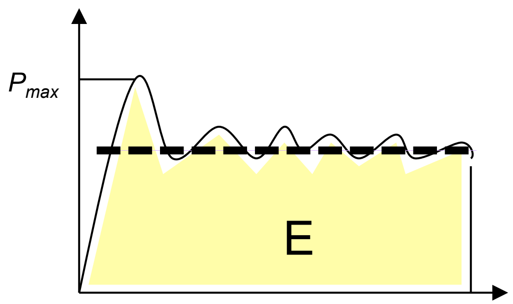
CRASHWORTHINESS OF COMPOSITE FUSELAGE STRUCTURES – MATERIAL DYNAMIC PROPERTIES

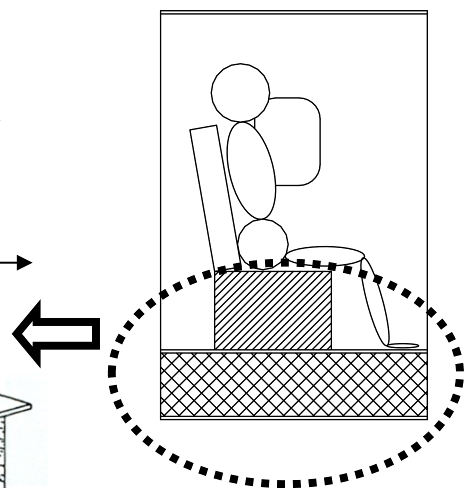
Suresh Keshavanarayana
Department of Aerospace Engineering

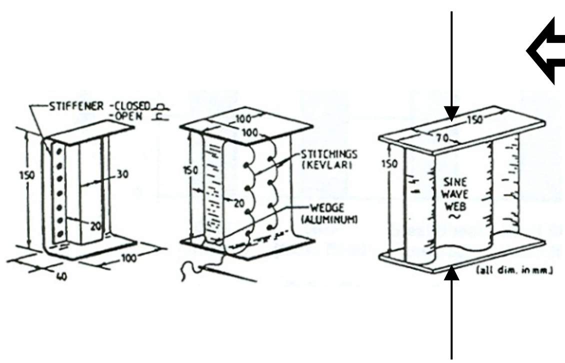
The Joint Advanced Materials and Structures Center of Excellence

Crashworthiness of Composite Fuselage Structures – Material Dynamic Properties

- Motivation and Key Issues



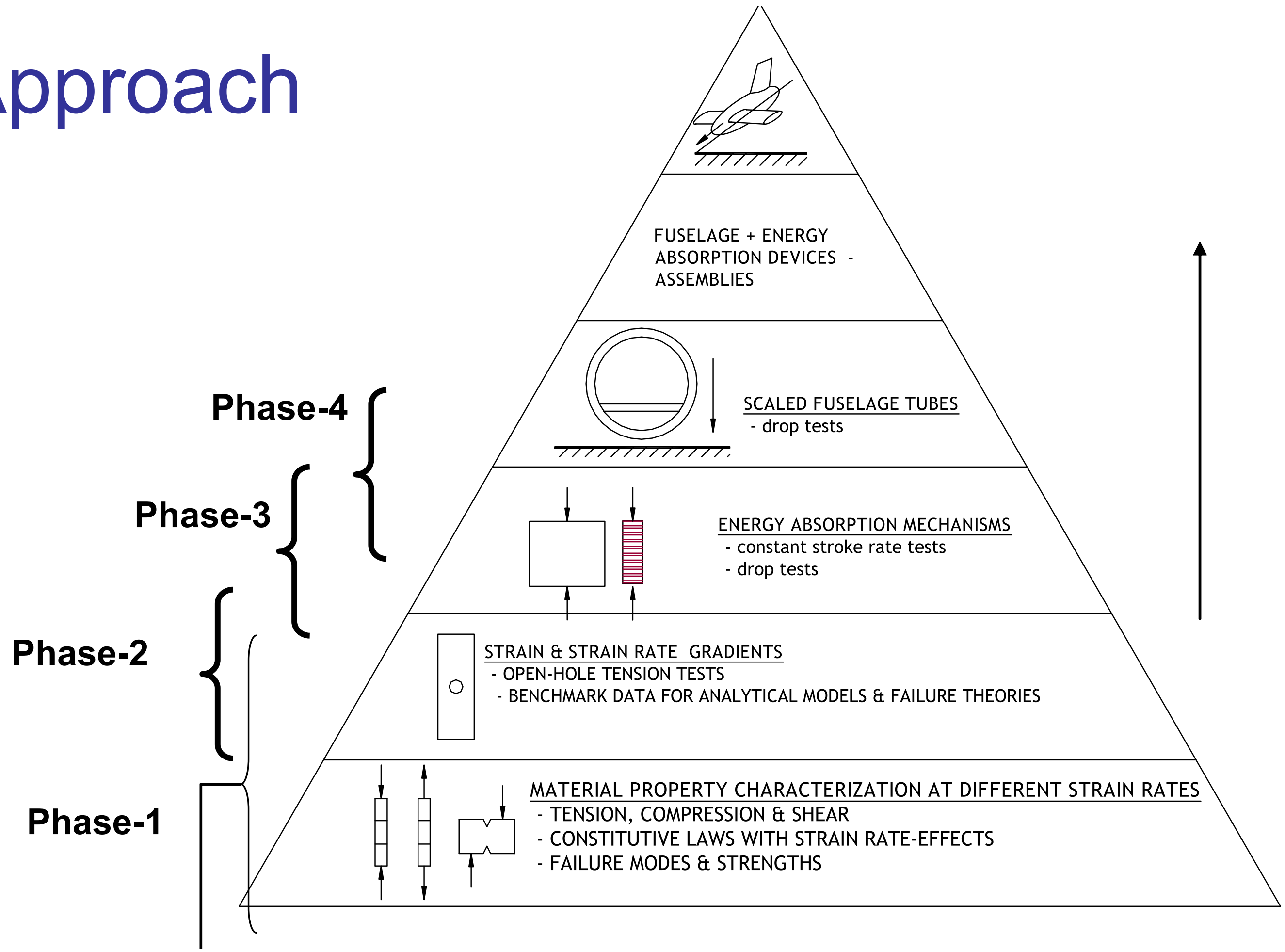




- Crashworthiness
  - maintain survivable volume
  - dissipate kinetic energy → alleviate occupant loads
- Energy absorption
  - Composite structures /energy absorption (EA) devices
    - Controlled failure modes
    - Maximize damage volume
    - Provision for sustained stability
  - Influencing factors
    - EA device geometry
    - Material
    - Rate sensitivity (?)

Hull D (1991) Comp. Sci Tech, 40.
Bannerman & Kindervater (1984) in Structural Impact and Crashworthiness
Bolukbasi & Laananen (1995) Composites, 26.
Carruthers, Kettle & Robinson (1998) Appl Mech Rev, 51.

- Approach


Phase-4
Phase-3
Phase-2
Phase-1
FUSELAGE + ENERGY ABSORPTION DEVICES - ASSEMBLIES
SCALED FUSELAGE TUBES
- drop tests
ENERGY ABSORPTION MECHANISMS
- constant stroke rate tests
- drop tests
STRAIN & STRAIN RATE GRADIENTS
- OPEN-HOLE TENSION TESTS
- BENCHMARK DATA FOR ANALYTICAL MODELS & FAILURE THEORIES
MATERIAL PROPERTY CHARACTERIZATION AT DIFFERENT STRAIN RATES
- TENSION, COMPRESSION & SHEAR
- CONSTITUTIVE LAWS WITH STRAIN RATE-EFFECTS
- FAILURE MODES & STRENGTHS

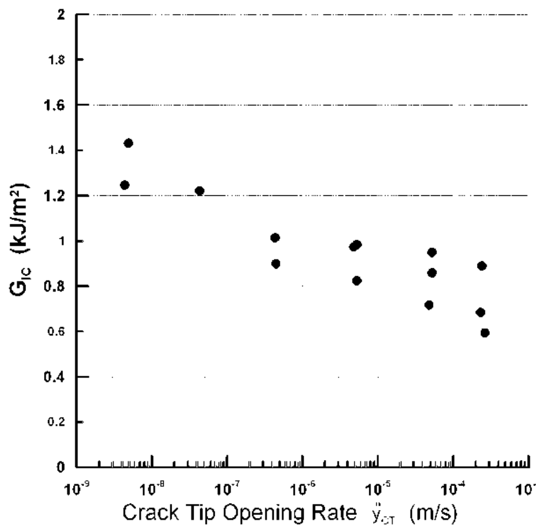
- Objective(s)
  - Literature Review
  - Material property characterization at different strain rates (10^{-4} s^{-1} to 10^{3} s^{-1})
    - Phase-1 : Tension, Compression & Shear
    - Phase-2 : Open Hole Tension, Interlaminar Shear, Pin Bearing
    - Phase-3 : Fracture Toughness (mode I & II)
    - Phase-4 : Characterization of EA device, Scaling effects, Dynamic characterization of CMH-17 material(in progress)

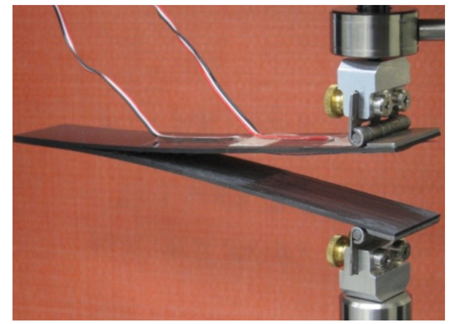
FAA Sponsored Project Information

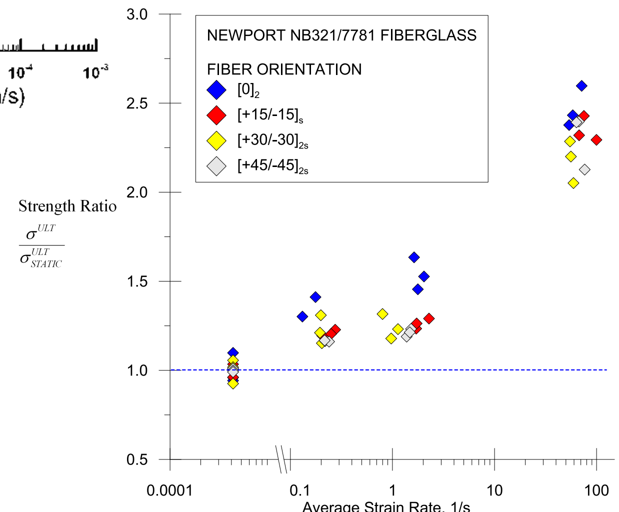
- Principal Investigators & Researchers
  - K.S. Raju
  - J.F. Acosta, N. Pratap, K.Y. Tan, S. Elyas, M. Siddiqui
- FAA Technical Monitor
  - Allan Abramowitz
- Other FAA Personnel Involved
  - Curtis Davis
- Industry Participation
  - CMH-17

Background..Rate Sensitivity

- Material Systems
  - NEWPORT material systems
    - NB321/3k70 Plain Weave Carbon Fabric (PWCF)
    - NB321/7781 Fiberglass
  - TORAY material systems
    - T800S/3900-2B[P2352W-19] BMS8-276 Rev-H- Unitape
    - T700G-12K-50C/3900-2 Plain Weave Carbon Fabric (PWCF)
- Rate Sensitivity
  - Dependent on material
  - Dependent on loading type (tension, compression, shear)
  - Fracture toughness exhibits trend opposite to that of in-plane properties

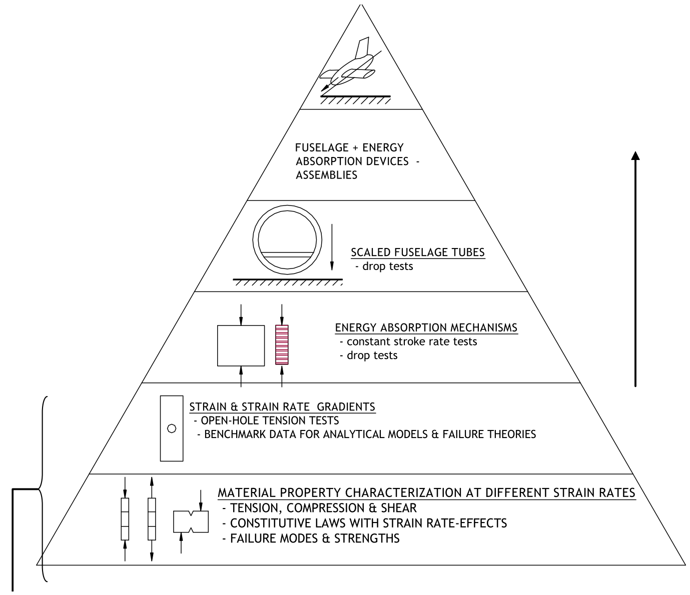






Ongoing Work..

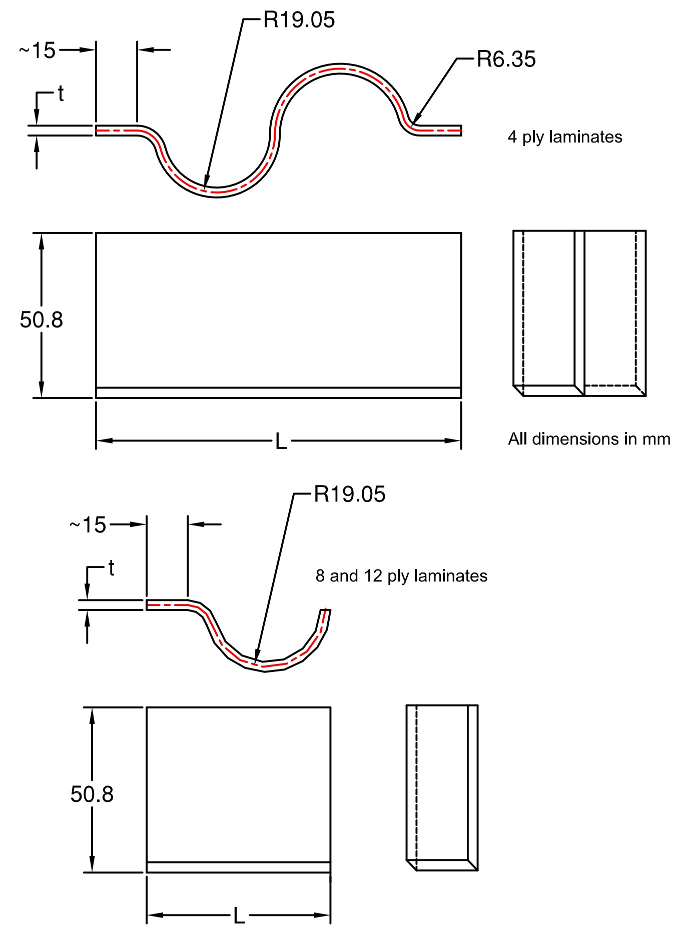
- Rate sensitivity of Energy Absorption (EA) Device
  - Corrugated beams (stable configuration)
  - Failure modes
  - Correlation with rate sensitivity of material properties (compression, fracture toughness)
- Scaling Studies
  - Tension
    - Observed rate sensitivity in sub-scale coupons applicable at larger scales?*
- Rate sensitivity of CMH-17 material



*** K.E. Jackson et. al, J.Comp. Matls., Vol.26, 1992**
J.G. Carillo & Cantwell, Comp.Sci.Tech. Vol.67, 2007.

Rate Sensitivity of EA device

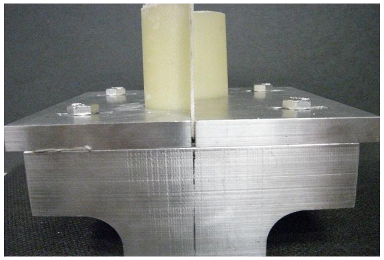
- Corrugated beam geometry
  - Stable configuration
  - Easy to fabricate
  - Captures failure mechanisms observed in tubes
  - 45° chamfered edge to trigger failure
- Material Systems
  - Newport NB321/7781 fiberglass
  - Toray T700G-12K-50C/3900-2 Plain Weave Carbon Fabric
- Stacking sequences
  - $[0]_n$ and $[\pm 45]_n$, where n=4,8 and 12

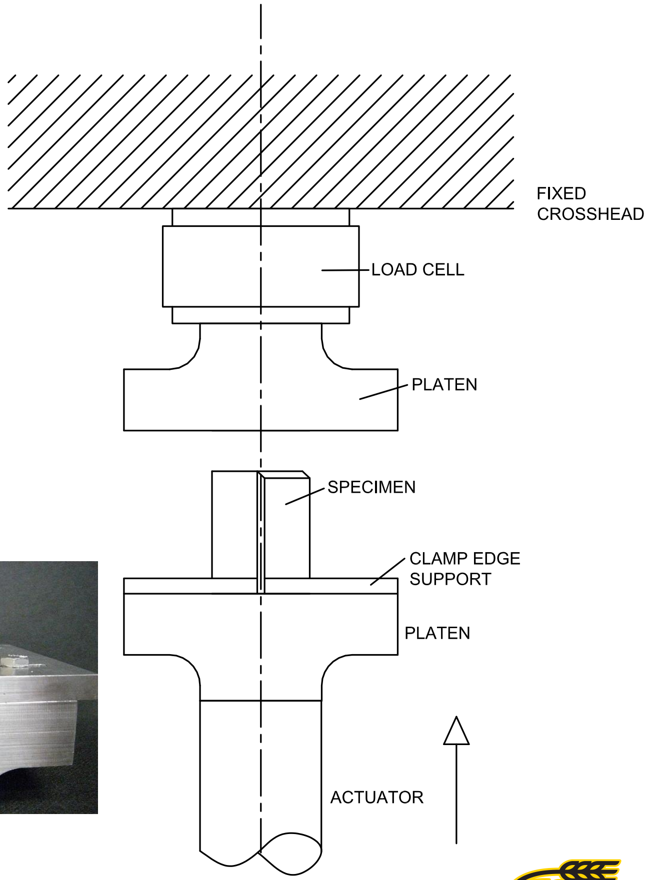


Farley, G. L., J. American Helicopter Society, October, 1987.
S. Hanagud et.al., J.Comp. Matls, Vol.23, May 1989.
P. Feraboli, J. Comp. Matls, Vol.42, No.3, 2008.

Rate Sensitivity of EA device

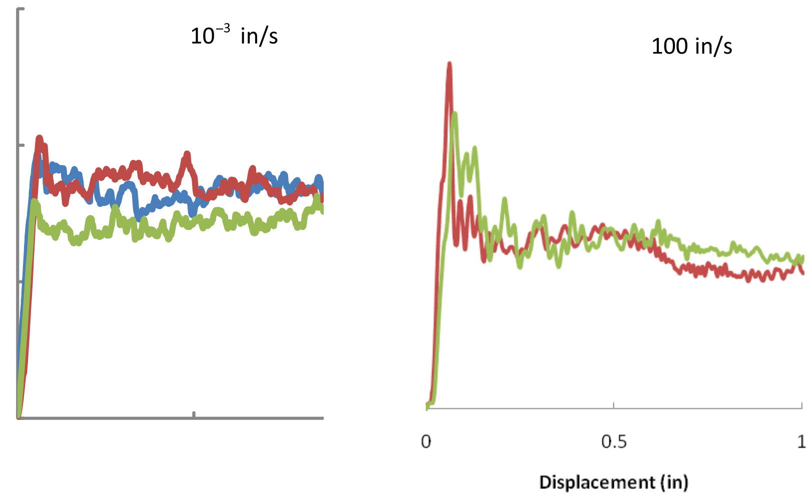
- Test Apparatus
  - Fixture
    - Specimen compressed between aluminum platens
    - Clamped-edge support along one edge of the specimen
  - Quasi-static tests
    - 44kN MTS electromechanical load frame
    - Strain gage based load cell
  - Dynamic tests
    - 25.5mm/s and higher
    - 24kN MTS high rate servo m/c
    - Piezoelectric load cell
- Data acquisition
  - Force, stroke and strain

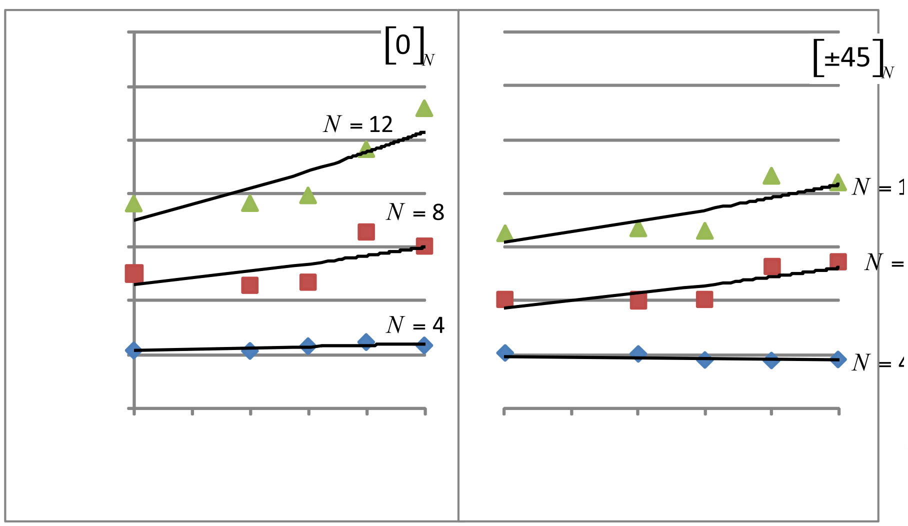




Results..EA device

- Peak loads increase with test speed.
  - Consistent with rate sensitivity of intrinsic material strength
- dependent on laminate thickness and stacking sequence



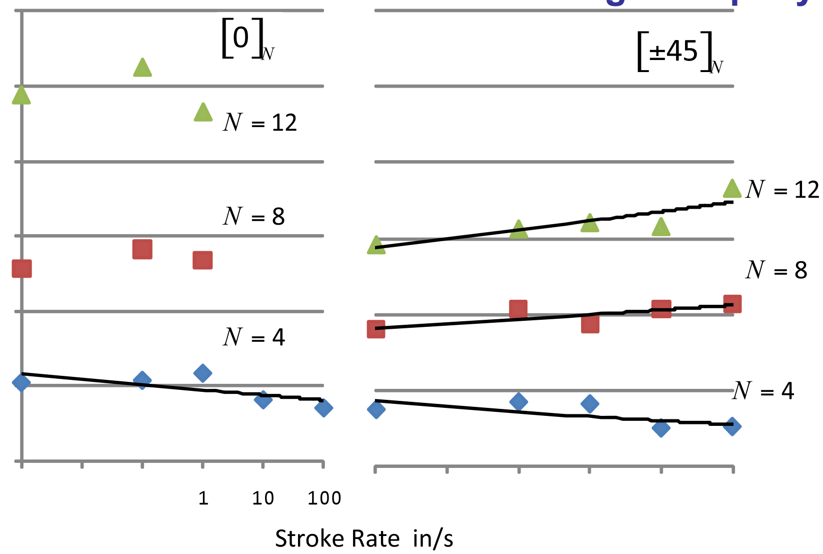


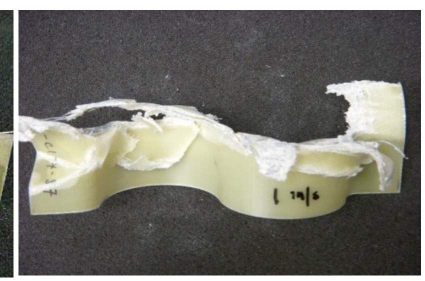
Toray T700G-12K-50C/3900-2 PWCF

Results..EA device

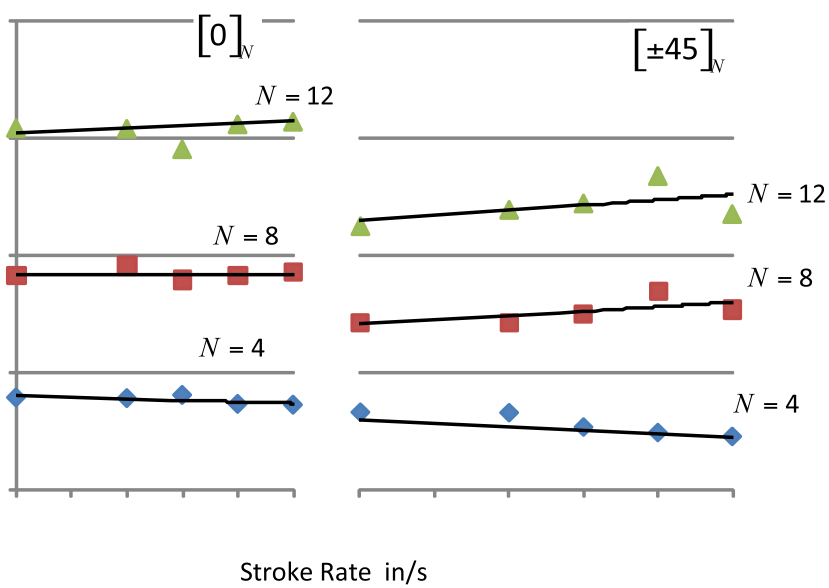
- Crush loads less sensitive to test speed
  - Multiple failure mechanisms with contrasting rate sensitivities

NB321/7781 fiberglass/epoxy

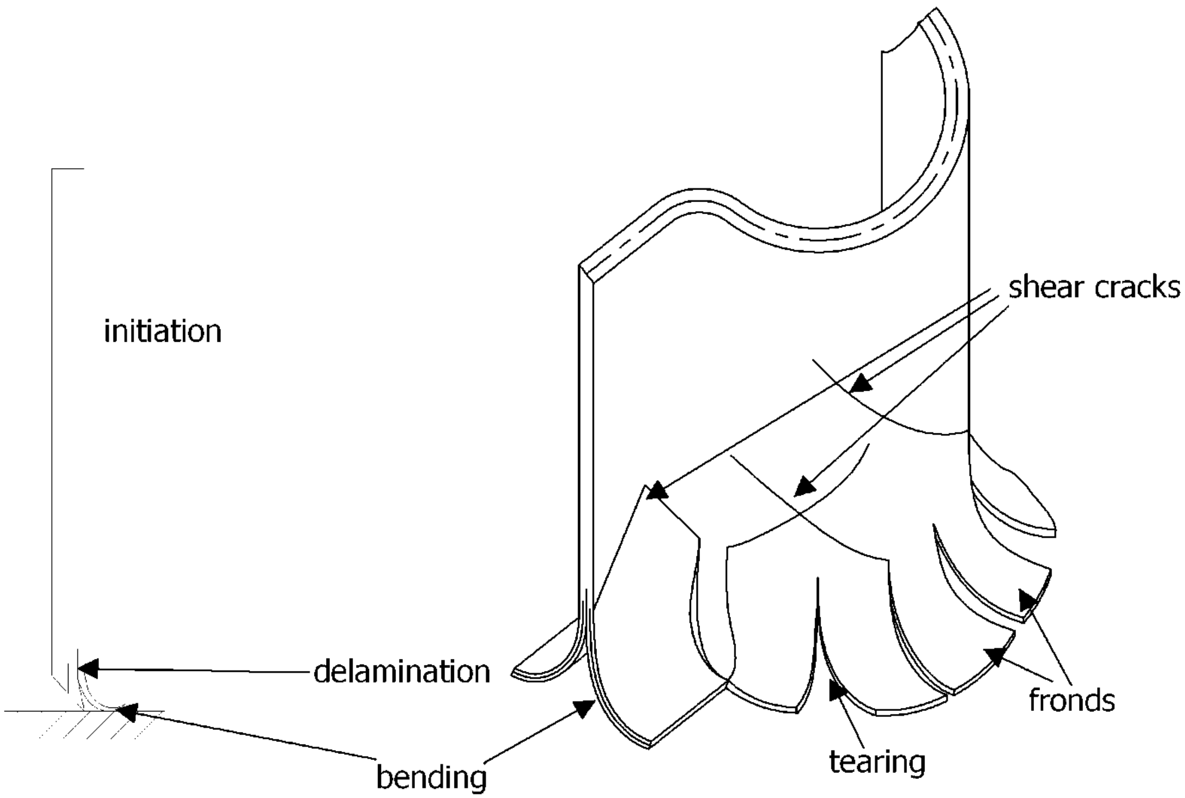


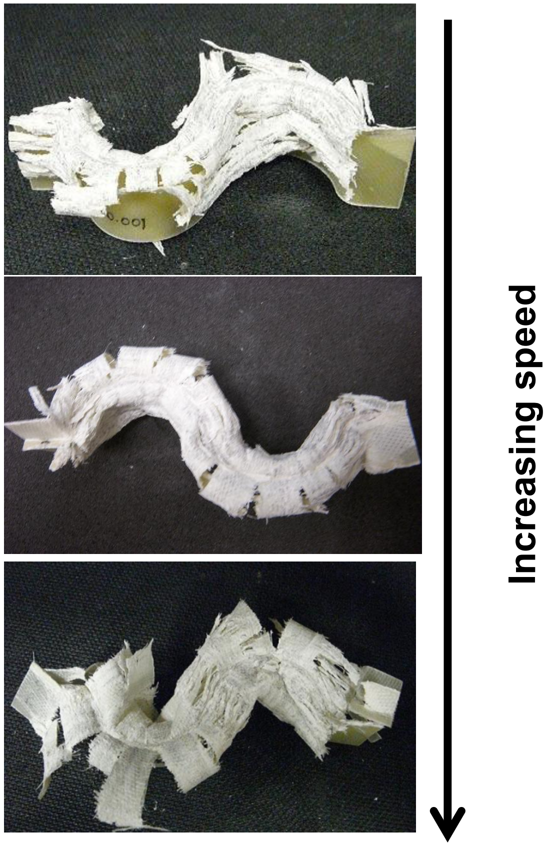


Toray T700G-12K-50C/3900-2 PWCF



Results..EA device

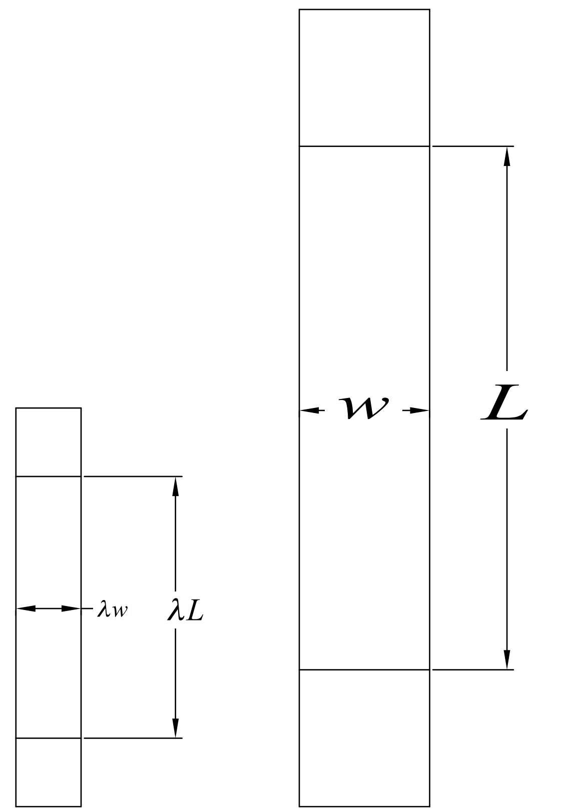




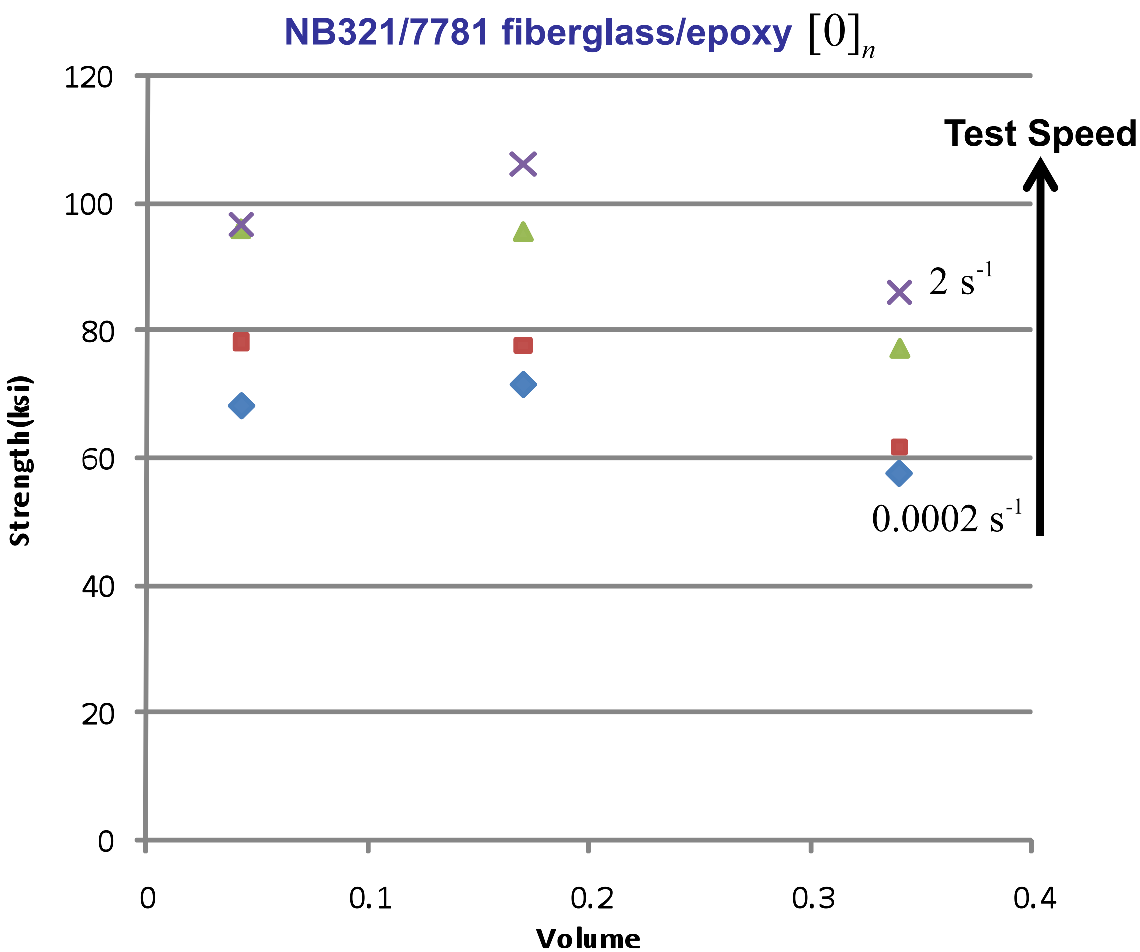
Scaling Studies

- Material Systems: NB321/7781; Toray Unitape
- Aerial (2D) Scaling (fabrics)
- Length (1D) Scaling (unitape)
  - Reduced load capability of test apparatus
- Strain rate range ~ quasi-static to ~10s^{-1}

Material	Stacking sequence	Scale λ	Width W (in)	Length L (in)
Newport NB321/7781 fiberglass	$[0]_4$ $[\pm45]_4$	0.25	0.50	2
		0.50	1.00	4
		1	1.00	8
Toray T800S/3900-2B Unitape	$[0]_4$	0.25	0.50	2
		0.50	0.50	4
		1	0.50	8
	$[+45/-45]_S$	0.25	0.50	2
		0.50	1.00	4
		1	1.00	8

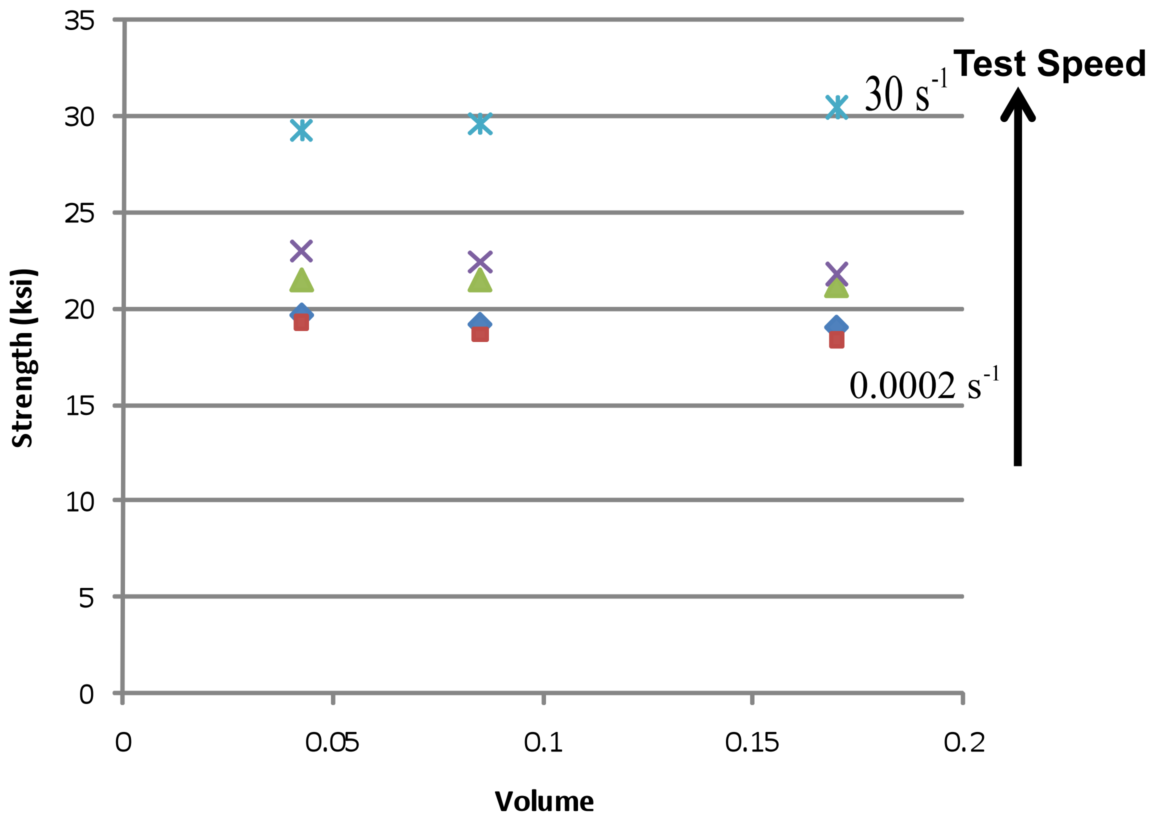


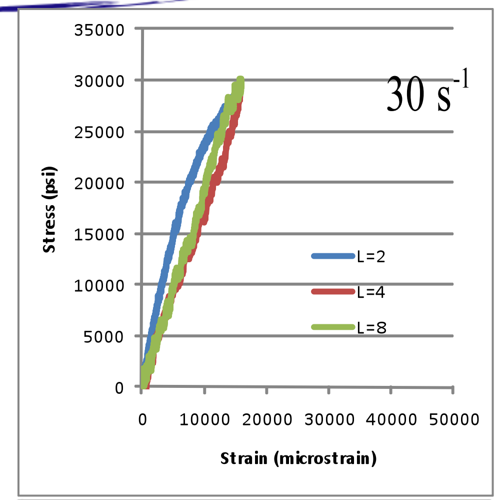
Scaling Studies..Results

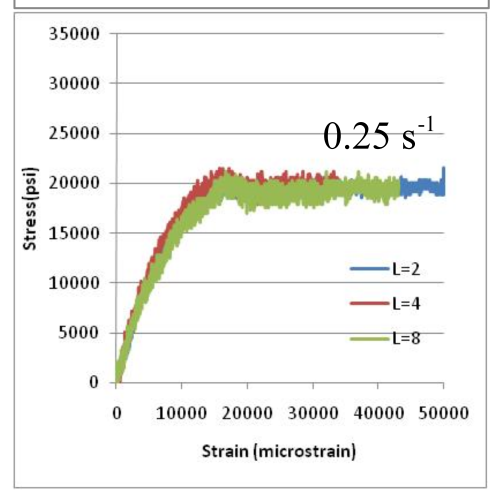


Scaling Studies..Results

Toray Unitape $[+45/-45]_S$







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Jackson K, Kellas S, Morton J. J Compos Mater 1992;26(18):2674–705.

Kellas S, Morton J. ASTM STP, vol. 1156.

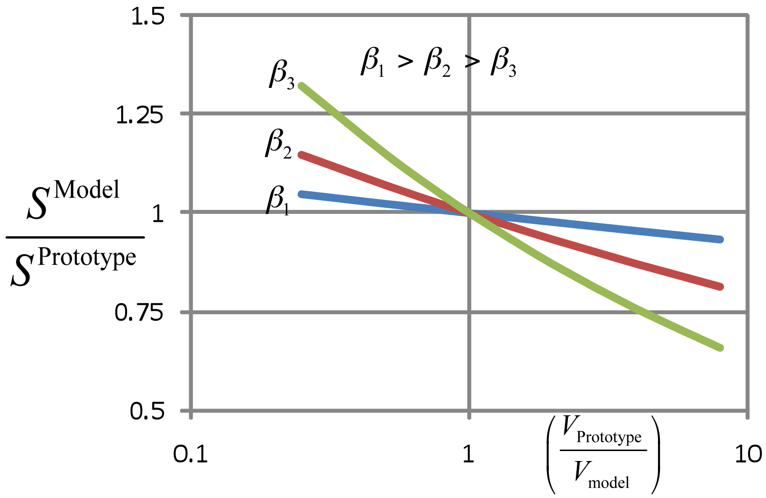
Scaling Studies..Weibull model

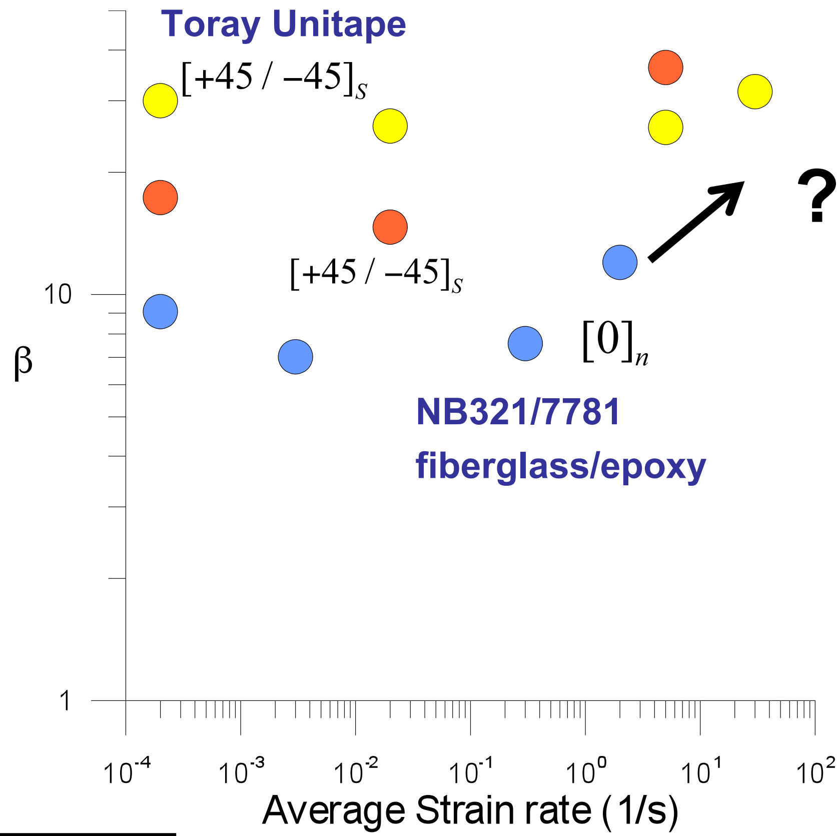
$$\frac{S^{\text{Model}}}{S^{\text{Prototype}}} = \left(\frac{V_{\text{Prototype}}}{V_{\text{model}}}\right)^{\frac{1}{\beta}}$$

$S \sim Strength$

$V \sim Volume$

$\beta \sim Weibull\ Shape\ parameter$





Bullock, R. E. 1974. "Strength Ratios of Composite Materials in Flexure and Tension," Journal of Composite Materials, 8:200-206.

Status/Ongoing work

- Scaling studies
  - Failure modes
  - Weibull model
    - Account for differences disproportional thickness and planar scaling
- Characterization of CMH-17 material
  - Tension, Compression, Shear, Fracture toughness
  - Testing under progress

A Look Forward

- Benefit to Aviation
  - Rate sensitive test data for candidate material systems
  - Scaling effects
  - Rate sensitivity of EA devices
- Future Needs
  - Implementation of existing rate sensitive constitutive models for the materials investigated at coupon level
  - Use rate sensitive constitutive models for analyzing EA device(s)
  - Test standards for dynamic material characterization