JAMS

Joint Center of Excellence for
Advanced Materials
Established December 2003

<u>Center of Excellence for Advanced Materials in Transport Aircraft Structures (AMTAS)</u>
University of Washington – Co-Lead
with Washington State University, Oregon State University, Edmonds Community College

OVERVIEW

The FAA-sponsored Center of Excellence for Advanced Materials in Transport Aircraft Structures (AMTAS) is a consortium of academic institutions, aerospace companies, and government agencies. AMTAS seeks solutions to problems associated with existing, near- and long-term applications of composites and other advanced materials in large transport commercial aircraft.

AMTAS' mission is to lead the aviation community by researching new ideas in advanced materials, educating and training aviation professionals, and facilitating knowledge transfer among industry, government, and academia.

AMTAS-sponsored activities are grouped into the following three areas:

Research. Perform studies related to composite materials and structures used in transport aircraft as well as the application of new nanotechnologies to transport aircraft.

Education. Train new and existing engineers and technicians through degree programs and short courses to ensure an educated workforce in the aerospace industry.

Knowledge Transfer. Foster knowledge exchange between government agencies, industry, and academia. Planned activities include seminars, workshops, presentations, and conferences.

University Staff

Mark Tuttle, Ph.D., Director, University of Washington, 206-685-6665, tuttle@u.washington.edu
Kuen Lin, Ph.D., Co-Director, University of Washington, 206-543-6334, lin@aa.washington.edu
Ellen Barker, Assistant to the Director, University of Washington, 206-543-0299, nelle@u.washington.edu

Affiliated Faculty: 14: see "Faculty" section

Students: 24**:** see "COE Students & Research Associates" section

FAA Program Manager: Curtis Davies, (609) 485-8758, curtis.davies@faa.gov

ACCOMPLISHMENTS

PROJECTS

ONGOING PROJECTS

PROJECT TITLE 1
Administration of the FAA Center for Excellence for Advanced Materials in Transport Aircraft Structures (AMTAS)

Abstract

In December 2003, the FAA announced a joint award to the University of Washington and Wichita State University to create a new Joint Advanced Materials and Structures (JAMS) Center of Excellence. This award established two centers, one led by the University of Washington and the second led by Wichita State University. The UW center is named the FAA Center for Advanced Materials in Transport Aircraft Structures (AMTAS).

AMTAS academic members include the UW, Washington State University, Oregon State University, and Edmonds Community College. As lead institution of AMTAS, the UW is responsible for overall administration of AMTAS, oversight of AMTAS projects conducted by all academic members, hosting of semiannual AMTAS meetings, and co-hosting with Wichita an annual technical meeting.

PI: Mark E. Tuttle, Ph.D., University of Washington Dept. of Mechanical Engineering

Staffing:
AMTAS staff members include:
- Mark Tuttle, Ph.D., Director
- Kuen Lin, Ph.D., Co-Director
- Ellen Barker, Assistant to the Director

PROGRESS

Website:
An AMTAS website/logo was developed and went public on November 29, 2004: http://depts.washington.edu/amtas/. The site is updated regularly and traffic continues to increase.

Mailing Lists:
Through a variety of sources including events and web site sign-ups, AMTAS has developed a self-selected contact list of more than 650 people. We regularly receive new contacts via our web sign-up form.

Events/Meetings:

Since the inception of the Center in December 2003, AMTAS has held, co-hosted and/or participated in 14 meetings.

1. Preliminary Working Meeting, 1/29/04, Seattle, Washington; 30 attendees
2. AMTAS Autumn 2004 Semiannual Meeting, 11/10/04, Seattle, Washington; 41 attendees
3. Composites Maintenance Workshop, 11/30–12/2/04, Renton, Washington; 64 attendees
4. FAA Centers of Excellence 4th Joint Meeting, 3/14–16, 2005, Orlando, Florida
5. AMTAS Spring 2005 Semiannual Meeting, 4/14/05, Edmonds, Washington; 53 attendees
6. JAMS 1st Technical Review meeting, 5/24–26/05, Wichita, Kansas; 60 attendees (with CECAM)
7. Composites Maintenance Workshop, 9/13–15/05, Chicago, IL; 60 attendees
8. AMTAS Autumn 2005 Semiannual Meeting, 10/13/05, Seattle, Washington; 55 attendees
9. AMTAS Spring 2006 Semiannual Meeting, 4/11/06, Seattle, Washington; 51 attendees
10. JAMS 2nd Technical Review meeting, 6/20–22/06, Seattle, Washington; 89 attendees (with CECAM)
11. AMTAS Autumn 2006 Semiannual Meeting, 10/19/06, Edmonds, Washington; 61 attendees
12. AMTAS Spring 2007 Semiannual Meeting, 4/12/07, Seattle, Washington; 83 attendees
13. AMS 3rd Technical Review meeting, 7/10–12/07, Atlantic City, New Jersey; 74 attendees (with CECAM)
14. AMTAS Autumn 2007 Semiannual Meeting, 10/25/07, Seattle, Washington; TBD

Short Courses:

Beginning in autumn 2006, AMTAS developed and offered a unique program—the **AMTAS Institute on Advanced Aircraft Composites**. This five-day, intermediate-level course is taught by academic and industry experts and provides an in-depth introduction to the use of advanced composite materials for aircraft. We have marketed this course worldwide and have attracted an international audience.

1. 9/18–22/06, Seattle, Washington; 23 attendees
2. 3/19–23/07, Seattle, Washington; 27 attendees
3. 9/17–21/07, Seattle, Washington; TBD

We plan to offer this course twice a year as well as develop additional professional development opportunities.

Collaborations:

University of Washington

1. Mark Tuttle and other AMTAS/UW faculty have been working on collaboration opportunities with a newly-formed University of Washington center called the Institute of Advanced Materials & Technology (i-AMT). The Center will leverage federally funded research by forming collaborations with academic, business, industry and government partners in areas of national interest and global challenges such as advanced materials, information technology, biotechnology, new energy sources, and nanotechnology.

International

1. Mark Tuttle and other AMTAS/UW faculty have collaborated on research and exchange opportunities with faculty from the University of Manchester (UK). These activities include composites-related research and education and people exchange. Research areas of interest to Manchester are 1) design methodologies, 2) 3-D aeroelastic design concepts, 3) low-cost manufacturing assembly, and 4) market analysis. Representatives from Manchester have made several visits to both Boeing and UW facilities. The first formal exchange included two University of Washington graduate students, Molly Phariss and Russ Caspe, who began their studies at the University of Manchester in September 2006.
2. Mark Tuttle was invited to be a featured speaker at the May 12, 2006 opening festivities of Manchester's new Northwest Composites Centre. His presentation is available at http://depts.washington.edu/amtas/publications/presentations/Tuttle_NWCC_5-06.pdf.
3. On March 3, 2006, nine representatives from the UK Dept of Trade & Industry and several UK companies on behalf of the National Composites Network visited with AMTAS members on an aerospace composites mission. Their goal was to help facilitate technology collaboration opportunities between the UK and the U.S., specifically in the area of engineering & materials and advances in the manufacture of advanced structural composites in aerospace. The meeting included presentations from both the UK and AMTAS. The report of this mission is available at http://depts.washington.edu/amtas/publications/reports/index.html.

   The UK group also visited C&D Zodiac, one of AMTAS' industry partners.

Communications:

In addition to promoting semiannual AMTAS meetings and other events, we communicate at least twice-yearly with our constituency via "News from AMTAS" e-mail messages.

PROJECT TITLE 2
Development of Reliability-Based Damage Tolerant Structural Design Methodology

Abstract
The overall objective of this project is to develop a probabilistic method to estimate structural component reliabilities suitable for design, inspection, and regulatory compliance. The proposed research spans a four-year period, consisting of two phases of study. The first three years (Phase 1) focused on methodology development and validation, while the fourth year (Phase 2) will concentrate on the application of the developed technology, such as inspection scheduling and maintenance service guidelines.

PI
Kuen Y. Lin, Ph.D., Professor, Dept. of Aeronautics and Astronautics, University of Washington

Student(s)
Chi Ho Eric Cheung, Graduate Research Assistant, Dept. of Aeronautics and Astronautics

Research Faculty
Andrey Styuart, Ph.D., Dept. of Aeronautics and Astronautics, University of Washington

The cooperative strategy is to partner this research with FAA and Boeing. The Boeing Company has committed to match the same level of funding from the FAA to support this research. Boeing personnel who have been participating in this project are: Dr. Cliff Chen, Dr. Razi Hamid, Dr. Matthew Miller, Mr. Gerald Mabson, and Dr. Mostafa Rassaian from Structures Technology Group, and Mr. Randy Coggeshall from New Airplane Developments, and Dr. Alan Miller from the 787 Technology Integration program. This cooperative arrangement ensures the successful completion and application of research results.

Progress
During 2004–2007, a new reliability-based damage tolerant design method has been developed for determining design allowable damage limit and optimum inspection schedule of aircraft structural components made of composite materials. Using the developed formulation, a general-purpose computer program, RELACS, has been established for the lifecycle reliability assessment of aircraft composite structures. The program is capable of analyzing reliability of a composite structure with the consideration of many variables, such as damage types and sizes, residual strengths, aging degradation, maintenance planning, etc., over the operational life. The RELACS program can handle various failure modes including static failure, excessive deformation, flutter and high amplitude limit cycle oscillation. Examples of applying RELACS to optimal design of damage tolerant structures as well as damage tolerance substantiation of such structures have been demonstrated.

The primary objectives of the 2007–2008 study are to enhance RELACS and apply the program to airplane design and maintenance scheduling. Specific tasks to be accomplished are described in the following:

Task 1: Demonstrate the potentials of the developed probabilistic method for airplane design and maintenance planning

In this task, we will collaborate with engineers from the industry, such as Boeing, to evaluate application potentials of the probabilistic design methodology and the RELACS program. The DERs in design groups as wells as maintenance and customer support engineers will be consulted. Use of the RELACS program in the design process and maintenance scheduling will be demonstrated. Feedback from the engineers will be used to refine the RELACS program.

Task 2: Develop an interface architecture to study damage growth characteristics in bonded structures with RELACS

An interface between RELACS and ABAQUS will be developed to accommodate disbond/delamination growth feature. Damage growth characteristics are often obtained by testing. However, if the test data are not available, they can be predicted by the finite element method (FEM) as well. In this task, the virtual crack closure technology (VCCT) in ABAQUS will be used to obtain the residual strength and disbond/delamination propagation behavior. These data will then be exported to RELACS to determine structural reliability and inspection schedule.

Task 3: Apply RELACS to study damage growth characteristics

Upon completion of Task 2, a practical example where damage growth is an important factor (e.g. a disbond in a structure) will be selected for analysis. FEM analyses will be performed to determine the stable growth behavior and residual strength. The analytical results will then be exported to RELACS to investigate the effects of disbond growth on the reliability and maintenance plan.

Task 4: Apply RELACS to study high-cycle fatigue and damage tolerance

We will begin to work with Dr. Mostafa Rassaian from Boeing on interfacing the Boeing-developed Sonic Response Analysis (SRA) tool with RELACS. The SRA tool is capable of analyzing structures under acoustic, vibration, pressure and temperature environments. A simple component will be identified and analyzed in NASTRAN to determine the sensitivity of high-cycle fatigue to the flaw size growth, after which RELACS will be used to determine the structural reliability. The analytical results will be verified in follow-on tests to be conducted by Boeing. This task demonstrates the potential applications of RELACS to a wide range of design problems.

During this reporting period, all the work items planned in Phase 1 have been completed. This includes a probabilistic formulation of the inspection intervals for aircraft composite structures subjected to accidental damage, development of analytical models for optimum maintenance planning as well as demonstration of example results.

PROJECT TITLE 3
Combined Global/Local Variability and Uncertainty in Integrated Aeroservoelasticity of Composite Aircraft

Abstract
Develop analytical, computational and experimental capabilities to address "Combined Global / Local Variability and Uncertainty in Integrated Aeroservoelasticity of Composite Aircraft." Computational capability development will focus on (a) quantification of effects on stiffness of key local effects in composite structures (damage, material variability, material degradation, etc.), (b) global linear and nonlinear aeroelastic/aeroservoelastic analyses capable of evaluating variations and uncertainty to such local effects, and (c) integrated local/global modeling capability of uncertain composite structures. Capabilities for simulation of the effects of control surface nonlinearities on aeroelastic and aeroservoelastic behavior of full scale airplanes will be developed and used to study effects of nonlinearity and uncertainty mechanisms and guide maintenance practices. Simultaneously, an experimental structural dynamic/aeroelastic testing capability will be developed at UW, and tests will be planned & conducted to study the effects of damage on the aeroelastic behavior of components and models.

PI: Eli Livne, Ph.D., University of Washington Dept. of Aeronautics and Astronautics
Co-PI: Prof. Mark Tuttle, University of Washington, Chairman, Mechanical Engineering Department, and AMTAS director

Student(s): Francesca Paltera, MS student, ME Department

The Research Team and Its Progress
Dr. Luciano Demasi, a post-doctoral research fellow, has been contributing to our effort in a number of areas: (a) automation of commercial aeroelastic codes and adaptation of design-oriented analysis concepts to the task of efficient repetitive analysis. This rapid calculation of behavior response of aeroelastic systems subject to structural variation is required for the statistical simulation technology developed here; (b) Development of an aeroelastic capability for nonlinear airframes, accounting for nonlinearities due to global large deformation and nonlinearities due to local large deformation, such as local buckling, delamination, etc.; Dr. Demasi has also been contributing to our education component—the introduction of composite construction into our airplane design courses.

Dr. Andrey Styuart, our Reliability/Uncertainty expert, has been developing statistical methods and tools for reliability and risk assessment in aeroelastic systems, taking into account damage and repair statistics (type, location, size) and translating them to variations in structural properties and resulting variations in flutter speed (linear and nonlinear) and dynamic response.

Boeing and FAA interactions (Carl Niedermeyer, manager 787/747 Flutter Engineering and Methods Development, Dr. Kumar Bhatia, Senior Technical Fellow, and Dr. James Gordon, Associate Technical Gellow): We have a continuous working relations with Boeing in the area of LCO (limit cycle oscillation) simulation, with focus on the problem of free-play, but with methods development that allow simulation of other structural nonlinearities and non-linear local structural effects. From 2D cases used to validate methods and codes the work progressed to full 3D configurations of the complexity and size of real passenger airplanes, and LCO simulation capabilities for such cases wee tested at Boeing using Boeing flight test results. This particular work will have a significant impact on the design and certification of passenger airplanes, and was strongly supported by Gerry Lakin (FAA, Flutter, Renton Office) before he retired.

Technical support by FAA experts has been provided by Peter Shyprykevitch, before he retired, Dr. Larry Ilcewicz, and by Curtis Davis as a program manager.

Experimental Capabilities: A modal testing system was purchased and installed. A first aeroelastic wind tunnel model representing a tail / rudder configuration has been designed and is now under construction (Francesca Palters, Prof. Mark Tuttle, with support from ME staff). The model includes a composite rudder, with provisions for representation (in the model) of different damage and failure modes, including delamination, debonding, and hinge failure. First vibration and aeroelastic tests are planned for the fall quarter of 2007.

General Plans

Flutter

- Continue development of the UW in-house simulation capability to include buckling (geometric nonlinearity) effects.
- Continue development of the integrated NASTRAN / ZAERO simulation environment.
- Test using models with complexity representative of real passenger aircraft, and
- Improve automation of analysis and computational speed to allow efficient execution of the large number of simulations needed for probabilistic studies.
- Use sensitivity analysis and approximations to utilize design optimization technology to address issues of reliability and optimal maintenance.

LCO

- Extend time-domain LCO simulation capability to complete airplanes and their finite element models.
- Integrate with probabilistic / reliability analysis.
- Continue development of LCO simulation tools for large-scale aeroelastically complex flight vehicles.
- Develop a probabilistic approach to nonlinear LCO problems using Describing Function simulation techniques.
- Design nonlinear small scale models (with different sources of service life and damage-related nonlinearity), carry out numerical simulations, correlate with structural dynamic tests, and proceed with aeroelastic wind tunnel tests.

Probabilistics & Reliability

- Link structural variation over time and damage modes to structural stiffness and inertia variations (including statistics).
- Continue development of a comprehensive reliability methodology for composite airframes (with design and maintenance consequences) covering aeroelastic / aeroservoelastic failure modes.

Project Title 4
Improving Adhesive Bonding of Composites through Surface Characterizations

Abstract
Peel ply surface preparation for co-bonding and secondary bonding of primary composite structures is becoming more common as the usage of composites is increasing in commercial aircraft. Peel ply surface preparation is attractive from a manufacturing and quality assurance standpoint because it reduces costs and minimizes the human factors present in other surface preparation techniques, such as grinding and grit blasting. However, there is not a fundamental understanding of the process variables that ensure a high quality, durable bond. The first year of research focused on bond quality of surfaces prepared using one 350 cure epoxy system Toray 3900, peel plies from a single source (Precision Fabrics, Inc.) and two epoxy based film adhesives (Metal Bond 1515-3 and AF555). Surface prepared using polyester peel plies resulted in good bonds with both adhesives. Surfaces prepared with nylon peel plies resulted in poor bonds with Metal Bond 1515-3, but acceptable bonds with the AF555 adhesive. Year two research focused on a variety of 250 cure peel ply/prepreg/adhesive showed that nylon peel ply produces the best bond and Polyester peel ply prepared surfaces did not bond well. In addition further research in Year two on bonding other 350 cure systems: Toray 3631 and Cytec 970 using peel ply surface preparation had different results than the Toray 3900 prepreg.

Following is a brief synopsis of our research results:

A given peel ply surface preparation that works with one prepreg-adhesive system will not necessarily work with any other prepreg-adhesive system; **each combination yields its own unique characteristics.**

- Bond Quality depends on:
  - Prepreg system (Resin and Fiber(?))
  - Peel Ply Material and Source
  - Adhesive
- Characterization Techniques (XPS, SEM and Surface Energy) provide useful information to help understand bonding requirements. The SEM surface examination revealed a potential cause of the problem – the polyester peel ply is interacting with the matrix to leave tendrils of material, indicates contamination

PI: Brian D. Flinn, Ph.D., PE; Co-PI: Fumio Ohuchi, Ph.D., University of Washington Dept. of Materials Science & Engineering

Student(s)
Current Students
Molly Phariss, MSE Ph.D. candidate, Research Assistant
Russell Caspe, MSE Ph.D. candidate, Research Assistant
Jeffery Saterwhite, MSE Masters candidate, Reasearch Assistant
Tucker Howie, MSE Ph.D. candidate, Research Assistant
Connor Keenan, MSE senior
Curtis Hickmott, MSE Junior
Rockey Aye, MSE Senior

Progress

Several in depth technical interactions have taken place with Peter Van Voast, Will Grace and Paul Shelley (Engineers from Boeing MRD) in the area of interest: bonding of structural composites for commercial transport aircraft. The results of these discussions helped formed the basis for the detailed experimental plan for this project that was presented at the FAA Coordination Meeting for Chemical Characterization Program, December 16, 2004, NIAR, Wichita, KS. In addition technical presentations and discussions of our research results have taken place at several meeting including al three JAMS technical reviews, several AMTAS semi-annual meetings, SAE CACRC committee meetings and international technical conferences (SAMPE 2005, 2006 and 2007). Three different students (Molly Pharris, Brian Clark and Jeff Saterwhite have been finalists at the SAMPE student symposiums and finished in the top three.

Our current research has focused on bond quality of fiber reinforced, epoxy matrix composite surfaces prepared using peel plies and bond with epoxy based film adhesives. We have studied systems composed of 6 different carbon and fiber glass prepregs, 10 different peel plies and 8 different film adhesives. Both 250 and 350 cure systems have been characterized and testing. Material systems (specific prepreg-peel ply–adhesive combinations) that produced strong bonds have been identified and reported. Materials systems that produced weak bonds and should not be used have also been identified and reported.

Summary of Experimental Findings

The results of mechanical testing demonstrated a significant difference in bond quality when joints are prepared with varying peel ply materials and adhesives.

1) All four weaves of polyester peel ply were easily removed from Toray 3900 laminate surfaces after curing and created surfaces that bonded well using either adhesive. The surfaces that were generated were in all cases interfacial between the peel ply fabric and the epoxy resin matrix. XPS surface characterization of the surface generated with polyester peel did not detect any anomalous materials on the surface as were found on nylon prepared surfaces. The bond failure was cohesive with average G_{IC} values of 908 and 809 J/m^2 for adhesives AF555 and MB1515-3, respectively.

2) Nylon peel plies were more difficult to remove from the Toray 3900 laminate and in some cases could not be removed without damaging the laminates. Finer weaves were easier to remove than coarser weaves. Laminate surfaces prepared with nylon peel plies bonded well with adhesive AF555 (all G_{IC}> 750J/m^2; cohesive failure). Laminate surfaces prepared with nylon peel plies bonded poorly with adhesive MB1515-3 (average G_{IC}< 165 J/m^2; adhesion failure). An explanation for this difference was found using SEM and XPS. The filaments of the removed nylon peel ply were shredded, and small fiber fragments were found on the corresponding composite surface after peel ply removal. This transfer of peel ply material to the bond surface was confirmed when XPS analysis revealed amide groups on the nylon-prepared composite. Adhesive MB1515-3 must have a chemical composition that does not bond well to epoxy surfaces contaminated with amides. Adhesive AF555 is tolerant of some level of amide contamination.

3) Precision Fabrics 60001 SRB release films created very poor bonding surfaces with both adhesives, the result of the transfer of the peel ply siloxane coating to the composite surface (confirmed by XPS).

4) Peel ply texture or peel ply moisture content had no significant effect on fracture energy or mode of failure.

5) Bond quality in 250 F systems depended on:
   a. Peel ply material and adhesive
   b. Nylon : high toughness bonds, cohesive failure all adhesives
   c. Polyester peel ply: low toughness, adhesion failure
   d. One adhesive bonded to all surfaces
   e. Opposite trend than Toray 3900 (350 F) system : Nylon bad, Polyester good
   f. The wetting envelopes generated for the various prepared surfaces gave limited insight into why polyester was inadequate.
   g. Surface energy of polyester surfaces>nylon surfaces
   h. The SEM surface examination revealed a potential cause of the problem—the polyester peel ply is interacting with the matrix to leave tendrils of material, indicates contamination

6) In 350 cure prepregs (Toray 3631 and Cytec 970 the Henkel EA-9895 peel ply-prepared surfaces performed well in actual adhesive bond quality and also contained the adhesive compounds within the wetting envelopes; surfaces after peel ply removal exhibited fractured epoxy regions and no visible fiber remnants

7) Although surfaces prepared with the dry polyester peel ply contained the adhesives well within their wetting envelopes, they did not show substantial cohesive character in failure

8) Cytec 970 prepared with the wet nylon peel ply and 3M AF 555 adhesive showed cohesive failure even though the adhesive was outside the boundaries of the wetting envelope

9) Surfaces which had visible peel ply contamination when observed by SEM did not produce strong bonds

Ongoing Research

These results raise several new questions regarding the effects of peel ply surface preparation on bond quality. The top issues—identified in consultation JAMS industrial partners are:

1) Effect of degree of cure of prepregs on peel ply removal, surface energy and bonding characteristics, both under and overcured.
2) Characterization of new systems (General aviation prepregs/peel plies/adhesives)-Toray.
3) Further investigation of differences in to different groups of prepregs, e.g. 250 F vs. 350F cure prepreg/peel ply interactions (related to 1 and 2).
4) Temperature and pressure effects on surface energy, prepreg/peel ply interactions and adhesive/substrate interactions.
5) Development of standard surface energy measurements for composite surfaces (peel ply, sanded, grit blasted, scarfed, etc) and investigation on effect of surface texture and fiber orientation.
6) Effect of time/environment (UV) on composite surfaces after surface preparation (peel ply, sanding)-i.e. how long can you wait to bond a surface after preparation.
7) Additional adhesives systems to be investigated such film vs. paste adhesives and including effects such as cure kinetics, viscosity and flow differences.

8) Methods to characterize prepreg manufacturing properties as a function of out time (tack, drape, etc) in conjunction with Bill Stevenson at WSU.

Expected Outcomes

The research findings from this program will provide a better understanding of the role peel ply surface preparation on bonding of composites. This understanding can lead to improvement in composite system compatibility (prepregs, peel plies and adhesives), a greater confidence in adhesive bonds and contribute to the development of QA methods to test the suitability of surfaces for bonding.

PROJECT TITLE 5

Course Development: Maintenance of Composite Aircraft Structures

Abstract

The goal of this proposal is to develop, in conjunction with AMTAS academic and industry partners, a syllabus and course material for an awareness course addressing the maintenance of composite aircraft structures.

PI: Charles C. Seaton, Edmonds Community College

Progress

Terminal Course Objectives (TCOs) have been developed with the input of industry, government, and academic subject matter experts. A workshop was conducted November 30 over a 3-day period. The objective of the workshop was to provide terminal course objectives (TCOs) for a 5-day survey course and laboratory workshop regarding composites repair, and included approximately 50 participants. In addition, 450 essential skills were identified.

Content has been developed for the TCOs by grouping these objectives into 11 major modules. A workshop was held in Chicago (September 13–15, 2005) with more than 60 subject matter experts to solicit feedback on the content. Incorporation of these comments was completed in November 2005. Deliverables for 2005 included the TCOs, content and course enhancements, including safety messages, testimonials and laboratory instructions.

Content has been finalized, and a technical center report is nearing completion for submission to the FAA for editing. The report includes curriculum framework, TCOs, content, suggested course organization, and a detailed appendix which describes how the curriculum was developed.

The final phase of the development will adapt the course content into an on-line class format. An important part of this development is the conduct of a 'beta' course with students having minimal knowledge in composite materials technology in order to solicit feedback. A generic training repair manual is also being produced to simulate an OEM's structural repair manual. This latter tool for educators is particularly important since structural repair manuals are, in general, considered proprietary.

Publications

Draft portions of the technical center report that summarizes material developments and feedback from the grant is available on the Edmonds Community College website at http://www.the-mpdc.com. This provides information in advance of the final report to be issued by the FAA technical center.

A final report will be provided by December 31, 2007 to the FAA Technical Center for final review and posting. Additional reports will be published for the training repair manual, and feedback on a 'beta' on-line course to be conducted in fall 2007.

Information Dissemination

Ongoing progress and final reports are to be a part of the AMTAS web site, or linked with http://www.the-mpdc.com. Materials and development progress have been presented through a variety of workshops and conferences, such as CMH-17, SAE and CACRC committees.

Completed Projects

Project Title 6
The Effect of Surface Treatment on the Degradation of Composite Adhesives

Abstract
To ensure the longevity of the commercial aircraft fleet, the long term durability of primary aircraft structure must be understood. The degradation of metals and their attachments (mechanical and adhesive) has been rigorously studied over the years. The introduction of composite materials in aerospace applications has presented challenges as methodologies that have successfully been used for metals do not always produce reliable results with new materials. This project considered the effect of surface treatments on composite adherends and accelerated test methods that may be used to reliably compare their long term degradation.

PI
Lloyd Smith, Ph.D., Washington State University School of Mechanical and Materials Engineering

Student(s)
Prashanti Pothakamuri, MS graduate student (graduated)
Daniel Stone, ME senior undergraduate student (graduated)
Craig Cordill, ME senior undergraduate student (graduated)

Additional Personnel
Peter Van Voast, Boeing
Will Grace, Boeing
Brian Flinn, University of Washington

Dissemination of Results

Pothakamuri, P., 2006. “Accelerated Degradation of Composite Adhesive Bonds,” Master in Science Thesis, Washington State University.

Smith, L., V., Pothakamuri, P. VanVoast, P. J., 2007. “The Effect of Surface Treatment on the Degradation of Composite Adhesives,” FAA Final Report.

Smith., L. V., 2007. “Accelerating Degradation in Composites and Their Adhesives,” American Society of Composites Annual Meeting, Seattle, WA.

Progress
BMS 8-276 form 3 laminates were processed using polyester, nylon and siloxane coated polyester peel ply. The effect of secondary abrasion was considered by sanding and grit blasting. All coupons were bonded with AF555 (3M) that was formulated to be resistant to moisture during bonding.

The AF555 adhesive was shown to be resistant to prebond adherend moisture content. The composite adherends, however, tended to fail by interlaminar shear as the moisture content increased. This occurred for both the low cost and classic material forms. The tendency toward adherend failure may have been influenced by a toughening film on the prepreg surface.

Of the surfaces prepared from the three peel plies, polyester provided superior shear strength and fracture toughness with cohesive and interlaminar failure modes. Secondary abrasive operations did little to improve adhesion beyond the polyester peel ply, and in some cases lowered the bond strength. Sanded surfaces had slightly higher strain energy release rates than peel ply, while grit blasted surfaces had significantly lower strain energy release rates. The grit blasting operation caused surface pitting which may have contributed to the reduced strength.

Combining stress, temperature and moisture was shown to accelerate degradation beyond the effect of these components individually. Temperature accelerated moisture diffusion. The residual shear strength was shown to decrease with creep stress. Crack growth in double cantilever beam specimens was also accelerated using a fluctuating load while immersed in water.

PROJECT TITLE 7
AF555 Hot/Wet Creep Response

Abstract
This was a Boeing-funded project though the AMTAS center, involving shear lap coupons exposed to hot water and creep stress. The objective of this study was to measure the effect of adherend moisture content on a moisture tolerant adhesive.

PI: Lloyd Smith, Ph.D., Washington State University School of Mechanical and Materials Engineering

Student(s): Prashanti Pothakamuri, first year graduate student (graduated)
Daniel Stone, ME senior undergraduate student (graduated)

Progress
Adherends were preconditioned to a dry or 1% moisture content before adhesive bonding into wide area lap shear coupons. They were then exposed to 0, 2, 3, or 4 ksi creep stress while immersed in 140F water for 1000 hours. The residual shear strength was observed to decrease with the applied creep stress to a maximum of approximately 20% of the control shear strength. The average wet adherend shear strength was comparable to the dry adherend shear strength, but slightly less for the 0 hour exposure. Failure surface examination showed primarily adherend failure, occurring in the matrix between the surface resin layer and fibers. The adherends preconditioned with 1% moisture tended to increase the amount of adherend failure slightly.

PUBLICATIONS

Demasi, L., and Livne, E., "Dynamic Aeroelasticity of Structurally Nonlinear Joined Wing Configurations Using Linear Modally Reduced Aerodynamic Generalized Forces", AIAA Paper 2007-2105, 48th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Honolulu, Hawaii, Apr. 23–26, 2007.

Demasi, L., and Livne, E., "Performance of Order Reduction Techniques in the Case of Structurally Nonlinear Joined-Wing Configurations", AIAA Paper 2007-2052, 48th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Honolulu, Hawaii, Apr. 23–26, 2007.

Lin, K.Y. and Styuart, Andrey, "Probabilistic Approach to Damage Tolerance Design of Aircraft Composite Structures," *Journal of Aircraft* (0021-8669) 2007m, vol. 44 no. 4.

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FACULTY

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Eli Livne, Ph.D. Professor	UW Dept. of Aeronautics and Astronautics	Aeroelasticity, aeroservoelasticity, multidisciplinary optimization, airplane design optimization, controls synthesis	eli@aa.washington.edu; 206-543-1950
Fumio Ohuchi, Ph.D. Professor	UW Dept. of Materials Science & Engineering	Nucleation and growth of thin films, surface and interface of electronic materials, physics and chemistry of layered materials, nanostructures	ohuchi@u.washington.edu; 206-685-8272
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Andrey Styuart, Ph.D. Acting Assistant Professor	UW Dept. of Aeronautics and Astronautics	Probabilistic structural design, composite materials; damage tolerance design, aerospace systems	stewav@aa.washington.edu; 206-543-6612
Mark Tuttle, Ph.D. Professor & Chair	UW Dept. of Mechanical Engineering	Applied solid mechanics, viscoelasticity, composite materials, and adhesion mechanics	tuttle@u.washington.edu; 206-685-6665

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Oregon State University

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Edmonds Community College

Name	Univ./Dept.	Expertise	E-mail/Phone
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COE STUDENTS & RESEARCH ASSOCIATES

University of Washington

Current COE-supported students:

- Rockey Aye, Dept. of Materials Science & Engineering, Senior
- Russell Caspe, Dept. of Materials Science & Engineering, MSE Ph.D. candidate, Research Assistant
- Chi Ho Cheung, Dept. of Aeronautics and Astronautics, Graduate Researcher
- Luciano Demasi, Dept. of Aeronautics and Astronautics, Post-doc Research Fellow
- Curtis Hickmott, Dept. of Materials Science & Engineering,Junior
- Tucker Howie, Dept. of Materials Science & Engineering, Ph.D. candidate, Research Assistant
- Conor Keenan, Dept. of Materials Science & Engineering, Senior
- Francesca Paltera, Dept. of Mechanical Engineering, MS/Ph.D. Student
- Molly Phariss, Dept. of Materials Science & Engineering, Ph.D. Candidate, Research Assistant
- Jeffery Saterwhite, Dept. of Materials Science & Engineering, Masters candidate, Research Assistant

COE-supported students who have graduated as of July 2007:

- Bjorn Ballien, MSE, BSc. June 2005
- Eric Brutke, MSE, BSc, graduated December 2006
- Brian Clark, MSE, Master of Science. June 2006
- Levent Coskuner, Dept. of Aeronautics and Astronautics
- Tucker Howie, Double major: MSE BSc, ME, BSc.
- Cary Huang, Dept. of Aeronautics and Astronautics
- Apichaya Meesaplak, Dept. of Aeronautics and Astronautics
- Dinda Padmasana, MSc. December 2006
- Jake Reeves, Dept. of Materials Science & Engineering
- Jeffery Saterwhite, BSc, June 2006
- Crystal Simon, Dept. of Aeronautics and Astronautics

Washington State University

Current COE-supported students:

- None; projects ended

COE-supported students who have graduated as of July 2007:

- Craig Cordill, School of Mechanical and Materials Engineering, senior undergraduate student (graduated)
- Prashanti Pothakamuri, School of Mechanical and Materials Engineering, graduate student
- Daniel Stone, School of Mechanical and Materials Engineering, senior undergraduate student

Oregon State University

- None; project to begin summer 07

Edmonds Community College

- None