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Environmental Factor Influence on Composite Design and Certification

2016 Technical Review

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Wichita State University/NIAR

Environmental Factor Influence on Composite Design and Certification

- **Principal Investigators & Researchers**
  - John Tomblin, *PhD*, and Waruna Seneviratne, *PhD*
  - Upul Palliyaguru, Caleb Saathoff, and Tharindu Jayaratne
- **FAA Technical Monitor**
  - Lynn Pham
- **Other FAA Personnel Involved**
  - Larry Ilcewicz, *PhD* and Curtis Davies
- **Industry Participation**

Kansas Aviation Research and Technology (KART)

Environmental Factor Influence on Composite Design and Certification

- **Motivation and Key Issues**

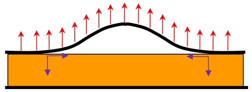
  Moisture absorption characteristics of composites can be coupled with realistic environmental data to design structurally efficient and economic composite components.

- **Objective**

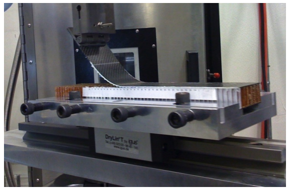
  Provide guidelines for the development of environmental enhancement and to establish practical levels of moisture content and corresponding environmental compensation factors for composite structures.

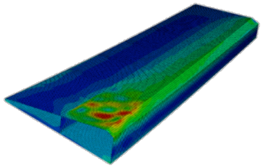
- **Approach**
  - The influence of sandwich parameters such as core size, density, and facesheet/core stiffness ratio on the onset and damage growth rate of sandwich composite
  - Understand the Ground-air-ground effect on onset and damage growth Damage growth in sandwich structures
    - Core types, core densities (24, 32 and 48kg/m³) & F/C thicknesses
  - Viscoelastic effects on thermal residual stresses

Approach



Stress Analysis





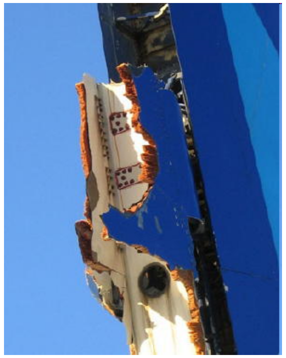
Failure Analysis

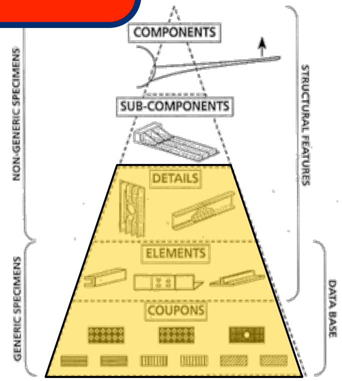
Experimental Data

Analytical Tools

Service Findings

Validation





Guidelines

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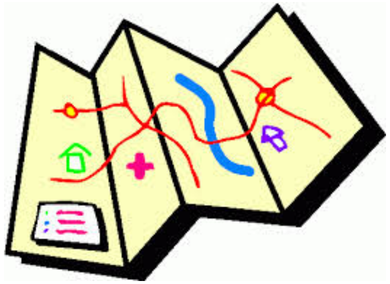
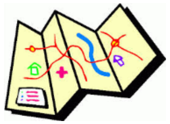
Overview of Presentation

- Guidance for developing and application of **environmental compensation factor** (ECF)
- The influence of sandwich parameters such as core size, density, and facesheet/core stiffness ratio on the onset and **damage growth rate of fluid-ingressed sandwich composite**
- Understand the **ground-air-ground effects** on onset and damage growth Damage growth in sandwich structures
- Viscoelastic behavior of thermal residual stresses (TRS) due to **hygrothermal history**



Environmental Compensation Factor (ECF)



- To satisfy FAA certification requirements for composite structures, FARs require compliance with 23.573, 23.603, 23.613 and 23.619 (can apply also to Part 25 aircraft). General guidelines for a composite structure should be considered which are over what is normally done for metallic certifications (i.e., account for the ***difference*** between composite and metallic structures in certification)
- An approach which may be used, when combined with analytical modeling, is to apply these “overloads” within the model to demonstrate compliance after a successful static structural test (may also be applied during the test) and demonstrating positive margins of safety throughout the structure

Will depend on material system, layup (lamina or laminate), failure mode, damage ….. Based upon some existing data, this could be as high as 1.32

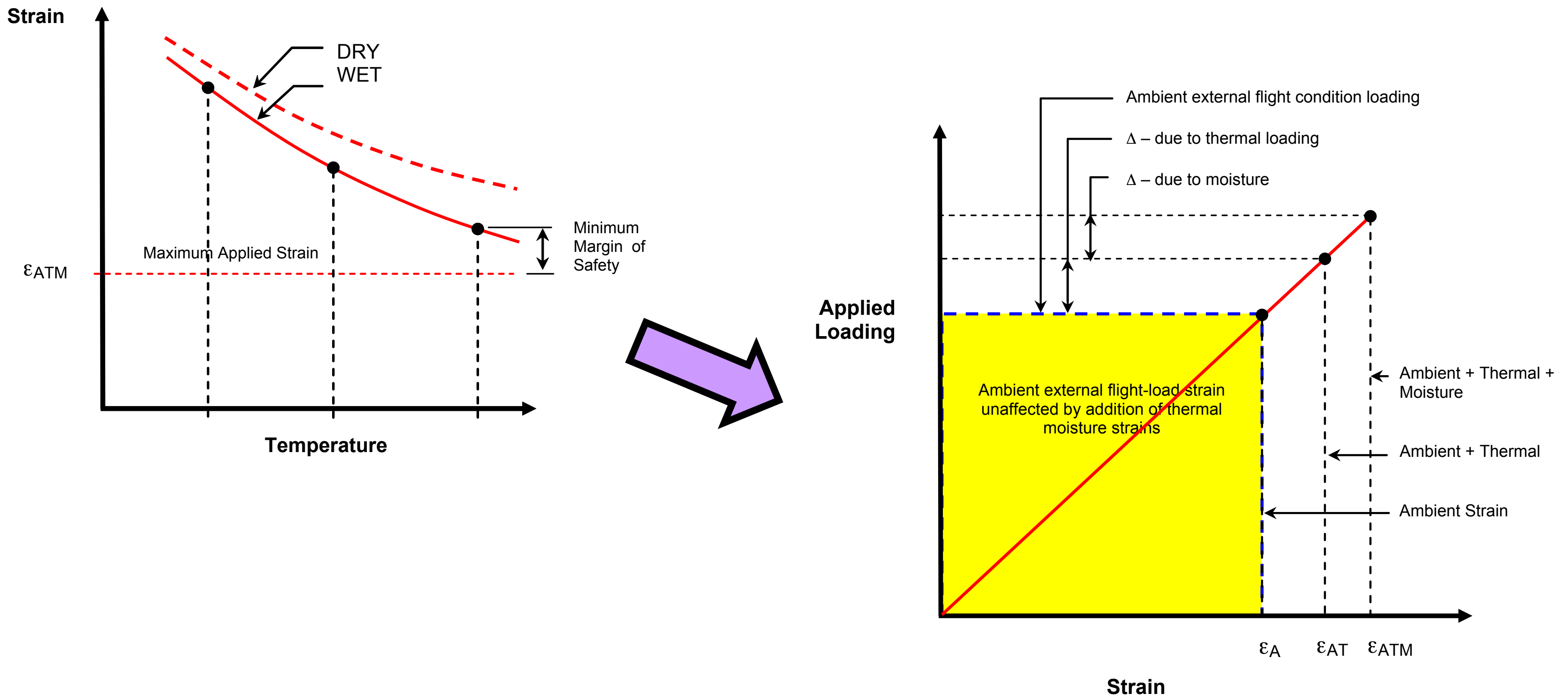
$$SLF = \frac{C_{\substack{composite\\ variability}} \; C_{\substack{composite\\ temperature}} \; C_{\substack{composite\\ moisture}}}{F_{\substack{metals\\ variablity}} \; F_{\substack{metals\\ temperature}} \; F_{\substack{metals\\ moisture}}}$$

Room for improvement in this based upon failure mode in temperature (based upon FEM M.S. model) and amount of moisture actually expected in structure during lifetime

Based on percentage of strength at 180 °F, approximately 1.04

1

ECF - Design & Certification



Typically, ECF is not applied to the full-scale fatigue test spectrum; it is applied to static/residual strength tests as an overload. ECF is substantiated through lower-level building-blocks of testing, i.e., ETW component/element testing.

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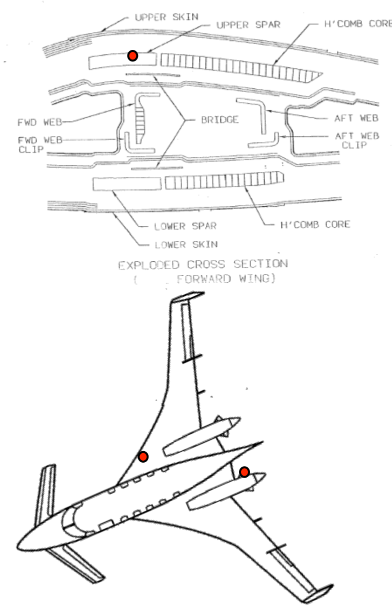
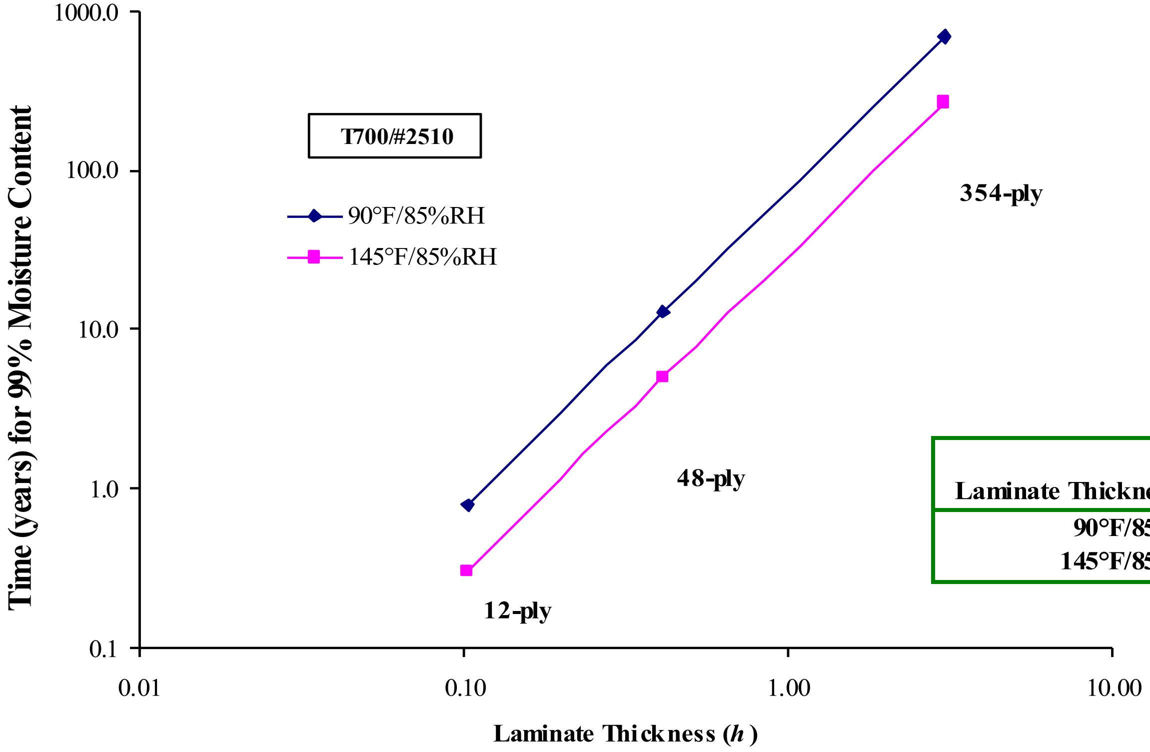
Moisture Absorption for Full Scale Articles

What is realistic?

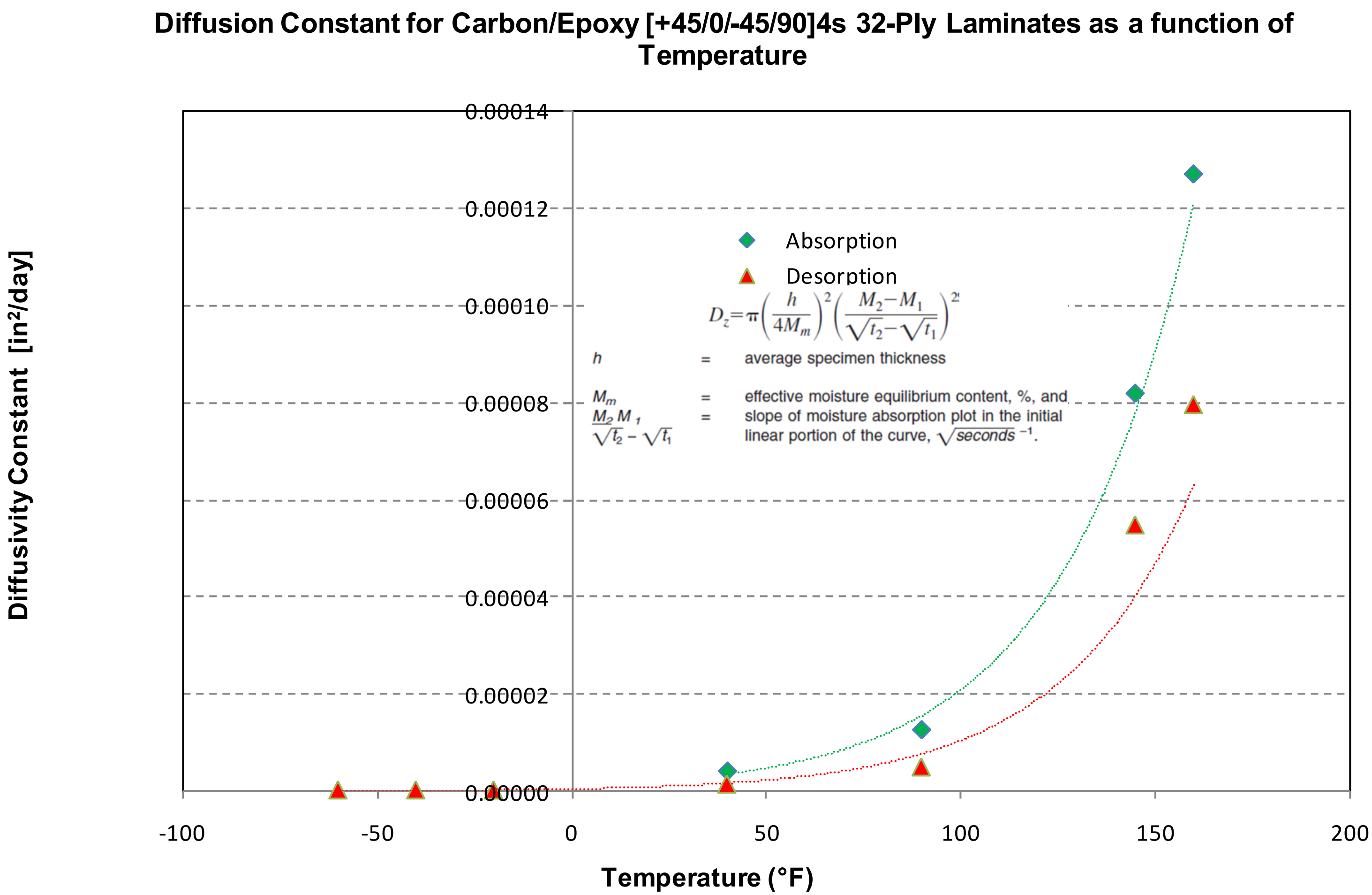
Effects of thickness on the moisture equilibrium can be used to generate customized (lower) ECFs for thick structure.



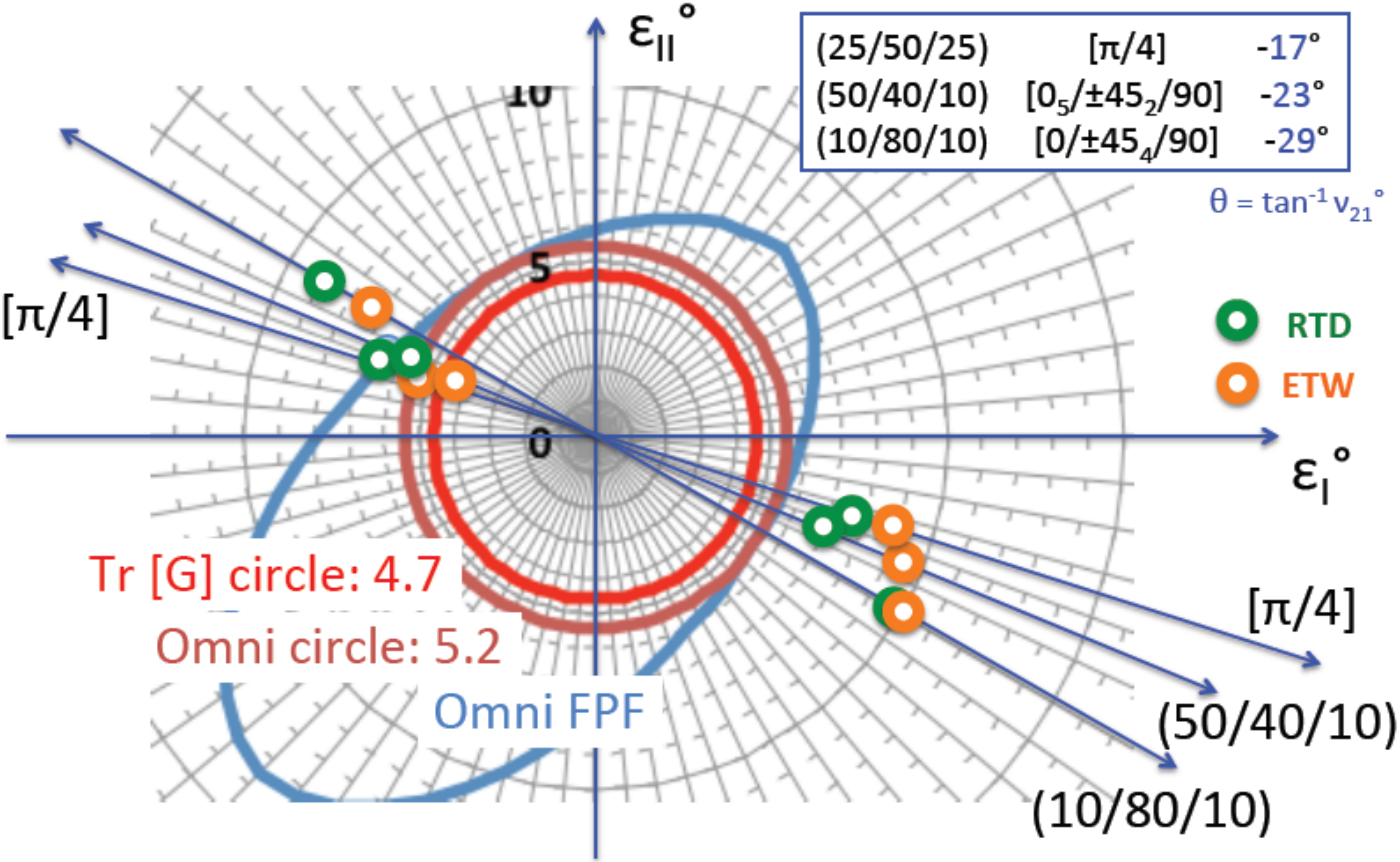


	Years for 99% Saturation		
Laminate Thickness (in)	**0.1032**	**0.4128**	**3.0444**
90°F/85%RH	0.8	12.8	696.6
145°F/85%RH	0.3	5.0	269.4

Diffusivity Constant

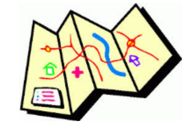


Environmental Effects



Plasticization ➔ reorientation of fibers
➔ higher hot wet properties in tensile loading

Research Overview on Sandwich Disbond Growth [2009 – 2016]

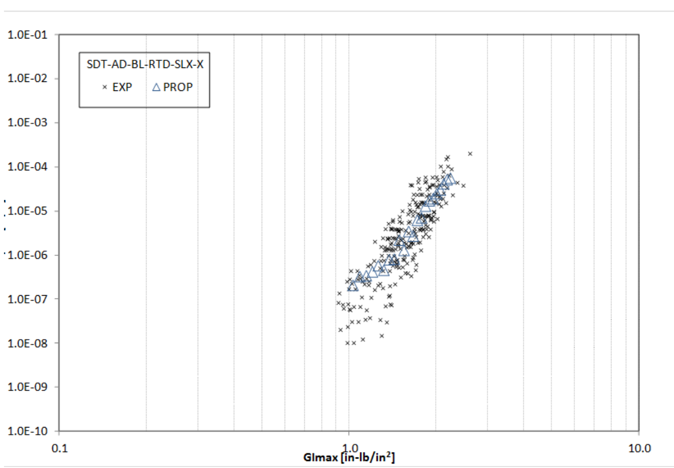


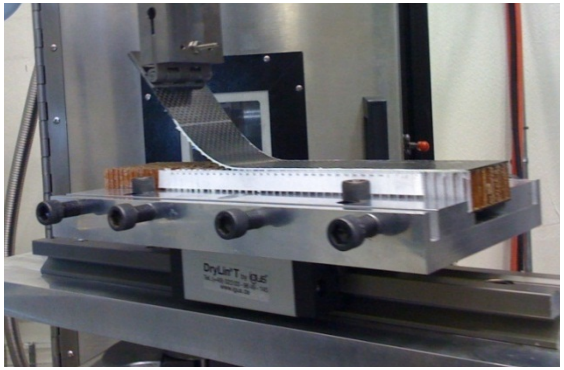
- Single-cantilever beam (SCB) testing
  - Test/conditioning procedures (2009 – 2010)
  - Static (2010 – 2012)
  - Fatigue (2011 – 2013)
  - Supplemental damage growth studies (2013 – 2014)
- Ground-air-ground (GAG) simulations
  - Edgewise compression (2014 – 2016)
    - Static
    - Fatigue
- Further studies (2016 – ....)
  - GAG testing with large flex test
  - Sandwich damage growth simulations

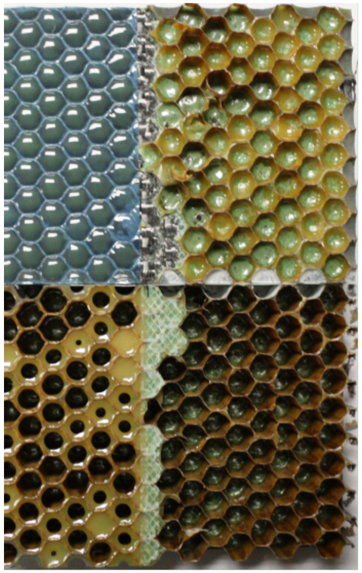
Accomplishments year to date…

Mode I (G1c) Fracture Toughness of Composite Sandwich Structures for Use in Damage Tolerance Design and Analysis

- Volume 1: ***Static Testing Including Effects of Fluid Ingression***
- Volume 2: ***Fatigue Testing Including Effects of Fluid Ingression***
- Volume 3: ***Supplemental Static Testing***







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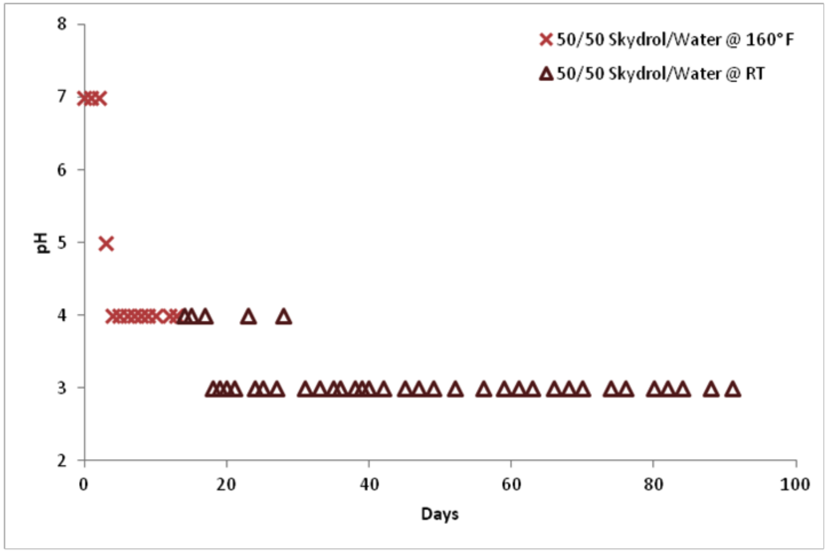
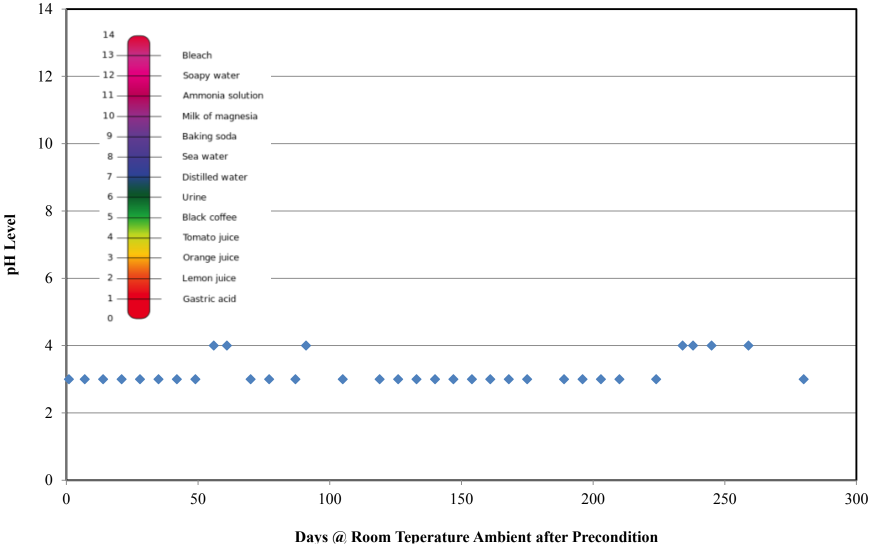
Skydrol Conditioning Procedure

- Mix the needed amount of 50% Skydrol and 50% water solution in the air tight container.
- Place the container inside the conditioning camber at 160 °F for 14 days, mixing thoroughly once a day.
- Remove the container from the conditioning camber and let set at room temperature until cooled.
- The solution should now be at 3-4 pH and will remain so for at least 90 days, if stored at room temperature.





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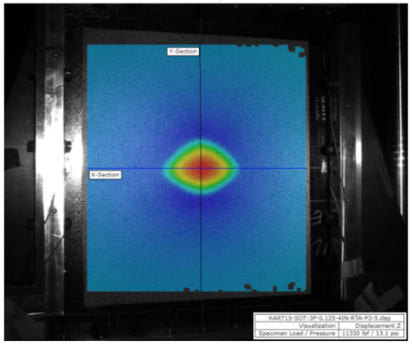
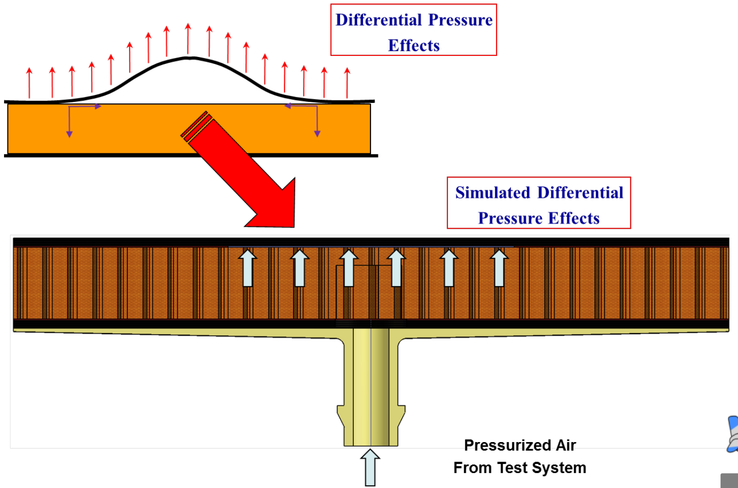
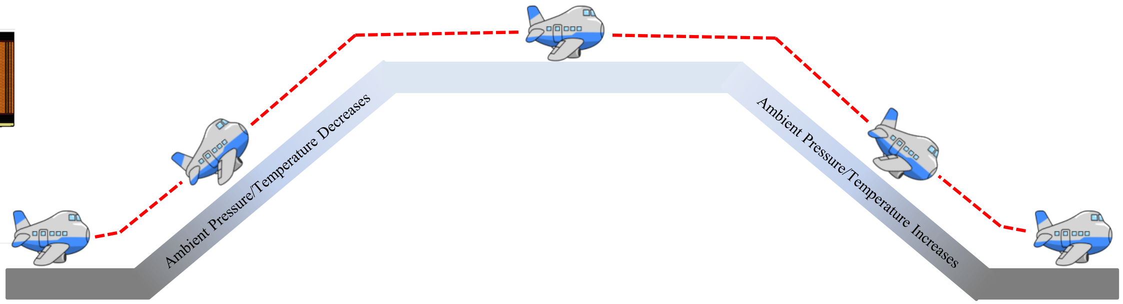
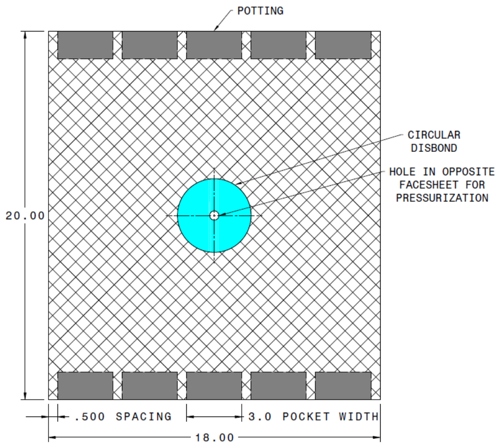
Ground-Air-Ground Cyclic Testing

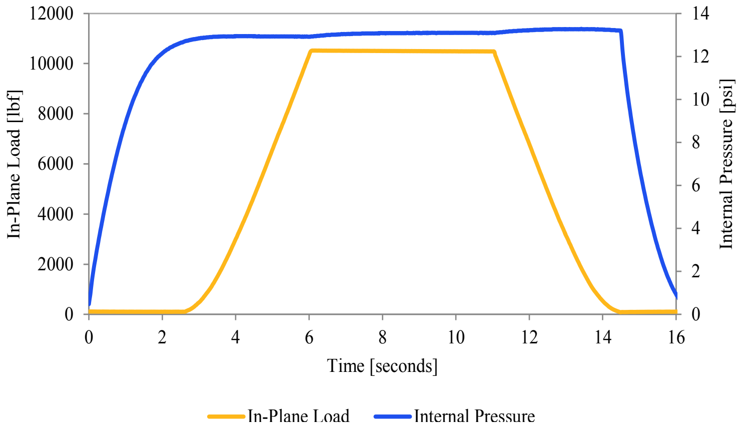
- Edgewise Compression











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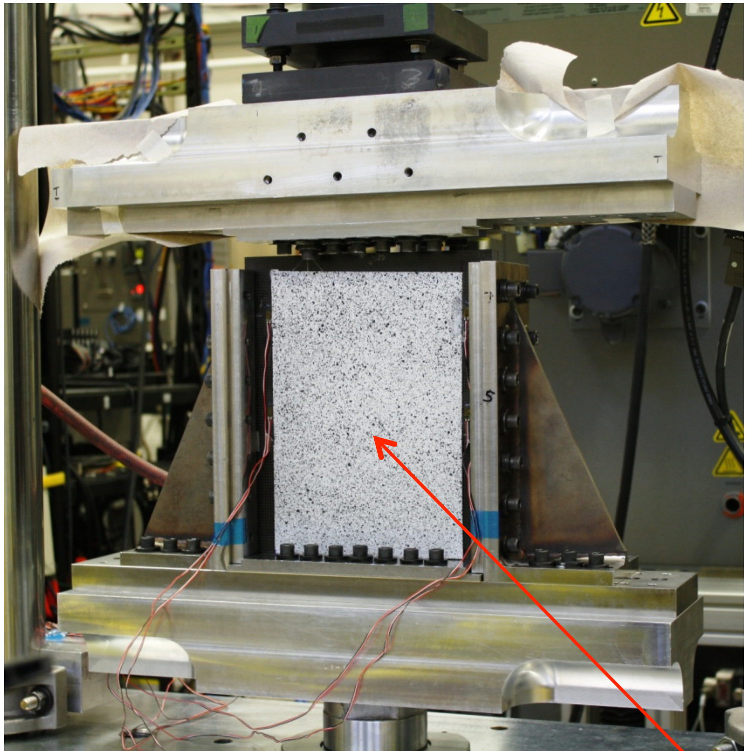
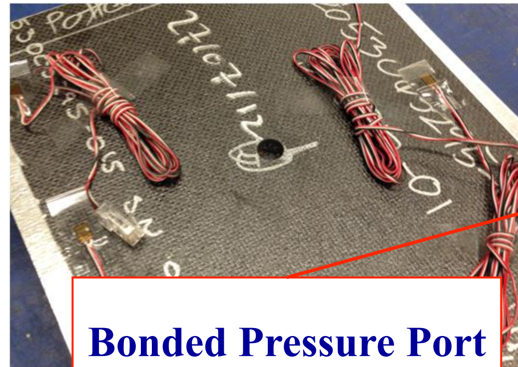
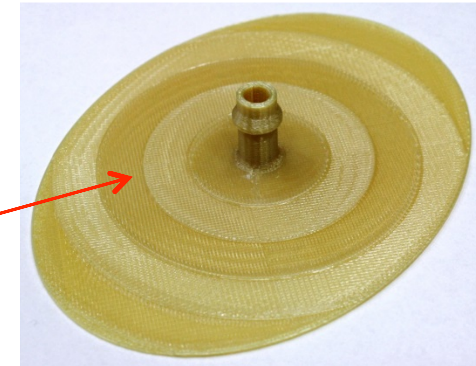
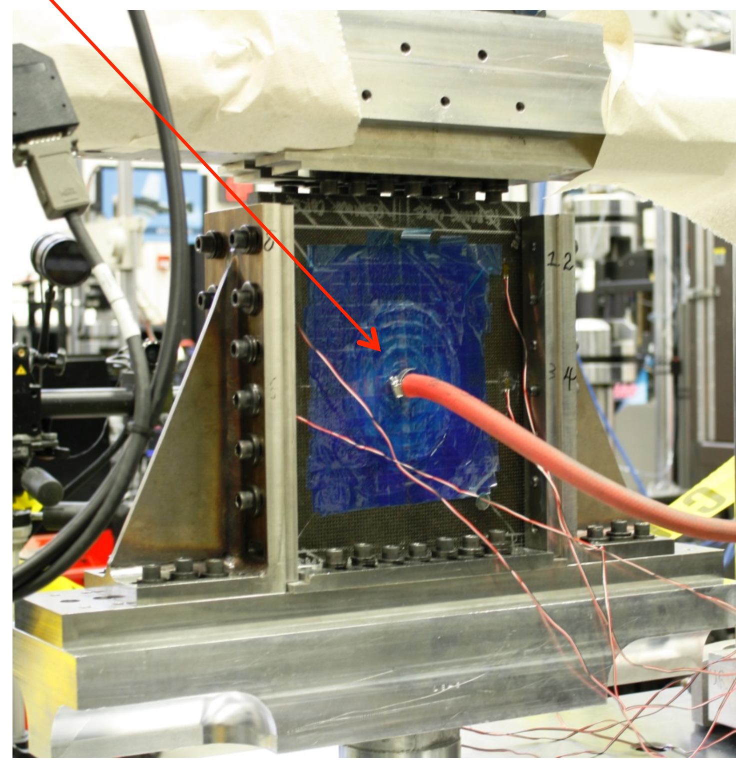
Edgewise Compression Test Setup







Bonded Pressure Port



DIC speckle pattern on Damage Side

Ability to accommodate various specimen sizes

- Test Specimen 18x20-inch

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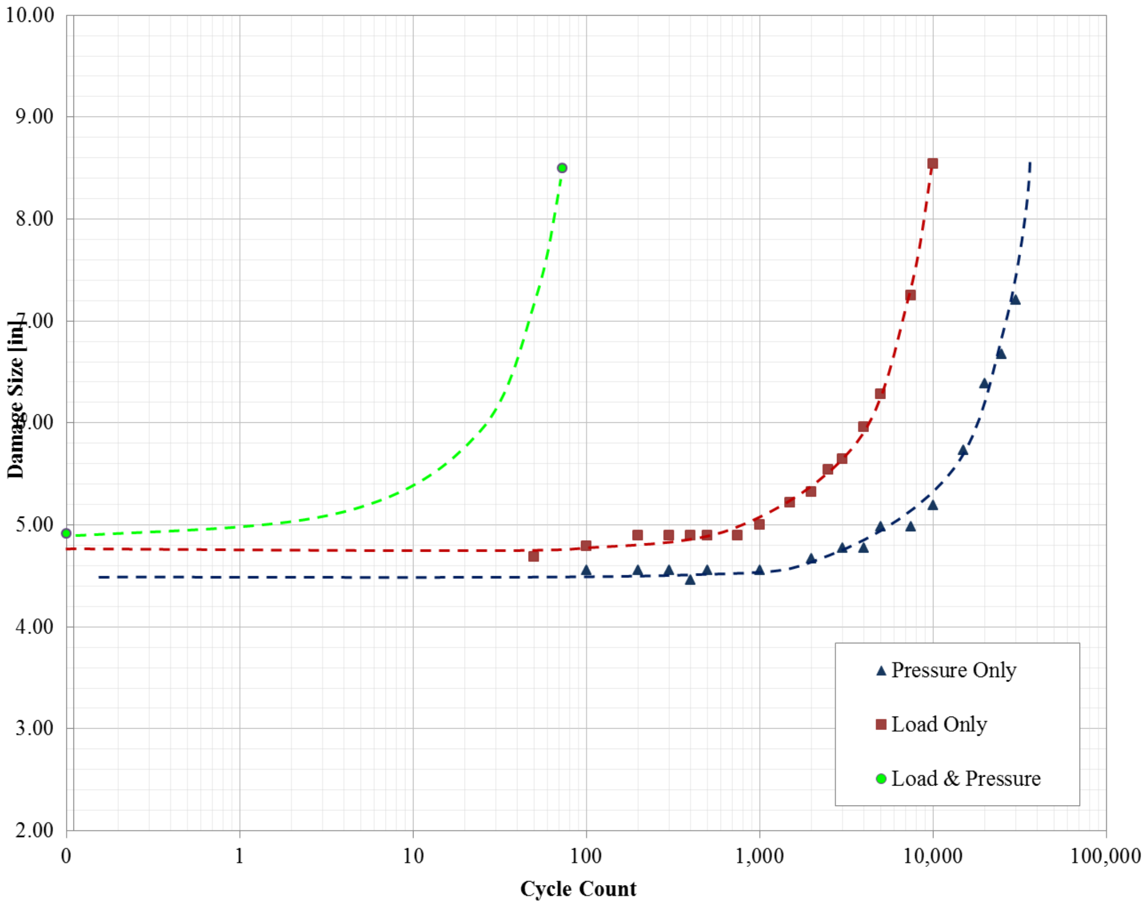
GAG Test Summary



SPECIMEN NAME	Pr. [psi]	MAX FATIGUE LOAD [lb]	MAX FATIGUE STRESS [ksi]	n
3P-0.125-4IN-RTA-LP-1	13.1	10834	9.993	73
3P-0.125-4IN-RTA-LP-2	13.1	11101	10.615	58
3P-0.125-4IN-RTA-LP-3	13.1	11320	9.943	65
3P-0.125-4IN-CTW-LP-1	13.1	10545	8.960	1151
3P-0.125-4IN-CTD-LP-1	13.1	11329	10.254	1121
3P-0.125-4IN-RTA-L-1	0.0	10834	10.947	11956
3P-0.125-4IN-CTW-L-1	0.0	11413	10.889	24000
3P-0.125-4IN-CTD-L-1	0.0	13498	12.092	26389
3P-0.125-4IN-RTA-P-1	13.1	N/A	N/A	41500
3P-0.125-4IN-CTW-P-1	13.1	N/A	N/A	-
4P-0.125-4IN-RTA-LP-1	13.1	14194	11.448	222
4P-0.125-4IN-RTA-LP-2	13.1	13960	9.723	330
4P-0.125-4IN-CTD-LP-1	13.1	13840	9.717	1872
4P-0.125-4IN-RTA-L-1	0.0	13701	11.034	11356
4P-0.125-4IN-RTA-P-1	13.1	N/A	N/A	-

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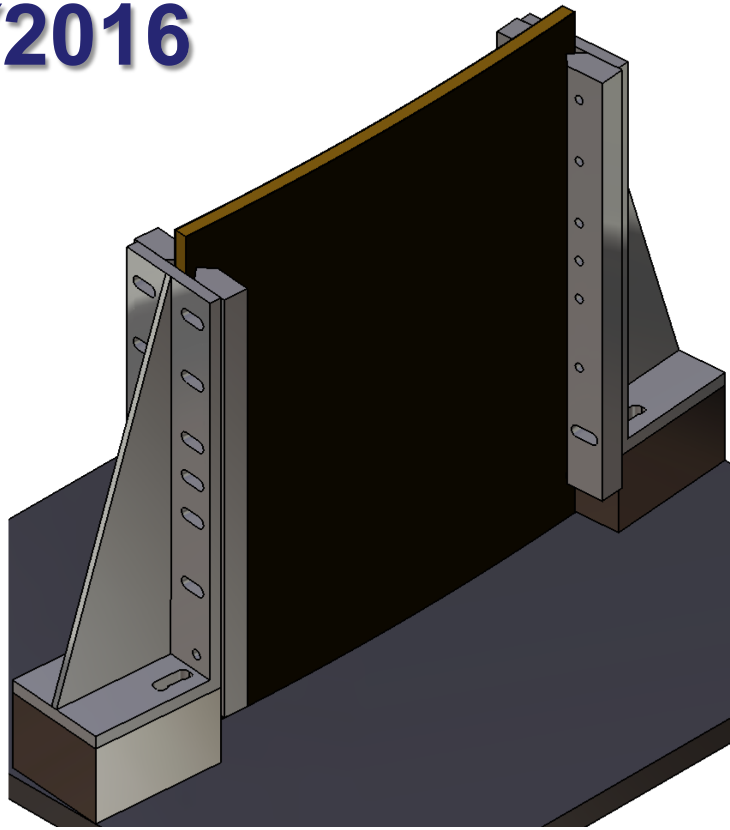
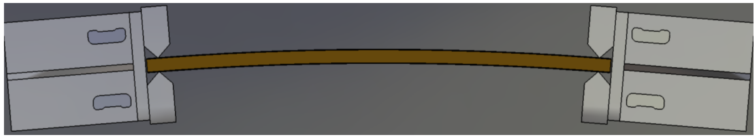
Curved Panel Testing – FY2016

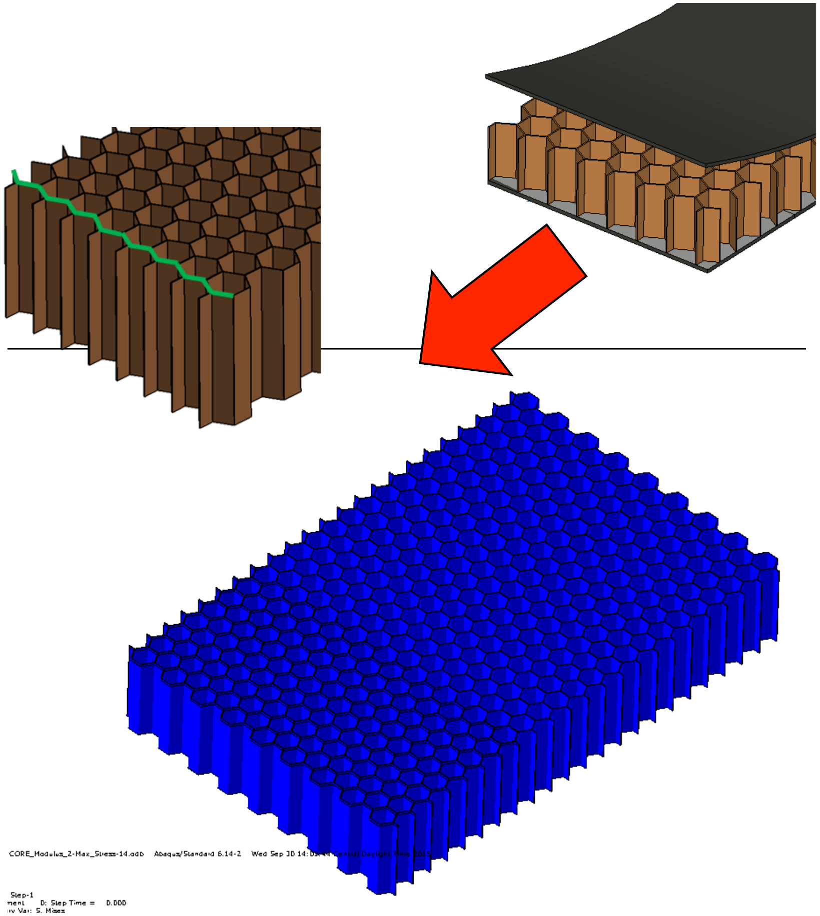


- **Curved Edgewise Compression Review**
  4. Panel Curvature
     - Representative cabin
  5. Panel Fabrication
     - Tool currently available
       - 110 inch radius
  6. Pressure System
     - Small modification to pressure port

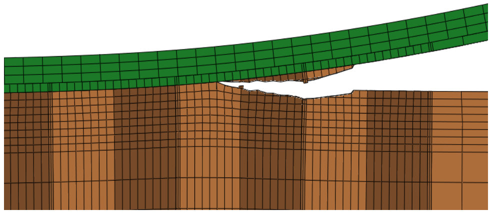
KART Ground-Air-Ground Test Matrix FY2016					
Test Article	Loading Conditions	Three Ply			
		Static		Fatigue	
		RTA	CTW	RTA	CTW
Curved Edgewise Compression	Internal Pressure Only			1	
	Axial Load Only	2	2	2	2
	Internal Pressure + Axial Load	3	3	3	3
Total Specimens Required		21			

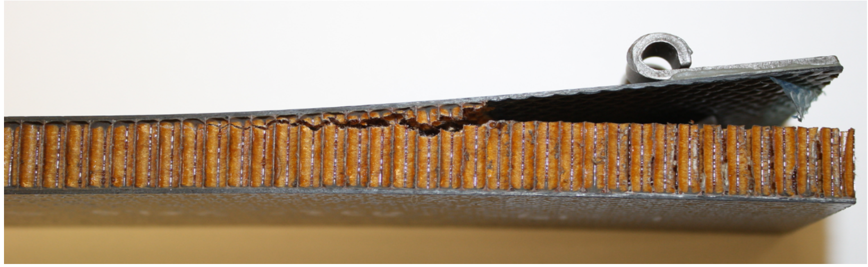


Development of Predictive Capabilities



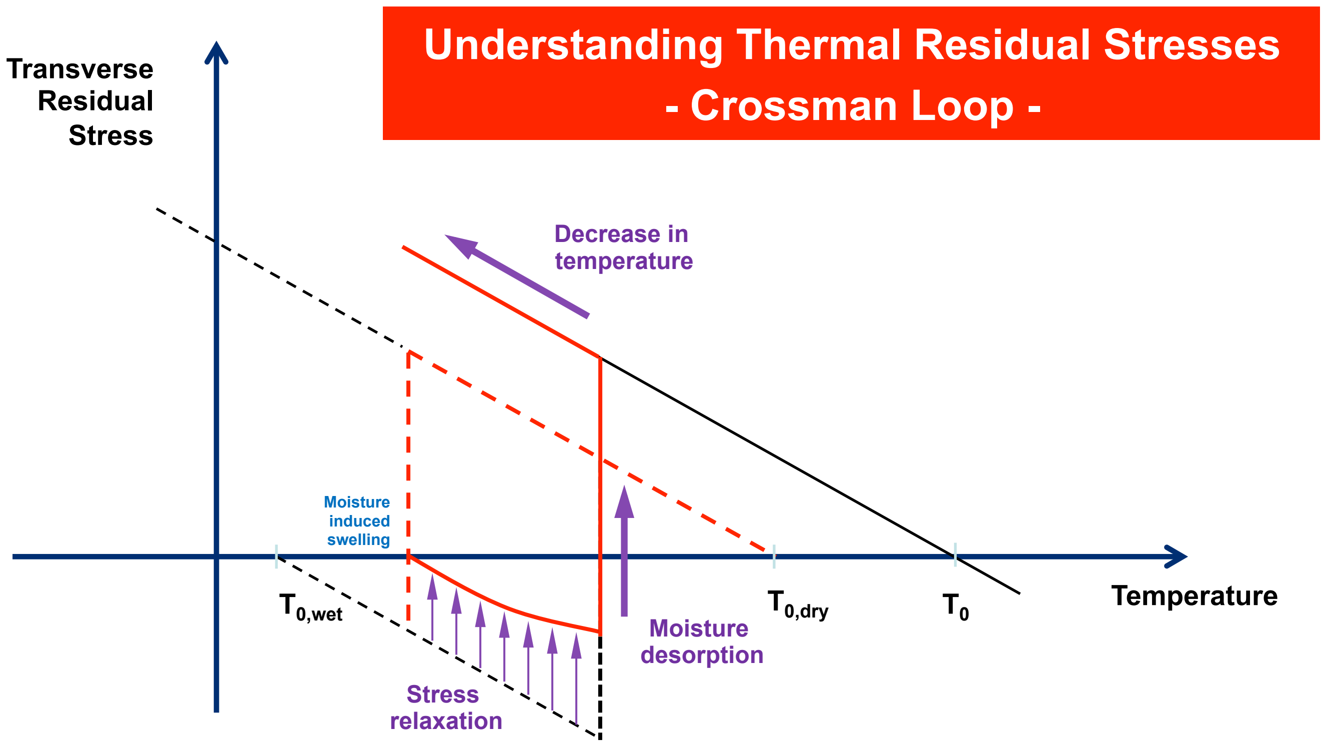
Anticlastic bending and irregular/wavy





Three dimensional non-planar crack

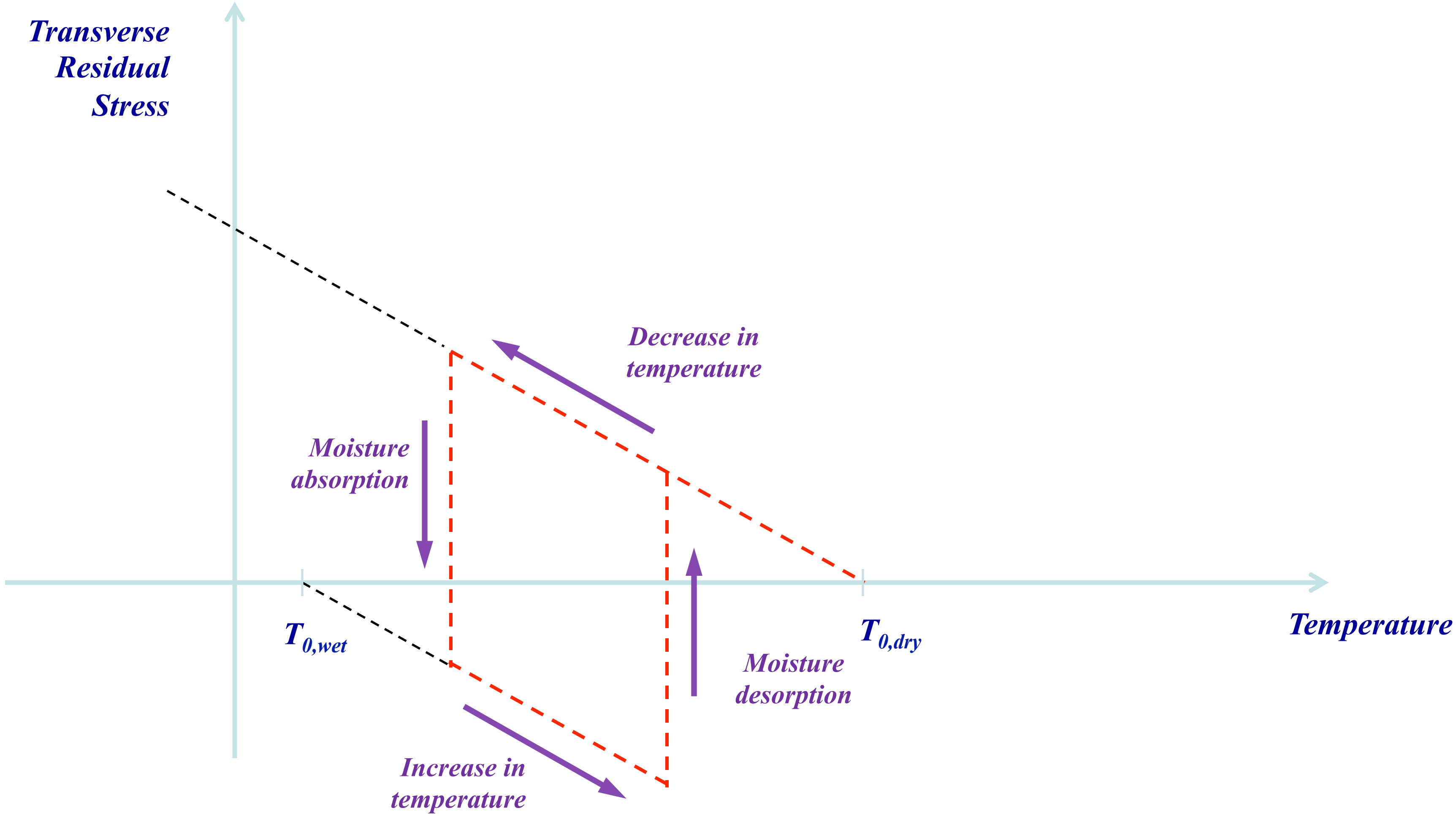
Viscoelastic Behavior of TRS due to Hygrothermal History



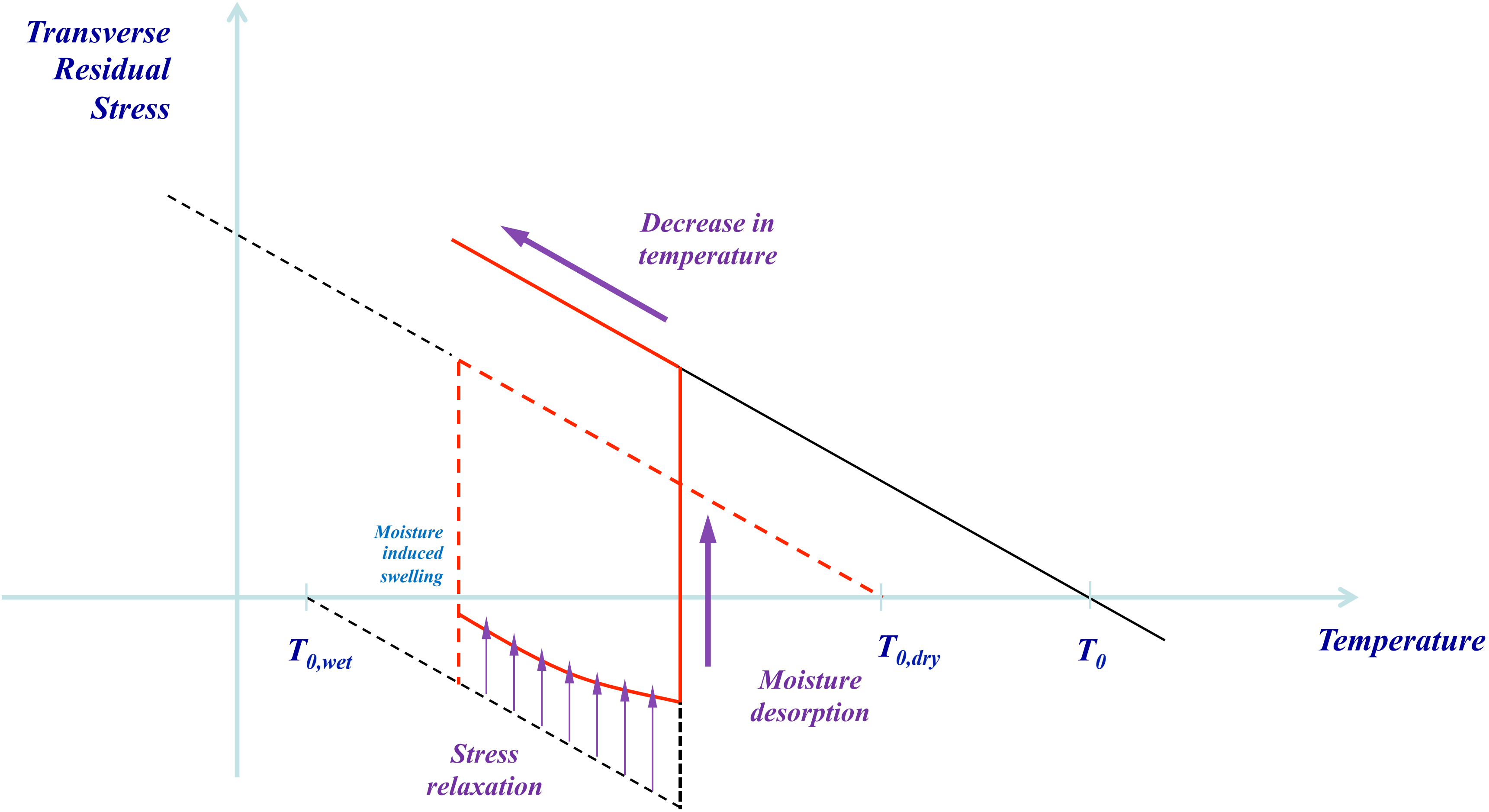
Research based on:

Rothschilds, R. J., Ilcewicz, L. B., Nordin, P., and Applegate, S. H., "The Effect of Hygrothermal Histories on Matrix Cracking in Fiber Reinforced Laminates," ***Journal of Engineering Materials and Technology*****, Vol. 110, pp. 158-168, 1988.**

Elastic Behavior of TRS



Viscoelastic Behavior of TRS due to Hygrothermal History



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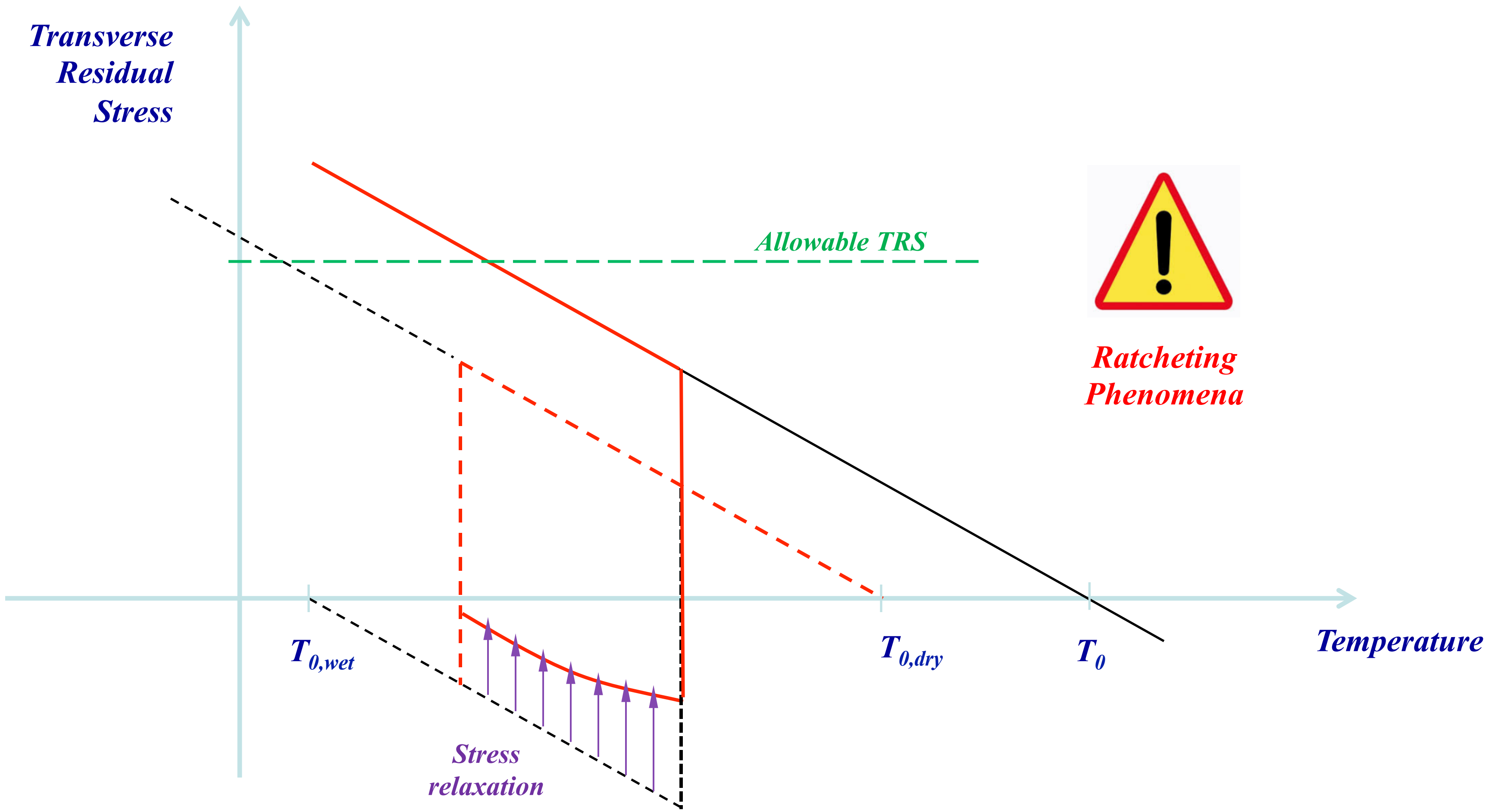
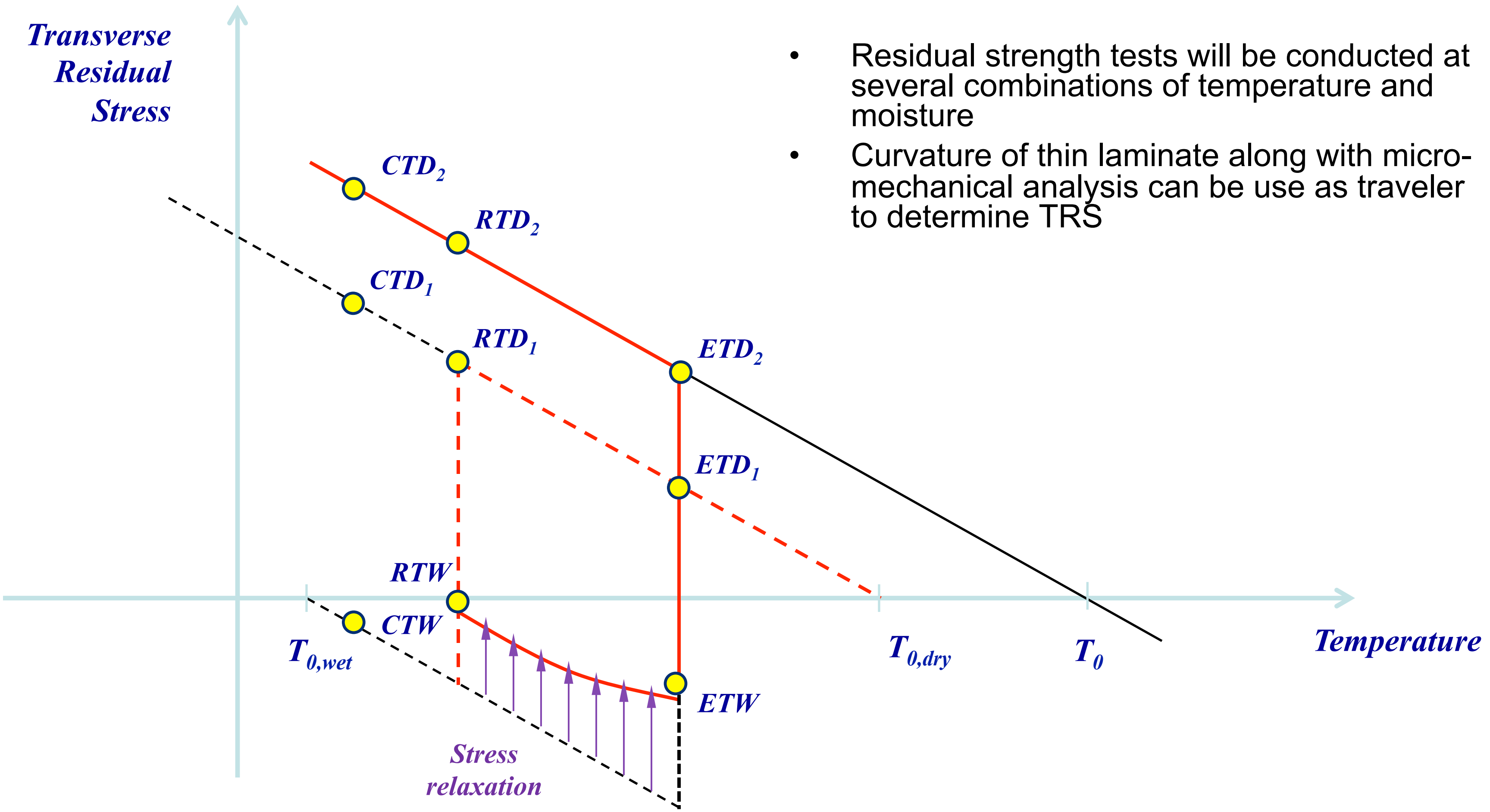
Safety Concern!

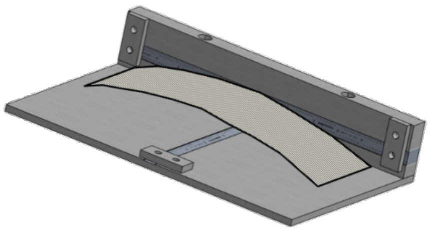


Residual Strength Evaluation

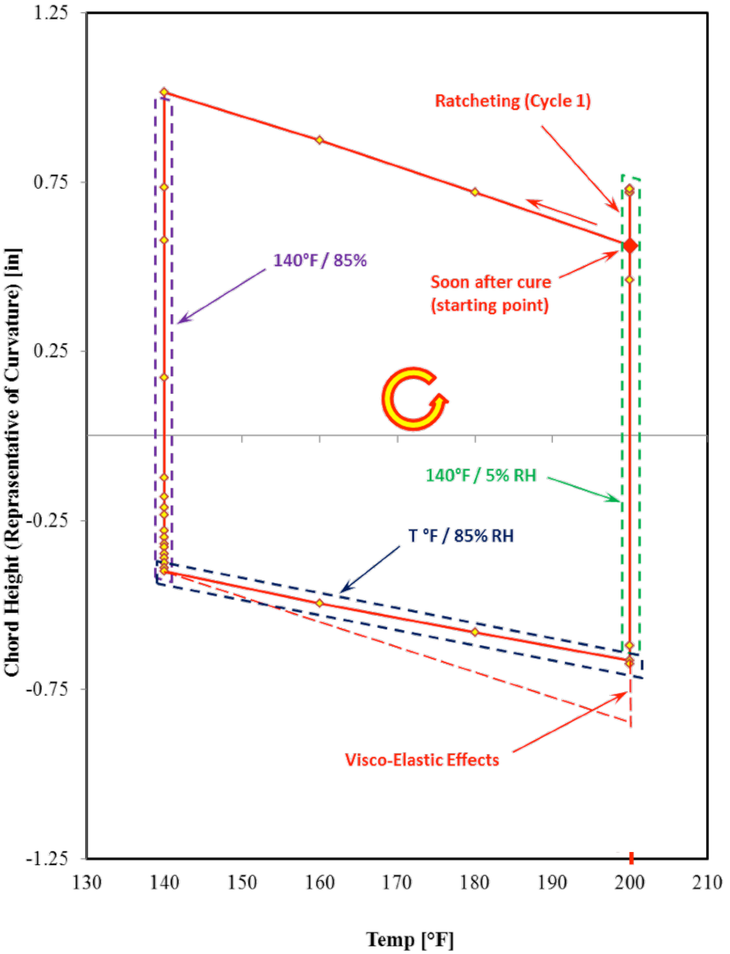


- Residual strength tests will be conducted at several combinations of temperature and moisture
- Curvature of thin laminate along with micro-mechanical analysis can be use as traveler to determine TRS

Hygrothermal Effects on Composite Splice Joints



- Thin Specimen Hygrothermal Cycling
  - Use curvature of thin unsymmetric laminate as a measure of residual stresses
  - Cycle thin laminate specimens through a Crossman Loop
  - Observe viscoelastic response and residual stress relaxation
  - Investigate ratchetting phenomenon



- Specimen Configuration
  - $[0_2/90_2]$ Unsymmetric Layup
  - Cytec T650/5320-1 UNI
  - 290 °F Cure
  - 0.022” panel thickness
  - 1.5” x 10” specimens

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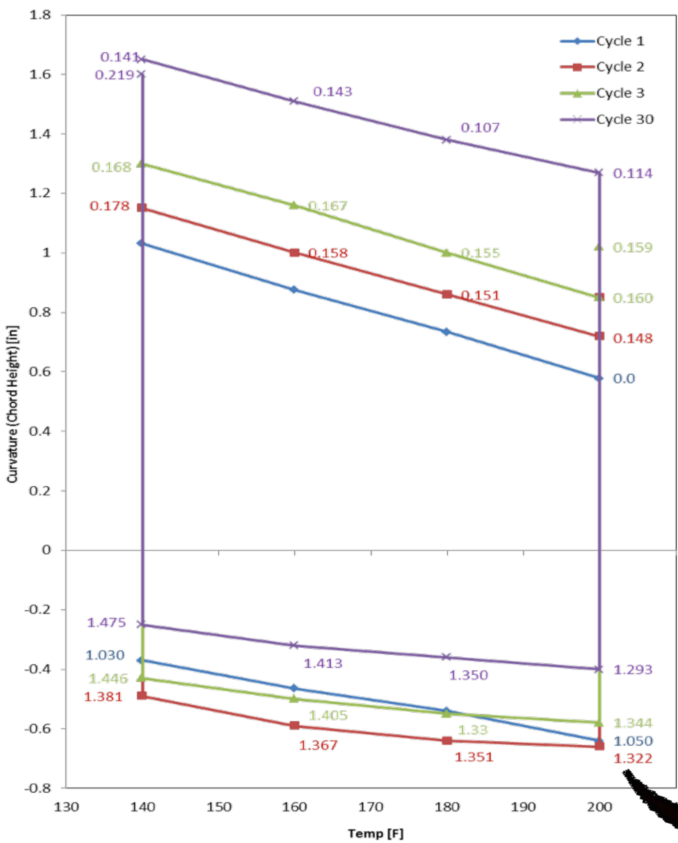
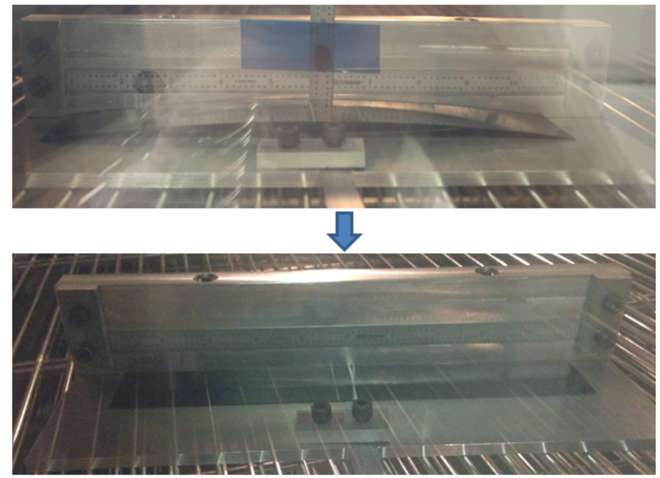
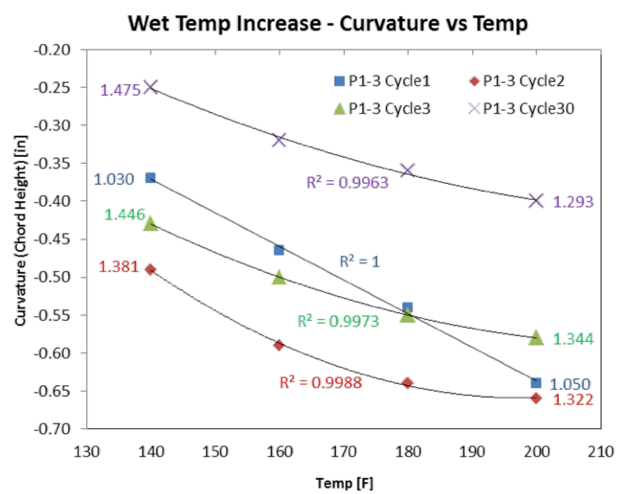
Ratcheting Effects – 4-Ply Specimens







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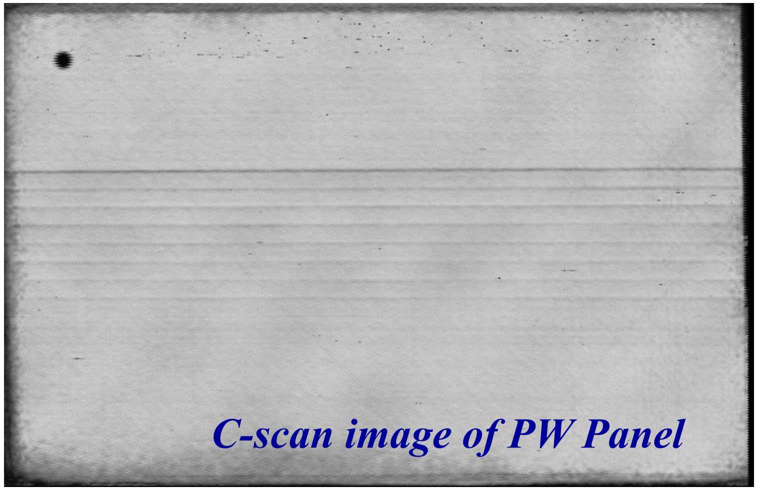
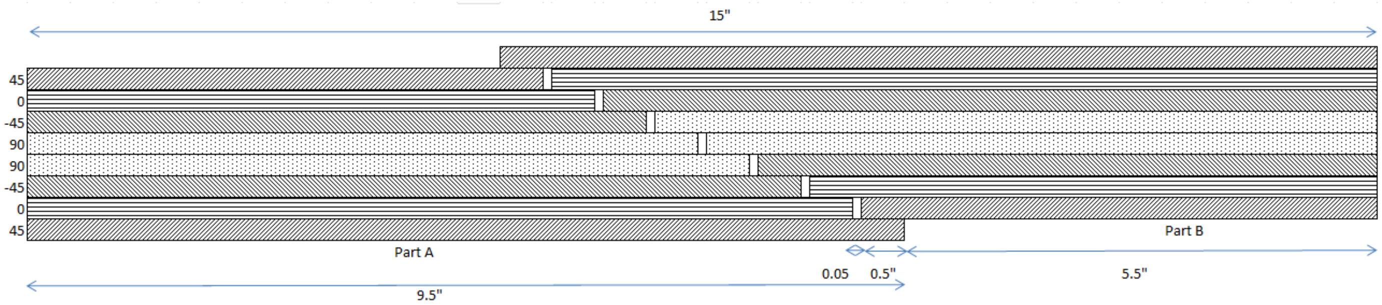
Spliced Tensile Specimens

- Panels manufactured with the above splice configuration
  - T650/5320-1 Unidirectional material
  - T650/5320-1 Plain-Weave material
- Quasi layup $[45/0/-45/90]_S$
- 0.5” Overlap, 0.05” Splice Gap
- 1.5”x12” tensile specimens



C-scan image of PW Panel



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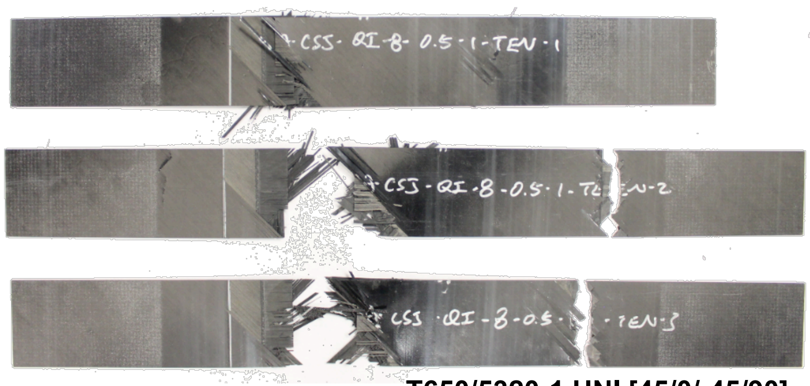
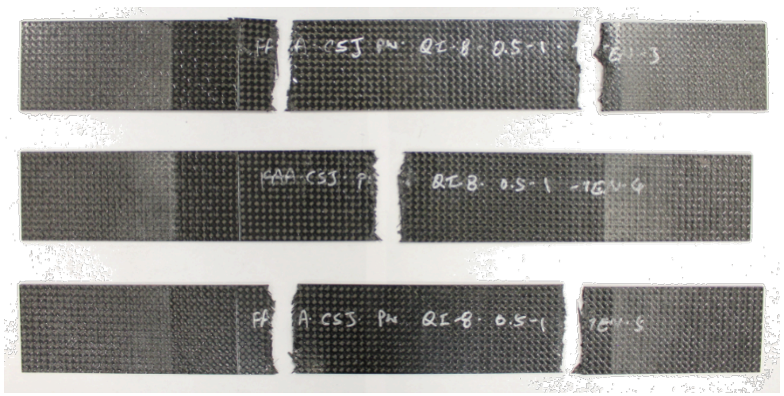
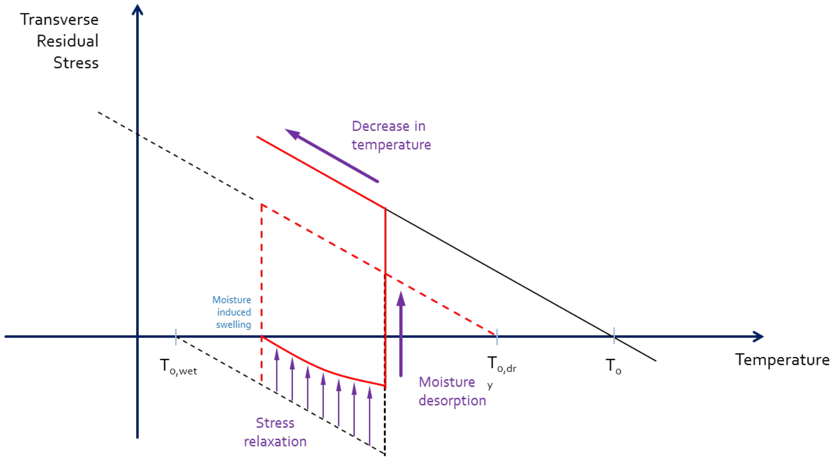
8-Ply Spliced Tensile Specimens

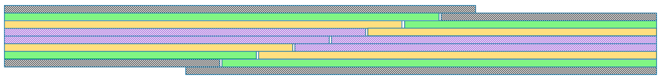


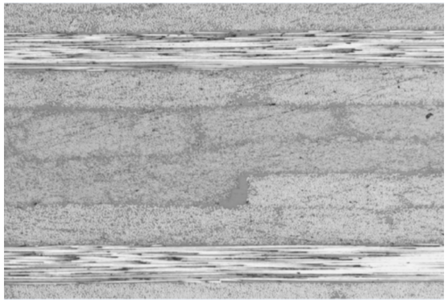
T650/5320-1 UNI $[45/0/-45/90]_s$



T650/5320-1 PW $[45/0/-45/90]_s$







Summary

- Guidelines for design and certification of composite structures related to environmental knockdown based on practical levels of moisture content and operational usage is in progress
  - Full-scale static strength demonstration
  - Durability and damage tolerance test substantiation
- SCB Testing
  - Fluid ingression phenomenon and the progressive damage growth due to entrapped fluids in sandwich structures
- GAG
  - Pressure and load combined loading significantly reduced the static strength and fatigue life of the sandwich structure
- Viscoelastic behavior of TRS
  - Ratcheting phenmenon is noted from cycle 1
  - Effects of hygrothermal cycling on mechanical properties of splice joints are under investigation

Looking Forward

- **Benefit to Aviation**
  - Systematic approach for developing environmental knockdown factors based on structural details
  - Possibility of extending the methodology for life extension strategies
  - Guidelines for substantiating sandwich structures
    - Fluid ingression phenomenon
    - GAG effects on damage growth
    - Effects of geometry and sandwich parameters on fracture toughness and damage growth rates
- **Future needs**
  - Test articles representing modern day composite structures
  - Environmental history data

End of Presentation.

Thank you.

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