Certification of Discontinuous Composite Material Forms for Aircraft Structures

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• **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
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
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
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 ← completed
  • HexMC Intercostals ← ongoing
• 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

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<th>Moduli (Msi)</th>
<th>B-Basis</th>
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<th>B-Max</th>
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<td>6.31</td>
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<td>Tension</td>
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<td>6.62</td>
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<table>
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<th>Strengths (ksi)</th>
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<tr>
<td>Tension</td>
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• 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

![Graphs showing experimental results for small and large specimens.]
Angle Buckling

Experimental Results

- Medium size angles fractured prior to (or simultaneously with) the onset of buckling
Predictions based on B-Basis Properties, Bracketed Initial Elastic Stiffnesses, Overpredicted Buckling/Failure Loads (illustrated using small angle test results)
• 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 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
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• 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*

- Buckling/failure loads predicted using the RLVE were roughly equivalent to analysis based on B-Basis modulus and B-basis strength
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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
Next Step: RLVE Analysis of HexMC Intercostals

These surfaces are fixed

650 lbf in + y direction
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/unidirectionalal properties (probabilistic)
Summary and Conclusions

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