Certification of Discontinuous Composite Material Forms for Aircraft Structures

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Certification of Discontinuous Composite Material Forms for Aircraft Structures

- Overall Objective: Simplify certification of discontinuous fiber composite (DFC) aircraft parts
- Technical Approach: HexMC (a DFC being used on the B787) selected as a model material. For this material, perform:
  - Experimental studies of HexMC mechanical behaviors, starting with simple coupon-level specimens and progressing towards "complex" parts
  - Study effects of processing (e.g., impact of material flow during compression molding on stiffness and strength)
  - Develop stochastic ("Monte-Carlo") analysis method
  - Compare measurements with analytical-numerical predictions

Certification of Discontinuous Composite Material Forms for Aircraft Structures

Principal Investigators & Researchers (all from UW):

- PI: Mark Tuttle
- Tuttle grad students: Michael Arce, Brian Head (MSME ’13), and Tory Shifman (MSME ‘11)
- (Prior to 2011 Paolo Feraboli and his students also involved)

FAA Technical Monitor

- Lynn Pham

Other FAA Personnel Involved

- Larry Ilcewicz

Industry Participation

- Boeing: Bill Avery
- Hexcel: Bruno Boursier, David Barr, and Marcin Rabiega

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Some results reported at earlier AMTAS and JAMS meetings:

- HexMC coupon tests exhibit relatively high levels of scatter
  - B-Basis elastic modulus value defined (analogous to B-Basis strength value)
  - B-Max elastic modulus value defined
- Probabilistic “Stochastic Laminate Analogy” (SLA) analysis
- HexMC angles tested in pure bending, up to buckling & fracture
- Buckling/failure loads for angles based on B-Max and SLA analysis methods were over-predicted
- Buckling/failure loads for angles based on B-basis modulus and B-basis strength are “reasonable”

Hypothesized source of error in SLA buckling/failure predictions:

- Although stacking sequence (and hence modulus) is assumed to vary throughout HexMC structure, stacking sequences were assumed to be symmetric…coupling effects due to non-symmetric stacking sequence are not accounted for… coupling effects may result in decreased buckling/damage/failure loads

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This explore this possibility:

- Extend the Stochastic Laminate Analogy analyses to include non-symmetric stacking sequences (i.e., include coupling effect).
- Revised approach called the “Random Layup Volume Element” (RLVE)
- Goal: apply the RLVE approach to:
  - HexMC angles in pure bending
  - HexMC Intercostals

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- Extend the Stochastic Laminate Analogy analyses to include non-symmetric stacking sequences (i.e., include coupling effect).

- Revised approach called the "Random Layup Volume Element" (RLVE)

- Goal: apply the RLVE approach to:
  - HexMC angles in pure bending ← completed
  - HexMC Intercostals ← ongoing

B-Basis Material Properties

- B-Basis and B-Max moduli based on experimental data
  - B-basis is the modulus over which 90% of the samples fall 95% of the time
  - B-Max is the modulus under which 90% of samples fall 95% of the time
- Failure predictions based on B-Basis and average strengths

Moduli (Msi)

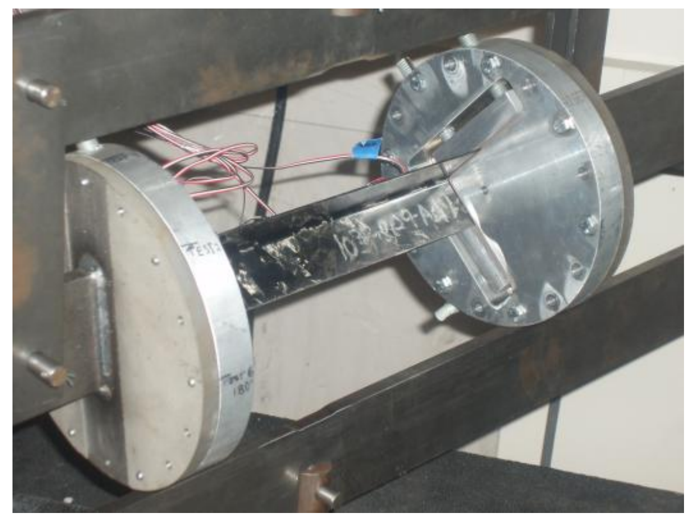
	B-Basis	Average	B-Max
Compression	5.36	6.31	7.27
Tension	5.58	6.62	7.65

Strengths (ksi)

	B-Basis	Average
Compression	50.2	57.0
Tension	40.2	49.9

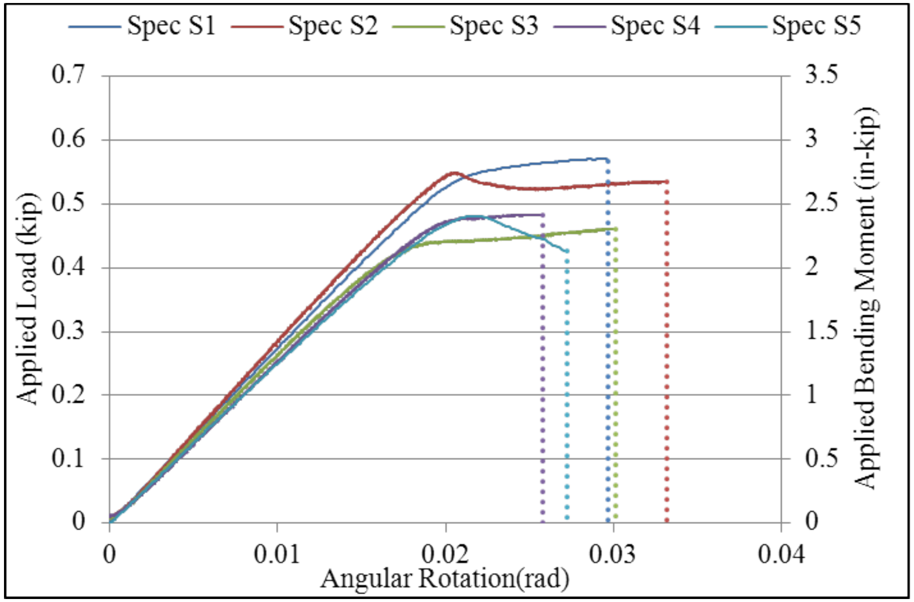
Angle Buckling
Experimental Testing

- Three sizes of angle beams compression molded from HexMC were tested in a four point bending fixture

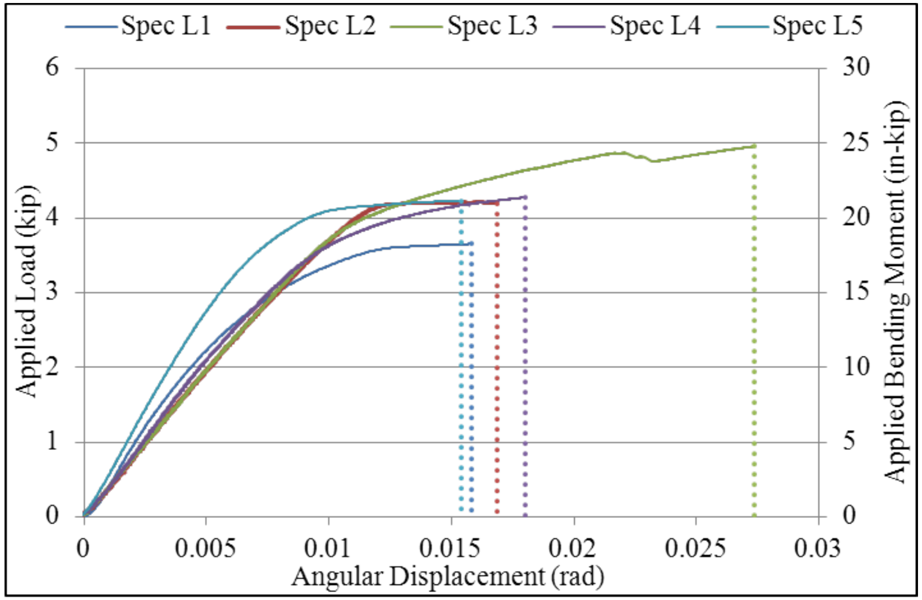


Angle Buckling
Experimental Results

- Both small and large angle sizes buckled/crippled well before fracture



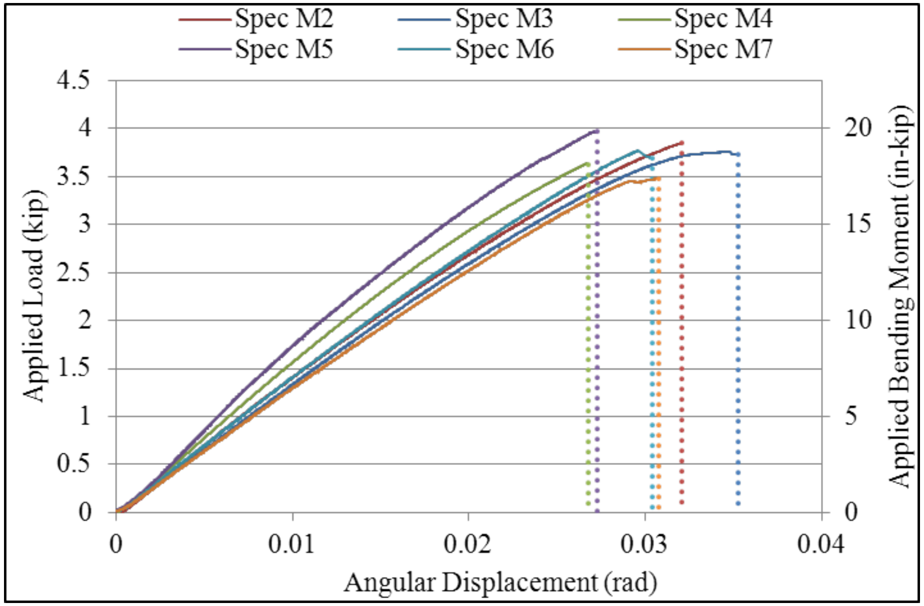
Small Specimens



Large Specimens

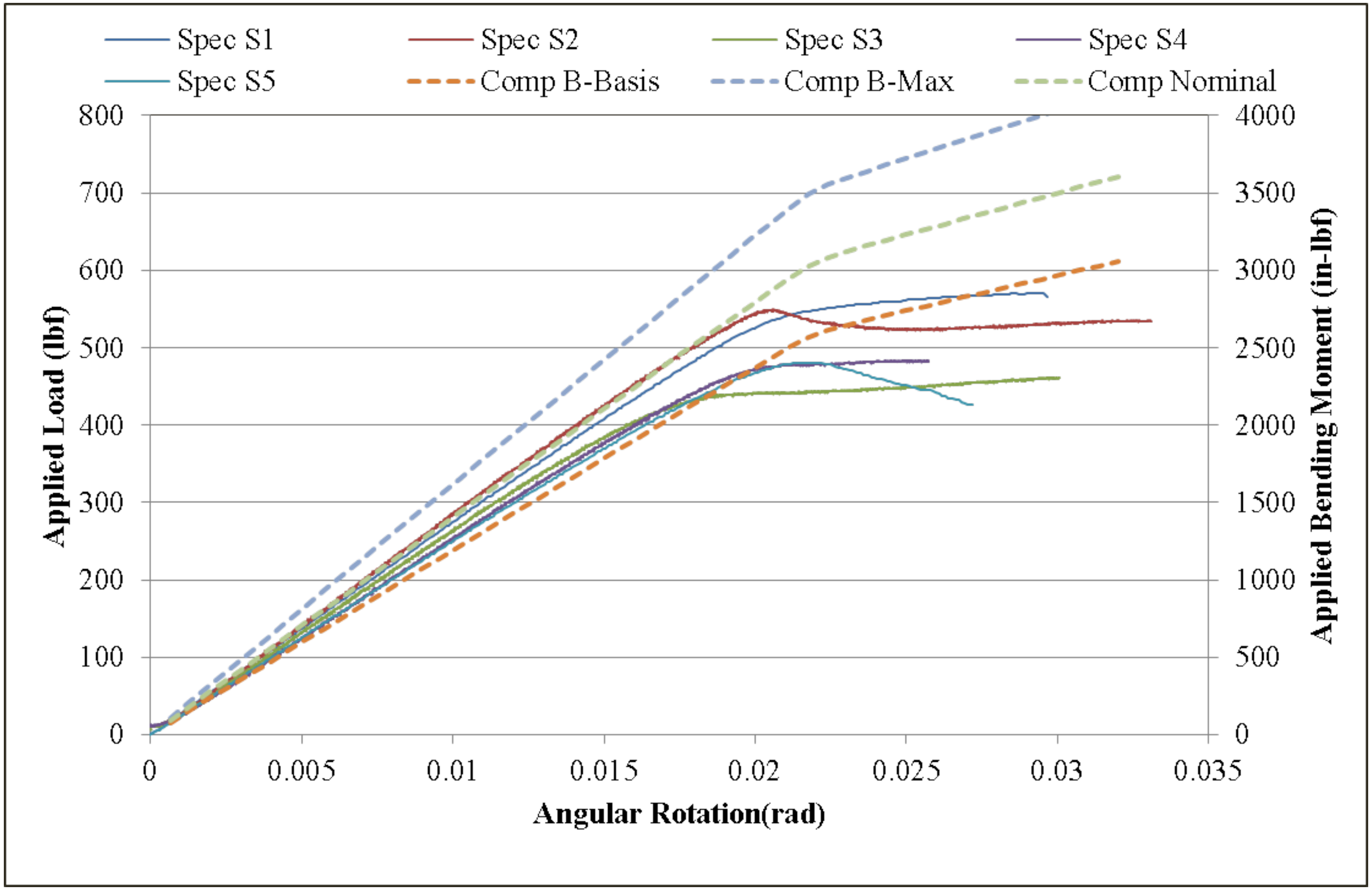
Angle Buckling
Experimental Results

- Medium size angles fractured prior to (or simultaneously with) the onset of buckling



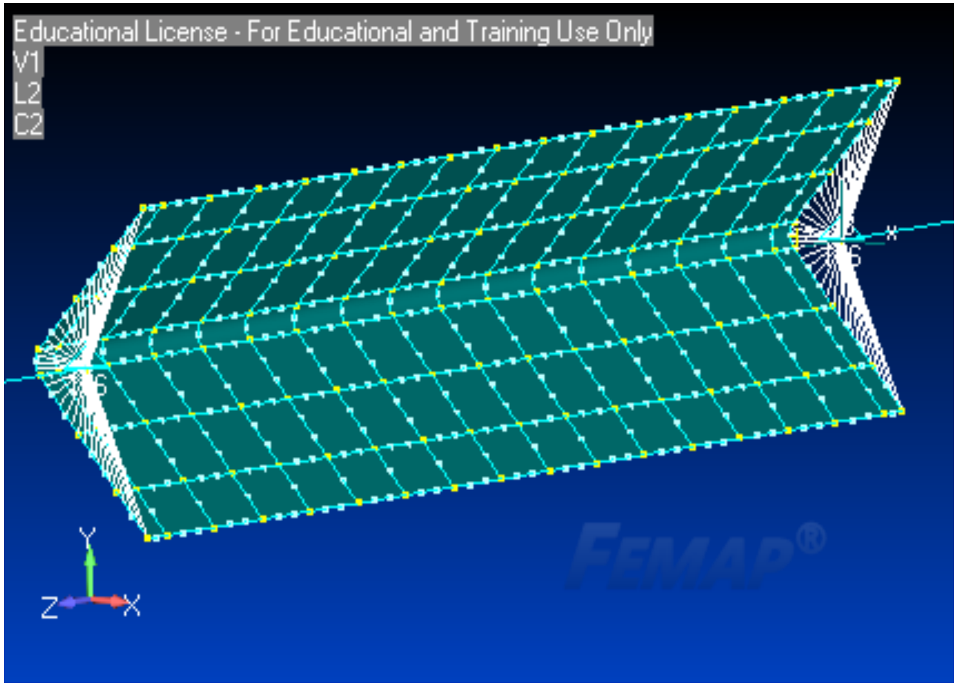
Medium Specimens

Predictions based on B-Basis Properties Bracketed Initial Elastic Stiffnesses, Overpredicted Buckling/Failure Loads *(illustrated using small angle test results)*



Summary of the Random Layup Volume Element (RLVE) Approach)

- Create RLVE regions of a recommended size
- Assign random stacking sequence to each RLVE region.
- Calculate stiffness and coupling factors of each RLVE using CLT
- Mesh model with user-specified element size
- Perform repeated analyses a statistically significant number of times



RLVE Regions and the Medium Angle

RLVE Analysis of HexMC Angles

- For each angle size:
  - 10 analyses performed
  - 5000 iterations for each analyses
- Each analyses required ~13, 36, and 44 mins to complete for the small, medium and large angles, respectively.
- The maximum and minimum buckling response predicted during any of the 10 RLVE analyses was compared to analyses based on the B-basis, B-max, and average modulus

RLVE Analysis of HexMC Angles

- (Suprisingly), RLVE approach had little impact on predicted elastic stiffnesses

RLVE Analysis

small angle

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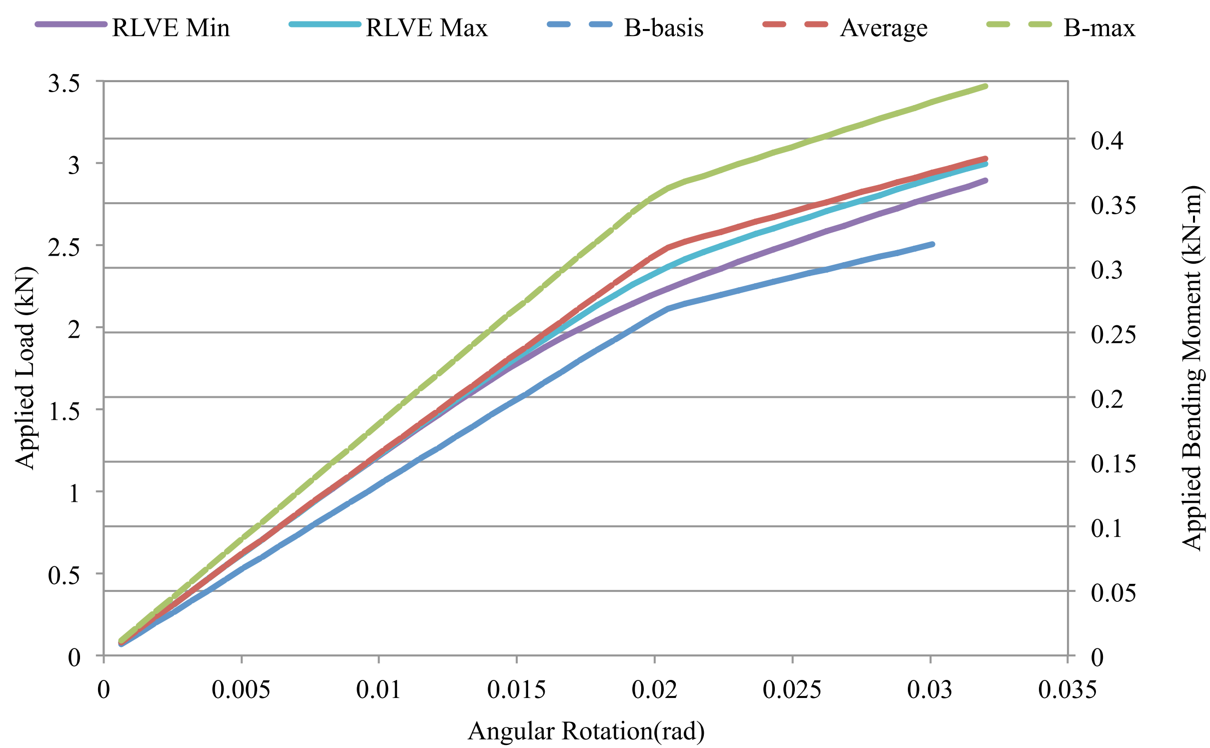

RLVE Analysis
large angle

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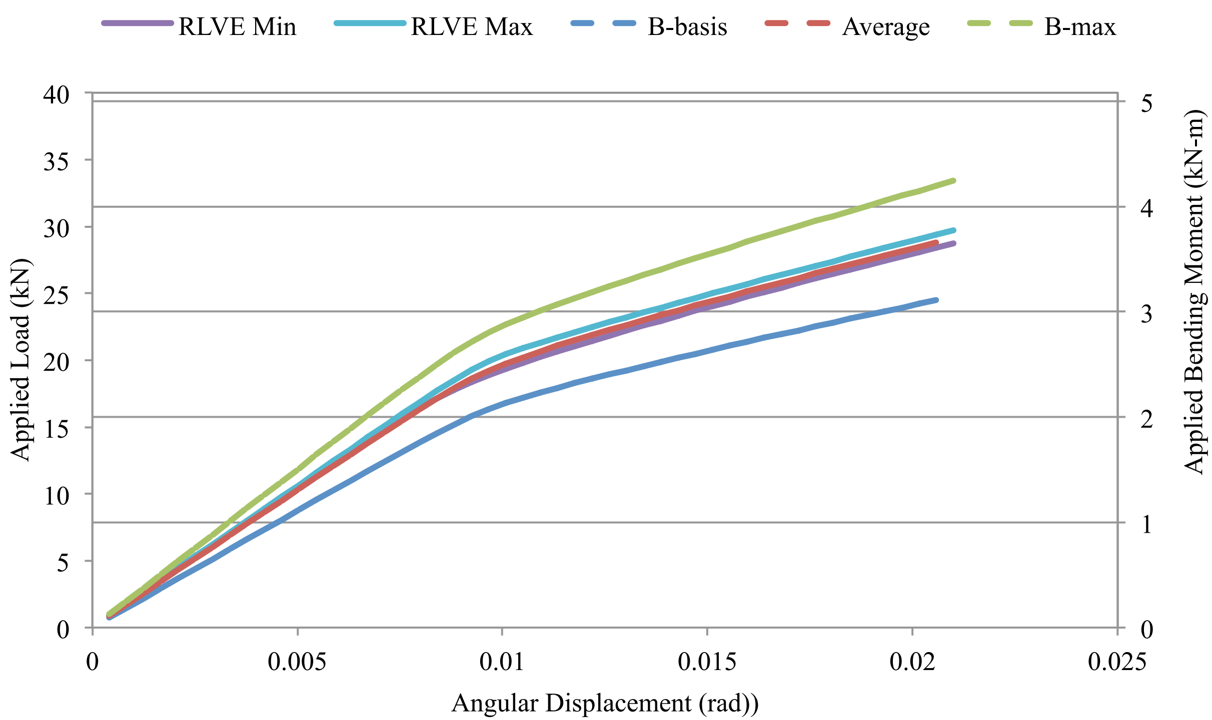

RLVE Analysis

- Buckling/failure loads predicted using the RLVE were roughly equivalent to analysis based on B-Basis modulus and B-basis strength

RLVE Analysis
small angle buckling loads

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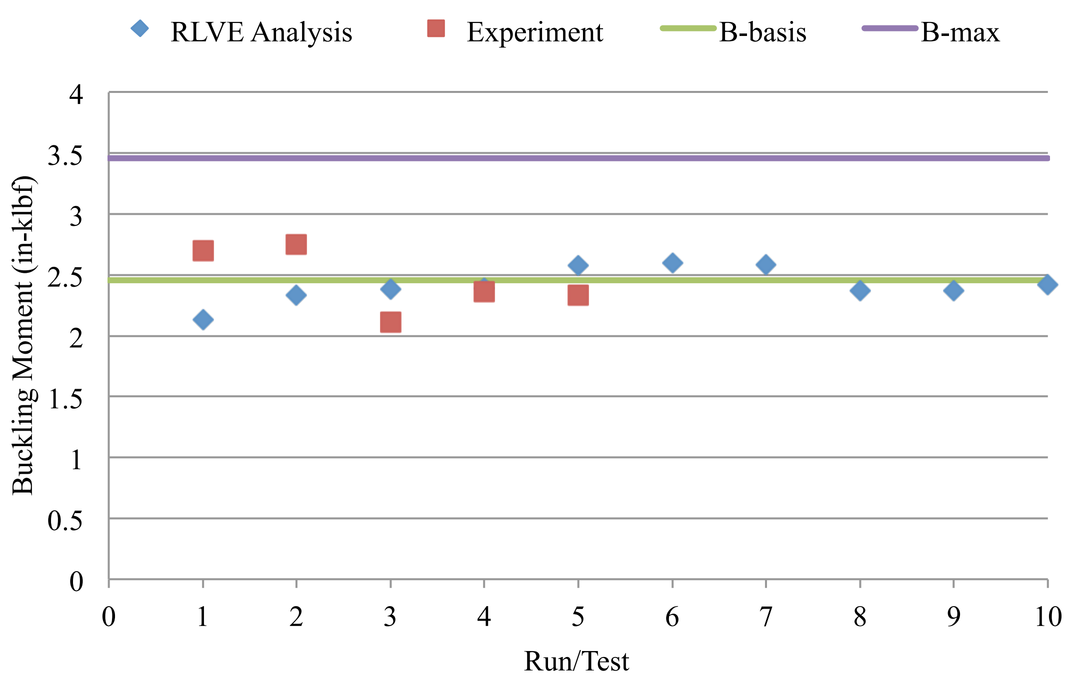
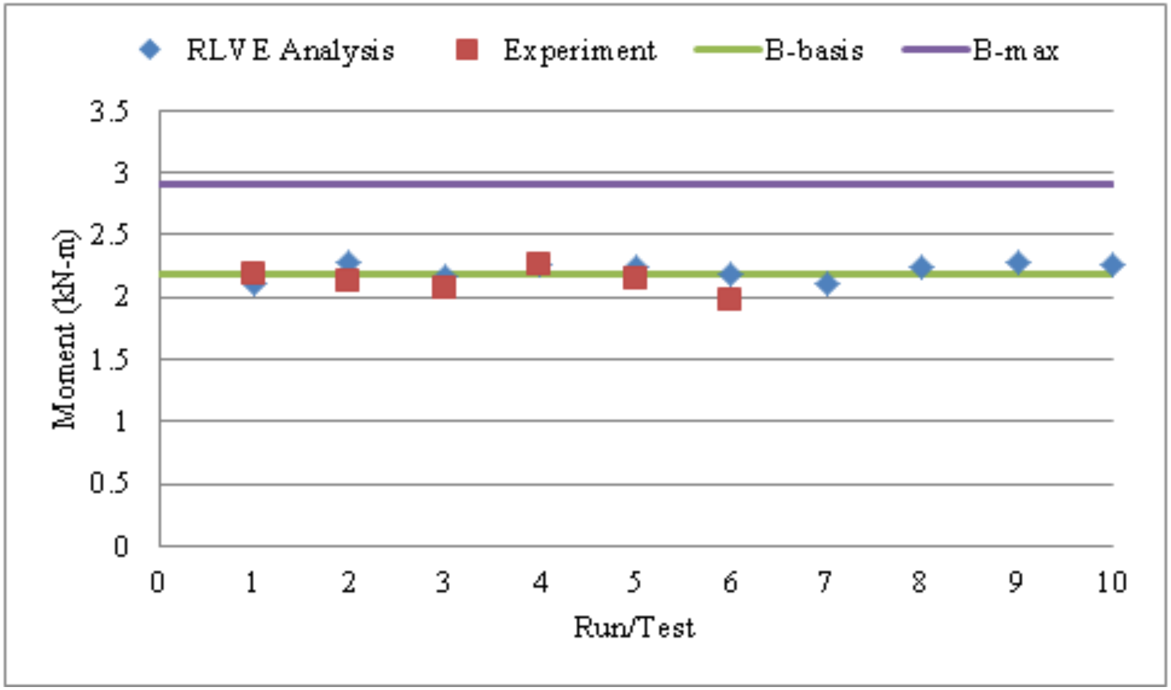


RLVE Analysis
medium angle fracture loads

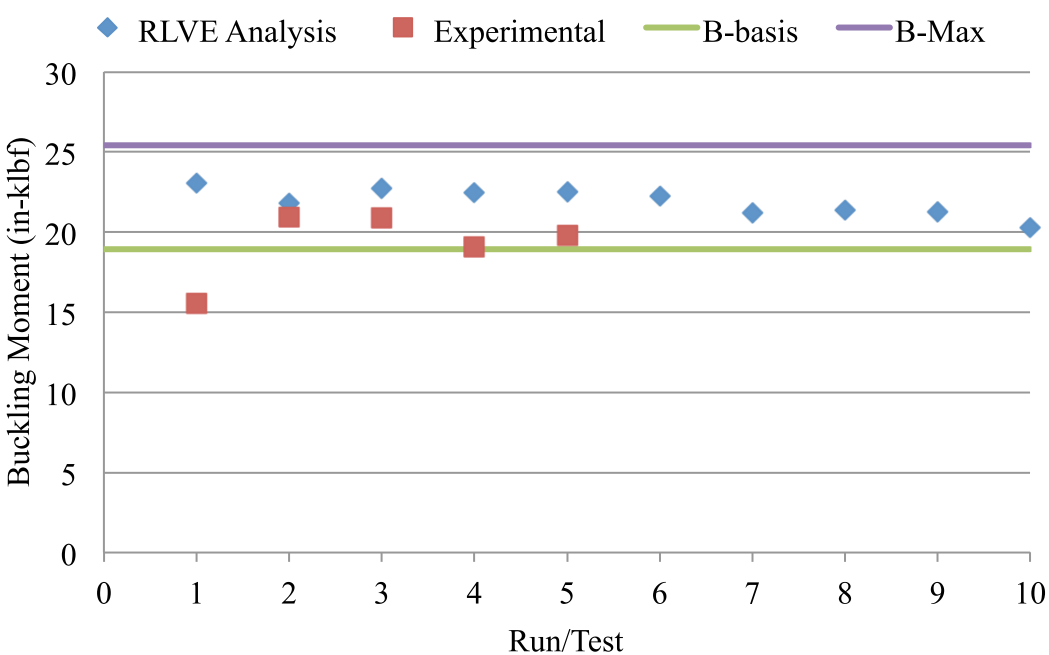
- Buckling/failure loads predicted using the RLVE were roughly equivalent to analysis based on B-Basis modulus and B-basis strength



RLVE Analysis

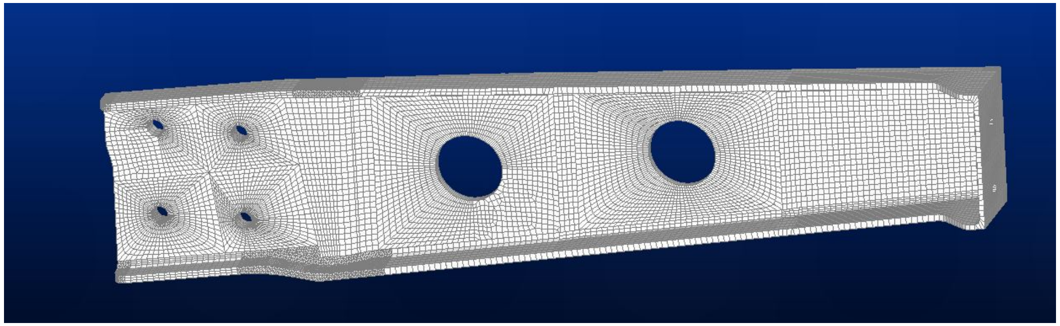
large angle buckling loads

- Buckling/failure loads predicted using the RLVE were roughly equivalent to analysis based on B-Basis modulus and B-basis strength



Next Step: RLVE Analysis of HexMC Intercostals

- Intercostals are being modeled using hexahedral elements
- Mesh generation (using FEMAP) has been very problematic and was only recently achieved
- Predictions based on the RLVE approach will be compared to B-basis analyses and reported at next JAMS/AMTAS meeting



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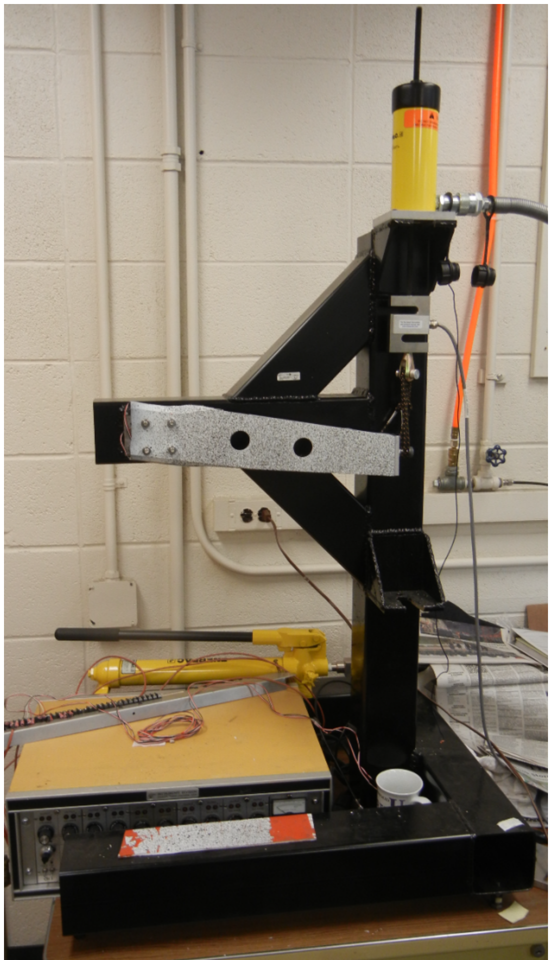
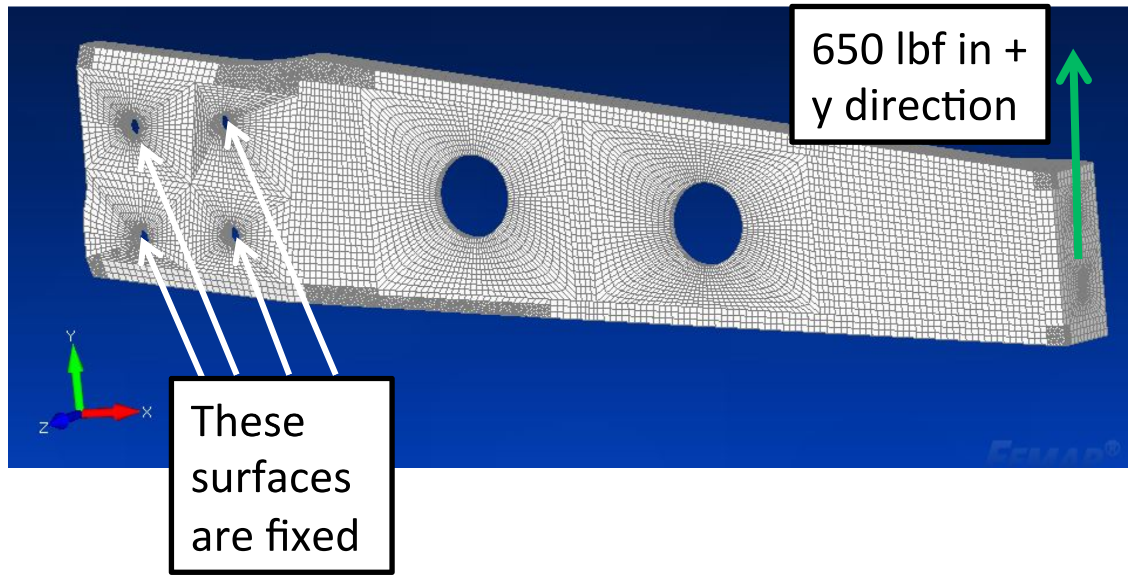
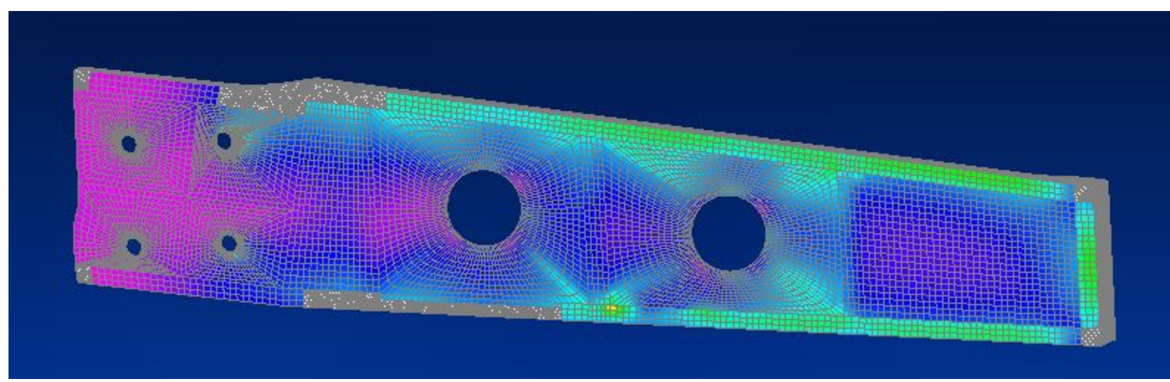
Next Step: RLVE Analysis of HexMC Intercostals







Summary and Conclusions

- Preliminary guidelines related to modeling HexMC structures are beginning to emerge:
  - Predictable response requires minimum gage thickness of ~0.12 in
  - Scatter in elastic response of "complex" HexMC structures bounded by analyses based on B-basis and B-Max modulus values
  - Buckling/failure loads of HexMC angles were reasonably-well predicted using either:
    - B-basis modulus and B-basis strength (deterministic)
    - RLVE analysis w/unidirectional properties (probabilistic)

Summary and Conclusions

- Next step is to apply RLVE approach to a HexMC intercostal – a more “complex” structure

Summary and Conclusions

Thank You!