Center for Advanced Materials in Transport Aircraft Structures (AMTAS)

Summary of the AMTAS/JAMS Center of Excellence

prepared by

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206-685-6665

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FAA Centers of Excellence (COE) are:

- Intended to foster collaborative research/education projects to advance the technologies of the aviation community
- Funded through cooperative agreements among academic institutions, their affiliate industrial partners, and the FAA
- FAA provides funds that must be matched 1:1 by non-federal sources
- Funded in three phases over a total period of 3-10 yrs
- Expected to be self-supporting thereafter
- Eight FAA COE’s currently exist:
  
  http://www.coe.faa.gov/established_centers.html
Dec. 2003: FAA announced Phase I funding for a new Joint Advanced Materials & Structures (JAMS) Center of Excellence; University of Washington (UW) and Wichita State University (WiSU) are co-lead universities

Both UW and WiSU have since established their respective programs:

- UW: Center for Advanced Materials in Transport Aircraft Structures (AMTAS)
- WiSU: Center of Excellence for Composites and Advanced Materials (CECAM)
AMTAS and CECAM activities are coordinated by JAMS Program Manager Curt Davies (W.J. Hughes Research Center, Atlantic City, NJ)

- AMTAS/JAMS: http://depts.washington.edu/amtas/
- CECAM/JAMS: http://www.niar.twsu.edu/newniar/coe/cecam.asp
AMTAS Participants

- AMTAS currently consists of:
  - Four academic partners
  - Eleven industrial partners
- All partners are located or have a significant presence within the Pacific Northwest
- Industry partner most actively involved is Boeing
- Funding began 1 September 2004 (AMTAS-JAMS operating for about 14 months)
AMTAS Participants

Academic Partners

• University of Washington (UW)
  - main campus in Seattle, WA
  - 35,000 students
  - http://www.washington.edu/

• Washington State University (WaSU)
  - main campus in Pullman, WA
  - 22,500 students
  - http://www.wsu.edu/

• Oregon State University (OSU)
  - main campus in Corvallis, OR
  - 18,000 students
  - http://oregonstate.edu/

• Edmonds Community College (EdCC)
  - Lynnwood, WA
  - 11,000 students
  - http://engr.edcc.edu/
AMTAS Participants
Current Industry Partners

- Bell Helicopter
- Boeing
- Composite Solutions
- Cytec Engineered Materials
- Heatcon Composite Systems
- Hexcel
- Intec
- Stoddard International
- Triumph Group, Inc.
- Zodiac
AMTAS Participants
Administered by the UW

- Prof. Mark Tuttle, Director
  206-685-6665
tuttle@u.washington.edu

- Prof. Kuen Lin, Co-Director
  206-543-6334
  lin@aa.washington.edu

- Ms. Ellen Barker, Assistant to the Director
  206-543-0299
  nelle@u.washington.edu
AMTAS Administrative activities

- Semi-Annual AMTAS meetings:
  - 29 Jan ’04: UW campus; 35 attendees
  - 10 Nov ’04: UW campus; 40 attendees
  - 14 April ’05: EdCC campus; 53 attendees
  - 13 Oct ’05: UW Campus; 55 attendees
AMTAS Administrative activities

- Website established and updated regularly:
  
  http://depts.washington.edu/amtas

- Reports provided to Curt Davies, JAMS Program Manager:
  - Monthly progress reports for all AMTAS projects
  - Quarterly fiscal reports for all AMTAS projects
AMTAS/CECAM-JAMS
Meetings

- 1\textsuperscript{st} Annual AMTAS/CECAM-JAMS Mtg hosted by WiSU; 24-26 May 2005 (Wichita, KS)

- 2\textsuperscript{nd} Annual AMTAS/CECAM-JAMS Mtg to be hosted by UW; 20-22 June 2006 (Seattle, WA)
Current AMTAS Projects

- Reliability-based Damage Tolerant Composite Design Methodologies (K. Y. Lin, PI)
- Combined Global/Local Variability and Uncertainty in Integrated Aeroservoelasticity of Composite Aircraft (E. Livne, PI)
- Improving Adhesive Bonding of Composites through Surface Characterization (B. Flinn, PI)
- The Effects of Surface Pretreatment on the Degradation of Composite Adhesives (L. Smith, PI)
- Short-Course Development: Maintenance/Repair of Composite Aircraft Structures (C. Seaton, PI)
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Development of Reliability-Based Damage Tolerant Structural Design Methodology:
Progress Report

Dr. Kuen Y. Lin and Dr. Andrey Styuart
Department of Aeronautics and Astronautics
University of Washington
October 13, 2005

The Joint Advanced Materials and Structures Center of Excellence
Research Team

- Principal Investigator: Dr. Kuen Y. Lin, Aeronautics and Astronautics
- Research Scientist: Dr. Andrey Styuart
- Research Assistants: Cary Huang, Crystal Simon
- FAA Technical Monitor: Peter Shyprykevich
- Other FAA Personnel: Dr. Larry Ilcewicz, Curtis Davies
- Industry Participants: Dr. Alan Miller, Dr. Cliff Chen, Dr. Hamid Razi (Boeing)
Motivation and Key Issues: Composite materials are being used in aircraft primary structures such as 787 wings and fuselage. In these applications, stringent requirements on weight, damage tolerance, reliability and cost must be satisfied. Presently there is no industry-wide standard to establish appropriate inspection intervals for a damage-tolerant structure based on the consideration of structural reliability, inspection methods, and quality of repair. An urgent need exists to develop a standardized methodology for establishing an optimal inspection schedule that provides minimum maintenance cost and maximum structural reliability.

Objective: Develop a probabilistic method to estimate structural component reliabilities suitable for aircraft design, inspection, and regulatory compliance.
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Approach

- The present study is based on a probabilistic failure analysis, with consideration of several factors including inspection intervals, statistical data on damage experienced in metal aircraft, damage detection capabilities, residual strength of new, damaged and repaired composite structures, and anticipated service loads/temperatures.

Phase I Research Tasks

- Develop a Probabilistic Method to Determine Inspection Intervals for Composite Aircraft Structures
- Develop Computing Tools and Algorithms for the Probabilistic Analysis
- Establish In-service Damage Database from FAA SDR and Other Sources
- Demonstrate the Developed Method on an Existing Structural Component
Typical In-service Damage – Hail Damage
Typical In-service Damage- Lightning Strike

- Engine Cowl

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PDF of Detected Damages

LogNormal Probability Density Functions for Baseline Fleet Damage Data, Ref. AR-95/17

\[ p_o(a) = \frac{1}{a\sigma \sqrt{2\pi}} \exp \left[ -\frac{1}{2\sigma^2} \ln^2 \left( \frac{a}{\theta} \right) \right] \]
Typical Damage Maps for a Wing
Performance of Multiple Devices for A Single Type of Test Specimen

Cumulative PoD of All Conventional NDI Devices for 6 Ply Carbon

- Airbus Tap Hammer
- Boeing Tap Hammer
- LEBT
- MIA
- Wichittech DTH
- Woodpecker

Probability of Detection

Flaw Size (Dia. in Inches)
Visual Inspection POD for Shiny Surface at 20 ft Distance

![Graph showing the Probability of Detection vs Damage Diameter](image-url)

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Identification of Critical Parameters

- Various Failure Modes
- Strength vs. Temperature
- Moisture Content vs. Time
- Residual Strength vs. Damage Size & Damage Type
- Probability of Detection vs. Damage Size & Damage Type
- Maximum Load vs. Time of Damage Existence
- Damage Size & Damage Type Spectra
- Structural Temperature Spectra

Strength Degradation due to Environmental Exposure

Probability of Failure

Inspection Intervals, Repair Criteria, Structural Risk

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Two methods, based on Importance Sampling and Monte-Carlo Simulation, have been developed for determining the inspection intervals.

Computer software (Version 1.2) for calculating the inspection intervals has been completed.

Database for Reliability-Based Damage Tolerance Analysis has been established.

Three sample problems with parametric studies have been demonstrated on existing structural components.

Results from the present study have been compared with those obtained by other methods and software (NESSUS).
Current AMTAS Projects

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Combined Global / Local Variability and Uncertainty in the Aeroservoelasticity of Composite Aircraft

Eli Livne
Department of Aeronautics and Astronautics
Aeroservoelastic Global / Local Variability and Uncertainty in Composite Aircraft

FAA Sponsored Project Information

• Principal Investigators & Researchers
  • Prof. Eli Livne
  • Dr. Luciano Demasi
  • Dr. Andrey Styuart
  • Mr. Levent Coskuner, PhD student

• FAA Technical Monitor
  • Peter Shyprykevich

• Other FAA Personnel Involved
  • Dr. Larry Ilcewicz - Composites
  • Gerry Lakin – Flutter
  • Curtis Davies

• Industry Participation (Boeing Commercial, Seattle)
  • Mr. Carl Niedermeyer – Flutter & Loads
  • Dr. Kumar Bhatia – Aeroservoelasticity and Multidisciplinary Optimization
  • Mr. James Gordon – Flutter & Dynamic Loads
Aeroservoelastic Global / Local Variability and Uncertainty in Composite Aircraft

• Motivation and Key Issues
  – Local structural variations in composite airframes due to damage and repair, material changes over time, and/or nonlinear mechanisms can affect global aeroelastic and aeroservoelastic stability and response.

• Objectives
  – Develop computational tools (validated by experiments) for local/global linear/nonlinear analysis of integrated structures/aerodynamics/control systems subject to multiple local variations/damage.

  – Develop a better understanding of effects of local structural and material variations in composites on overall Aeroservoelastic integrity.

  – Establish a collaborative expertise base for future response to FAA, NTSB, and industry needs in R&D, training, and education.
Aeroservoelastic Global / Local Variability and Uncertainty in Composite Aircraft

Part I

Aeroservoelastic Sensitivity and Uncertainty in Composite Aircraft

Sensitivity analysis

Local structural variation and global system’s behavior
Aeroservoelastic Global / Local Variability and Uncertainty in Composite Aircraft

Status – Uncertainty of Linear ASE Systems

- The UW code SMART used to design a simple model composite vertical tail
- Sensitivity analysis demonstrated with SMART: sensitivity of aeroelastic poles with respect to structural material changes
- Analysis & sensitivity results will be used to create approximate behavior surfaces representing behavior variation due to structural variations for use in reliability analysis
- Progress was made on the SMART – NASTRAN interfaces and on improvements in SMART.
- An in-depth assessment of the NASTRAN-based aeroservoelastic optimization capability at the Polytechnic of Milan (considered as a potential NASTRAN-based capability to adopt) was completed
- A NASTRAN model of a realistic vertical tail / empennage – has not been received yet
Aeroservoelastic Global / Local Variability and Uncertainty in Composite Aircraft

Vertical Tail / Rudder FEM

- 767-size vertical tail / rudder structure
- Fixed at root
- Rudder actuated at 5 pivot points along hinge line
- All composite structure: *Graphite/Epoxy and E-Glass/Epoxy*
- 11 Property cards:
  - 2 skin cards; 4 web cards;
  - 2 caps cards; 2 vertical stiffener cards
  - 1 actuator card
- 232 Nodes
- 1851 Elements:
  - 1308 Membranes; 503 Bars;
  - 35 Rigid Links; 5 Rotary Actuators
Aeroservoelastic Global / Local Variability and Uncertainty in Composite Aircraft

Effect of Local Material Property Change on Aeroelastic Poles
(Poles at a given flight condition determine stability of motion)

\[ \lambda = \lambda_R + j\lambda_I \rightarrow e^{\lambda t} \]

pole = 1, comp = open-loop

Change in elastic modulus (E) of composite skin panels at root (all layers [0/90/+45/-45]; both sides)
Effect of Local Structural Change on Aeroelastic Poles

Change in rudder mass (moisture absorption?)

pole = 3, comp = open-loop
Aeroservoelastic Global / Local Variability and Uncertainty in Composite Aircraft

Part II

Control Surface Limit Cycle Oscillations

Nonlinear structural effects in actuator / composite control surface assemblies

Methods development

Validation
Aeroservoelastic Global / Local Variability and Uncertainty in Composite Aircraft

The Benchmark 2DOF Airfoil / Flap System

Fig. Ref. Dowell & Tang

Freeplay $\pm \delta$

Nonlinear Spring
Two Approaches to LCO Simulation

- A frequency domain approach: assume harmonic oscillation and search for the amplitude & frequency and the flight speed at which such harmonic oscillation will happen; use describing function approach to reduce nonlinear task to linear.

- A time domain approach: solve the nonlinear state space equations of the system for different flight conditions and initial conditions
Aeroservoelastic Global / Local Variability and Uncertainty in Composite Aircraft

Automated LCO Simulation in the Frequency Domain for Uncertain Systems

- Frequency Domain Analysis Module features:
  - Theodorsen aerodynamics
  - Describing function for non-linearity
  - V-g-? flutter analysis
  - Fair comparison with tests

- Issues
  - Resolution of problems and completion of the automated LCO frequency-domain capability for 2D airfoil-flap systems is still a work in progress
Once a satisfactory Roger Fit is obtained, a state space system can be constructed for the time domain solution.

- **Time Domain Solution**
  A working time domain code has been implemented and some preliminary LCO results are available.

Sample LCO result for 3 DOF Airfoil and Flap System
Aeroservoelastic Global / Local Variability and Uncertainty in Composite Aircraft

Status

- **Frequency domain LCO prediction**
  - Numerical Analysis Module 3-4 DOF (describing functions): completed
  - Comparison with test results: Fair

- **Time domain LCO prediction**
  - Working time domain LCO simulation code has been constructed, and verification with available data is in progress. In the near future, the current time domain LCO simulation will be extended to a 3 dimensional, multi degree of freedom model.

- **Reliability / Uncertainty Analysis**
  - Numerical Analysis Module completed for stable branch
  - Interface with NESSUS completed
  - NESSUS license acquired
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Improving Adhesive Bonding of Composites Through Surface Characterization

(of Peel Ply Prepared Surfaces)

Brian D. Flinn, Molly K.M. Phariss and Fumio Ohuchi
Department of Materials Science and Engineering

The Joint Advanced Materials and Structures Center of Excellence
FAA Sponsored Project Information

- Principal Investigators & Researchers
  - Brian D. Flinn (PI)
  - Fumio Ohuchi (Co-PI)
  - Molly Phariss (Ph.D. Candidate, U. of Wa.)
  - Bjorn Ballien (Senior, U. of Wa.)
- FAA Technical Monitor
  - Peter Shyprykevich
- Other FAA Personnel Involved
  - Curt Davies, Larry Ilcewicz
- Industry Participation
  - Boeing: Peter Van Voast, William Grace, Paul Shelley
- JAMS Participation
  - Lloyd Smith (WaSU): Parallel study on durability
  - Bill Stevenson (WiSU) and Xiangyang (Joe) Zhou (FIU): samples
Improving Adhesive Bonding of Composites Through Surface Characterization

• Motivation and Key Issues
  – Peel ply surface preparation is being used for bonding primary structure on Boeing 777 and 787 and other commercial transport aircraft
  – Good bonds are produced but questions remain:
    • How can suitability of a surface for bonding be determined
    • Does contact angle (wettability) correlate with bonding
    • What is the effect of peel ply texture on surface and bonding
    • What is the effect of moisture in peel ply before cure

• Objective
  – Develop further understanding of the effect surface preparation has on the durability of primary structural composite bonds through surface analysis coupled with mechanical testing and fractography
Improving Adhesive Bonding of Composites Through Surface Characterization

• Approach
  – Prepreg BMS 8-276 form 3 (Toray)
  – Peel/Release Plies
    • Materials: polyester, nylon and SRB release (siloxane finish)
    • Texture: Fine, medium and coarse weaves
    • Moisture Content: dry to saturated
  – Adhesive Types
    • Cytec MB1515-3 and 3M AF555
  – Characterization
    • SEM
    • Surface Chemistry (ESCA/XPS, SIMS)
    • Profilometry
    • $G_{IC}$ DCB fracture testing (ASTM D-5528)
Peel Ply Surface Preparation

Fracture Possibilities Upon Peel Ply Removal

- Fracture of the epoxy between peel ply and carbon fibers
  - Fresh, chemically active, epoxy surface is created
- Interfacial fracture between the peel ply fabric fibers and the epoxy matrix
- Peel ply fiber fracture
- Interlaminar failure

> Fracture Mode controls surface characteristics and bond quality

The Joint Advanced Materials and Structures Center of Excellence
Task 1: Peel Ply Material Type

- Laminates produced with 3 peel/release plies
  - Polyester BMS 8-308 (Precision Fabrics 60001)
    - Currently used for primary structural bond prep.
  - Nylon scoured and heat set (Precision Fabrics 52006)
  - Super Release Blue (60001 with siloxane coating)
- Samples removed for surface characterization
  - SEM, XPS, Contact Angle (wettability), SIMS
- Laminates bonded and machined into DCB specimens
Peel Ply Surface Prep. - SEM Results

- All samples show acceptable surface on macro scale
  - Interfacial fracture between the peel ply fabric fibers and the epoxy matrix
  - Limited epoxy fracture between peel ply fibers

Composite surface after removal of:

Nylon

Polyester

SRB
XPS Survey Scan Results

Laminate surfaces before bonding, after peel ply removal

- Si explains SRB low bond quality....Siloxane coating transfers
- Amount of N on nylon peel ply prepared sample surprising

<table>
<thead>
<tr>
<th>Peel Ply</th>
<th>%C</th>
<th>%O</th>
<th>%N</th>
<th>%Si</th>
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</thead>
<tbody>
<tr>
<td>Nylon</td>
<td>77.5</td>
<td>12.6</td>
<td>9.8</td>
<td>Tr.</td>
</tr>
<tr>
<td>Polyester</td>
<td>75.5</td>
<td>21.6</td>
<td>1.9</td>
<td>1.0</td>
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<tr>
<td>SRB</td>
<td>68</td>
<td>24.2</td>
<td>0.9</td>
<td>6.9</td>
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</table>
XPS High-Res Results

<table>
<thead>
<tr>
<th>Peel Ply</th>
<th>Species</th>
<th>BE (eV)</th>
<th>%</th>
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</thead>
<tbody>
<tr>
<td>Nylon</td>
<td>CC/CH</td>
<td>285</td>
<td>71</td>
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<tr>
<td></td>
<td>CN</td>
<td>286.2</td>
<td>17.1</td>
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<tr>
<td></td>
<td>Amide (NC=0)</td>
<td>288</td>
<td>11.9</td>
</tr>
<tr>
<td>Polyester</td>
<td>CC/CH</td>
<td>285</td>
<td>63.8</td>
</tr>
<tr>
<td></td>
<td>CO/(CN)</td>
<td>286.5</td>
<td>24.9</td>
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<tr>
<td></td>
<td>COO</td>
<td>289.2</td>
<td>8.8</td>
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<tr>
<td></td>
<td>Shakeup?</td>
<td>291.8</td>
<td>2.4 (broad)</td>
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<tr>
<td>SRB</td>
<td>CC/CH</td>
<td>285</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>CO</td>
<td>286.7</td>
<td>19.1</td>
</tr>
<tr>
<td></td>
<td>COO</td>
<td>289.3</td>
<td>9.8</td>
</tr>
<tr>
<td></td>
<td>Shakeup?</td>
<td>291.8</td>
<td>1.1 (broad)</td>
</tr>
</tbody>
</table>

Amide detected on nylon prepared surface - nylon transfer to surface?

The Joint Advanced Materials and Structures Center of Excellence
## Task 1: Peel Ply Material Type

<table>
<thead>
<tr>
<th>Adhesive</th>
<th>Polyester Prepared</th>
<th>Nylon Prepared</th>
<th>SRB Prepared</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Failure Mode</strong></td>
<td>Cohesive</td>
<td>Cohesive &amp; Interlaminar</td>
<td>Adhesion</td>
</tr>
<tr>
<td>$G_{IC}$ (J/m$^2$)</td>
<td>909.6</td>
<td>910.7</td>
<td>93.9</td>
</tr>
<tr>
<td><strong>Adhesive B</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Failure Mode</strong></td>
<td>Cohesive</td>
<td>Adhesion</td>
<td>Adhesion</td>
</tr>
<tr>
<td>$G_{IC}$ (J/m$^2$)</td>
<td>812.3</td>
<td>122.1</td>
<td>86.0</td>
</tr>
</tbody>
</table>

$G_{IC}$ and Contact Angle do not always correlate
- $G_{IC}$: Polyester $>>$ Nylon $>$ SRB
- Contact Angle: Nylon $<$ Polyester $<<$ SRB
Task 2: Peel Ply Texture

SEM’s of As-Received Peel Plies

Fine 160 x103
(PF 52006)

Medium 101 x 82
(PF 52008)

Coarse 60 x 50
(PF 52000)

• Different weaves, deniers, filament diameters will produce different surfaces on laminate
Task 2: Peel Ply Texture

- All polyester peel plies successfully removed
- Nylon peel plies were more difficult to remove
  - Fine weaves were removed without damage
  - Coarse weaves have not been removed without damage to laminate
    (3 attempts, different technicians)

<table>
<thead>
<tr>
<th>Material</th>
<th>Precision Code</th>
<th>Warp (ends/in.)</th>
<th>Fill (picks/in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyester</td>
<td>60001</td>
<td>70</td>
<td>50</td>
</tr>
<tr>
<td>Polyester</td>
<td>60001 VLP</td>
<td>70</td>
<td>50</td>
</tr>
<tr>
<td>Polyester</td>
<td>60004</td>
<td>120</td>
<td>59</td>
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<tr>
<td>Polyester</td>
<td>60005</td>
<td>90</td>
<td>58</td>
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<tr>
<td>Nylon 6,6</td>
<td>52006</td>
<td>160</td>
<td>103</td>
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<tr>
<td>Nylon 6,6</td>
<td>52008</td>
<td>101</td>
<td>82</td>
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<td>Nylon 6,6</td>
<td>50000</td>
<td>60</td>
<td>50</td>
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<tr>
<td>Nylon 6,6</td>
<td>40000</td>
<td>76</td>
<td>51</td>
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<tr>
<td>Nylon 6,6</td>
<td>41661</td>
<td>60</td>
<td>50</td>
</tr>
</tbody>
</table>
Task 2: Peel Ply Texture

- Peel ply texture does not seem to affect bond quality
Task 3: Peel Ply Moisture Content

- No specifications on moisture content of peel ply
- Saturation of polyester peel ply 60001
  - Dried peel ply
  - Soaked at 80°F/90% RH and 140°F/95% RH
  - Measured mass change at 0.5, 1, 2, 4, 18 hrs
  - No measurable weight change at 80°F/90% RH
  - 25% weight gain at 140°F/95% RH after 0.5 hours
  - no change at longer times
  - Bonded with AF555
- Cohesive failure in all samples

No significant difference in surface chemistry or mechanical properties detected
Conclusions

- Polyester: No Material Transfer; Strong Bonds
- SRB: Siloxane Coating Transfers; Weak Bonds
- Nylon: Fiber May Transfer; bond depends on adhesive
  - Significant nitrogen, amide groups, detected
    - May have contributed to the poor bond quality
    - Further investigation needed
    » Chemical or mechanical transfer?
- Contact angle did not correlate well with $G_{IC}$
  - Wetting is necessary....
    ....but not always sufficient for good bond
- Peel Ply Texture – no detectable effect
- Peel Ply Moisture- no detectable effect
Current AMTAS Projects

- Reliability-based Damage Tolerant Composite Design Methodologies (K. Y. Lin, PI)

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- The Effects of Surface Pretreatment on the Degradation of Composite Adhesives (L. Smith, PI)

- Short-Course Development: Maintenance/Repair of Composite Aircraft Structures (C. Seaton, PI)
The Effect of Surface Treatment on The Degradation of Composite Adhesives

Lloyd Smith
Prashanti Pothakamuri

AMTAS Fall 2005
Outline

• Year 1
  ▪ The effect of adherent moisture content prior to bonding on adhesion
  ▪ Peel Ply study
  ▪ Modified Wedge Crack
Adherend Moisture Effects

• Pre-cured adherends soaked to 1% moisture content prior to bonding uncured skin
• Wide Lap Shear (WLS) specimens creep loaded for 1000 hrs
  Wet: immersed in 140°F H₂O
  Dry: ambient lab conditions
• Lap Shear strength measured following 1k hr creep

<table>
<thead>
<tr>
<th>Coupon</th>
<th>Process</th>
<th>Creep Stress (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WLS</td>
<td>Dry</td>
<td>3  3  3  3</td>
</tr>
<tr>
<td>WLS</td>
<td>Wet</td>
<td>3  0  3  3</td>
</tr>
</tbody>
</table>
Adherend Moisture Effects

- **Status**
  - Exposure completed 6/8/05
  - 2 wet coupons and 2 dry coupons at 4 ksi failed during exposure
## Adherend Moisture Effects

<table>
<thead>
<tr>
<th>Type of Load</th>
<th>Dry Failure Mode</th>
<th>Wet Failure Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ksi</td>
<td>90% adherend 10% cohesive</td>
<td>95% adherend 5% cohesive</td>
</tr>
<tr>
<td>2 ksi</td>
<td>97% adherend 3% cohesive</td>
<td>n/a</td>
</tr>
<tr>
<td>3 ksi</td>
<td>95% adherend 5% cohesive</td>
<td>95% adherend 5% cohesive</td>
</tr>
<tr>
<td>4 ksi</td>
<td>60% adherend 40% cohesive</td>
<td>98% adherend 2% cohesive</td>
</tr>
<tr>
<td>4 ksi</td>
<td>98% adherend 2% cohesive</td>
<td>99.5% adherend 0.5% cohesive</td>
</tr>
<tr>
<td>Creep rupture</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Adherend Moisture Effects (4k ksi, dry)
Adherend Moisture Effects
(4 ksi rupture, wet)
Peel Ply Study

- Measure fracture toughness and shear strength as a function of surface preparation and exposure duration
- 140°F, H₂O, 60% UTS (~3 ksi)
- Saturate coupons before applying load

<table>
<thead>
<tr>
<th>Coupon/peel ply</th>
<th>0 hrs</th>
<th>2k hrs</th>
<th>4k hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCB/60001</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>DCB/Nylon</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>DCB/SRB</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>WLS/60001</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>WLS/Nylon</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>WLS/SRB</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
Peel Ply Study

- Saturation has taken longer than anticipated
  - Goal: 1k hrs
  - Current: > 3k hrs
Modified Wedge Crack

• Compare crack growth rates
• 140°F, H₂O, wedge

<table>
<thead>
<tr>
<th>Coupon/peel ply</th>
<th>Uni</th>
<th>Compliant*</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC/60001</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>WC/Nylon</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>WC/SRB</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

*Same layup as used in Peel Ply study
Modified Wedge Crack

- For Uni specimens:
  - Crack growth rates are comparable
  - Rate of SRB is slightly higher
  - All SRB coupons failed by 750 hours
  - Rate of SRB would be higher if longer coupons were used

- Compliant coupons awaiting saturation of Peel Ply Study specimens
Current AMTAS Projects

- Reliability-based Damage Tolerant Composite Design Methodologies (K. Y. Lin, PI)

- Combined Global/Local Variability and Uncertainty in Integrated Aeroservoelasticity of Composite Aircraft (E. Livne, PI)

- Improving Adhesive Bonding of Composites through Surface Characterization (B. Flinn, PI)

- The Effects of Surface Pretreatment on the Degradation of Composite Adhesives (L. Smith, PI)

- Short-Course Development: Maintenance/Repair of Composite Aircraft Structures (C. Seaton, PI)
Course Development: Maintenance of Composite Aircraft Structures

Process, Progress and Results

Charles Seaton – Principal Investigator, Edmonds Community College
Participants

- **Principal Investigator:**
  - Charles Seaton (Edmonds CC)

- **Additional Researchers:**
  - Dennis Vincent, Laura St. John (Edmonds CC)
  - Peter Smith, Keith Armstrong (Consultants)
  - Joe Hafenricher (Boeing)
  - Chad Robson (US Navy - Cherry Point)

- **FAA Technical Monitors:**
  - Peter Shyprykevich, Larry Ilcewicz, Curt Davies

- **Additional Industry Participation:**
  - Al Miller (Boeing)
  - Eric Casterline (Heatcon)
Course Development: Maintenance of Composite Aircraft Structures

**Motivation and Key Issues:**
- Dramatic increase in use of composites in new aircraft mandates additional knowledge and training in composite maintenance and repair for inspectors, technicians, and engineers.
- Practitioners must appreciate major issues surrounding composite maintenance in preparation for further study.
- Worldwide need.

**Objectives:**
- Develop Terminal Course Objectives (TCO) for industry to standardize introductory survey course content.
- Develop materials for web-based short course and regional “hands-on” laboratory.
This course…

- Provides an overview of the issues involved in composites’ maintenance and repair, beginning with a common level of knowledge of composite materials terminologies and concepts

- Is not intended to provide training that qualifies students as composite repair practitioners
Curriculum Development
Collaboration of Industry & Academia & Government

Workshops during curriculum development
- FAA/Industry/Academia Workshop in Seattle, WA (November/December 2004) Establish course framework by identifying terminal course objectives (TCOs)
- Tele-conference (April 2005) - ~10 participants
- FAA Workshop (Chicago - Sept 2005) Evaluate content relative to course framework as defined by TCOs

Results
- 2004 workshop – 450 skills identified; 60+ TCOs; 11 major areas (‘modules’)
- Workshop report posted on AMTAS web-site for review: Jan 05
- Workshop attendees invited to evaluate progress and provide suggestions via tele-conference: April 28, 2005
- Increase in scope, resulting in prerequisite course plus additional content detail and tools
- Major Achievement:
  - Consensus on course expectations
  - 11 MODULES: Group body of knowledge into manageable segments
Modules

TCO A Module - Understand Basics of Composite Materials Technology
TCO B Module - Understand the Basics of Composite Materials Maintenance and Repair
TCO J Module - Understand other Critical Elements of Composite Maintenance and Repair
TCO C Module – Understand Roles and Responsibilities
TCO D Module – Recognize Composite Damage Types and Sources
TCO E Module – Identify and Describe Information Contained in Documentation
TCO F Module – Describe Composite Laminate Fabrication and Bonded Repair Methods
TCO G Module – Perform a Bonded Composite Repair
TCO H Module – Describe Composite Damage and Repair Inspection Procedures
TCO I Module – Describe Composite Laminate Bolted Assembly and Repair Methods, and Perform and Inspect a Bolted Composite Repair
TCO K Module – Case Team Studies
## Tuesday

**Intro to Composite Maintenance & Repair Timeline**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Topics</th>
<th>Mode(s):</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Morning</strong></td>
<td>8:00 to 9:50</td>
<td><strong>Primary Mode(s):</strong> Lecture&lt;br&gt;&lt;br&gt;<strong>Supplemental Mode(s):</strong> P. Pt Presentation, Testimonial from Practitioner</td>
<td>TCO [E] Identify &amp; describe information contained in documentations&lt;br&gt;<strong>E1:</strong> Describe requirements in material &amp; process specifications and structural repair manuals&lt;br&gt;<strong>E2:</strong> Demonstrate use of source documents&lt;br&gt;<strong>E3:</strong> Identify &amp; demonstrate use of regulatory documents&lt;br&gt;<strong>E4:</strong> Understand the requirements and engineering approvals necessary for valid sources of technical information &amp; maintenance instructions</td>
</tr>
<tr>
<td><strong>Morning</strong></td>
<td>9:10 to 10:10</td>
<td><strong>Intermission</strong></td>
<td>Total Time: 20 min</td>
</tr>
<tr>
<td><strong>Morning</strong></td>
<td>10:10 to 12:00</td>
<td><strong>Primary Mode(s):</strong> Lecture&lt;br&gt;&lt;br&gt;<strong>Supplemental Mode(s):</strong> P. Pt Presentation, Video, Testimonial from Practitioner</td>
<td>TCO [F] Describe composite laminate fabrication &amp; bonded repair methods&lt;br&gt;<strong>F1:</strong> Understand the basics of composite laminate fabrication&lt;br&gt;<strong>F2:</strong> Understand the basics of composite bonded repair&lt;br&gt;<strong>F3:</strong> Describe the detailed processing steps necessary for laminate fabrication [factory], bonded repair [field], and Material Review Board (OEM)&lt;br&gt;<strong>F4:</strong> Describe key characteristics and processing parameters for laminate fabrication&lt;br&gt;<strong>F5:</strong> Identify typical processing defects which occur in composite laminate fabrication &amp; bonded repair.</td>
</tr>
<tr>
<td><strong>Afternoon</strong></td>
<td>12:00 to 1:00</td>
<td><strong>Lunch</strong></td>
<td>Total Time: 1 hr</td>
</tr>
</tbody>
</table>
Posting & Links of Workshop Results

Detail of Workshop: [www.mpdc.biz](http://www.mpdc.biz)

Overview: [depts.washington.edu/amtas/](http://depts.washington.edu/amtas/)

Links: [www.niar.twsu.edu/newniar/](http://www.niar.twsu.edu/newniar/)
Challenges

- Intellectual Property issues vs traditional goals of academia (e.g., public dissemination of knowledge)
  - Boeing – Airbus – Bell - FAA
  - Cytec – Hexcel – Toray

- Federal ITAR (and EAR) regulations
  - Restricts participation/dissemination based on national origin
  - Current UW policy: remain ITAR compliant by only accepting projects that fall under the "fundamental research" ITAR exemption
  - New university policies under consideration
Challenges

Phase I funding “nearly” certain... Phase II and III funding likely but subject to political & federal budget realities

AMTAS must become “self sufficient” (i.e., no FAA funding for administrative costs) by end of Phase III - or sooner

Current FAA matching funds may limit involvement of new partners
Solutions

- Evolve to a Regional Advanced Materials and Manufacturing Center supporting multiple industries
  - Aeronautics, automotive, trucking, electronics, health products, sporting goods, wind energy, highways/infrastructure, etc

- Encourage dialogue between university, industry, and governmental reps on IP and ITAR issues
Concluding Comments

- AMTAS/JAMS provides an opportunity for industry to leverage R&D expenditures by utilizing 1:1 matching FAA funds.
- Industry can also collaborate directly with AMTAS faculty/students (i.e., without FAA matching funds).
- Efforts to expand to a regional advanced materials and manufacturing center that supports multiple industrial segments are underway.