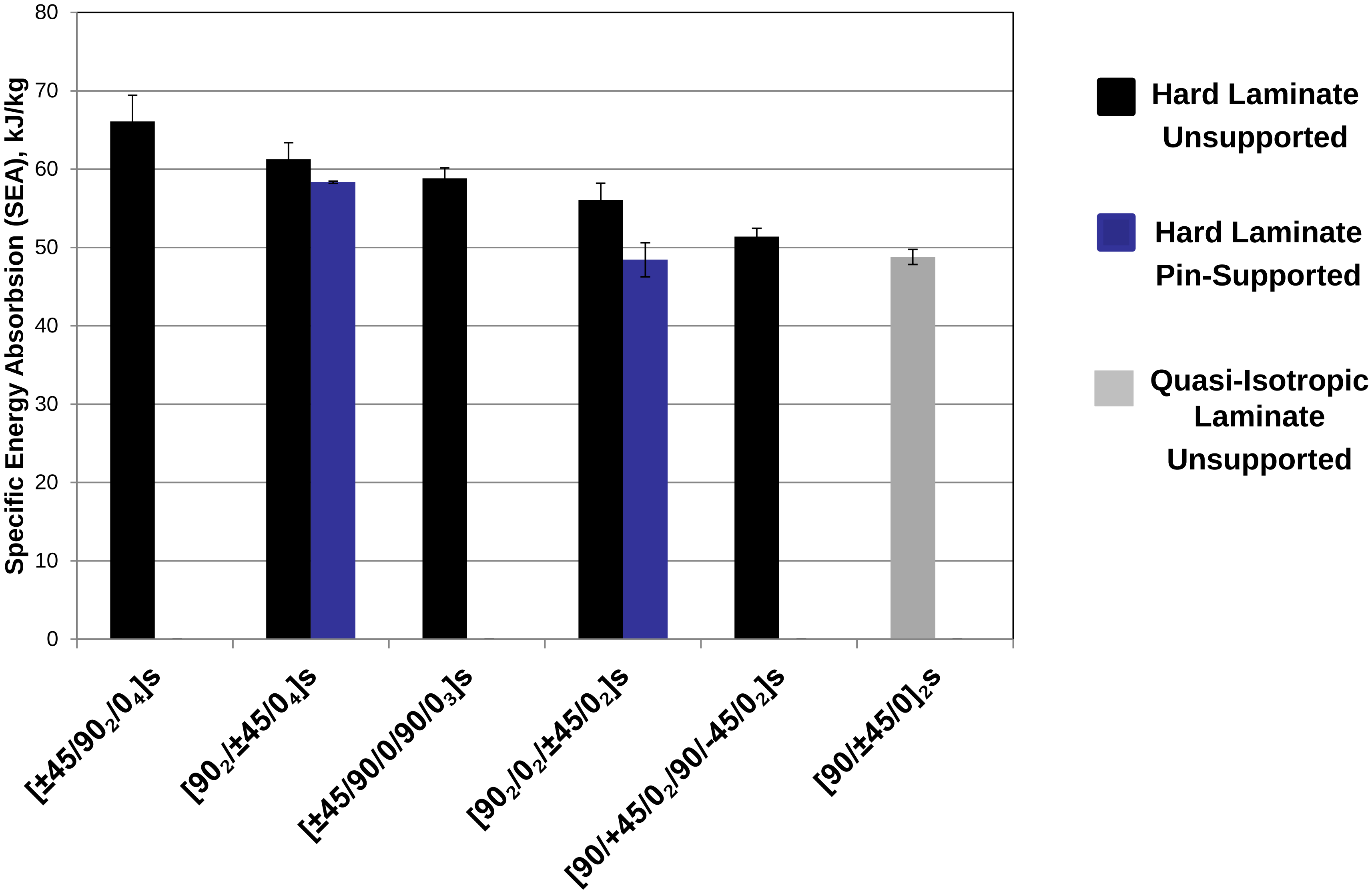
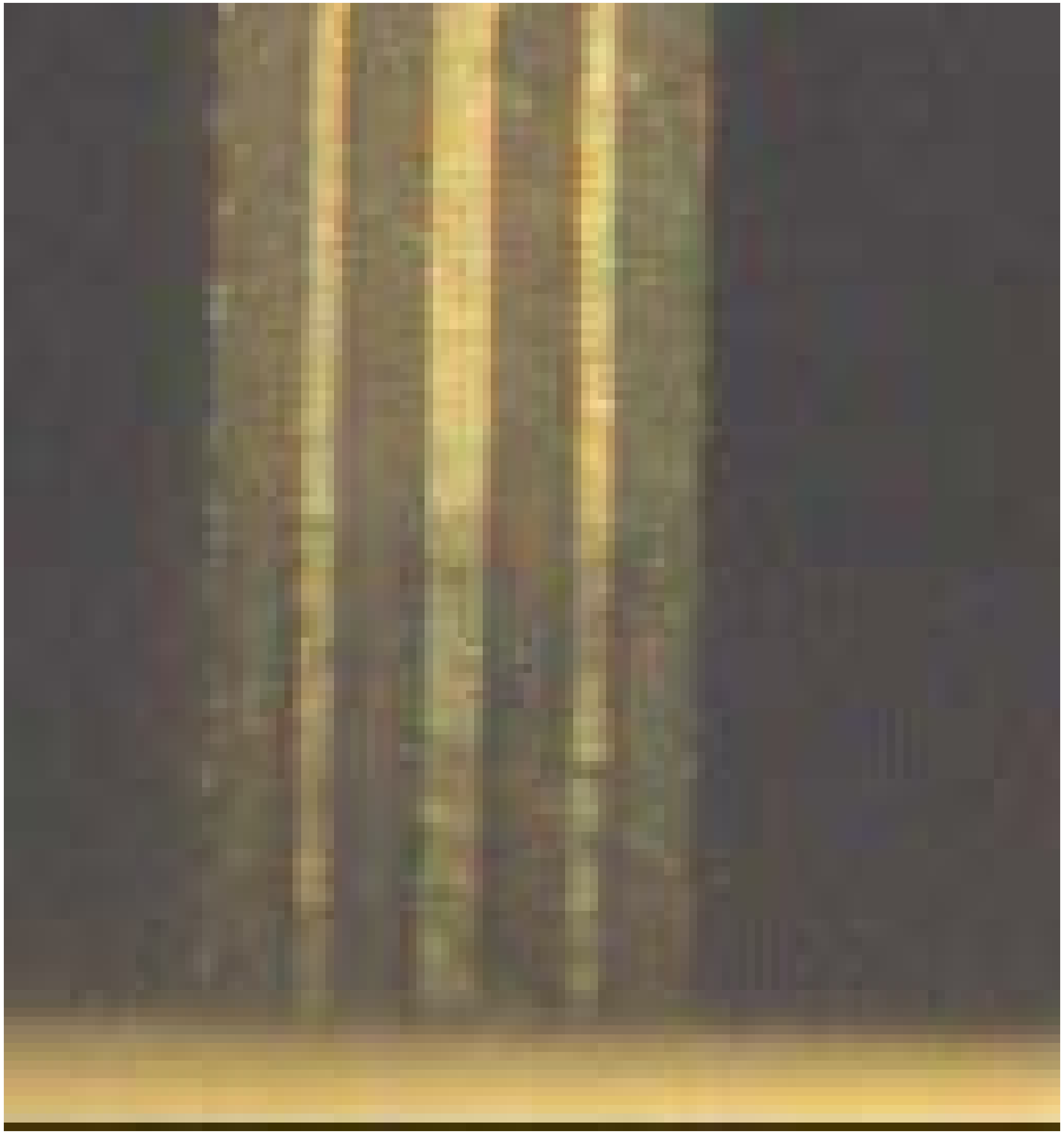
Initial Crush Test Results: Laminate Comparison



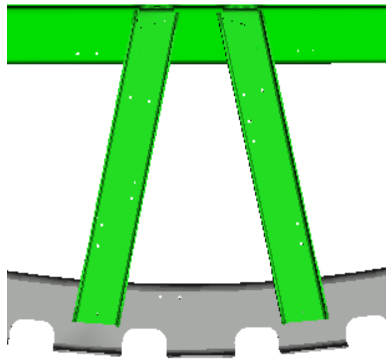
High Speed Video Results: Crush Failure of Quasi-Isotropic Laminate

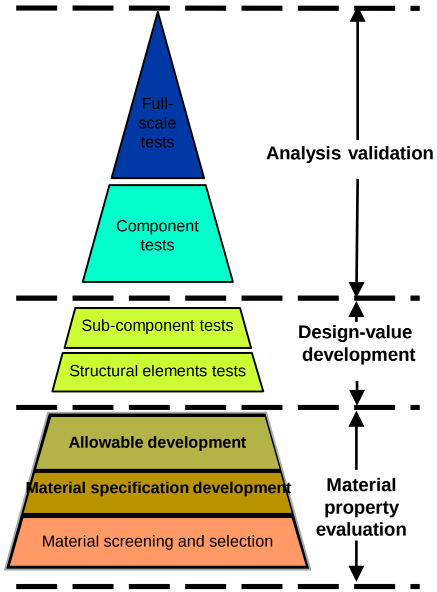


$[90/\pm45/0]_{2S}$

Upcoming Work

- Completion of flat coupon crush testing of selected laminates
- Selection of laminates for use in components of composite stanchion
- Dynamic shear and compression testing
- Fabrication and testing of C-channel sections (Strut #3)
- Identification of other coupon-level tests required for crush analyses
- Identification of structural element tests to support building block approach

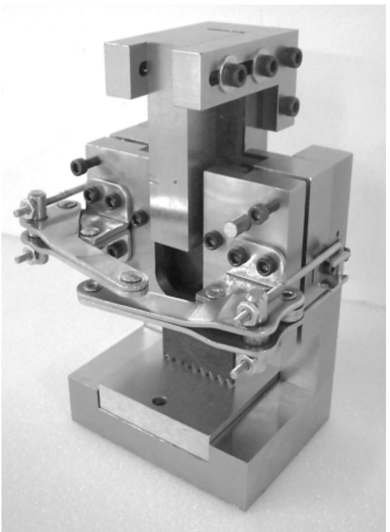


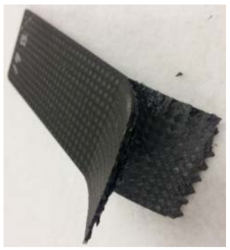


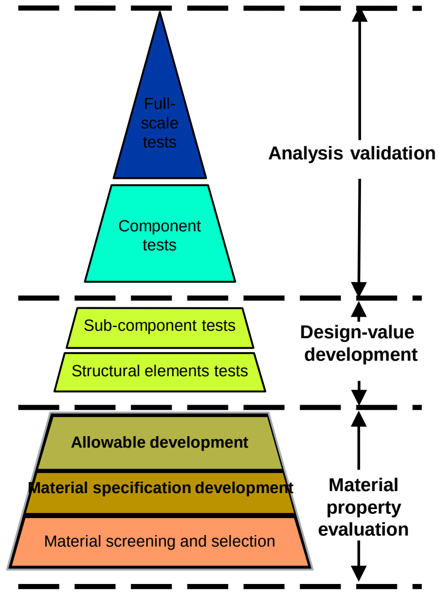
Summary:
Benefits to Aviation

- **Flat-coupon crush test methods for crashworthiness assessment of composite materials and laminates**

- **Establishment and demonstration of building block approach to composite crashworthiness certification**







Thank you for your attention!

Questions?

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