Environmental Factor Influence on Composite Design and Certification

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The Joint Advanced Materials and Structures Center of Excellence

Environmental Factor Influence on Composite Design and Certification

- Motivation and Key Issues
  - Moisture absorption characteristics of composites, which follow Fick's second law, can be coupled with realistic environmental data to design structurally efficient and economic composite components. This research will provide guidance to establish practical levels of moisture content and corresponding environmental compensation factors for composite structures.
- Objective
  - Develop guidelines for the development of environmental enhancement factors for static strength loading

Approach

- Develop guidelines for the development of environmental enhancement factors for static strength loading
- Use data developed at lamina, laminate, element and subcomponent to demonstrate application
- Incorporate a probabilistic model, which accounts for the environmental factors affecting composite design
- Address any additional research & development needs with environmental factors as budget allows, i.e. effects of non-Fickian processes such as capillary action along fiber/matrix interface and through cracks and voids, effects of surface cracking in the resin at free edges due to swelling stresses resulting from moisture desorption on subsequent moisture absorption, environmental factors for adhesive joints and sandwich construction, etc.

FAA Sponsored Project Information

- **Principal Investigators**
  - John Tomblin, *PhD*
  - Waruna Seneviratne, *PhD*
- **FAA Technical Monitors**
  - Curtis Davies
  - David Westlund
- **Other NIAR Personnel Involved**
  - Upul Palliyaguru
  - Andrea Bowers
- **Industry Participation**
  - Bombardier, Cessna, Hawker Beechcraft, Spirit Aerosystems

Environmental load factor

- 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

Static Load Factor

SLF = Static Load Factor **» represents the difference in load factor between a composite and metallic 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

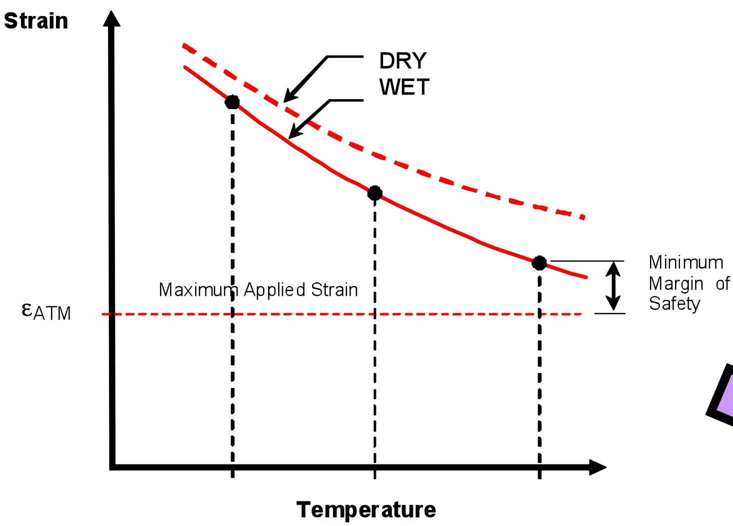
$$SLF = \frac{C_{\substack{composite\\variability}} \; C_{\substack{composite\\temperature}} \; C_{\substack{composite\\moisture}}}{F_{\substack{metals\\variablity}} \; F_{\substack{metals\\temperature}} \; F_{\substack{metals\\moisture}}}$$

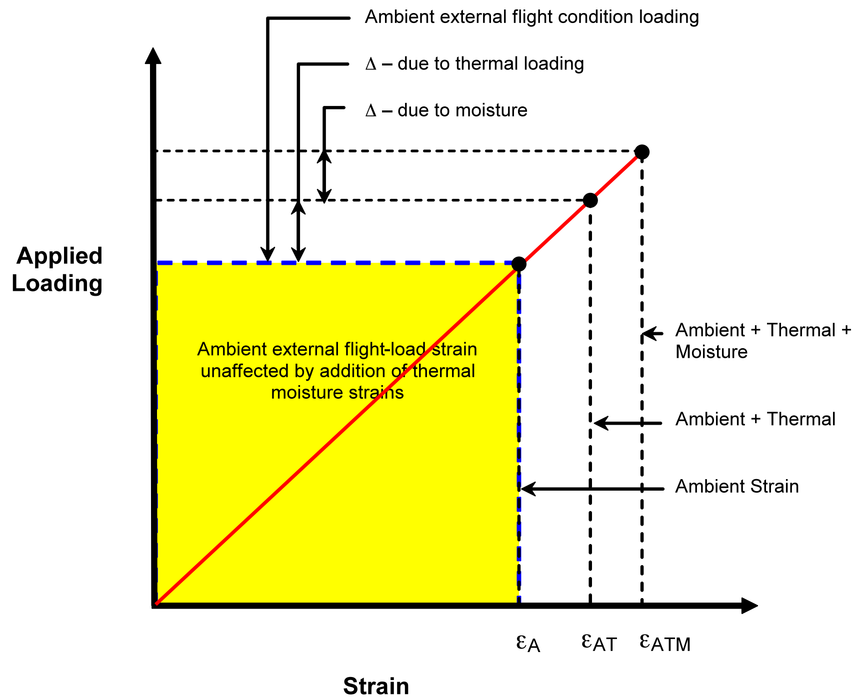
Room for improvement in this based upon failure mode in temperature (based upon FEM M.S. model) and amount of moisture actually expected in structure during lifetime

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

1

Design & Certification

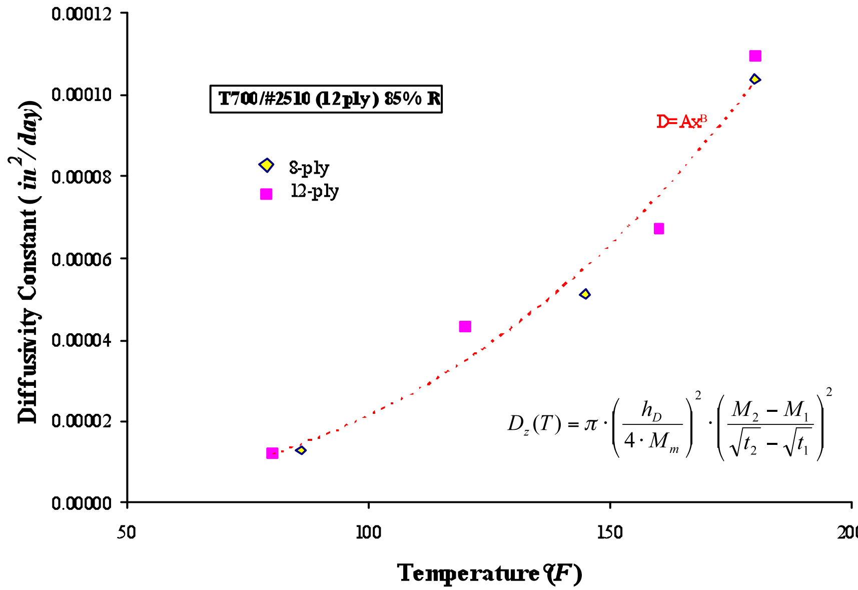




Analysis Assumptions

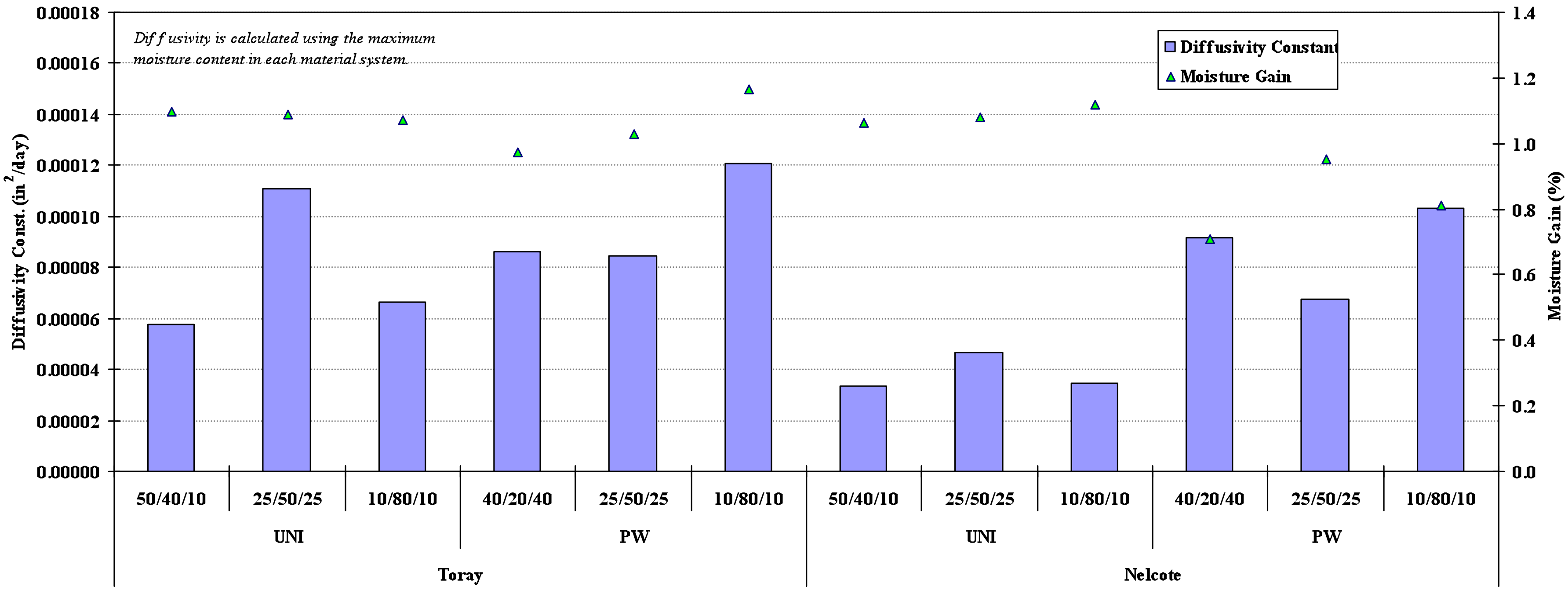
- Fickian Diffusion
  - Assumptions
    - Moisture concentration behaves according to:

$$\frac{\partial c}{\partial t} = D_z \frac{\partial^2 c}{\partial z^2}$$



    - Diffusion behavior constant through thickness
      - Cloth vs. Uni differences are negligible
    - Steady state only
    - Two sided diffusion
    - Through the thickness diffusion dominates
      - End effects neglected

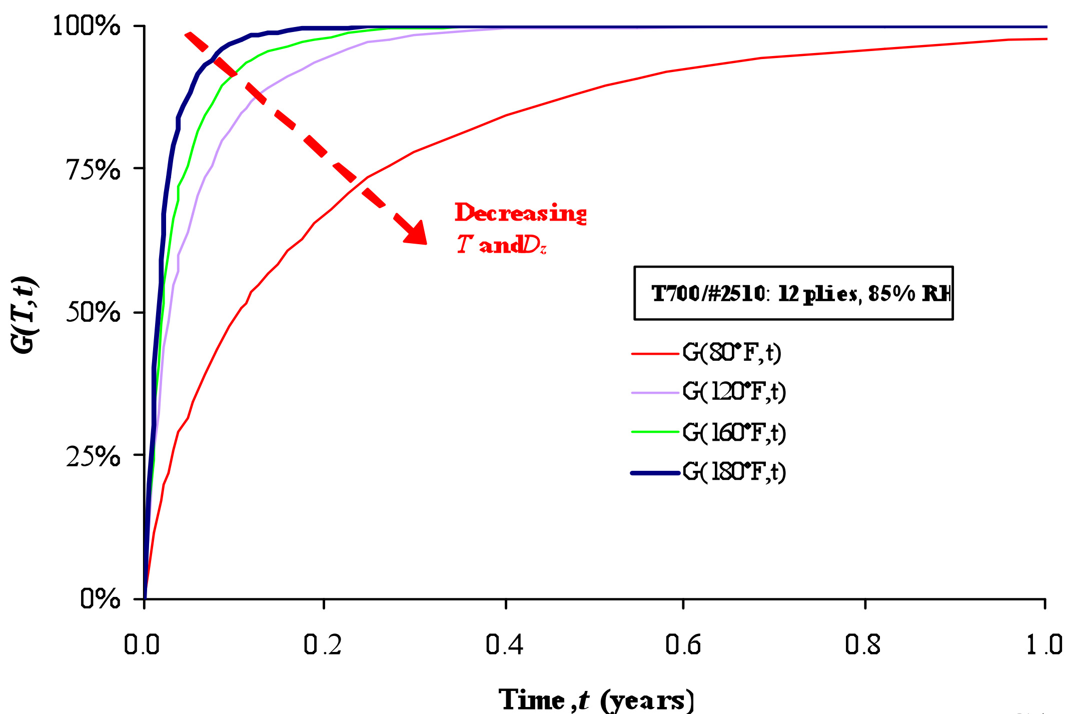
Diffusivity

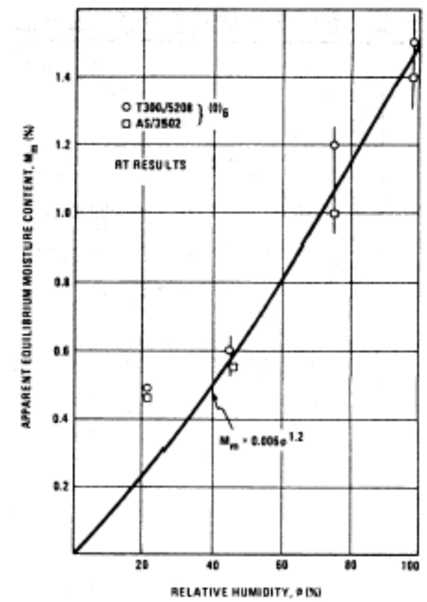


- Diffusivity was calculated using the maximum moisture content (per AGATE criterion) in **each material system**.

Saturation Levels

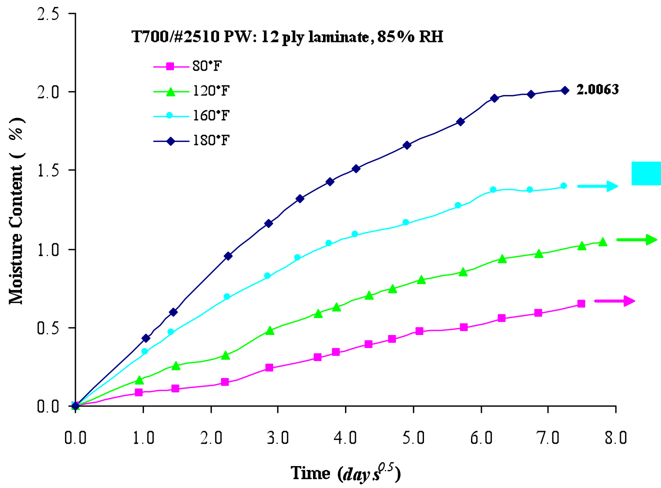
- *G(T,t)* is the ratio of moisture level at a given time to the saturated moisture content *(M_m)*

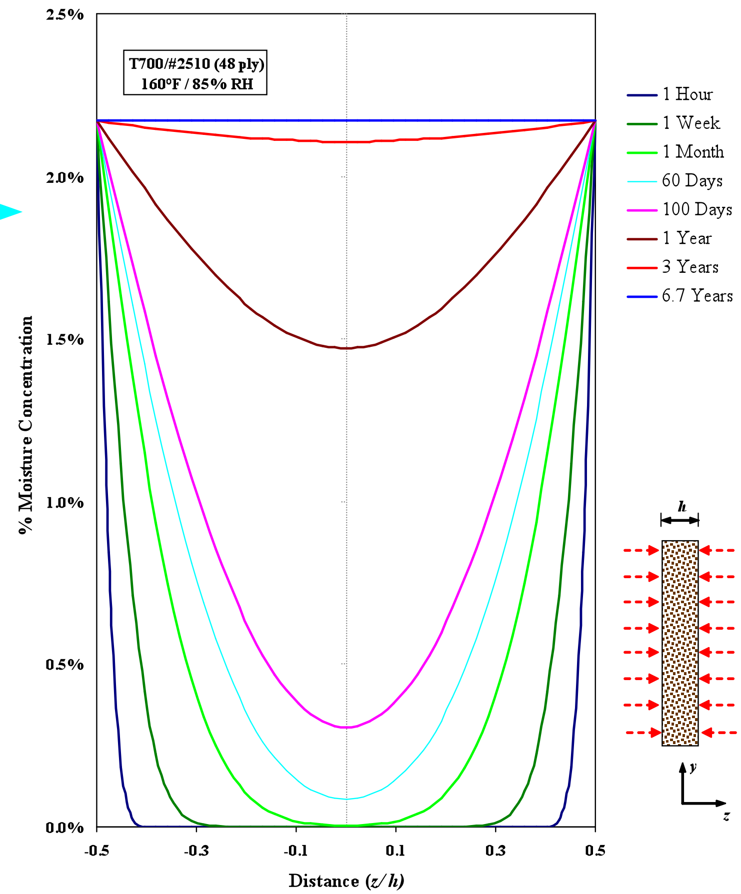




$$G(T,t) = 1 - \exp\left[-7.3 \cdot \left(\frac{D_z(T)\cdot t}{h^2}\right)^{3/4}\right]$$

Moisture Absorption

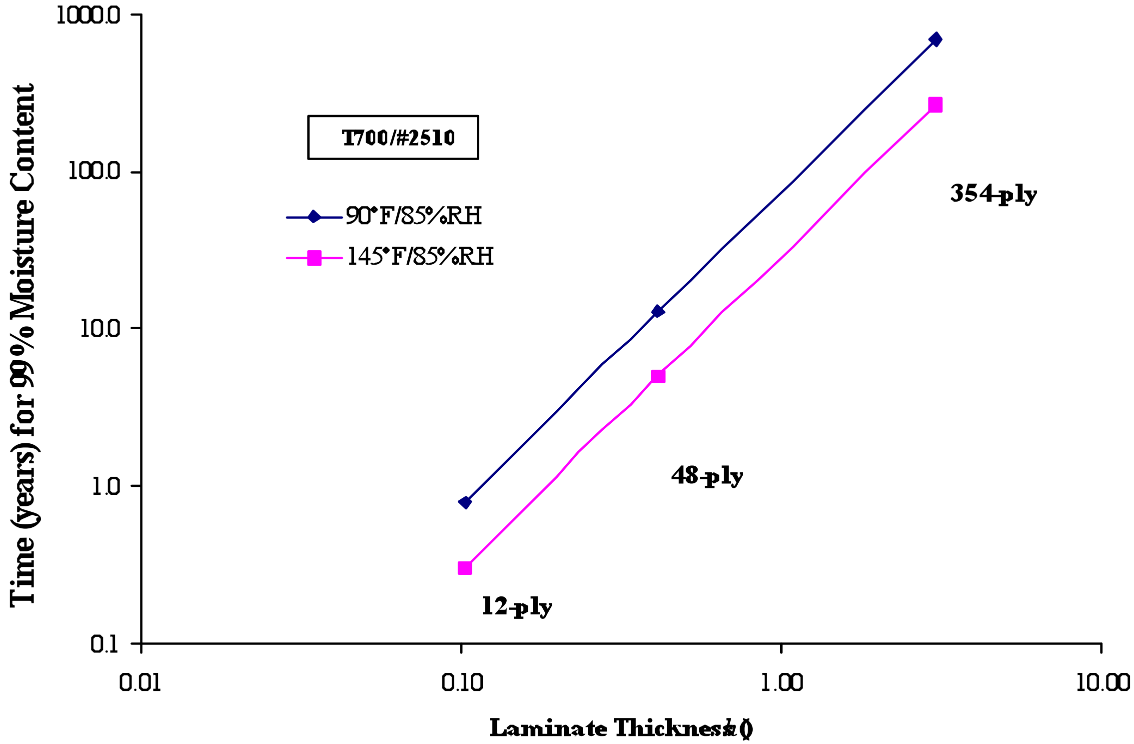


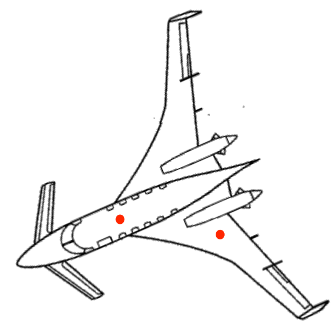


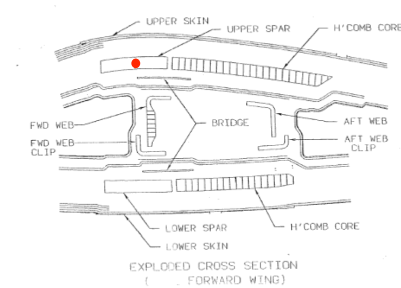
Moisture Absorption for Full Scale Articles

- What is realistic?

Laminate Thickness (in)	Years for 99% Saturation		
	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

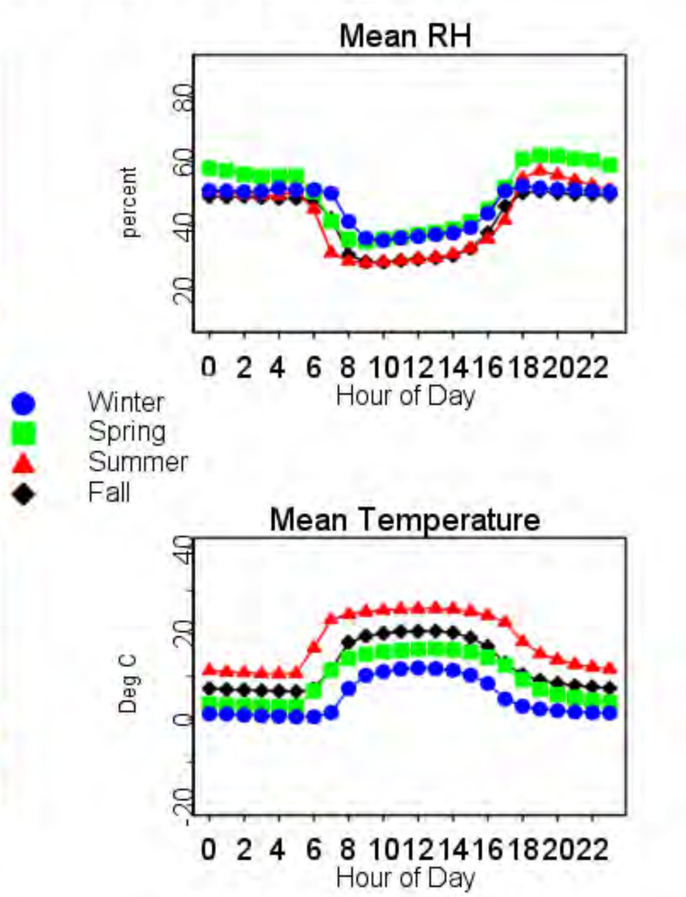




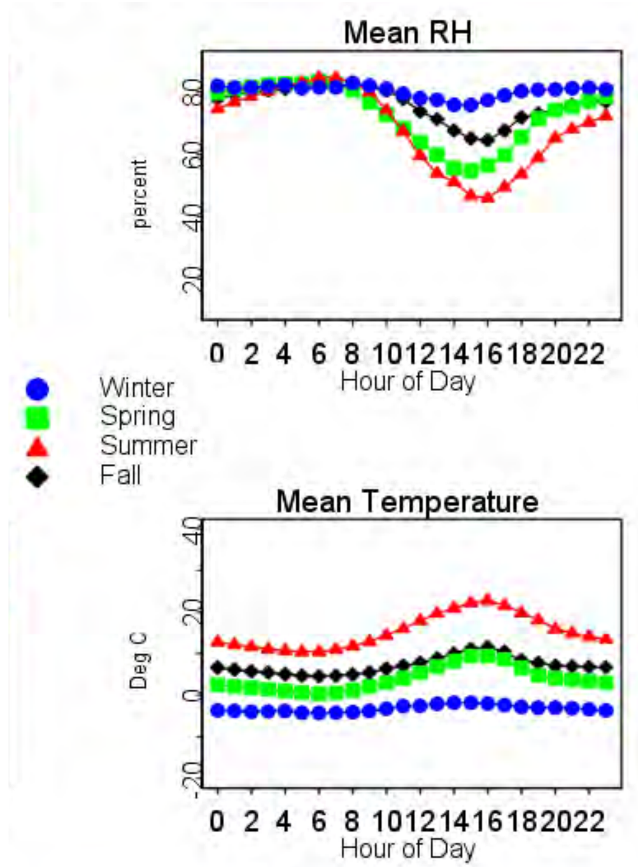


Environmental Data

San Gorgonio
64,164 Obs., 1 Mar 1989 - 31 May 1999

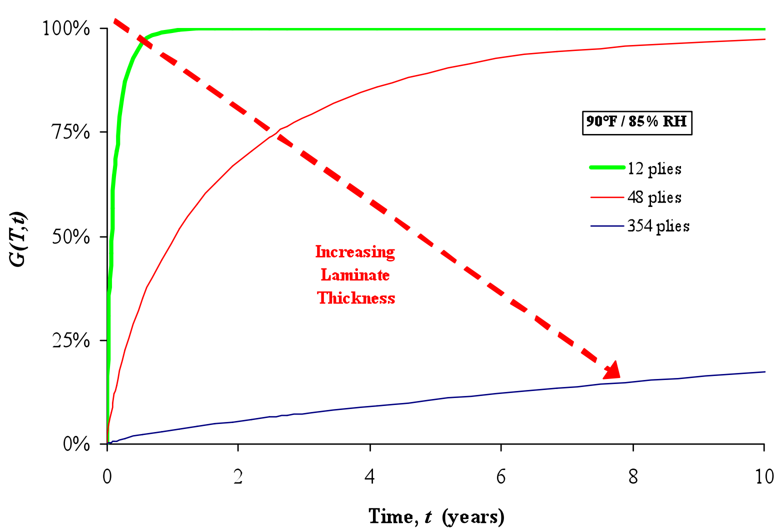


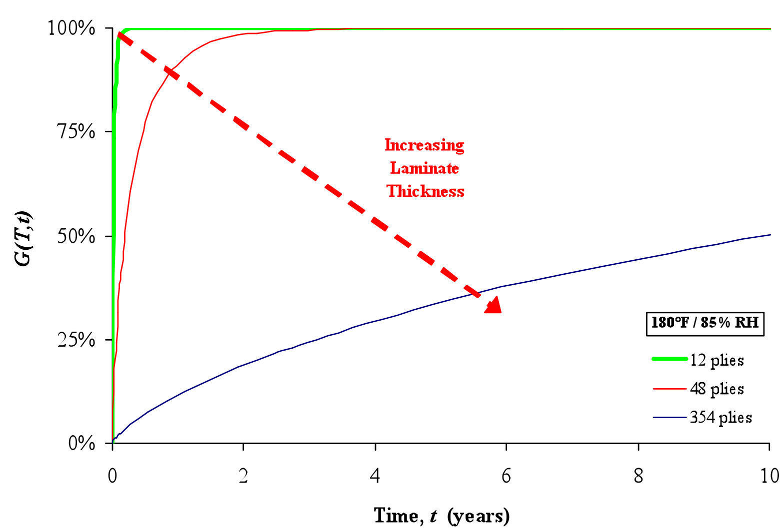
Glacier Natl. Park
35,495 Obs., 20 Jan 1989 - 31 May 1999



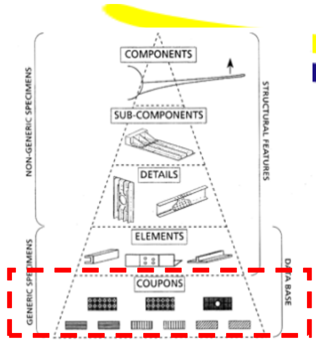
Service life Assumptions

- Assume 10 years continuously in worst case conditions.
  - ***<u>This does not indicate a 10 year service life</u>***. Merely the worst case that would happen in 10 years with no time at altitude or other drier locations.
  - Max. saturation levels and conditioning criterion
    - Condition a representative article such that it reaches the same saturation level expected for the full scale aircraft in a worst case environment



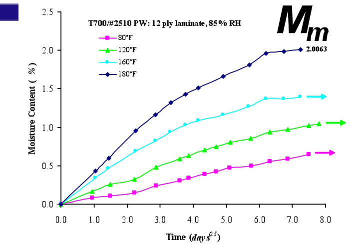


Enhanced Design & Certification Approach



D_Z

M_m



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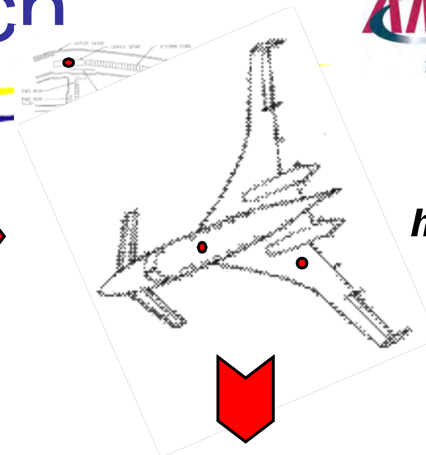
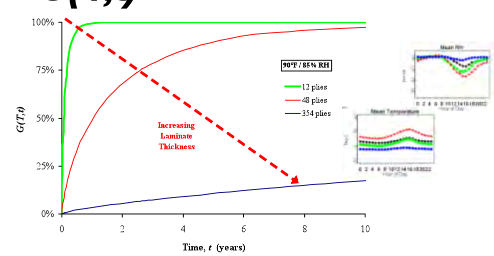
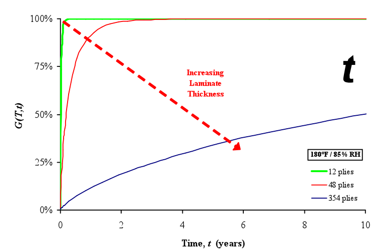
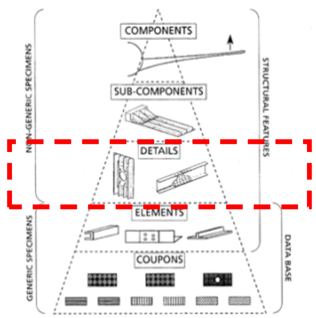


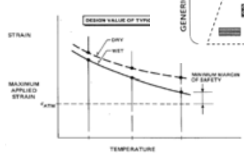
G(T,t)

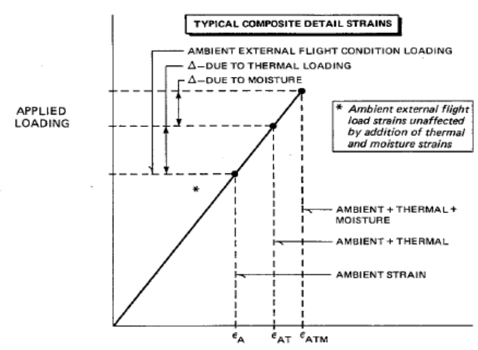


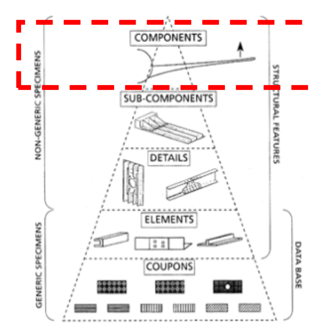
t





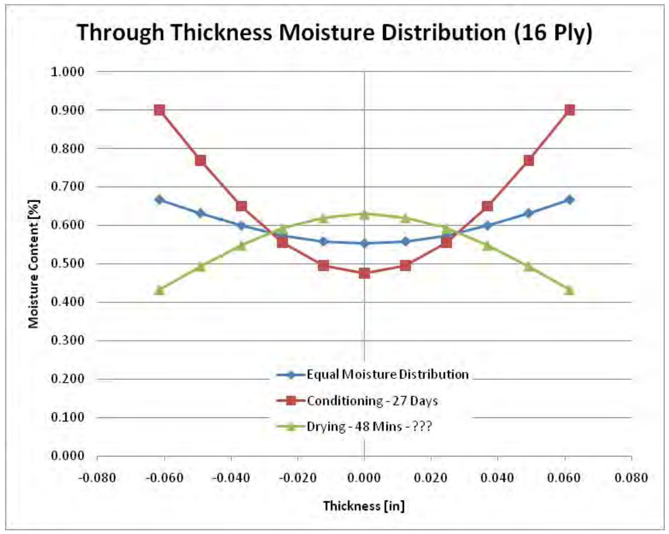






Moisture Absorption/ Desorption

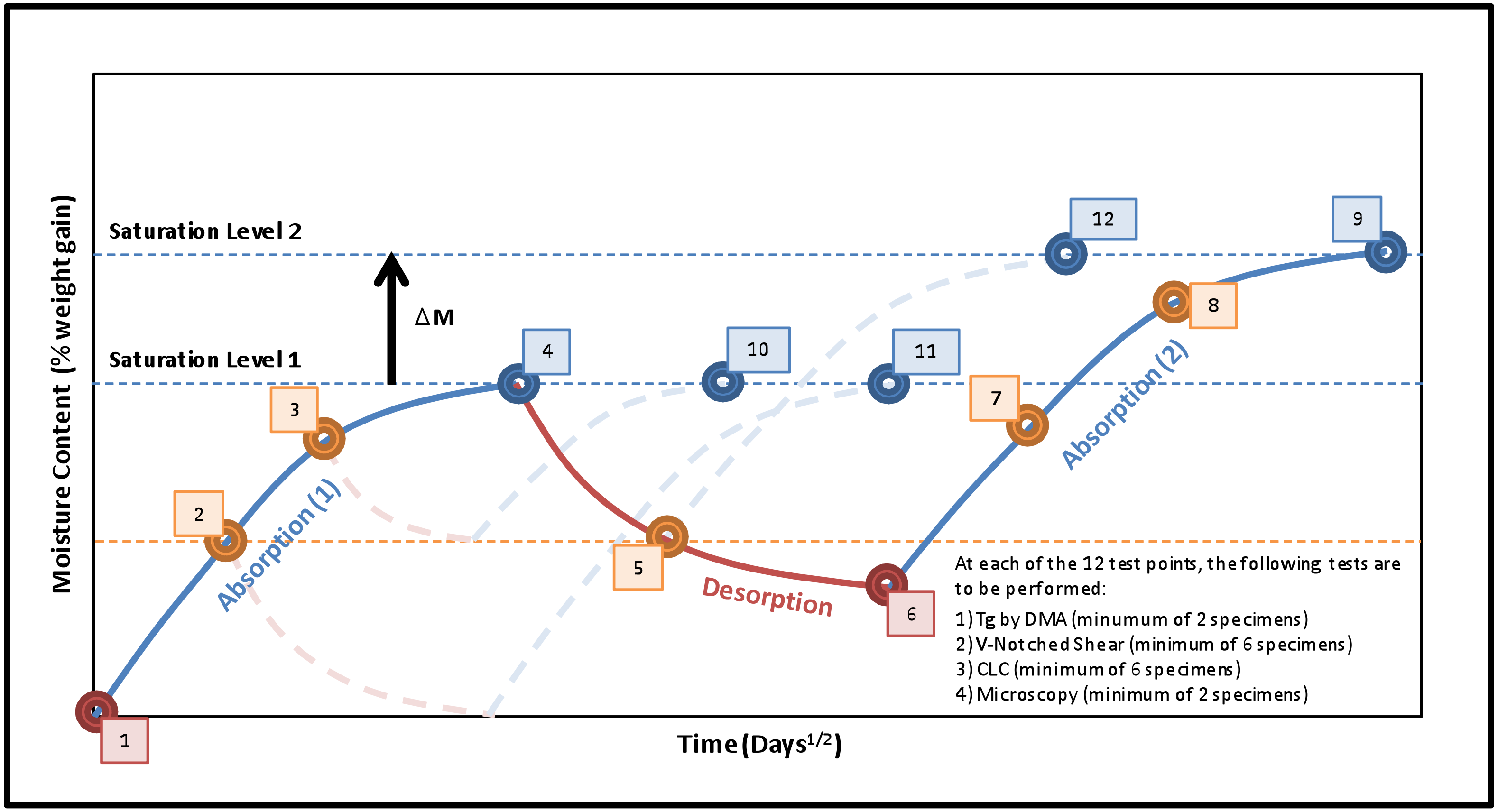
- Same moisture level, but different moisture distribution through the thickness
  - Mechanical properties
  - Thermal properties
  - Subsequent moisture absorption



Cyclical Moisture Absorption Study

- Material: Cytec 7714A/M46J/12K
- Layup: [0/90]8s (CLC, V-notch)
  [0/90]2s (DMA, microscopy)
- All specimens machined and dried prior to baseline testing (RTD and ETD @ test pt 1) and start of conditioning
- Combined-Loading Compression (CLC)
  - 2 x 6 inch specimens

Cyclic Moisture Absorbance



Cyclical Moisture Absorption Study

Conditioning at 145°F, 85% RH

Test Point	Pre Test Condition	Testing: Temperature °F	Testing: Relative Humidity %	Testing: Test Condition --	Number of Specimens Conditioned/Test Method: Tg by DMA ASTM D7028	V-Notched Shear ASTM D5379	CLC ASTM D6641	Microscopy --
1a	Fully Dried (Baseline)	ambient	ambient	RTD	3	8	8	3
1b	ETD - Fully Dried (Baseline)	180	ambient	ETD	n/a	8	8	n/a
2a	Partially Saturated (estimated 50% level 1), Fully Dried	ambient	ambient	RTD	3	8	8	3
2b	ETD - Partially Saturated (estimated 50% level 1), Fully Dried	180	ambient	ETD	n/a	8	8	n/a
3a	Partially Saturated (estimated curve knee), Fully Dried	ambient	ambient	RTD	3	8	8	3
3b	ETD - Partially Saturated (estimated curve knee), Fully Dried	180	ambient	ETD	n/a	8	8	n/a
4a	Saturated (level 1)	ambient	ambient	RTW	3	8	8	3
4b	ETW - Saturated (level 1)	180	ambient	ETW	n/a	8	8	n/a
5a	Fully Saturated, Partially Dried (to 50% level 1)	ambient	ambient	RTW	3	8	8	3
5b	ETW - Fully Saturated, Partially Dried (to 50% level 1)	180	ambient	ETW	n/a	8	8	n/a
6a	Fully Saturated, Fully Dried	ambient	ambient	RTD	3	8	8	3
6b	ETD - Fully Saturated, Fully Dried	180	ambient	ETD	n/a	8	8	n/a
7a	Fully Saturated, Fully Dried, Partially Saturated (estimated 50% level 2), Fully Dried	ambient	ambient	RTD	3	8	8	3
7b	ETD - Fully Saturated, Fully Dried, Partially Saturated (estimated 50% level 2), Fully Dried	180	ambient	ETD	n/a	8	8	n/a
8a	Fully Saturated, Fully Dried, Partially Saturated (estimated curve knee), Fully Dried	ambient	ambient	RTD	3	8	8	3
8b	ETD - Fully Saturated, Fully Dried, Partially Saturated (estimated curve knee), Fully Dried	180	ambient	ETD	n/a	8	8	n/a
9a	Saturated (level 2)	ambient	ambient	RTW	3	8	8	3
9b	ETW - Saturated (level 2)	180	ambient	ETW	n/a	8	8	n/a
10a	Partially Saturated (estimated curve knee), Partially Dried (to 50% level 1), Fully Saturated	ambient	ambient	RTW	3	8	8	3
10b	ETW - Partially Saturated (estimated curve knee), Partially Dried (to 50% level 1), Fully Saturated	180	ambient	ETW	n/a	8	8	n/a
11a	Partially Saturated (estimated 50% level 1), Fully Dried, Fully Saturated	ambient	ambient	RTW	3	8	8	3
11b	ETW - Partially Saturated (estimated 50% level 1), Fully Dried, Fully Saturated	180	ambient	ETW	n/a	8	8	n/a
12a	Fully Saturated, Partially Dried (to 50% level 1), Fully Saturated	ambient	ambient	RTW	3	8	8	3
12b	ETW - Fully Saturated, Partially Dried (to 50% level 1), Fully Saturated	180	ambient	ETW	n/a	8	8	n/a
				Total Specimens (Required + Extras)	**36**	**192**	**192**	**36**

Summary

- Methodology development and testing underway
- Guidelines for design and certification of composite structures related to environmental knockdown based on practical levels of moisture content and operational usage
- Math model (user-friendly computer program) for developing moisture level in a structure based on usage history (or expected usage)
  - If temperature/moisture history is tracked during service, the data along with the math model can be used for possible life extension strategies (extraction of unused life)

A Look Forward

- **Benefit to Aviation**
  - Systematic approach for developing environmental knockdown factors based on structural details
  - Possibility of extending the methodology for life extension strategies
- **Future needs**
  - Test articles representing modern day composite structures
  - Environmental history data