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Buckling/Crippling of Structural Angle Beams Produced using Discontinuous-Fiber Composites

2012 Technical Review

presented by:

Mark Tuttle
University of Washington

Buckling/Crippling of Structural Angle Beams Produced Using Discontinuous-Fiber Composites

- Motivation and Key Issues
  - Use of compression-molded discontinuous fiber composites (DFC) in transport aircraft is increasing
  - Method(s) of predicting stiffness/failure of complex DFC parts have not been fully explored
  - Certification of DFC parts currently achieved by testing large numbers of individual parts (i.e., certification by “point design”)
  - Point design is time-consuming, costly, and likely leads to over-conservative part designs
  - Desire to transition to certification based on analysis supported by experimental testing

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Buckling/Crippling of Structural Angle Beams Produced Using Discontinuous-Fiber Composites

- Motivation and Key Issues (continued)
  - A compression-molded DFC called HexMC™ being used in the Boeing 787
  - Basic material properties of HexMC (e.g., tensile-compression stiffness & strength) measured using coupon specimens show high levels of scatter compared with continuous-fiber composites:
    - Feraboli et al:
      (a) *J. Composite Materials*, Vol 42, No 19 (2009)
      (b) *J. Reinf. Plastics and Composites*, Vol 28, No 10 (2009)
      (c) *Composites Part A*, Vol 40 (2009)
  - Can mechanical behavior of a “complex” part be predicted based standard analyses techniques and coupon data?

Buckling/Crippling of Structural Angle Beams Produced Using Discontinuous-Fiber Composites

- Objective
  - Determine whether the elastic and failure behavior of of HexMC angle beams (a “complex part”) subjected to pure bending loads can be well-predicted based on nominal HexMC properties measured using coupon specimens

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Buckling/Crippling of Structural Angle Beams Produced Using Discontinuous-Fiber Composites

- Approach
  - Prismatic HexMC angle beams with three cross-section sizes tested in 4-point bending
  - Elastic tests (reported during JAMS 2011):
    - Tested in six orientations relative to the bending moment vector
    - Three replicate tests:
      (3 sizes x 3 replicates x 6 orientations = 54 tests)
    - On average, bending stiffnesses well-predicted: scatter comparable to scatter in coupon tests reported by Feraboli
  - Fracture tests (the focus of this presentation)
    - Beams tested to failure in one orientation
    - At least five replicate tests for each beam size
    - Measurements compared with FE analyses performed using NASTRAN

Buckling/Crippling of Structural Angle Beams Produced Using Discontinuous-Fiber Composites

- Principal Investigators & Researchers:
  - PI: Mark Tuttle
  - Grad Students: Tory Shifman, Brian Head
- FAA Technical Monitor
  - Lynn Pham
- Other FAA Personnel Involved
  - Larry Ilcewicz and Curt Davies
- Industry Participation
  - Boeing: Bill Avery
  - Hexcel: Bruno Boursier and David Barr

HexMC Angle Beams

- Compression molded by Hexcel
  - 4.8 x 89 mm ("Large") (0.188 x 3.5 in)
  - 4.8 x 64 mm ("Medium") (0.188 x 2.5 in)
  - 2.5 x 43 mm ("Small") (0.097 x 1.7 in)

- After receipt all beams were machined to 36 cm (14 in) length

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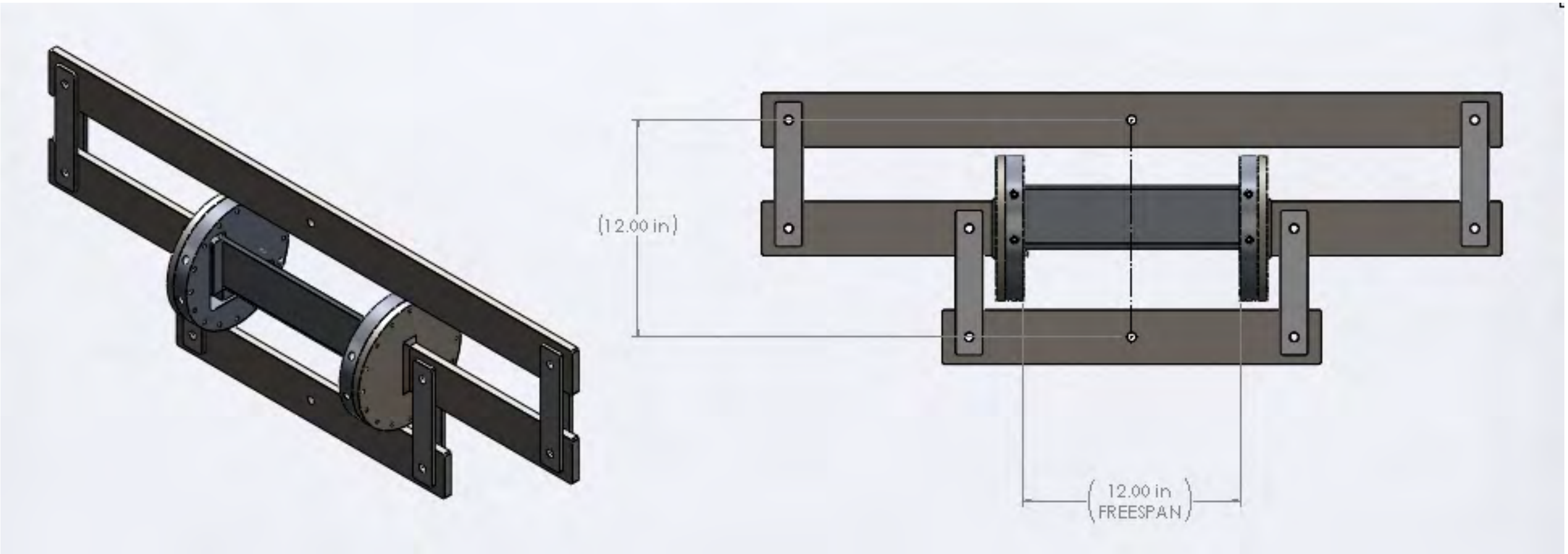
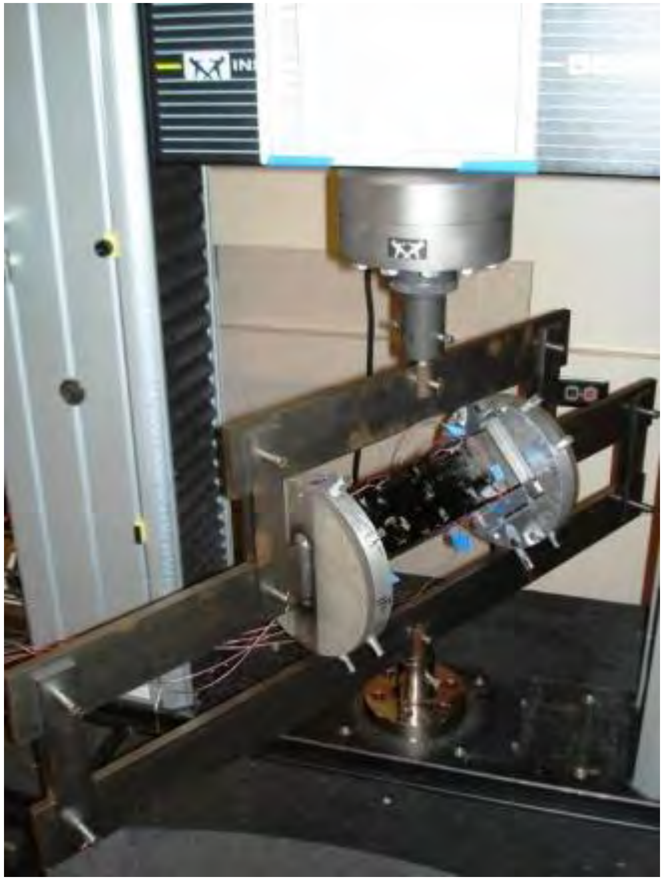
HexMC Angle Bend Tests

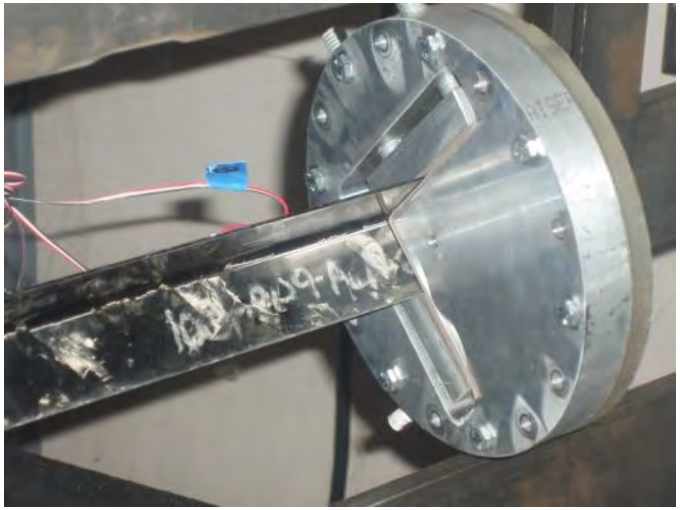
- HexMC angle beams subjected to four point bending loads

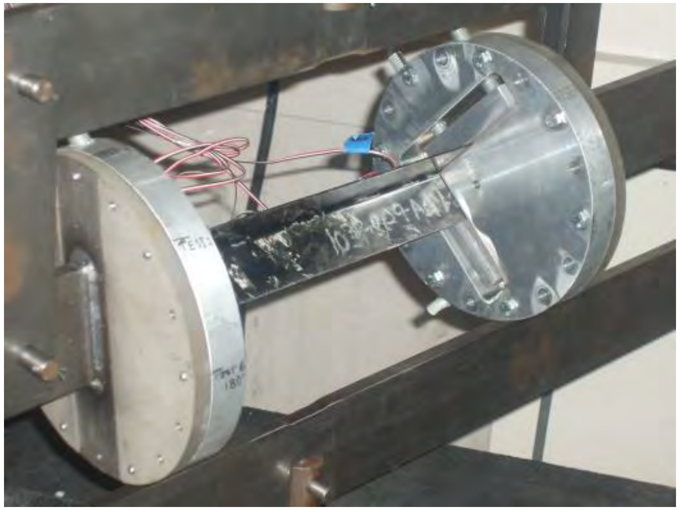


Four-Point Bending Fixture

- Fixture mounted in Instron 5585H Universal Test Frame







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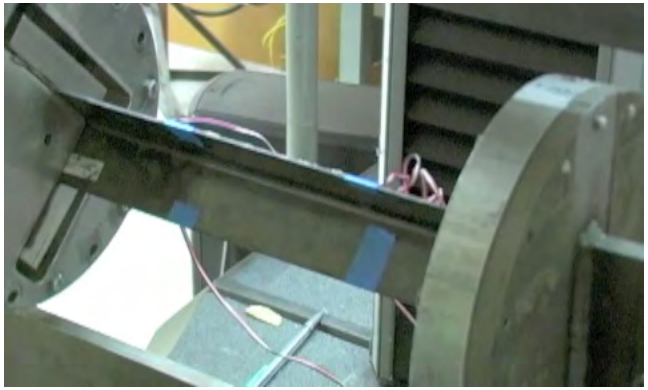
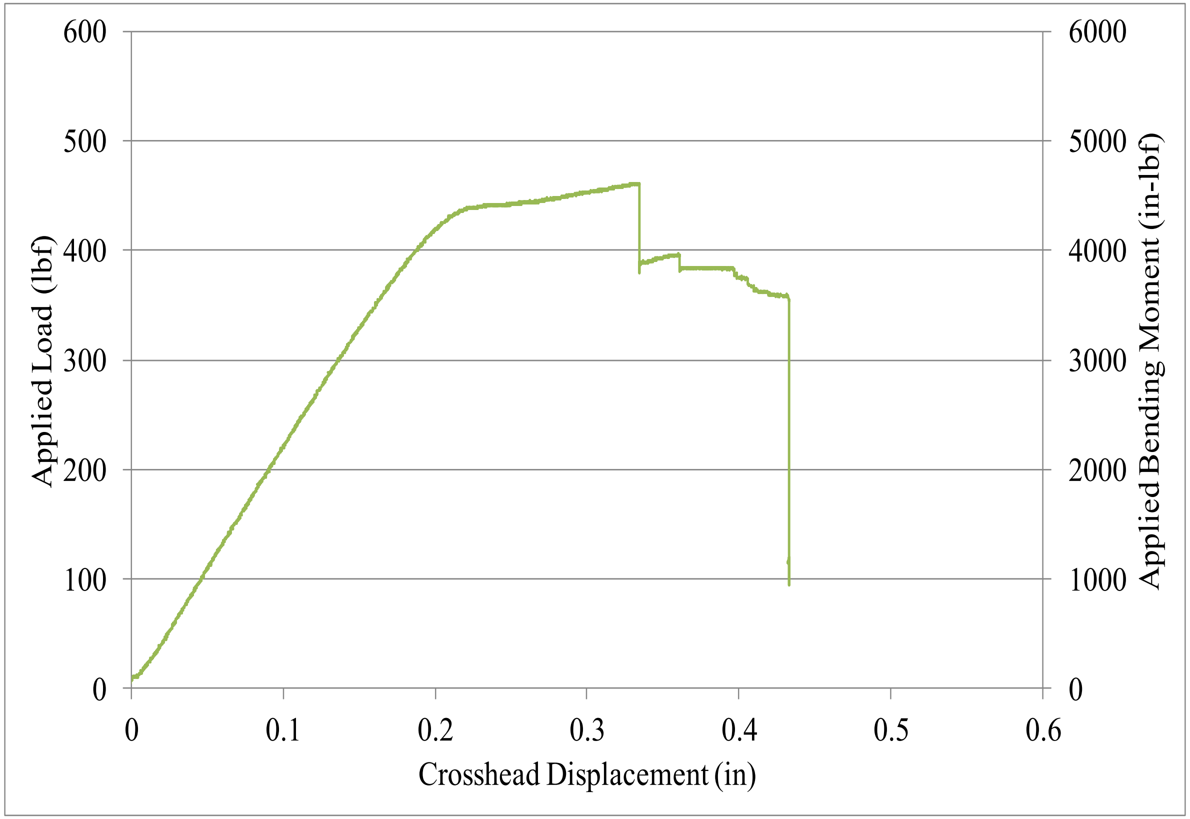
Typical Test – Small Beam Specimen S3





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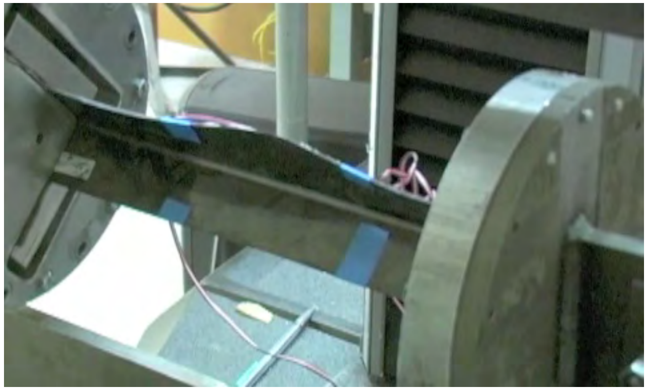
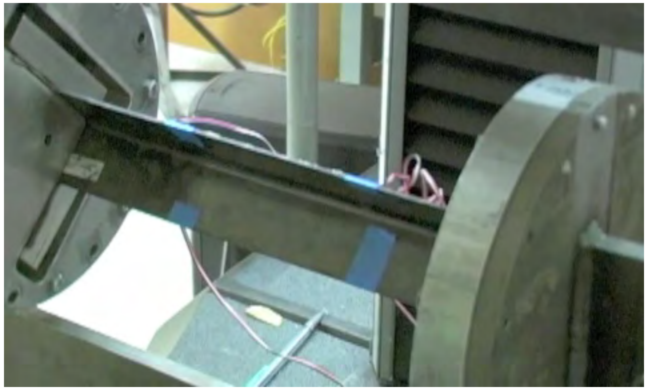
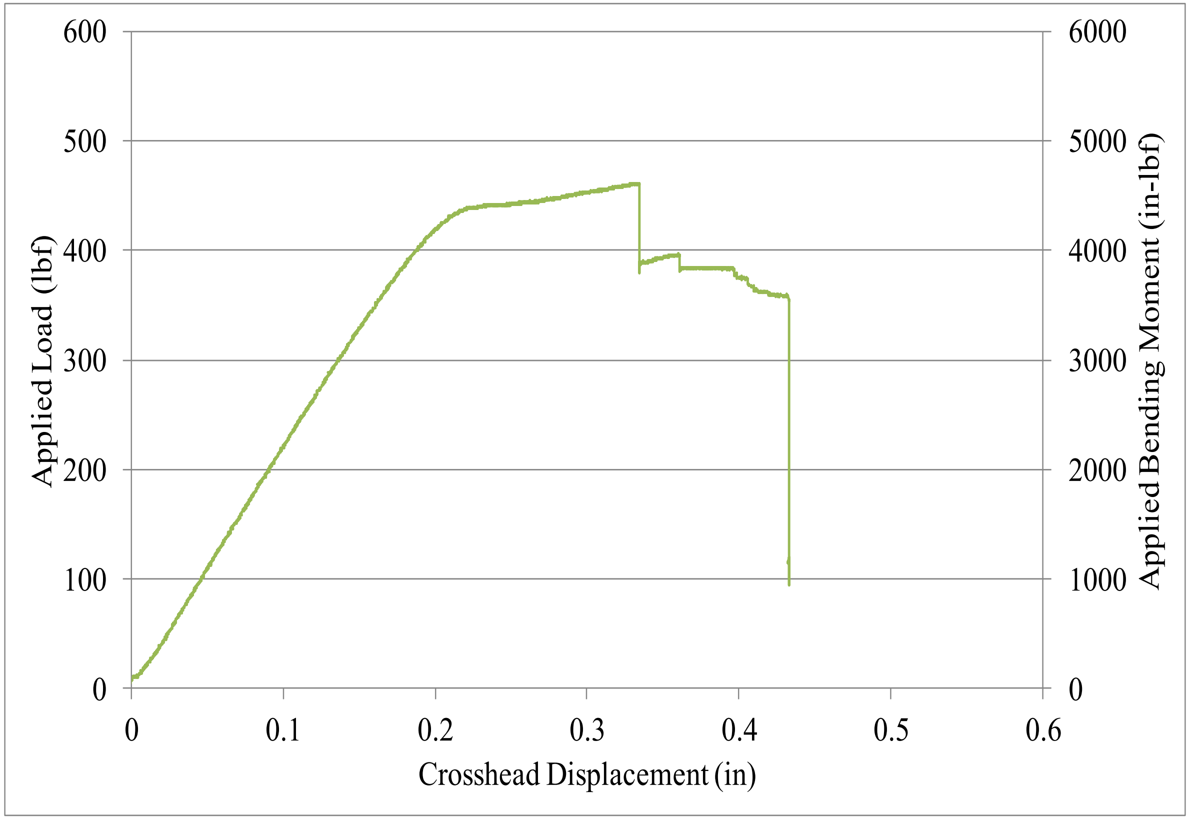
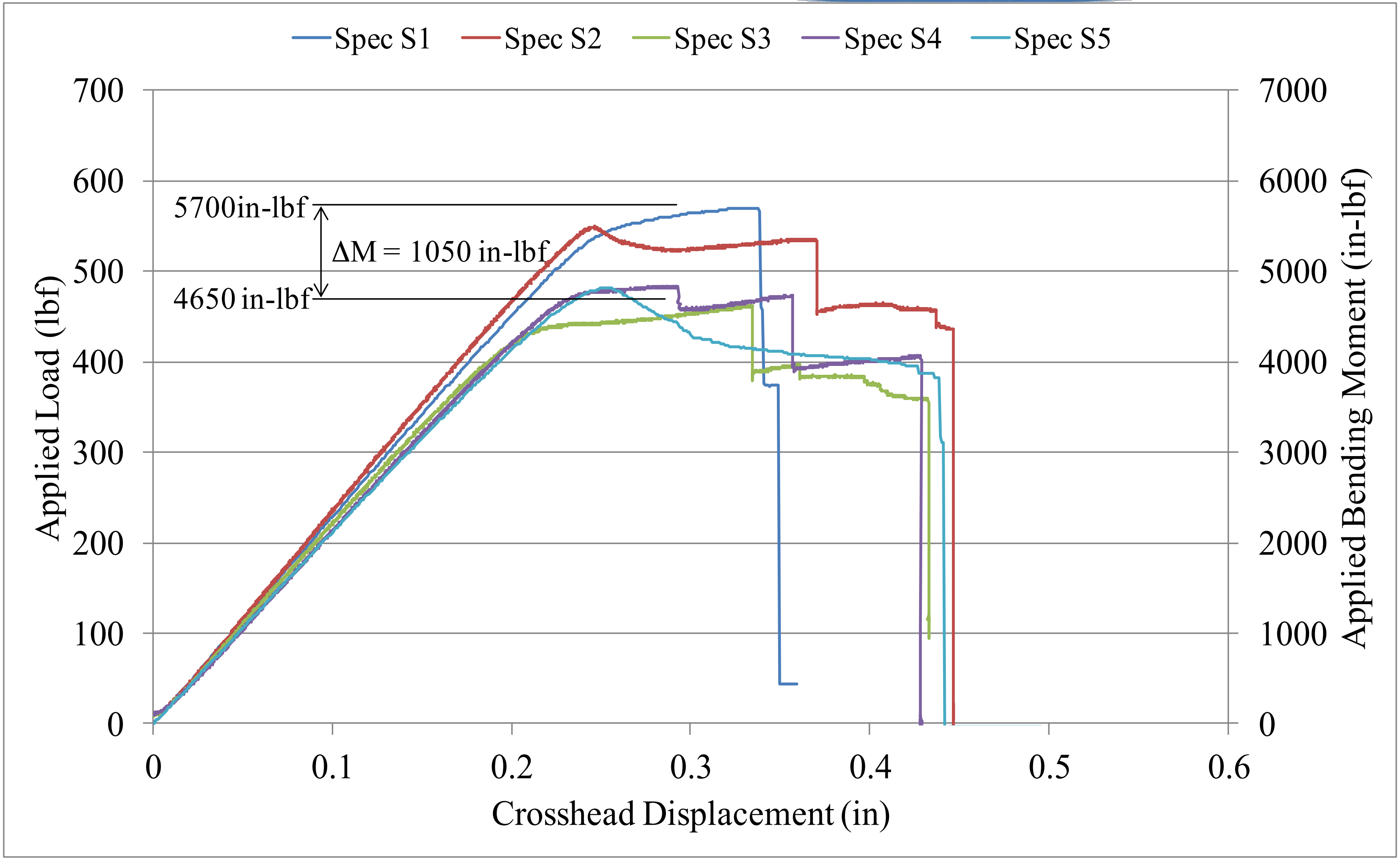






All Small Beam Results



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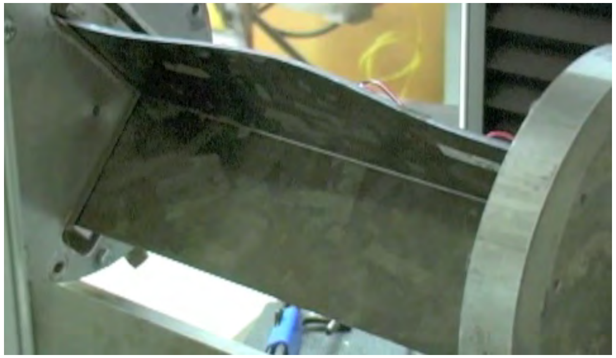
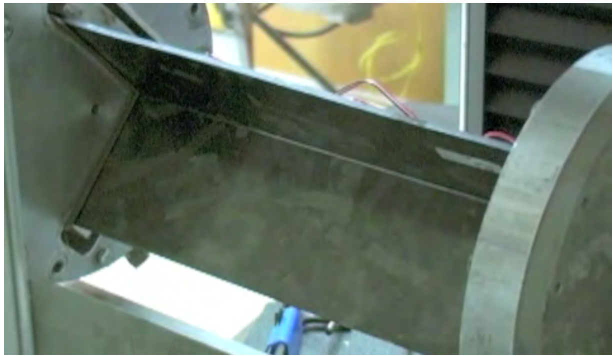
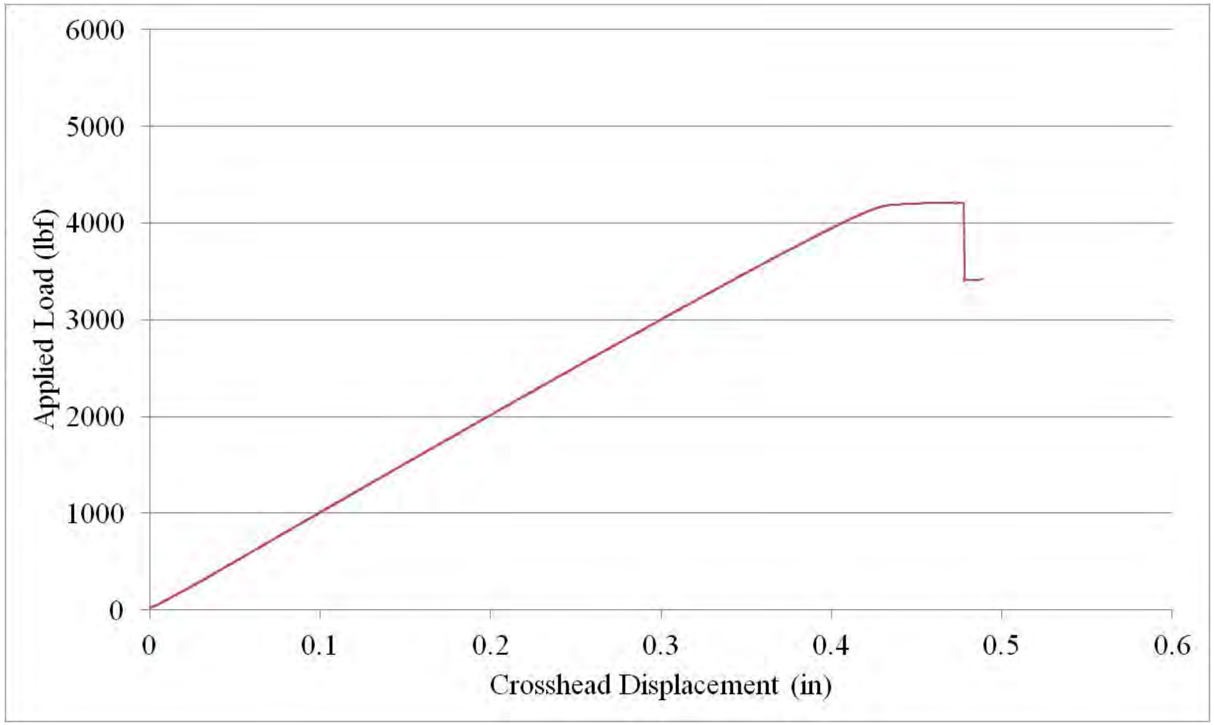
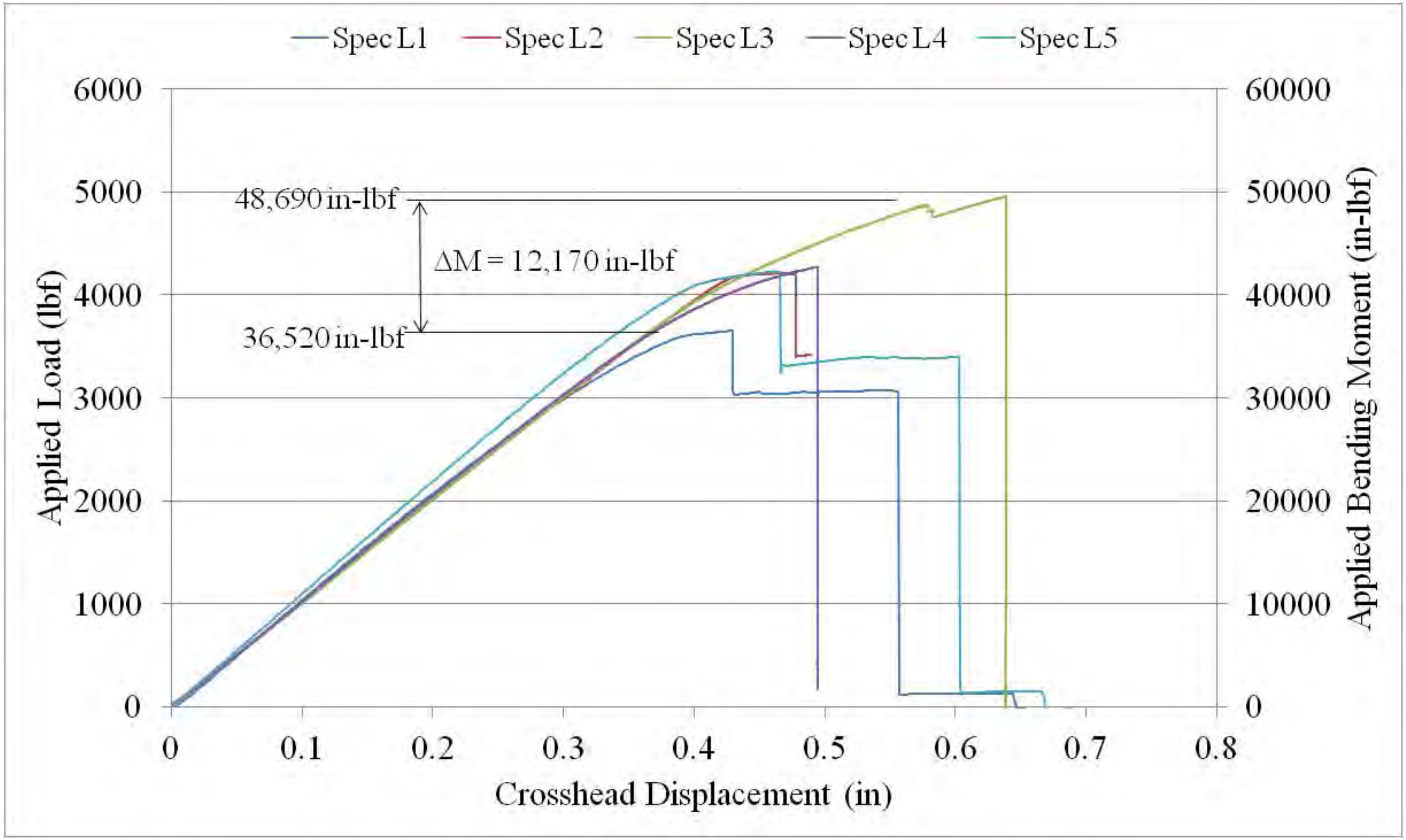
Typical Test – Large Beam Specimen L2







All Large Beam Results



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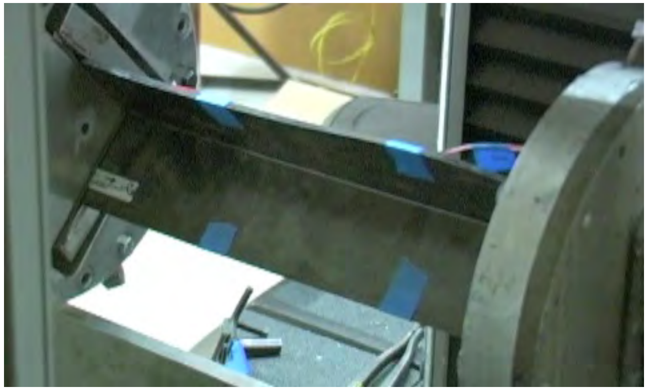
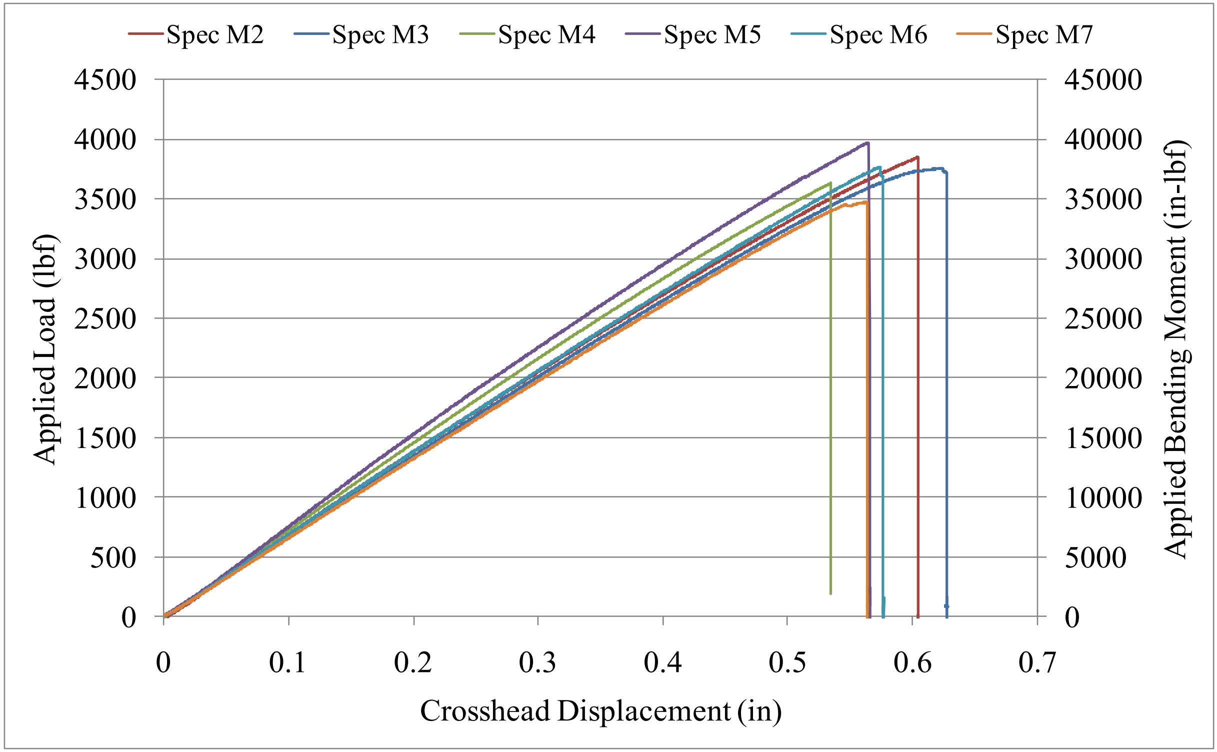
All Medium Beam Results

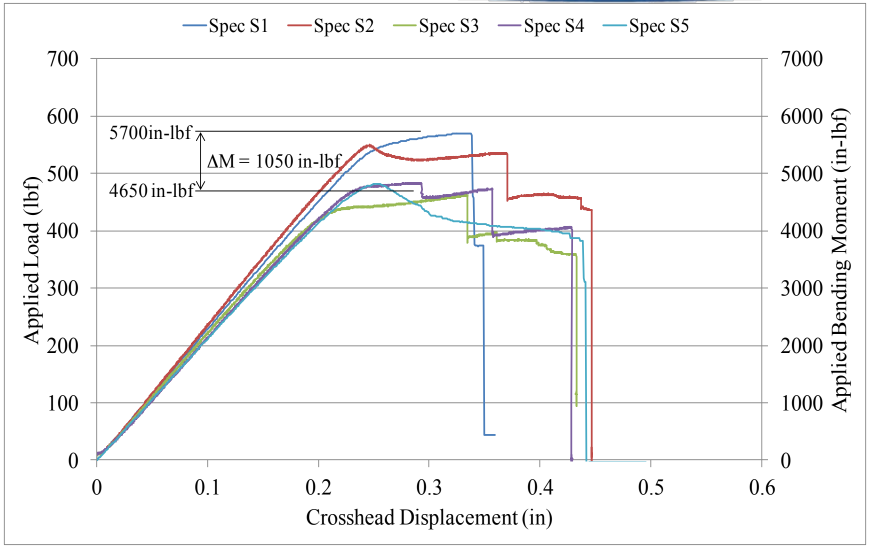


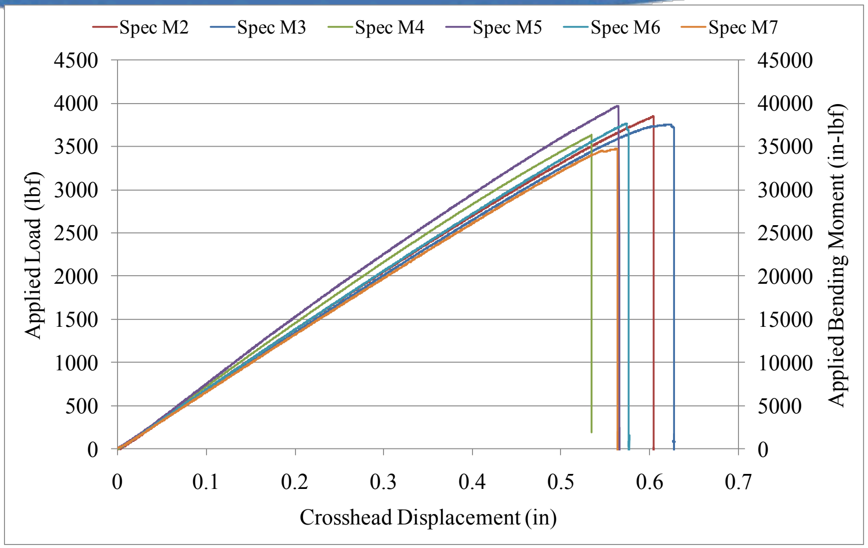
Specimen M3 at 3700 lbf ↔37,000 in-lbf

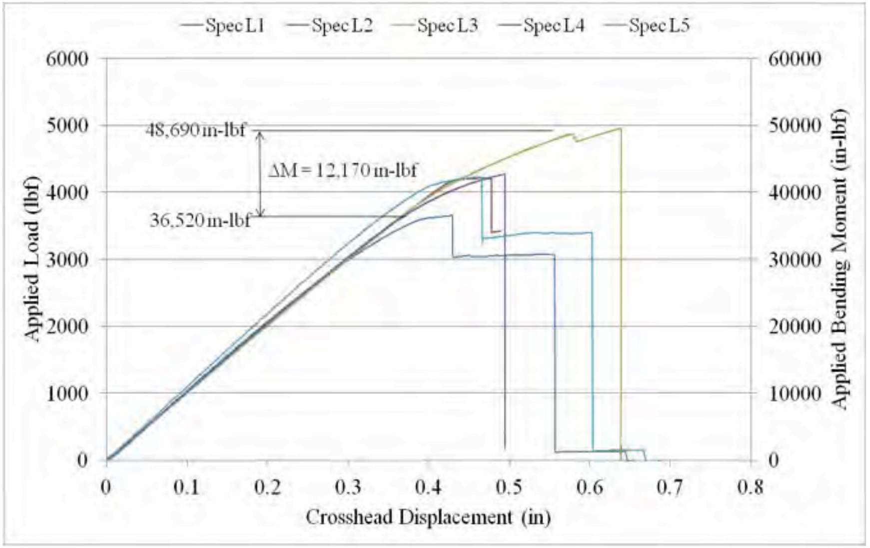
Specimen M3 at 3000 lbf ↔30,000 in-lbf



Summary – All Experimental Results







- For small and large beams:
  - (a) compressive flange buckles at loads/displacements well before fracture
  - (b) fractures in compressive flange only
- For medium beams:
  - (a) bending moment necessary to cause buckling *or* fracture nearly identical
  - (b) fractures in both tensile and compressive flanges

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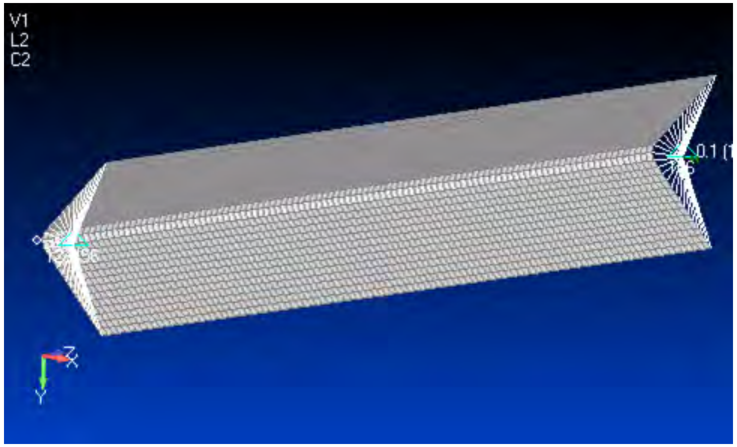
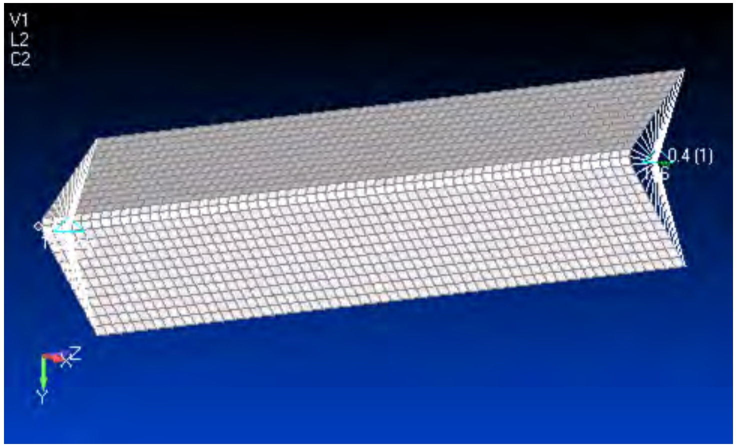
FEA Modeling

- Beams modeled in FEMAP, a pre/post processer for the NX Nastran solver
- Modeled with Shell Elements
  - Solid elements were also tried
  - Element size sensitivity studies done
- Modeled over a range in moduli measured by Feraboli [1]
  - 5.10 Msi to 7.66 Msi
  - Also modeled over a range of Poisson's ratios
- Boundary conditions
  - Fixed left end
  - Enforced rotation of right end
- Compared to range in tensile strengths reported in [1]
  - 36.9 ksi to 44.5 ksi

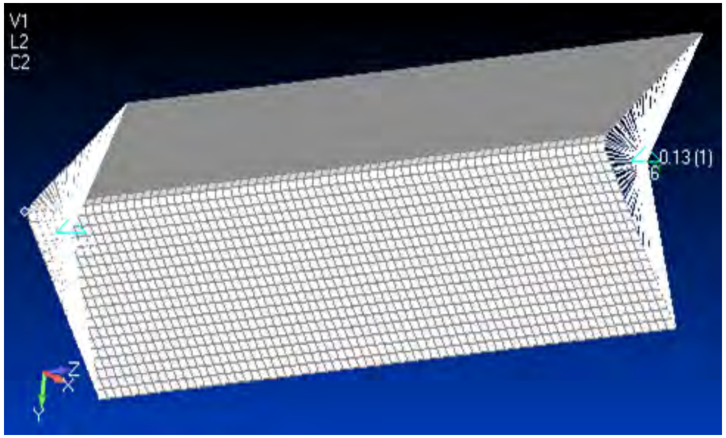
FEA Meshes



Small Angle Mesh



Medium Angle Mesh



Large Angle Mesh

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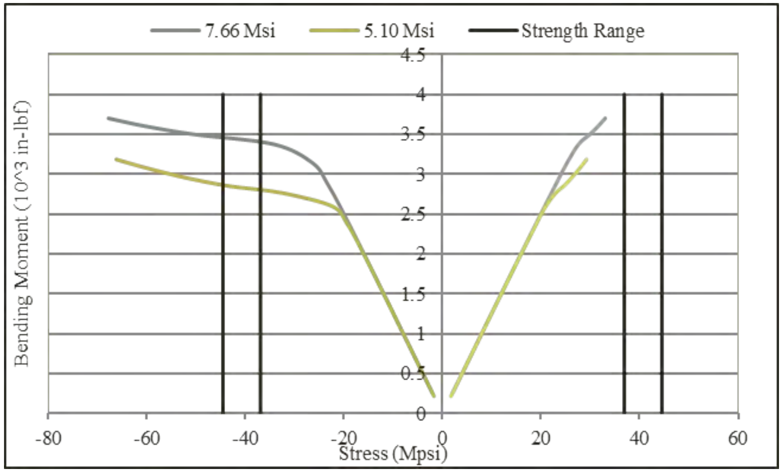
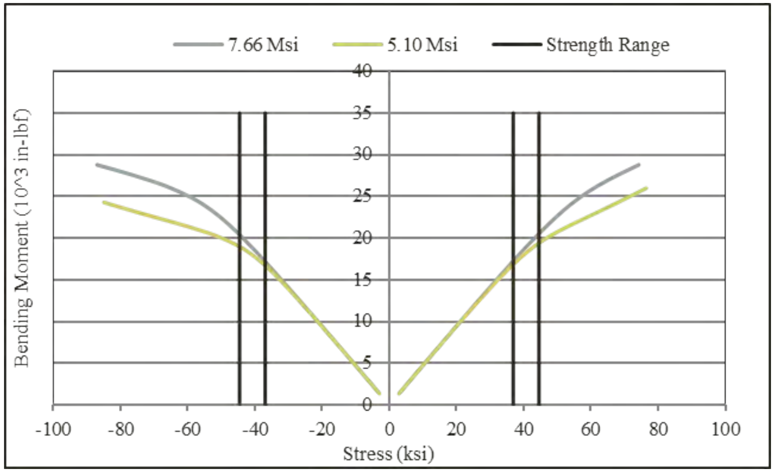
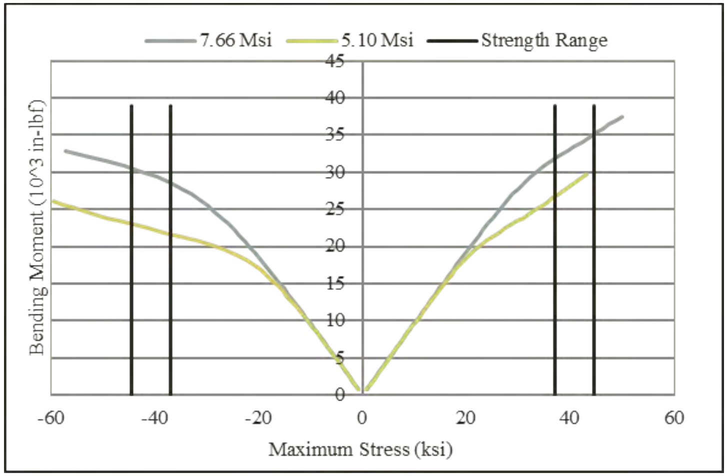
FEA Results



Small Angle Mesh



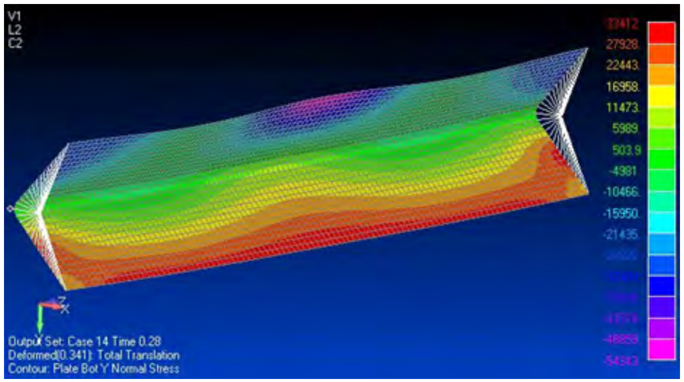
Medium Angle Mesh



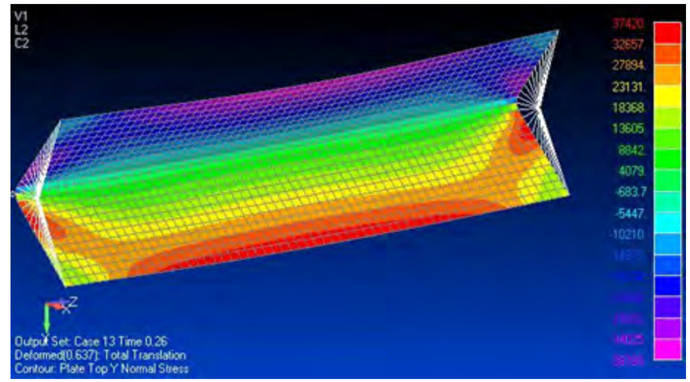
Large Angle Mesh

FEA Results

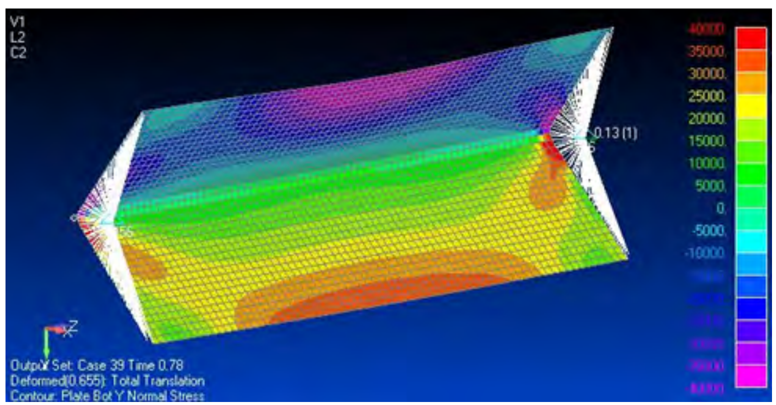
- High Modulus Beams Stress Contour



Small Angle



Medium Angle



Large Angle

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Predicted vs. Measured

	Measured Buckling Moment (in-lbf)	Predicted Buckling Moment (in-lbf)	% Difference	Measured Failure Moment (in-lbf)	Predicted Failure Moment (in-lbf)	% Difference
Small Beam	2765	3207	16.0	2850	3450	21.1
	2191.634	2612	19.2	2340	2780	18.8
Medium Beam	N/A†	22050	N/A	19840	20400	2.82
	N/A†	17050	N/A	17350	16700	-3.75
Large Beam	22647	25250	11.5	24350	30540	25.4
	17705	17180	-2.98	18260	21660	18.6

†Some of the medium specimens reached 10% deviation from linear within ~10 in-lbf of failure

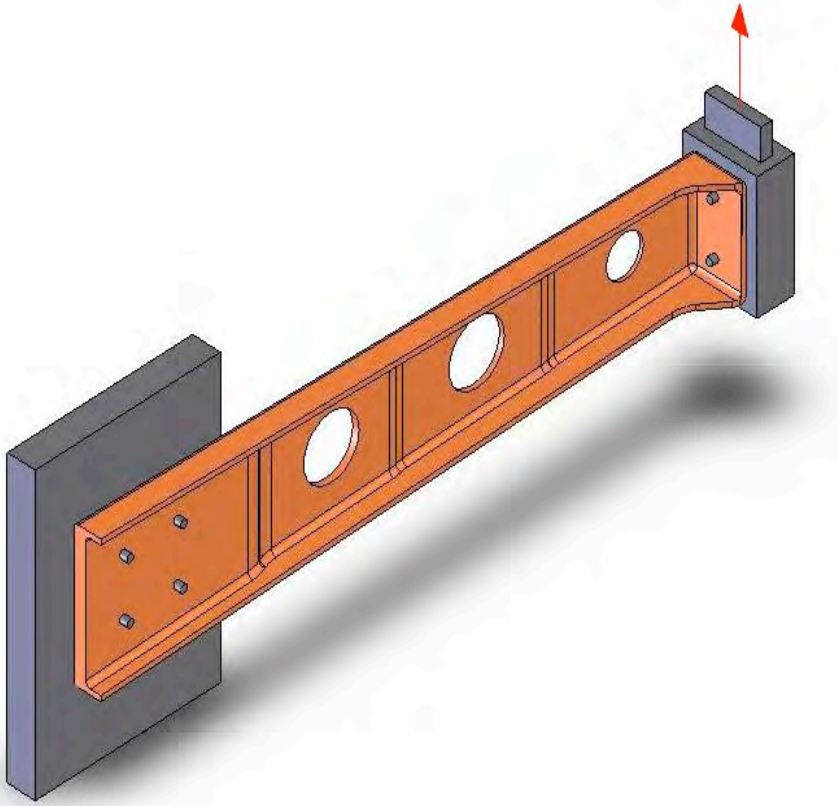
- Buckling defined as >10% deviation from linear behavior

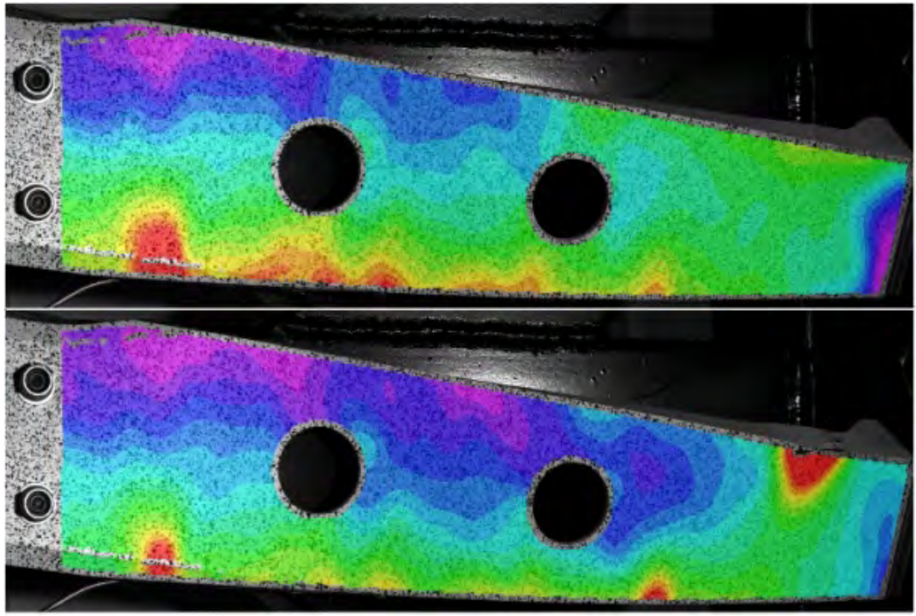
Summary

- Overall goal: simplify certification of DFC aircraft parts
- Objective of current study: Determine if nominal properties measured during coupon-level tests can be used to predict response of HexMC angles in bending
- Results:
  - Elastic stiffness (JAMS '11): Average elastic bending stiffnesses reasonably well-predicted: scatter comparable to scatter in coupon tests reported by Feraboli
  - Buckling/fracture (focus of this presentation):
    - Predicted buckling of compressive flange in small and large beams agrees with measurements; however
    - Buckling and failure loads overpredicted (FE analysis will be repeated using compressive modulus and strength measured by Feraboli)
    - FE analysis of medium beam consistent with measurements (e.g., buckling load predicted to be slightly higher than fracture load)

Principal activities for next year

- Study mechanical performance of an intercostal (both experimental and FEA)





Looking Forward

- Benefit to Aviation:

  Results of this study will ultimately help establish a method to certify DFC aircraft parts by analysis supported by experimental measurements.

Thank you for your attention!

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