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Certification of Discontinuous Fiber Composite Forms for Aircraft Structures

2014 Technical Review

Michael Arce and Mark Tuttle
University of Washington

Certification of Discontinuous Composite Material Forms for Aircraft Structures

- Motivation and Key Issues
  - Certification of DFC parts currently achieved by testing large numbers of individual parts (certification by "point design")
  - Project goal is to transition to a certification process based on analysis supported by experimental testing

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Certification of Discontinuous Composite Material Forms for Aircraft Structures

Technical Approach: HexMC (a DFC being used on the B787) selected as a model material. HexMC prepreg consists of randomly-oriented "chips" of B-staged AS4-8552 (8mm x 50mm). For this material, perform:

- Experimental studies of HexMC mechanical behaviors, starting with simple coupon-level specimens and progressing towards "complex" parts
- Study the effects of processing (e.g., impact of material flow during compression molding on stiffness and strength)
- Develop stochastic analysis methods (aka "probabilistic" or "Monte-Carlo" analyses)
- Compare measurements with analytical-numerical predictions

Certification of Discontinuous Composite Material Forms for Aircraft Structures

Current Researchers (University of Washington):

- Prof. Mark Tuttle (PI)
- Michael Arce, MS Student

Additional Participants (University of Washington):

- Prof. Paolo Feraboli
- Graduate students: Marco Ciccu, Tyler Cleveland, Brian Head, Marissa Morgan, Tory Shifman, Bonnie Wade

FAA Personnel:

- Lynn Pham (Tech Monitor), Larry Ilcewicz, Curt Davies

Industry Participation:

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

Certification of Discontinuous Composite Material Forms for Aircraft Structures

Major topics of earlier papers/presentations:

- HexMC coupon tests (e.g., UNT, OHT, UNC, OHC); properties exhibit relatively high levels of scatter; HexMC is notch insensitive

  Feraboli et al: (a) *J. Composite Materials*, Vol 42, No 19, (b) *J. Reinf. Plastics and Composites*, Vol 28, No 10, (c) *Composites Part A*, Vol 40

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- "High-flow" and "ply-drop" panel tests: material flow causes modest chip/fiber alignment (optical microscopy) and measureable change in stiffness and strength (coupon tests)

    Tuttle/Shifman: JAMS '09 & '10, AMTAS Fall '09 and Spr '10

(original presentations available: http://depts.washington.edu/amtas/events/index.html)

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- Modeling stiffness/strength via stochastic laminate analogy

  Feraboli/Ciccu: JAMS '10 & '11, AMTAS Fall '10

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Major topics of earlier papers/presentations (continued):

- Measurement/prediction of elastic bending stiffness of HexMC angle beams with non-symmetric cross-sections (FEM analyses based on *chip properties* and the stochastic laminate analogy approach)

  Feraboli et al: JAMS ’11, Tuttle/Shifman: AMTAS Fall '10, JAMS '11

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- B-basis and B-Max measures of modulus (inferred from UW HexMC *coupon data*) used during FEM analyses of HexMC beams; predicted elastic stiffnesses bound both measurements and stochastic predictions
  Tuttle/Head: AMTAS Fall '12 & ’13

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  Tuttle/Head: AMTAS Fall '12 & ‘13

- Measurement/prediction of crippling/buckling/fracture of HexMC angle beams with symmetric cross-sections (FEM analyses based on both the stochastic laminate analogy approach using chip properties and the deterministic B-Basis and B-Max approach using HexMC coupon data):
  Tuttle/Head/Arce: AMTAS Fall ‘13

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Focus of this presentation:

- Prediction of the elastic stiffness of a HexMC intercostal:
  - Based on *chip properties and* the stochastic laminate analogy approach
  - Based on B-basis and B-Max *HexMC properties* and deterministic analyses
- Comparison of predicted intercostal stiffness with measurements obtained using Digital Image Correlation

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Material Properties

For the stochastic analyses, chips properties are assumed to be equal to those of unidirectional AS4/8552:

Elastic Properties (Msi)			
E_{11}	E_{22}	G_{12}	ν_{12}
19.4	1.4	0.766	0.32

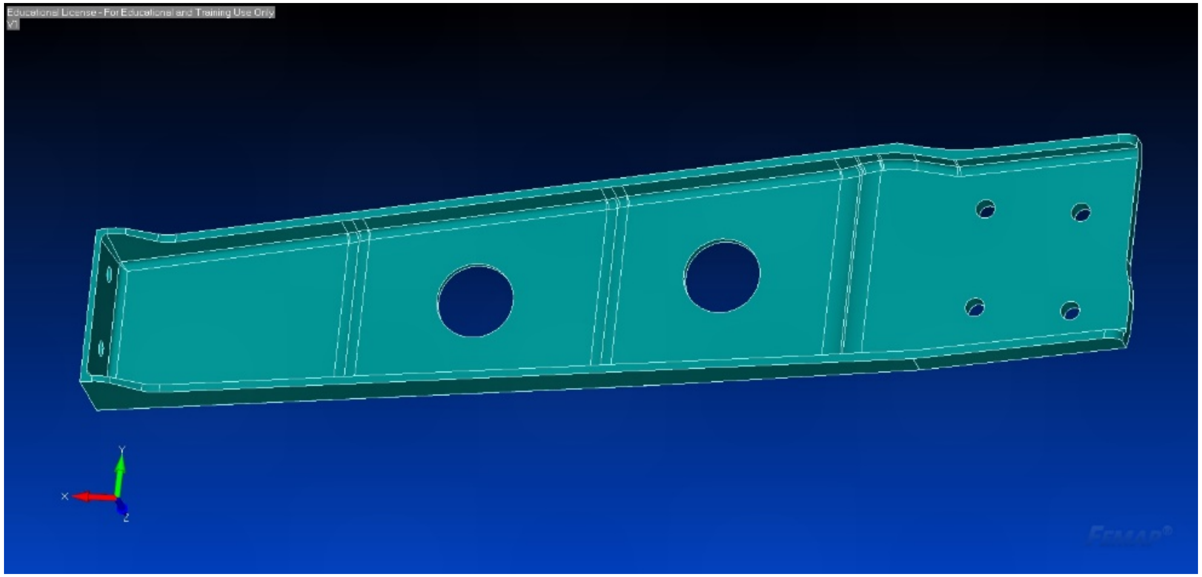
For the deterministic analyses the B-Basis, Average, and B-Max moduli inferred from UW coupon tests are:

Moduli (Msi)

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

Modeling

The geometry of the intercostal is deceptively complex: faces meet at skewed angles, and there are multiple thickness changes.

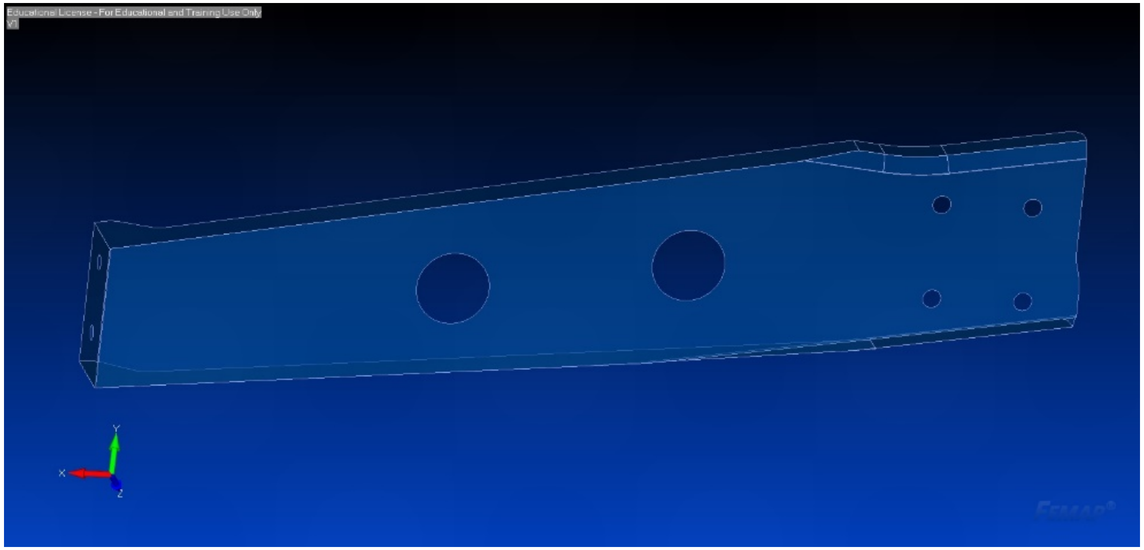


Modeling

Model created with midsurfaces generated from solid model.

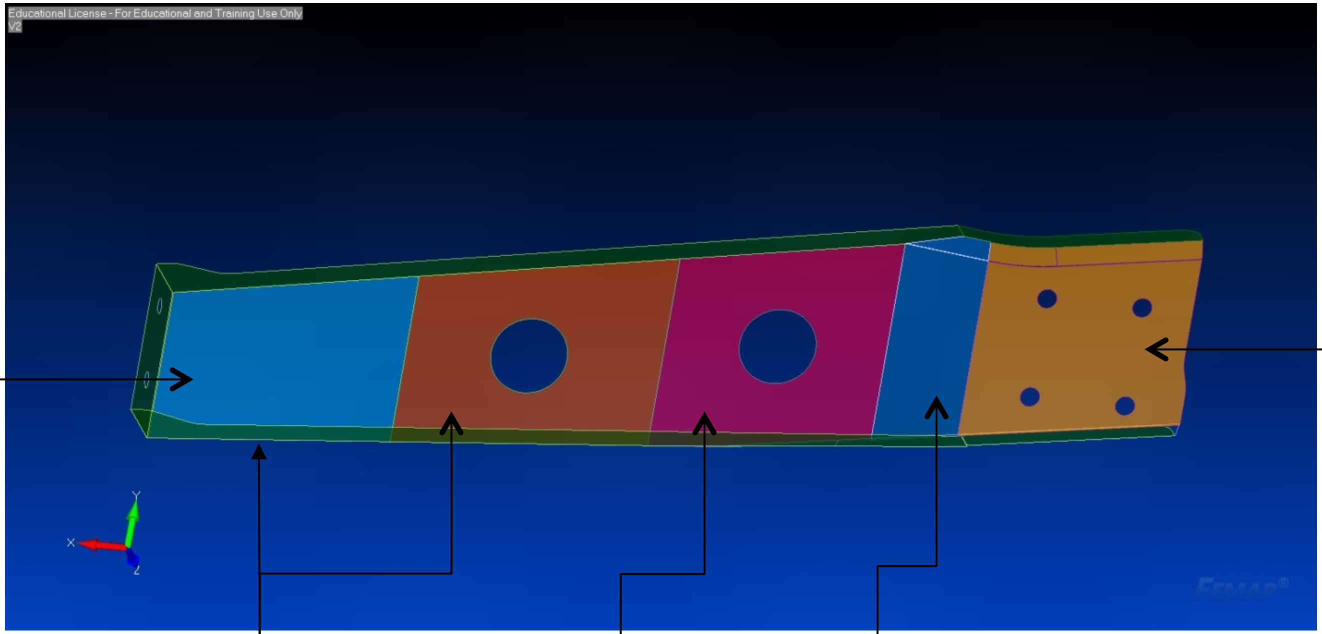
Element type is Nastran pcomp - laminate shell elements.

Sheet solids were aggregated into one manifold solid.



Thickness Variation

Intercostal was discretized into regions by thickness



Thinnest Region: 0.08 inches 16 "plies"

24 "plies"

32 "plies"

48 "plies"

Thickest Region: 0.32 inches 64 "plies"

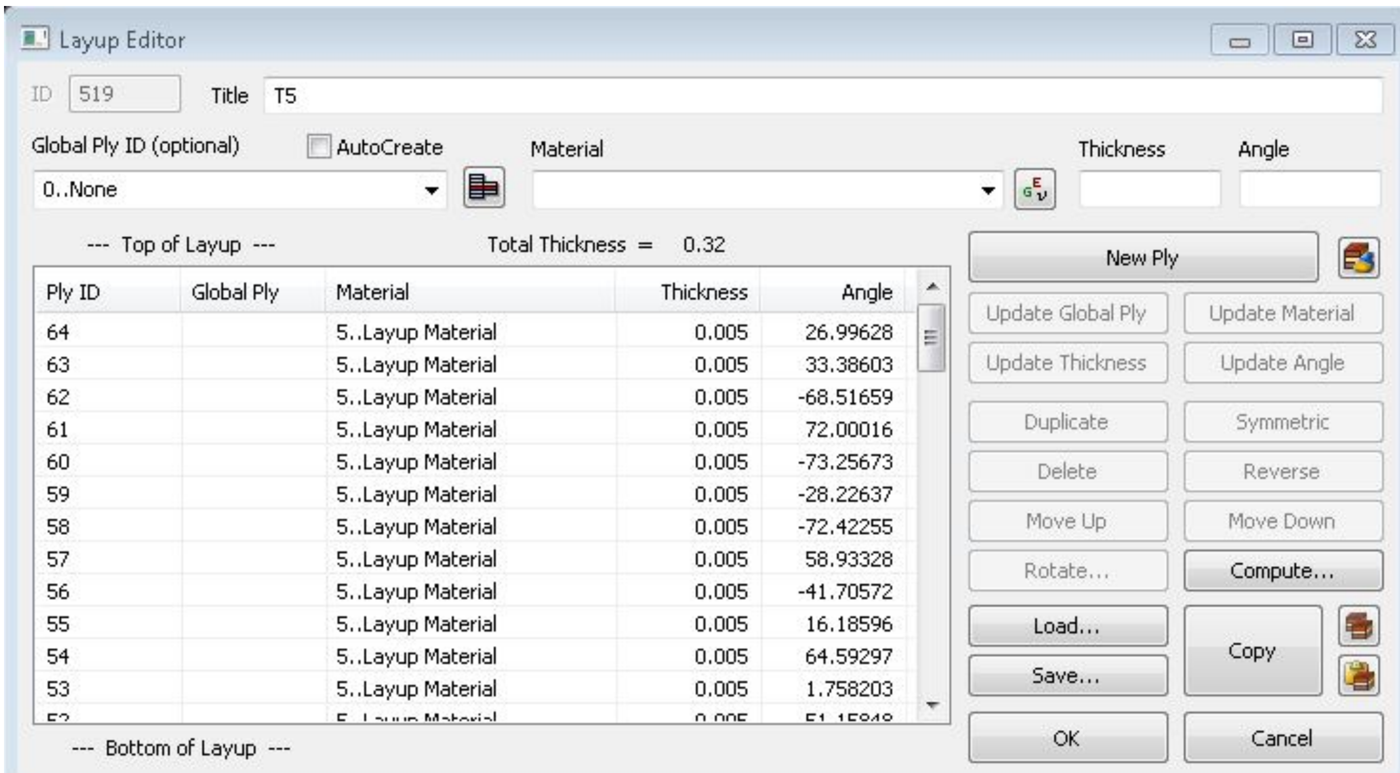
Stochastic Laminate Analogy (SLA)

To apply the SLA approach the structure is subdivided into Random Layup Volume Elements (RLVEs), the size of which was determined based on coupon test data (Head, ‘13).

Each RLVE is treated as a multiangle composite laminate with randomly-selected ply fiber angles. The number of plies in a given RLVE equals the number of through-thickness chips, reflecting part thickness

Random Layup Generator

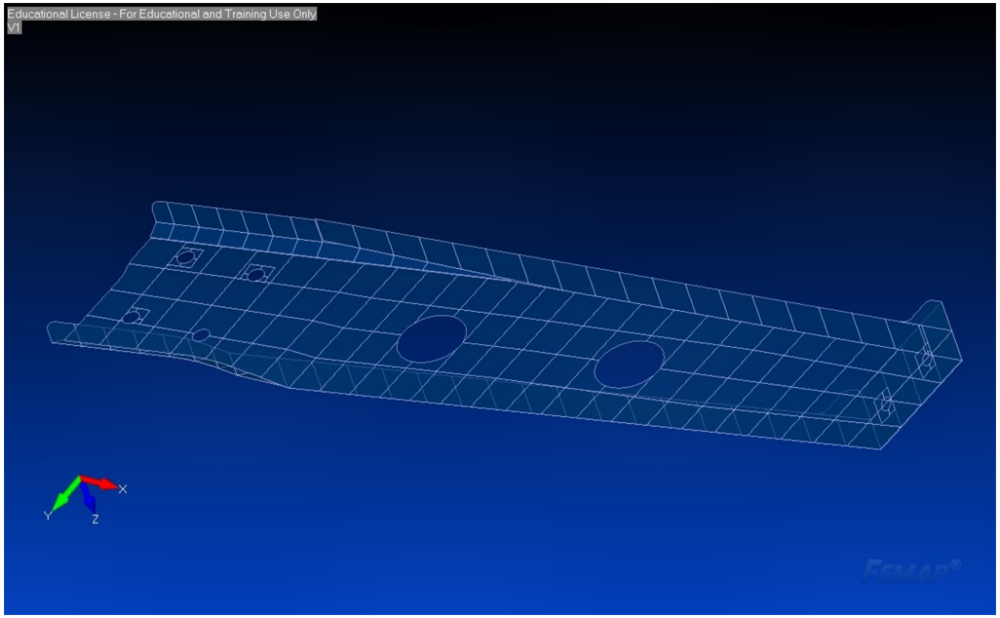
A random stacking sequence is selected for each RLVE before each analysis.



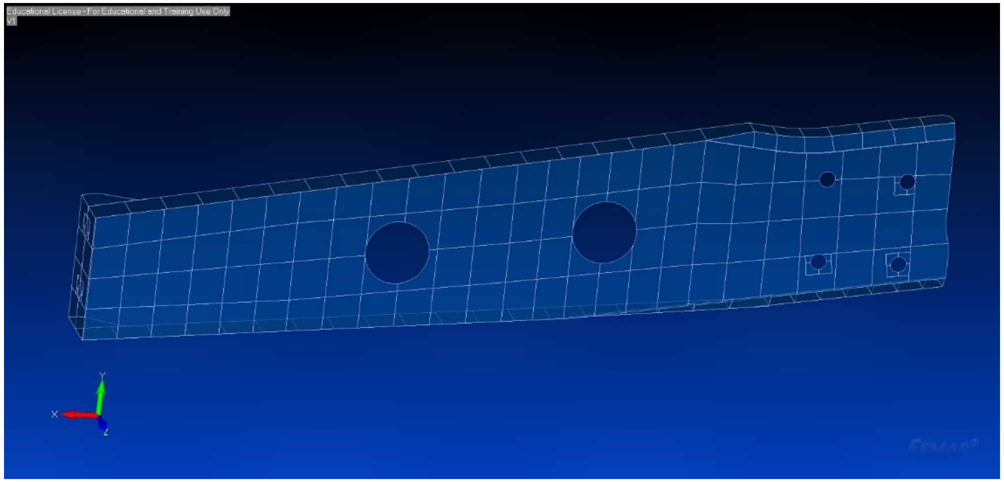
RLVEs

RLVEs are nominally 0.76” square (as recommended by Head ‘13)

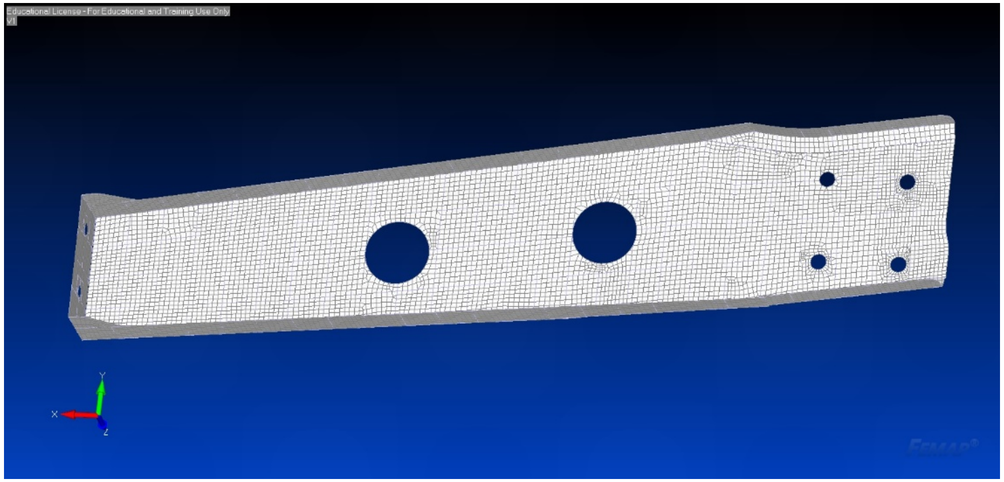
Due to non-uniform geometry the RLVEs in the present analyses may not be square, and have dimensions ranging from 0.66” – 0.76”



RLVE and Mesh

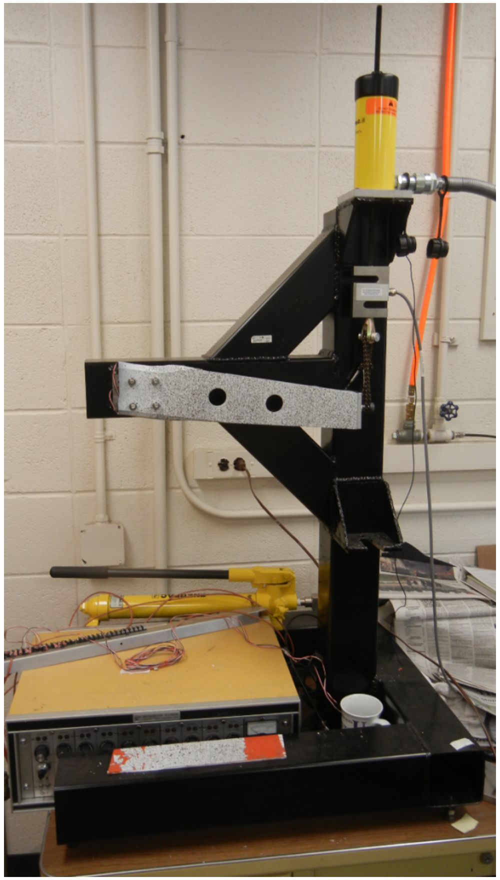


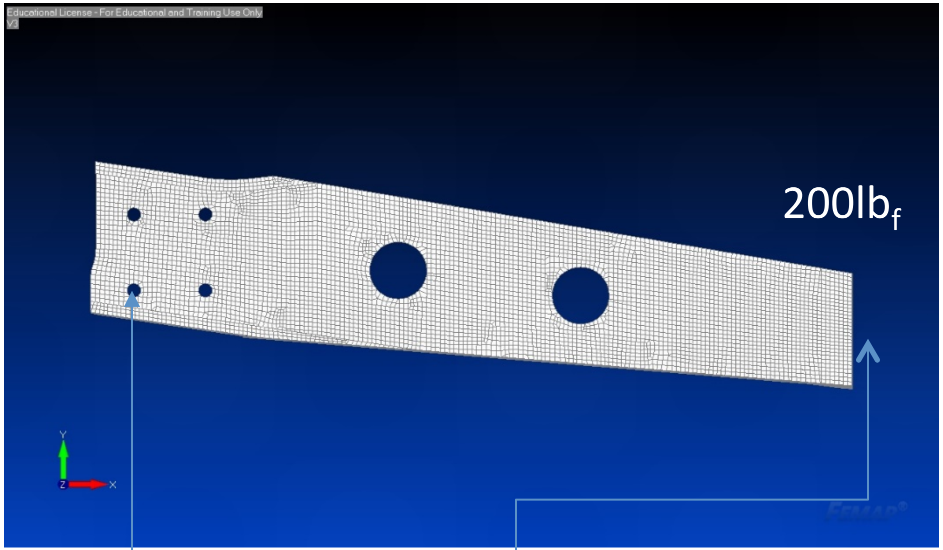
Top image shows RLVEs



Bottom image shows the FE mesh:
9235 nodes and
8915 elements

Load and boundary conditions





6 intercostals were tested on a hydraulic frame; displacements and strains measured using Digital Image Correlation.

Fixed boundaries

Force per area is applied on the near end face.

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Stochastic Analyses:

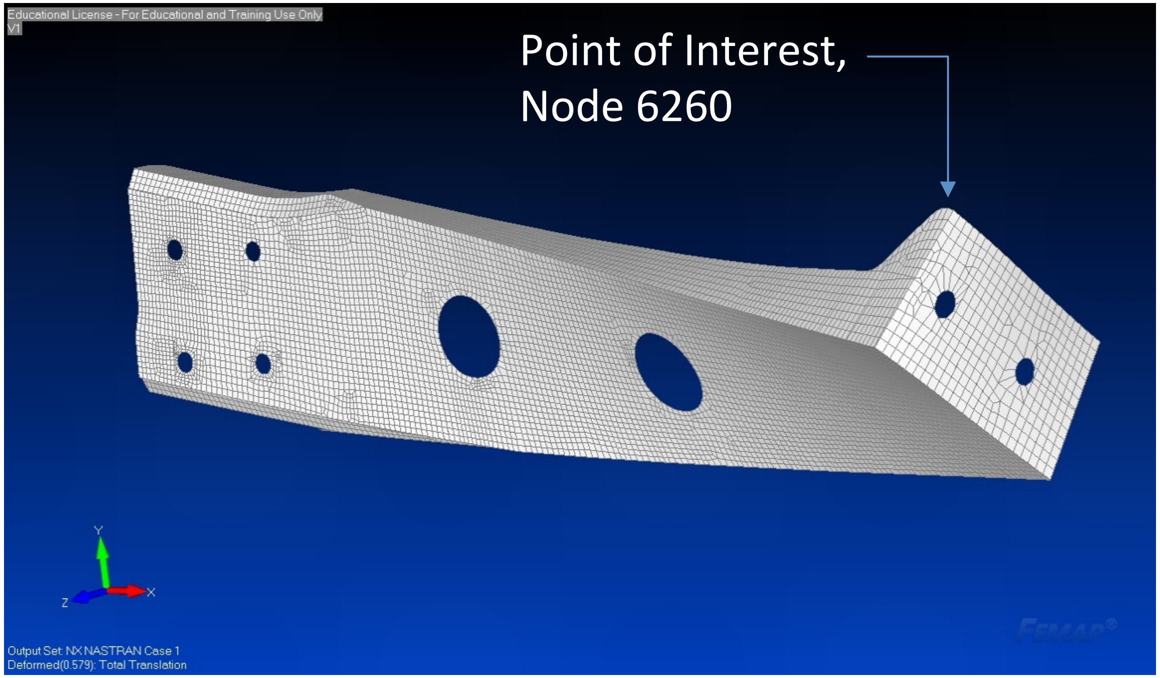
1000 FE runs, ~ 25 hour total analysis time
Each analysis averages 24 seconds

Deterministic Analyses:

6 FE runs, using B-Basis, Average, and B-Max properties in tension and compression
Total analysis time ~ 30 seconds

Comparison of Stochastic vs Deterministic Analyses

The magnitude of deflections at node 6260 predicted during 1000 SLA analyses are compared to those predicted by analyses based on B-basis, Average, and B-Max properties



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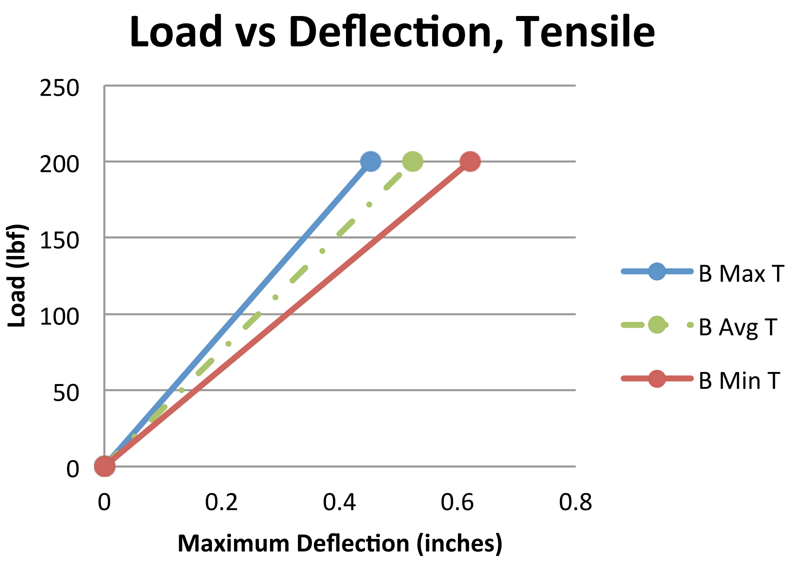
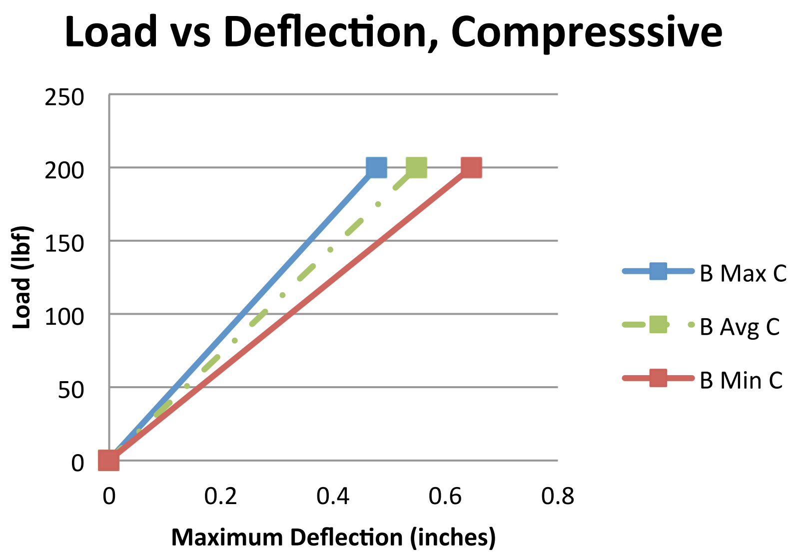
Deterministic Results Analysis





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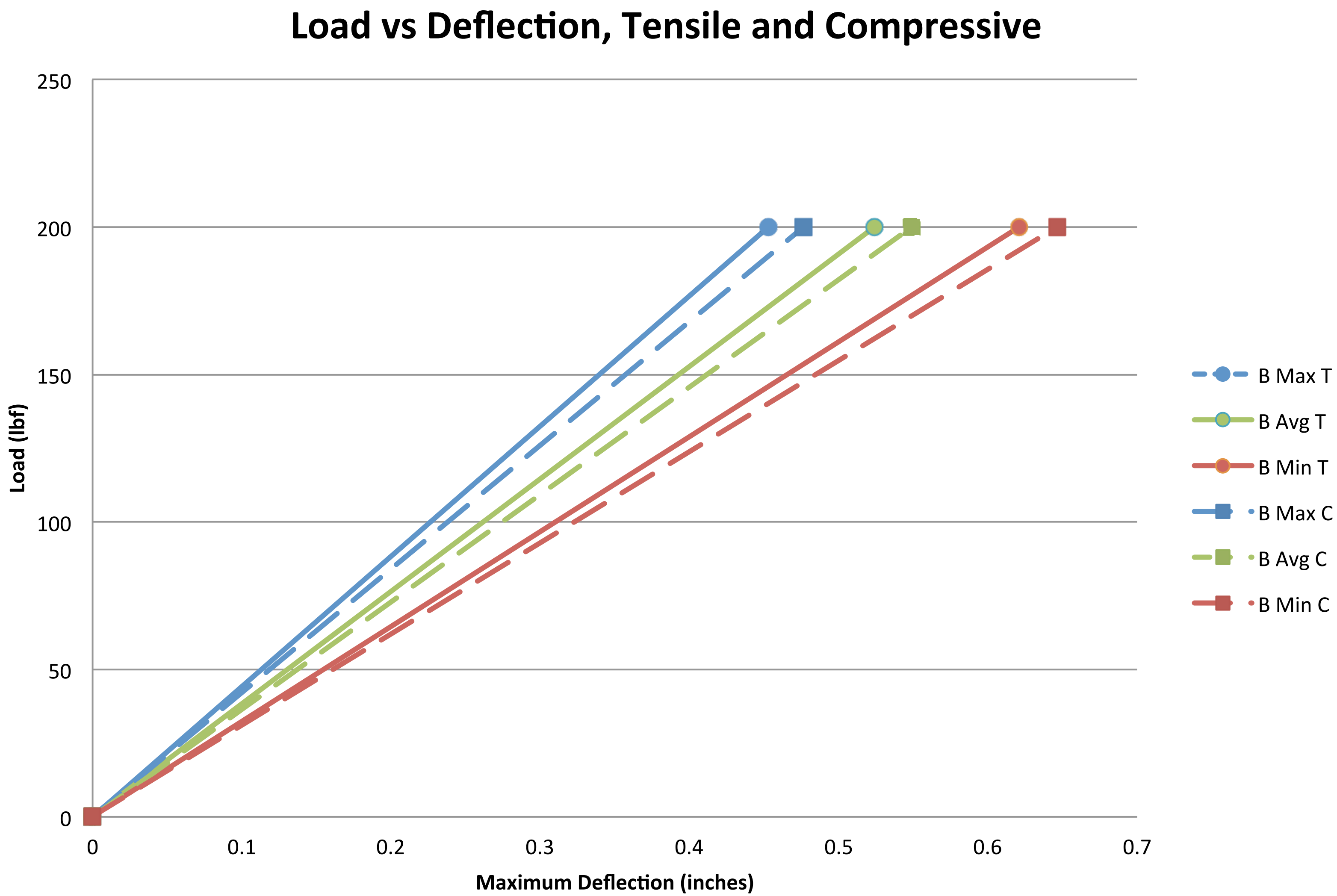
Deterministic Results, Superimposed



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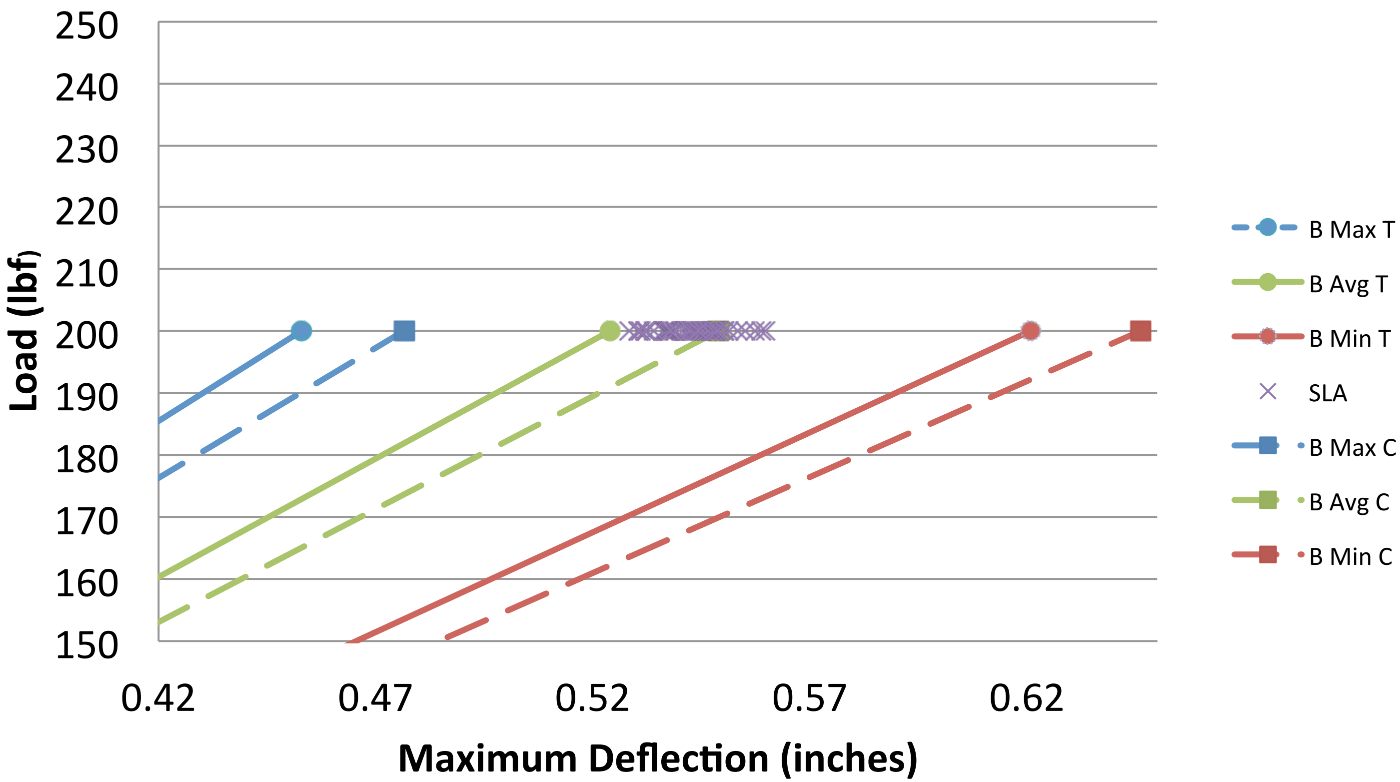
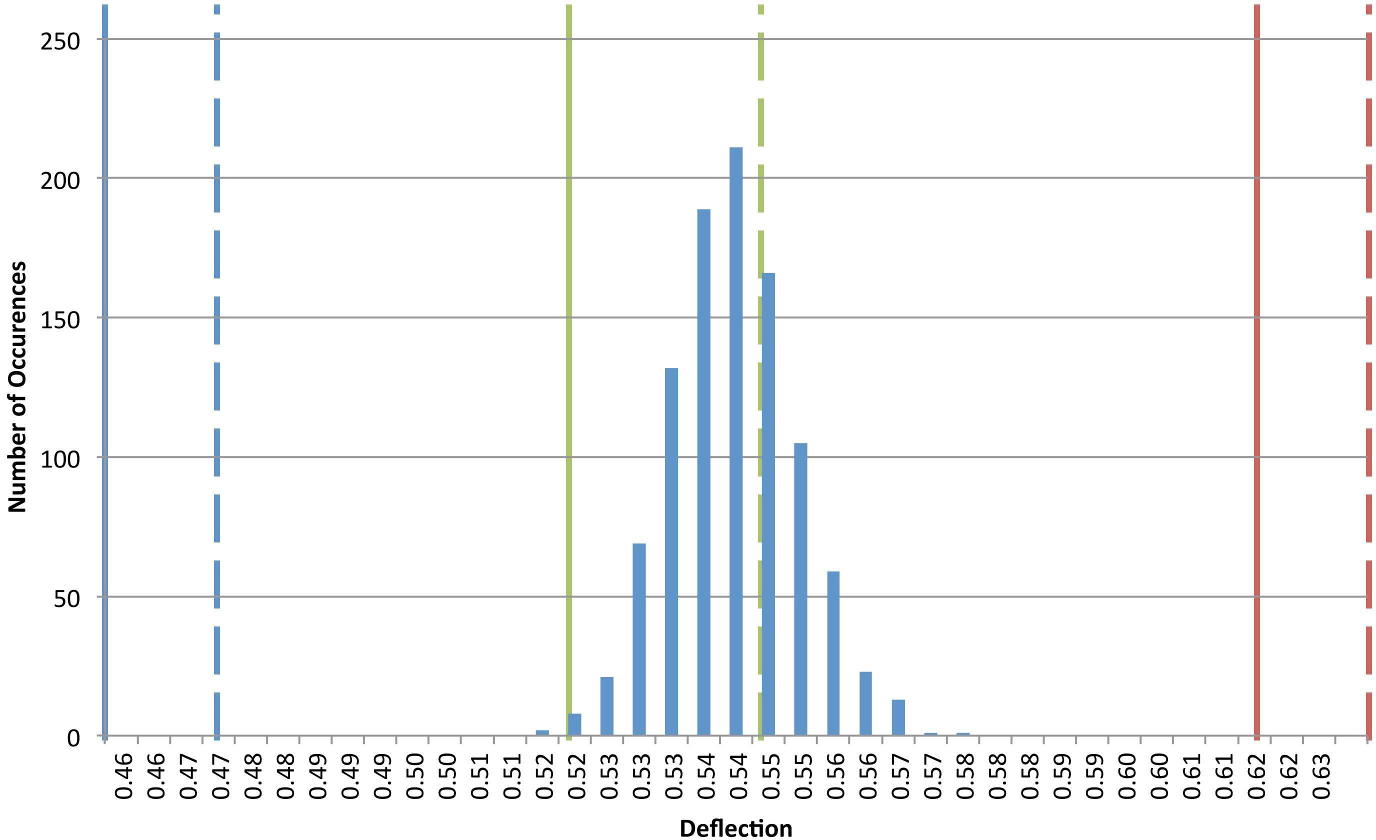
Stochastic Results

Results centered on B-Average Compression, spread approaches B-Average Tension



Distribution of Stochastic Results



Tension ———— Compression — —

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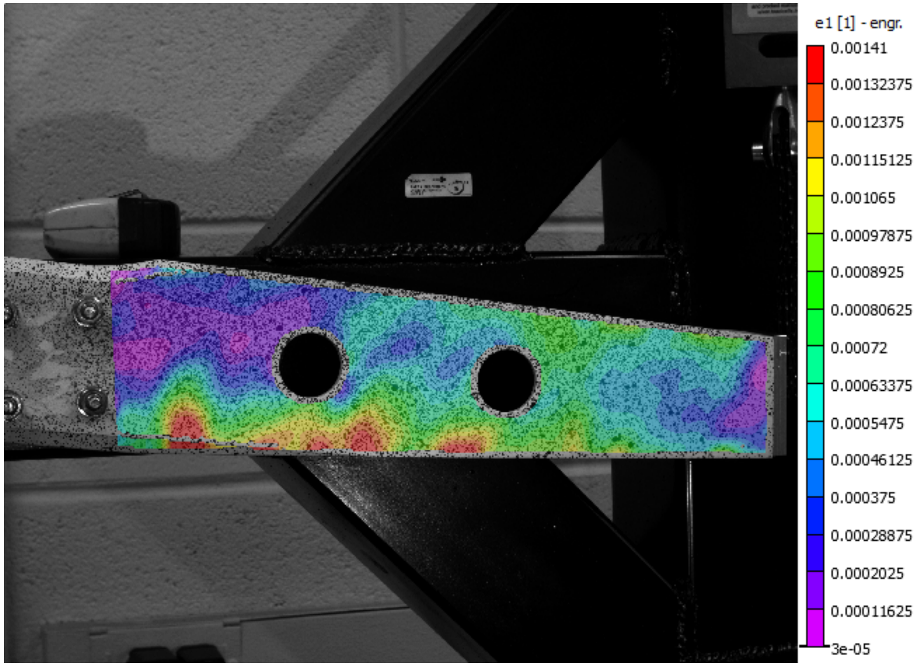
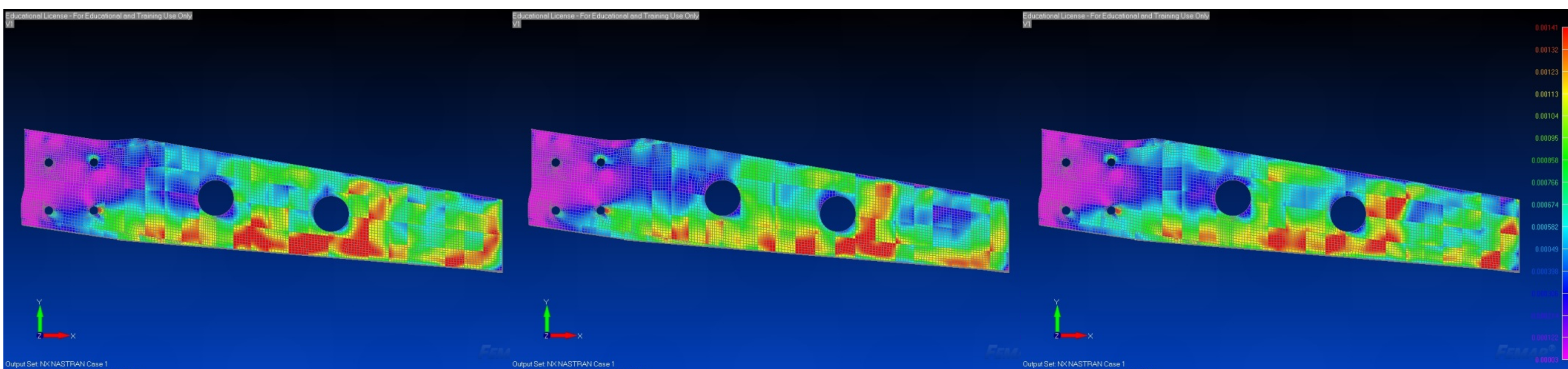
Contour Plots



Left: Contour Plot of Major Principal Strain, Measured Using DIC

Bottom: Left to right, Predicted Contour Plots of a Relatively Compliant, Average, and Relatively Stiff Stochastic Analysis



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Next Steps

Failure analysis of intercostals will be performed to compare predictions based on stochastic analyses deterministic analyses (failure criterion to be determined)

Use stochastic and deterministic analysis methods to study behavior of compressively-loaded HexMC angles already tested at Hexcel

Develop engineering rules/guidelines for conducting buckling/stability analyses of HexMC structures, in a form suitable for inclusion in the HexMC Design Guide

Thank You!

Are there any questions?

End of Presentation.

Thank you.

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Convergence Study

Final mesh size is 0.78, following software recommendation